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Statement of Perspective. The word *zygon* means the yoking of two entities or processes that must work together. It is related to *zygote*—meaning the union of genetic heritage from sperm and egg, a union that is vital in higher species for the continuation of advancement of life. The journal *Zygon* provides a forum for exploring ways to unite what in modern times has been disconnected—values from knowledge, goodness from truth, religion from science. Traditional religions, which have transmitted wisdom about what is of essential value and ultimate meaning as a guide for human living, were expressed in terms of the best understandings of their times about human nature, society, and the world. Religious expression in our time, however, has not drawn similarly on modern science, which has superseded the ancient forms of understanding. As a result religions have lost credibility in the modern mind. Nevertheless some recent scientific studies of human evolution and development have indicated how long-standing religions have evolved well-winnowed wisdom, still essential for the best life. *Zygon*'s hypothesis is that when long-evolved religious wisdom is yoked with significant recent scientific discoveries about the world and human nature, there results credible expression of basic meaning, values, and moral convictions that provides valid and effective guidance for enhancing human life. *Zygon* also publishes manuscripts that are critical of this perspective, as long as such papers contribute to a constructive reflection on scientific knowledge, human values, and existential meaning.

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Editorial

The New Cosmology

In this Editorial for the December 2025 issue, you will find a brief overview of the articles included in this issue, both in the general section and in two thematic sections, including one book symposium, as well as an overview of books reviewed in the latest edition of *Reviews in Science, Religion and Theology*.

Article

This issue contains one general article. Ligita Ryliškytė examines the evolving relationship between theology and science, critically highlighting the risks of subsumption in both directions; she argues that genuine engagement requires a unity-in-distinction—preserving the relative autonomy of each discipline while fostering responsible dialogue.

Theology and Philosophy Engage the New Cosmology (by Eric Priest, David Wilkinson, and Mary Ann Meyers)

This thematic section is based on a symposium on the interactions between Cosmology, Philosophy, and Theology held in Jerusalem in March 2019 (funded by the John Templeton Foundation, the 55th in the Humble Approach Initiative series held under the aegis of the John Templeton Foundation and organized by Mary Ann Meyers). The symposium brought together world leaders on the study of these three fields, who shared their research and insights on this intriguing topic of great current interest from very different disciplines and viewpoints. A majority of those present agreed to develop their presentations for publication in this thematic section of *Zygon: Journal of Religion and Science*, which has since been augmented by articles from other experts in astronomy and the philosophy of religion.

Advances in understanding our universe, its nature and how it might have come to be, including the monumental discovery in 2016 of space-time distortions, known as gravitational waves, and the amazing images released in April of 2019 of the edge of a black hole, are helping to shape and refine our cosmic view. Our comprehension of the cosmos has been shifting from the imagined to one that is observed, measured, and validated by science. What these new developments have brought into sharper view are more profound

open questions that are most effectively illuminated with a cross-disciplinary lens. With this approach in mind, the present thematic section aims to capture that rich intellectual pan-disciplinary engagement.

The issue presents our current understanding of the origin and evolution of the universe and our place within it, through the critical insight rendered by philosophy and theology. Its purposes include increasing awareness of modern physical cosmology, encouraging dialogue and research across disciplinary boundaries, and, not least, bursting myths and stereotypes as it sets out what we know, what we could learn, and what we can't ever know about where we have come from and where are headed in a cosmos swirling with dark matter and dark energy.

An introductory article by Eric Priest presents a background to the subject, reviewing what we are learning in key areas of astronomy and astrophysics, and reflecting on the philosophical and theological implications of new findings for traditional systems of inquiry and belief. It also summarizes the main aspects of the various contributions to this thematic section.

Cosmologist John Peacock reviews the standard model of cosmology, in which the universe is expanding and accelerating, driven by dark energy. Where small density enhancements are present, gravity causes them to collapse and form stars, galaxies and large-scale clustering. About 15% of this is normal matter, but 85% is dark matter which, unlike normal matter, does not scatter electromagnetic radiation. An overview is given of the development and the success of the model, together with the fundamental questions that remain open.

Mathematician and astronomer Bernard Carr describes the nature of black holes. They represent one of the most enigmatic classes of object in the Universe. Indeed, the term has entered popular parlance to mean "problematic and difficult escape from." Yet, in fact, they are very simple in some respects having only three basic properties, namely, mass, rotation, and electric charge. They come in three generic categories, the first being miniscule back holes, which are thought to be formed by ultra-high energy collisions and can have incredibly short lifetimes. They have yet to be detected, even in our most powerful particle accelerators, whereas the other two categories have been observed and studied. Stellar-mass black holes result from the ultimate fate of stellar gravitational collapse. Finally, super massive black holes lying at the center of galaxies have masses that range from tens of thousands to millions and even billions of times the mass of the Sun.

Bernard Carr also stresses that the boundary between philosophy and physics may be blurred because many new ideas in astronomy are not easily testable, a property that has been traditionally demanded of science. Cosmology and black holes provide such examples when the nature of time and of singularities is under discussion. Physics and theology have also been linked historically in the development of our understanding of cosmology and black holes and, indeed important research on both has been conducted by priests.

Some cosmological questions concerning the origin of the universe have religious undertones, and the science of cosmology is closely related to that of black holes.

Physicist Bernard Schutz describes the importance of gravity for the evolution of life and summarizes the properties and discovery of gravitational waves by LIGO (the Laser Interferometer Gravitational Wave Observatory). It is the emission of gravitational waves that occasionally allows pairs of neutron stars to merge and produce kilonova explosions that are now known to be the main source of heavy elements above iron in the periodic table. Notably, they produce radioactive isotopes ^{238}U and ^{232}Th of uranium and thorium. Decay of these isotopes produces heat which is essential in maintaining plate tectonics, and which in turn has been a major driver in human evolution and in particular of cognition.

Astrophysicist Jennifer Wiseman considers planets and the question as to whether there exists life beyond Earth. The year 1995 saw the first detection of a planet orbiting another star outside our solar system, which has led to the recent discoveries of 5,000 such exoplanets in our region of the Galaxy, many of them very different from our own solar system planets. This is fueling an interest in astrobiology, how such life could have evolved and how to detect it. No extraterrestrial life has yet been detected, but the generation of the chemical building blocks in other stars needed for life to form and thrive implies a universe connected to life. Pondering the possibility of life in many of the billions of planets in our universe enriches and deepens our sense of awe, as well as the faith of believers.

Astrophysicist Nidhal Guessoum discusses Islamic approaches to cosmology and how they have evolved over time. He begins by giving a brisk review of the main approaches of Muslim thinkers from a thousand years ago to today. Then the ways cosmology has evolved with modern science and astronomy is summarized, with a focus on and what new ideas need to be adopted by a "cultural cosmology" that includes philosophy, religion, and culture at large. Muslim thinkers are challenged to incorporate new ideas and reinterpret the old anthropocentrism and the classical argument from design. They need a "big history" approach to the cosmos, earth, and humanity. Some important notions that Islam brings to human culture are presented that may be of interest to theists in general as well as non-theists.

Physicist and astronomer Marcello Gleiser summarizes the arguments for a pathway to a biocentric worldview that have been recently presented in his book *The Dawn of a Mindful Universe* (2023). His conception arises from recent astronomical discoveries about the distributions of planets around other stars, as well as the realization that all life on Earth is interconnected and co-dependent. The biocentric worldview is a response to the amazing uniqueness of the Earth's biosphere and its current fragile state due to centuries of human aggression. It puts forward an ethics of belonging that puts life center-stage as we struggle to chart a path toward a sustainable future.

Philosopher of science Brian Pitts suggests that the big bang singularity does not provide evidence for the existence of God in the sense that it does not help the modern Kalam cosmological argument for theism. The Kalam formulation of the cosmological argument has three parts: everything that begins to exist has a cause of its existence; the universe began to exist; therefore the universe has a cause of its existence. However, the notion of a beginning requires a first moment, and at the big bang singularity there is no such first moment, or more generally the solution cannot be extended back right up to the singularity.

Theologian and astrophysicist Rodney Holder reflects on the startling fact that our universe has very special properties that have led to the evolution of intelligent life. Conditions near the big bang and the constants embedded in the laws of physics are tightly constrained. The universe is therefore shot through with meaning and value because it has produced creatures with rational powers to understand it and to appreciate its value. The fine tuning demands an explanation, one of which is simply that God designed the universe this way, intending that life would evolve and that rational creatures with a free will would arise who would explore God's handiwork and would relate to God. Another explanation is that perhaps there is a better "theory of everything" in which the various constants would be determined by something else. However, the question would still arise: why is that particular theory selected? A third explanation is that a myriad of other universes exists, called a multiverse, each with different values for the fundamental constants, but then what determines which of the possible multiverses exists?

Theologian and cosmologist Adam Hincks discusses the apparent fine tuning of many physical parameters that make our universe hospitable to life, and whether this may be used as an argument for God from design. He critically reviews the concept of fine tuning and deduces that the claim that God is its most probable cause has several technical difficulties. Furthermore, talking about God as a probable explanation treats God at the same level as the empirical world and thereby ignores God's transcendence, which is central to Abrahamic religions. In addition, God's creation is not a physical process and so not accessible to empirical study. Finally, fine tuning gestures towards God not primarily because God is its explanation but because a sense of wonder is engendered by the concept. Either God chose to create a finely tuned universe bypassing any natural mechanism, or fine tuning can be explained with a natural theory. However, this does not sit well with the Judeo-Christian-Islamic doctrine of creation *ex nihilo* ("from nothing"). At issue are different ways of conceiving of causality: what modern scientists mean by "cause" when speaking of fine tuning is not necessarily the same as what ancient and mediaeval theologians meant. Can their premodern notions map onto the contemporary scientific situation? The answer may depend on the distinction between ordinary causality and the transcendent causality that accounts for why there is anything at all.

Philosopher of physics Christopher Smeenk brings a philosophical perspective, stressing that we need to consider the usefulness of fine-tuning arguments and what we need to know about a given theory for a fine-tuning argument to be successful. He compares features that are necessary as a consequence of underlying laws and those that are contingent on the existence of complex structures at a variety of scales (and possibly the development of life). But too often, he says, fine-tuning arguments have been naive about what is contingent, notably those applied to the universe's initial state. It would be interesting to investigate whether what we already know imposes unexpected limitations on the space of possibilities?

Finally, theologian David Wilkinson compares scientific and Christian views on the future of the universe and of humanity. The long-term future predicted by science is a cold and lifeless cosmic state, which is unable to provide optimism and challenges views of progress in which creation continually gets better. But Christian theology emphasizes the bodily resurrection of Jesus and the focuses on a new creation, which can provide a fruitful conversation with the scientific picture. Furthermore, it regards science as a gift of God that can transform life and can be used to advance God's purposes.

Book Symposium (by Mladen Turk)

The Book Symposium in this issue features *Critical Approaches to Science and Religion* (2023), edited by Myrna Perez, Ahmed Ragab, and Terence Keel. It has four commentators: Megan Loumagne Ulishney, Elizabeth Pérez, Peter Harrison, and James Miller. Perez, Keel, and Ragab respond to the comments.

Books reviewed in *Reviews in Science, Religion and Theology*

Reviews in Science, Religion and Theology is a quarterly joint publication of the European Society for the Study of Science and Theology (ESSSAT) and the International Society for Science and Religion (ISSR) and is distributed free to all members of ESSSAT and ISSR. In order to give readers of *Zygon: Journal of Religion and Science* an overview of recent publications, we include the list of books reviewed in the latest *Reviews* issue (in this case, September 2025):

- Robin Attfield, *The Ethics of the Climate Crisis*, Cambridge: Polity Press, 2024
- Peter Harrison. *Some New World: Myths of Supernatural Belief in a Secular Age*, Cambridge: Cambridge University Press, 2024

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Theology and (or/from/above) Science

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This article examines the evolving relationship between theology and science, critically evaluating three untenable approaches: theology or science (separation), theology from science (subordination of theology), and theology above science (subordination of science). Engaging with the works of Michael Buckley, Ian Barbour, Paul Tyson, and others, it highlights the risks of subsumption in both directions. Drawing on Bernard J. F. Lonergan's philosophy of self-appropriation, the article argues that genuine engagement requires a unity-in-distinction—preserving the relative autonomy of each discipline while fostering responsible dialogue. By emphasizing a shared search for understanding, Lonergan's generalized empirical method is presented as a philosophical framework for cross-disciplinary collaboration that resists both conflict and reductionism. This approach offers a philosophical foundation for interdisciplinary engagement, preventing epistemic compartmentalization while affirming the integrity of both fields.

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Introduction

Since the dawn of modernity, "the relationship between the physical sciences and the religious dimension of life has radically altered," as noted by Michael Buckley (1998, 31). Buckley outlines four significantly different relationships that have shaped the interaction between science (in the modern sense) and theology: subsumption, separation or isolation, alienation, and correlation. By subsumption, Buckley refers to the early modern tendency of theologians to turn to the natural sciences to secure warrants for their fundamental assertions about God, first rendering the sciences functionally subservient to theology, then creating the possibility for the denial of God as an unnecessary hypothesis (Buckley 1987, 2004). Subsequently, theology and science became increasingly isolated and methodologically indifferent to one another (separation). With the advent of the nineteenth-century evolutionary theories of Charles Darwin and Alfred Russel Wallace, this separation escalated into alienation and conflict, though the extent of this conflict was often exaggerated and overstated. Surprisingly, Buckley observes, the twentieth century saw the emergence of a new trend: correlating science and theology, which encompasses multiple possibilities.

This new trend is indicated by the leading voices in contemporary theology and science engagement. For example, consider the last two of Ian Barbour's (2000, 7–38) widely recognized four models of interaction between science and theology—conflict, independence, dialogue, and integration. Some later developments, such as Elizabeth Johnson's (2014, 11–12) work, introduce a fifth model that highlights another aspect of correlating the two fields: practical cooperation.[1]

However, these widely known "taxonomies" do not seem entirely satisfying. Most importantly, they fail to sufficiently account for what might be called new forms of "subsumption" (to use Buckley's term) of one field by the other. Such subsumption appears to work in two directions: the subsumption of theology by science and the subsumption of science by theology.[2] The former (what I call a "theology *from* science" approach) seems to repeat the early modern mistake of seeking the warrant for theology's proper claims in science. The latter (what I call a "theology *above* science" approach) entails reverting to premodern models of engagement, reclaiming theology as the "queen of sciences." As we will see in greater detail later, this latter move aligns with the interests of radical orthodoxy (Tyson 2022).

This article seeks to explore and confront the newly emerging risks of subsumption. If we are to move beyond the conflict between theology and science—whether real or perceived—what viable paths lie ahead? In particular, what sustains the "and" that enables their genuine engagement, and what causes this conjunction to shift into something else, such as "or," "from," or "above"? This article shows that answering such questions requires making

explicit the latent philosophical commitments that are de facto operative in the interaction between theology and science. The approach taken here builds on Bernard J. F. Lonergan's philosophy of self-appropriation. Drawing on Lonergan's generalized empirical method, I contend that the possibility of genuine engagement between theology and science lies in the dynamic unity of consciousness—a unity that remains a unity-in-distinction, thus preserving the relative autonomy of each field.

My argument proceeds in two parts. First, I frame the problem by examining several contemporary accounts of the theology–science relationship, resulting in a typology of three untenable alternatives. In the second part, I discuss a fourth, more promising alternative, what I call a "theology *and* science" approach, clarifying its philosophical foundations through the lens of Lonergan's work. While my focus here is primarily on theology's engagement with the natural sciences—arguably the epicenter of the alienation between theology and science—I believe that, *mutatis mutandis*, this reflection is also applicable to theology's engagement with other disciplines.

Part One: Clarifying the Problem

What Buckley termed "correlation" between theology and science is multifaceted, and I propose that some of its dimensions still need to be made more explicit—a primary goal of this first part. As the title of this article suggests, the three untenable alternatives for a viable engagement between theology and science can be summarized as the "theology *or* science," "theology *from* science," and "theology *above* science" approaches.

Theology or *Science*

The "theology *or* science" approach hermeneutically seals theology off from science. This approach is relevant for our purposes for two reasons: first, it is often marked less by an active stance than by a tacit lack of mutual engagement from both sides—a dynamic that needs to be made explicit. Second, it affirms the distinction between theology and science, which results in a limited but still significant overlap with the objectives of this study. However, as we will briefly see, contrary to the desideratum endorsed here, the "theology *or* science" approach readily transforms distinction into separation.

No doubt, very few contemporary theologians would actively oppose theology's engagement with science or advocate for the nonoverlapping magisteria (NOMA) thesis, which calls for respectful noninterference between religion and science (e.g., see Gould 1999, 4–6). This is especially true for Roman Catholic theologians whose vision is shaped by ecclesial commitments. The post-Vatican II magisterial documents have consistently advocated for theology's interdisciplinary engagement. For example, John Paul II's often-cited 1988 letter to George V. Coyne, S.J., Director of the Vatican Observatory,

affirms: "Science can purify religion from error and superstition; religion can purify science from idolatry and false absolutes. Each can draw the other into a wider world, a world in which both can flourish."

More recently, Pope Francis's (2023, §3; translation mine) apostolic letter *motu proprio*, *Ad theologiam promovendam*, underscores that "a synodal, missionary and 'outgoing' Church can only be matched by an 'outgoing' theology." This letter urges theology "not to close itself up in self-referentiality, which leads to isolation and insignificance, but to grasp itself as embedded in a web of relationships, first and foremost with other disciplines and other knowledge" (Francis 2023, §3). Following *Veritatis Gaudium* (Francis 2017), Pope Francis envisions a theology that is not merely interdisciplinary or multidisciplinary but, above all, cross-disciplinary:

> [The approach endorsed here] is of cross-disciplinarity, that is, interdisciplinarity in a strong sense, as distinct from multidisciplinarity, understood as interdisciplinarity in a weak sense. The latter certainly fosters a better understanding of the object of study by considering it from multiple points of view, which nevertheless remain complementary and separate. Instead, cross-disciplinarity should be thought of as "situating and stimulating all disciplines against the backdrop of the Light and Life offered by the Wisdom streaming from God's Revelation." (Apostolic Constitution *Veritatis Gaudium*, Proem, 4c) (Francis 2023, §5)

This magisterial incentive notwithstanding, one cannot help but wonder to what extent theologians are actually equipped for this task. As Buckley (1998, 35) puts it, rather bluntly, "how many members of the Catholic Theological Society of America or of Catholic Theology Departments have anything that could qualify as scientific literacy?" Apparently, without such literacy, verbal endorsements of engagement may amount to little more than a de facto endorsement of the "theology *or* science" approach.

As Buckley (1998, 35) reminds us, without engaging other disciplines, "theology loses [its] vitality." When theologians overlook challenging scientific questions—whether due to scientific *naïveté* or personal preference—they risk missing an opportunity to, as Lonergan puts it, rise to "the level of our own time" (Crowe 2017, 3–4). For example, can a theologian today truly discuss death as a punishment for sin without considering how this aligns with current understandings of biological evolution? Can contemporary theological discussions of suffering, sin, and human complicity in them be adequately addressed without reference to social and human sciences?

At the same time, as I explore in greater detail later, proponents of the "theology *or* science" approach are right to maintain the distinction between the two fields. In the words of John Paul II (1988), "[b]y encouraging openness

between the Church and the scientific communities, we are not envisioning a disciplinary unity between theology and science like that which exists within a given scientific field or within theology proper."

Barbour's (2000, 17) discussion of the "independence" model of engagement between religion and science explicitly clarifies the specifics of this distinction: the two fields are "distinguished according to the questions they ask, the domains to which they refer, and the methods they employ." The independence approach also rightly acknowledges that "each mode of inquiry is selective and has its limitations" (Barbour 2000, 17). However, when the distinction implied in the relative autonomy of the two fields turns into separation, with each field asserting absolute autonomy, it results in an unacceptable compartmentalization of natural and supernatural knowledge. Distinction turned into separation yields the zero-sum fallacy of "either nature or God," thus foreclosing the possibility of genuine cross-disciplinarity.

Michael Hanby (2013, 1–37) argues that such a separation is symptomatic of modern naturalism, which takes science to be the first truth discourse—a recurring theme within radical orthodoxy, explored further in the later section on Paul Tyson's work. Hanby locates the root of the problem in what he terms an "extrinsicist" understanding of the relation between science, metaphysics, and theology, one that ignores the tacit metaphysical and theological assumptions constitutive of science as knowledge of the parts within the whole order of being. Were these assumptions made explicit, they would at least raise the question of the ontological ground of being. However, extrinsicism is willfully ignorant of ontology or sound theology. By casting science as an alternative to metaphysics and theology, it "incoherently makes God into a finite object … regarding divine and natural agency as mutually exclusive alternatives in the order of being," and thereby rendering science and theology mutually exclusive forms of explanation in the order of knowledge (Hanby 2013, 34).

The foregoing brings us back to my original question: How do we bridge the divide between science and theology? The next two sections examine what happens when this question is answered by the de facto revival of either the early modern or medieval models of "subsumption." Let us begin by considering the risk of subordinating theology to science.

Theology from *Science*

What might be called the "theology *from* science" approach risks reshaping theological commitments to fit the confines of empiricist and reductionist epistemologies. While proponents of this approach may claim to integrate science and theology, in practice, they risk subordinating theology to science as the primary authority on knowledge.

As Buckley's analysis of the modern origins of atheism shows, this move has a precedent. According to Buckley, the early modern Christian apologists'

fascination with the arguments from design eventually led to the denial of the very thing they were trying to protect: the existence of God. Buckley (1987, 67) observes: "In the absence of a rich and comprehensive Christology and a Pneumatology of religious experience, Christianity entered into the defense of the existence of the Christian God without appeal to anything Christian." The apologists' bracketing of what was uniquely religious in theology (e.g., scripture and liturgy), and their reliance on the physics of the time to "prove" God's existence, was as good as acknowledging that, in Charles Taylor's (2007, 226) words, "religion must retreat before reason." Theism that sought to prove God's existence from Isaac Newton's universal mechanics—explaining all of reality save the ultimate cause in terms of natural reasons—ultimately negated itself. Turning the apologists' argumentative strategy on its head, the intellectuals with atheistic inclinations soon replaced Newton's nonmechanical First Cause, God, with the notion of dynamic matter. Once science had filled in enough gaps, the "God of gaps" was no longer needed (Buckley 2004, 30–36).

The contemporary forms of subordinating theology to science differ from the early modern deist arguments from design both in content and in their fundamental theological commitments. For instance, they no longer support an impersonal model of the God–world interaction but rather a relational one. Similarly, they are concerned not with proving God's existence but with —in accord with theology's "turn to history"—proving the credibility of God's compassion.

To provide an example of this new subordination of theology to science, consider the twentieth-century transmutations of the theological notion of *kenosis*. Isolated from its biblical Christological context, *kenosis* is often reinterpreted to reject classical theism in favor of process thought and panentheistic metaphysics of creation. This trend can be illustrated by the apparently uncritical application of the term *kenosis*—which the Bible reserves for speaking of the mystery of the Word Incarnate—to the inner life of the Trinity and the doctrine of creation.[3] This seems to reflect a subtle epistemological reductionism, as an empirical view of a dynamic and changing world is attributed to God *in se*. This trend is made fully explicit in process theology's concept of the "dipolar God."[4] Process theology posits divine dipolarity as a kenotic act, where the Creator enters into a relationship with creation by acquiring a temporal aspect within God's own being (e.g., Clayton 2015). The "God of classical attributes" is rejected, with even divine omniscience no longer deemed acceptable. As John Polkinghorne (2008, 68) observes: "The idea [of a dipolar God] seems to imply a kenosis of divine omniscience, resulting in God's possession of a current omniscience (knowing all that is now knowable) rather than an absolute omniscience (knowing all that will ever be knowable)." Rather defensively, he adds, "It would not be a divine imperfection not to know the future, if the future is not yet there to be known" (Polkinghorne 2008, 68).

Although such a perspective may hold pastoral appeal, it raises fundamental questions: What becomes of a God who is perpetually in the process of becoming? Is a suffering Trinity genuinely good news for a suffering world? If all of God's creative acts are inherently kenotic, what then is the significance of Christ's historical incarnation in Palestine? Though engaging, such questions fall outside the scope of the present discussion. They highlight the confusion, rather than clarity, that often arises when theology is epistemologically subsumed by science.

Similarly, though less conspicuously than in process theology, the risk of deriving theology *from* science (as mediated by natural empiricism) can be discerned in the various new forms of panentheism, such as Philip Clayton's (2015) "open kenotic panentheism," Ilia Delio's (2013, 79) "christification" of the cosmos, and John Haught's (2005a, 16–17) "evolutionary descent of God," which allows speaking of "God's kenotic relationship to the entirety of nature" and "God's own suffering."[5] To be sure, panentheism is far from a homogenous phenomenon. Thus, Haught (2005b, 68) might be right that "in many instances [panentheism] is a completely orthodox theological position." In itself, its intention to find a middle ground between classical theism and pantheism manifests a laudable effort to integrate the shift in scientific paradigm with the Christian theological commitment to God's transcendence-in-immanence (Brierley 2004, 3).

However, as Niels Gregersen (2004, 20) notes, all forms of panentheism still "share the intuition of a living two-way relation between God and world, within the inclusive reality of God."[6] If this is true, the question remains whether one can metaphysically differentiate between pantheism ("all God") and panentheism ("all in God"). We still need to ask, following Janet Soskice's (2018, 50) insight, whether any version of panentheism allows a theistic affirmation that "[t]he world is entirely dependent on God, but God is not dependent on the world." Furthermore, as Celia Deane-Drummond (2009, 40) notes with respect to Teilhard de Chardin's apparent panentheism—a source of inspiration for both Delio and Haught—his understanding of the cosmic Christ "seems to rest on metaphysical theory and cosmology rather than the evolutionary biology of Charles Darwin." However, contemporary versions of panentheism do not seem equally equipped to incorporate adequate metaphysics, insofar as they subscribe to ontological monism and, in Deane-Drummond's (2004, 233) words, fail to affirm "the radical particularity of Christ as the revelation of God expressed in the mystery of the incarnation."[7]

The foregoing reflection is not intended to dismiss the need to critique any elements within classical theism that may support "dominologies" (Keller 2003). However, when it comes to offering an equally intellectually coherent alternative to classical theism, it will not suffice to fall back on process theology or dismiss metaphysics altogether. At the very least, an adequate critique should

carefully examine its own potential for error—particularly the tendency to mistake divine impassibility as a psychological rather than ontological category. Even more importantly for the purposes of this article, it must interrogate its own epistemic commitments.

Theology above *Science*

Paul Tyson's recent book, *A Christian Theology of Science: Reimagining a Theological Vision of Natural Knowledge*, brings the epistemological commitments involved in the theology and science dialogue to the forefront, arguing that the contemporary culture accords science the status of the "first truth discourse" (Tyson 2022, 7). Theology, lacking the properties of an empirical science, then finds itself looking up to science for guidance and approval—even when it comes to its properly theological claims. Similarly to other representatives of the radical orthodoxy perspective on science and theology (e.g., Cunningham 2010; Hanby 2013), Tyson is rightly worried about the dangers this poses.

As both Tyson and Conor Cunningham remind us, when science is uncritically enthroned as the measure of all things, tacitly accepting the hegemony of reductive ontological naturalism, both theists and atheists are worse off. Crucially, they both overlook that science develops; therefore, grounding their arguments about God on this or that new scientific discovery alone is like building a house on sand. In Cunningham's witty idiom, "the theology that marries the science of today will be the widow of tomorrow," and, *mutatis mutandis*, the same holds for militant atheism of the sort promulgated by Richard Dawkins (Cunningham 2010, 266). Tyson (2022, 73), for his part, is especially concerned with theology's fate: by capitulating to reductive naturalism, he contends, "Christian theology largely produced its own demise."

Tyson's "theology *of* science" provides valuable diagnostic insights. Unfortunately, the book effectively exemplifies what I call the "theology *above* science" approach—an instance of ordering not theology to science (as discussed in the previous section) but science to theology. Tyson (2022, 3) advocates for a theological framework that "incorporates science into itself and purports to be in a position to stand, in some sense, above science and to explore the validity of the warrants of scientific truth that science itself must simply assume." This effort to unify science and theology by subordinating science to theology as the primary truth discourse, within which the meaning of natural knowledge is to be interpreted, yields a new kind of subsumption that denies a relative autonomy of science.

Though Tyson's solution is ultimately dissatisfying, his diagnosis is quite insightful. He rightly laments the compartmentalization of knowledge into smaller and more controllable silos, suggesting that "specialization and domain limitation" give "our aspirations to know and control reality a semblance of plausibility" but complicate the integration of knowledge (Tyson 2022, 1).

The unity of truth has been discarded as a vestige of an outdated worldview, and now competing epistemic commitments drive a wedge between natural and supernatural knowledge. The result, Tyson (e.g., 2022, 31) argues, is a "remarkable reversal"—the nineteenth-century shift from Christian theology as the public first truth discourse to modern science. Tyson (2022, 2) observes: "In our present times, the functionally materialist knowledge categories of science act as the dominant first truth discourse of Western modernity's overarching framework of academic meaning … [T]he reductively naturalist first truth discourse of our academy tacitly disciplines whatever is on the other side of science (say, religion) to be commensurate with its own functionally materialist first truth commitments."

Tyson argues that this reversal has turned the relationship between the two interpretive commitments upside down. While premoderns engaged in a theology-to-science dialogue, interpreting the natural world within a theological framework aimed at understanding higher meaning and value, post-Victorians unreflectively subscribe to a science-to-theology interpretive framework.[8] As a result, modern science now feels entitled to pass judgment on the true meaning of Christian theology. Because modern science is reductively physicalist, religious beliefs are often deemed backward, mythical, or outright delusional and thus relegated to the private sphere. The major problem, Tyson (2022, 32–33) argues, is epistemological: the shift from a theocentric ontological foundationalism that trusts God as the ultimate source of being and knowing to an egocentric epistemological foundationalism that grounds reasoned understanding in the individual knower. Moreover, this "remarkable reversal" remains unacknowledged, as participants are blind to their own latent metaphysical and epistemological commitments (see Tyson 2022, 132, 143).

Instead of attempting to relate the various silos through a range of "interdisciplinary knowledge adventures, usually defined by the conjunction *and*," Tyson (2022, 98) advocates for theology to reclaim its place as the queen of sciences by reviving "a religion-to-science interpretative outlook on natural knowledge." He unapologetically favors the radical orthodoxy approach to the relationship between theology and science, as evidenced both by his penchant for rhetorical inflation[9] and his call for theologians to leave the secular academy behind to establish uncontaminated centers of Christian learning (Tyson 2022, 127, 170–76). Even more disappointingly, Tyson's (2022, 1) otherwise commendable search for a framework that "enables us to organize disparate types of knowledge into a single framework of meaning"—which aligns with his radical criticism of secular culture—ultimately rests on a confusing retrieval of Platonic epistemology.

Tyson's return to the key insight of classical realism—such as he discerns in Plato—is rather helpful. After all, only if the true is the intelligible (as well as the good, the beautiful, etc.) can one affirm God as real (Tyson 2022,

112–22). However, his attempt to translate Plato's epistemological categories into contemporary terms comes across as both awkward and underdeveloped. The greatest issue lies in Tyson's peculiar juxtaposition of knowledge and understanding: natural sciences typically wield "bare knowledge," while theology holds genuine understanding (see Tyson 2022, 119–21, 124–26).[10] The lack of clarity regarding the relationship between understanding and knowledge—terms Tyson does not clearly define—arguably leads to an oversight, obfuscating the fact that both theology and science offer distinct instances of genuine understanding.[11]

In summary, an attempt to reverse the modern relationship between theology and science by flipping it upside down—such as by Tyson—effectively denies the relative autonomy of both fields and suggests a reductionism of its own kind: the "supernaturalization" of all knowledge. By extension, it fails to make a compelling case for bringing theologians and scientists together as equal partners in an ongoing conversation. In light of these concerns with the "theology *above* science" approach, an alternative means of reclaiming the unity of knowledge seems necessary, to which we turn next.

Part Two—Theology *and* Science: Unity in Distinction

Tyson's attempt to reclaim theology as the "first truth discourse" risks what Lonergan (2018, 274) calls illegitimate sacralization, which must be resisted by liberating "a secular domain from the once but no longer appropriate extension of the sacral."[12] While Tyson (2022, 143) blames historical criticism for delivering the final blow in theology's dethroning, Lonergan (2018, 274) suggests that the pre-Vatican II Roman Catholic defensive suppression of engaging with the signs of the times was an instance of an (illegitimate) extension of "the medieval sacralization of philosophy and science, of society and law." Analogous to Buckley's analysis of Christianity's complicity in the origins of modern atheism, Lonergan (2018, 274) proposes that it was a "[p]ersistent age-long rearguard action … maintained in the Roman Catholic Church" that, more than a hundred years later, contributed to the rise of secularism—"the outraged and outright rejection of all religion as the futile champion of a dead and unlamented past."

Hence, Lonergan proposes that the spheres of the sacred and the secular (and, by extension, of theology and science) should have their relative autonomy: there is a legitimate secularization, and it is to be fostered. In Lonergan's (2018, 273) terse assessment, the sacralization of the secular that came with the advent of Constantine, which made culture, sociopolitical life, economy, technology, philosophy, and science subordinate parts of a religious worldview, was like "building one's house not on a rock but upon sand." The Babylonian cosmology implicit in scripture readily aligned with Ptolemaic astronomy, and the Greek influences in the New Testament and the apocrypha allowed for a merger between the biblical understanding of humanity and Aristotelian views

of human nature. However, the rise of modern science revealed the inherent fragility of subordinating science to theology and sacralizing specific scientific paradigms. As Lonergan (2018, 273) observes, the "sacralized construct of [human beings] and [their] universe was impugned, and impugned successfully, by Copernicus, Galileo, and Newton, by Darwin and Freud, and by the swarm of philosophies and counter-philosophies that began at least with Descartes."

In light of the foregoing, the main aim of what follows is to examine the conditions for the possibility of a unity-in-distinction between theology and science—that is, the possibility of asserting their relative autonomy without turning that autonomy into separation. I believe this possibility lies in the application of what Lonergan calls "generalized empirical method." The following four sections progressively make this claim explicit by: (1) explaining the isomorphism between theological and scientific inquiry; (2) clarifying Lonergan's notion of self-appropriation; (3) identifying the transcultural aspect of generalized empirical method; and (4) bringing these elements to bear on the unity-in-distinction of theology and science.

Common Search for Understanding

In his pre-*Method* essay, "Isomorphism of Thomist and Scientific Thought," Lonergan proposes that the isomorphism between theology and science—and, by extension, the possibility of their dialogue—is grounded in the common search for understanding, not simply in the fact that the same mind carries out the search. In response to the question, "Why are Thomist metaphysics and scientific thought isomorphic?," he wrote:

> Clearly, it is not enough to say that both types of thought proceed from the same human mind, for it is quite easy to point to a variety of philosophies that proceed from the human mind without exhibiting any notable isomorphism with scientific thought. The answer, then, must envisage the human mind under some precise aspect; and the relevant aspect, I submit, is neither truth nor certitude nor deduction nor necessity nor universality nor conception nor inquiry nor intuition nor experience nor a priori synthesis nor apperceptive unity nor description nor phenomenology nor induction nor, indeed, any mere combination of these. The relevant aspect is understanding. (Lonergan 2005, 138)

This suggests that, as we will see Lonergan proposing later, the unity of theology and science does not rest on a shared set of propositions or common beliefs but on a common search for understanding: insofar as people are engaged in the genuine search for understanding, they will be able to hold tensions arising from incommensurate theoretical frameworks and even apparent contradictions and clashes between scientific inquiry and dogmatic assertions. In the words of Cardinal John Henry Newman (2008, 224), despite "momentary collisions,

awkward appearances, and many forebodings and prophecies of contrariety," both sides must continue their work "with full faith in the consistency of [the] multiform truth."

As Lonergan (2017, 168) explains, an act of understanding or insight precedes concepts rather than follows them; it is "a prepropositional, preverbal, preconceptual event." Insight "consists in a grasp of intelligible unity or relation in the data or image or symbol. It is the active ground whence proceed conception, definition, hypothesis, theory, system" (Lonergan 2017, 200). Hence, understanding is not to be confused with one's formulation of the meaning of what has been understood or with the judgments concerning the truth of one's understanding and formulation. In order to develop a concept and discern its validity, one must first understand (Lonergan 2017, 151), and there are multiple ways to express the content of an insight in concepts (Lonergan 2017, 201).

Insofar as both science and theology seek understanding that is always prior to conceptualization or formulation, they can find common ground. However, finding common ground does not mean collapsing the two fields into one. According to Lonergan, the relative autonomy of science and theology is not just a desideratum that follows from legitimate secularization. It is also a mark of humanity's cultural development, which he theorizes in terms of the three "stages of meaning." These stages represent the expansion of human capacity to control meaning beyond the linguistic and symbolic means of common everyday communication (the realm of "common sense"): "In the first stage conscious and intentional operations follow the mode of common sense. In a second stage besides the mode of common sense there is also the mode of theory, where the theory is controlled by a logic. In a third stage the modes of common sense and theory remain, science asserts its autonomy from philosophy, and there occur philosophies that leave theory to science and take their stand on interiority" (Lonergan 2017, 85).

Lonergan's two best-known works, *Insight* (Lonergan 1992) and *Method in Theology* (Lonergan 2017), are fundamentally devoted to fully articulating the third stage of meaning, interiority. This stage emerges when cultural conditions empower the human mind—on an unprecedented scale—to grasp both the polymorphism of consciousness and the unified dynamism of cognition across diverse contexts, including ordinary, religious, and scientific domains.[13] This self-possession of the mind, an interiorly differentiated consciousness—which, in *Insight's* terms, begins as a "sufficiently cultured consciousness" (Lonergan 1992, 22)—also makes it possible to account for interdisciplinary differences without making distinctions into separations.

Lonergan's contribution demonstrates that the engagement between theology and science cannot be grounded merely in their complementarity, what David Fergusson (2012) terms "compossibility," or the modification

of core Christian beliefs to suit the whims of the latest scientific discovery.[14] Nor can their unity arise from reinstating theology as "the queen of sciences." Neither is it grounded, first and foremost, in latent metaphysics and *theologia naturalis* as intrinsic to the sciences, as Hanby (2013, 21) would have it. For Lonergan, the unity-in-distinction between science and theology originates from the fundamental structures of inquiry that underlie its every form. These structures, disclosed through the practice of Lonergan's "first philosophy"—self-appropriation—illuminate and unify different domains of knowledge, thus avoiding false dichotomies.[15]

Self-Appropriation

Self-appropriation provides a pathway for unifying theology and science by going behind the activities of inquiry and insight in the plurality of contexts, including daily life (common sense), scientific exploration (theory), and theological reflection (religion). It examines the cognitional processes underlying all forms of human knowing. Through the practice of self-appropriation, Lonergan firmly aligns with realism.[16] Like Tyson (2022, 97–98), Lonergan rejects the idea that the ultimate criterion of truth lies in the empirical measurement of sensory data. Instead, truth, for Lonergan, is grasped through critically reflective understanding that is attentive, intelligent, rational, and responsible.

Through self-appropriation, Lonergan's voyage into the realm of interiority yields what he in *Insight* terms a generalized empirical method—an approach that explicitly identifies the basic pattern of human cognition by applying empirical method to the data of consciousness. In *Method in Theology*, Lonergan calls it "transcendental method," insofar as it concerns human self-transcendence in knowing, willing, and loving.[17] Transcendental method makes explicit that human knowing is a dynamic structure characterized by the fourfold enlargement of consciousness: experience is sublated (that is, enriched and transformed) by the desire to understand, understanding by the desire to judge based on evidence, and judgment by the desire to ground responsible decisions in genuine value. To know in a full sense, therefore, is to understand correctly and responsibly (or to take responsibility for one's correct knowing). Moreover, to know what we do when we know (cognition) and why doing that really counts as knowing (epistemology) demands self-reflexivity that is akin to reduplication of the cognitional operations of experiencing, understanding, judging, and deciding.[18]

The basic pattern of coming to know—through experiencing, understanding, judging, and deciding—is normative, though not in a foundationalist sense. That is, transcendental method does not rest on self-evident principles or beliefs derived from revealed knowledge. It rests on "making explicit the basic normative pattern of the recurrent and related operations of human cognitional process" (Lonergan 2017, 26) that results in self-appropriation, a kind of inductive thinking. Its normativity lies in the fact that one cannot truly know

without asking and answering all relevant questions: questions for understanding (e.g., What? Why? How? When? Where?), questions for reflection (Yes? No? Is it so?), and questions for evaluation, deliberation, and decision (Is it good? Is it worthwhile?). For Lonergan (2017, 17), this "normative pattern of recurrent and related [cognitional] operations" is empirically verifiable. Denying it would result in a performative contradiction, as passing judgment against it would itself involve engaging in the very process of asking and answering the relevant questions, as outlined earlier (Lonergan 2017, 23).

Lonergan's transcendental method helps clarify what makes the three approaches to the theology and science relationship discussed earlier in this article philosophically unacceptable. In a nutshell, they all rest on false premises about human cognition.

The "theology *or* science" approach rests on the premise that there is no way to genuinely reconcile the valid (but insufficient) insights of idealism (that we know the intelligible) and materialism (that we know through sense experience). In contrast, taking idealism to be a "half-way house" between his own critical realism and materialism, Lonergan (1992, 22) shows that what constitutes knowing is a correct understanding of data supplied by both sense and consciousness.

The "theology *from* science" approach betrays a penchant for what Lonergan (2017, 247) calls naïve realism—that knowing amounts to extroversion, as if we know by "taking a good look." This is illustrated, for instance, by Polkinghorne's (2001, 98) endorsement of the scientist's "instinctive realism," which endeavors to "align epistemology and ontology as closely as possible" (Polkinghorne 2001, 100), in effect tacitly collapsing knowing and being. Accordingly, to affirm that "God knows things as they really are," Polkinghorne (2001, 103) feels the need to posit a temporal pole in God.[19]

Finally, the "theology *above* science" approach, as exemplified here by Tyson, tacitly succumbs to philosophical postmodernity's view of reason as a "foundationed" process, fated to undo itself due to the incommensurability of competing first premises (such as "either theocentrism or egocentrism"). Instead, Lonergan disambiguates the foundations of knowing as "logically first premises" from foundations understood as an authentic person, circumventing the foundationalist problem *tout court*. For him, it is human authenticity—understood as ongoing self-transcendence in pursuit of genuine understanding, truth, and value—that is the remote principle of every truly human inquiry and progress (Lonergan 2017, 106, 272, 380).

Lonergan (2017, 370) argues that generalized empirical (or transcendental) method, as briefly explained earlier, is central to sustaining unity across diverse fields of inquiry: "Through the self-knowledge, self-appropriation, and self-possession that result from making explicit the basic normative pattern of the recurrent and related operations of human cognitional process, it becomes

possible to envisage a future in which all workers in all fields can find in transcendental method common norms, common critical, dialectical, heuristic procedures, common foundations, and systematics." This statement suggests that generalized empirical method possesses a transcultural foundation from which both specific methodologies and common norms are derived. Allow me to explore these aspects further, beginning with the transcultural basis.

Transcultural Basis

As explored earlier, Tyson's radical orthodoxy argument can be encapsulated as "one (propositional) truth, therefore one first truth discourse." Lonergan, however, contends that the unity of theology and science can no longer rest on a shared set of premises that emerge from a common field of knowledge or propositional truths held in common; the era of Aristotelian science is over. Yet, from moving beyond common premises "does not follow that there are to be no foundations at all" (Lonergan 2017, 367). Lonergan (2017, 367) further explains: "As there are firsts in the order of premises, so too there is a first in the order of methods. That first is transcendental method, and its function is to provide foundations when one moves from the abstractness of logic and the Posterior Analytics, of human nature and the human soul, to the concreteness of individual human subjects in their historical milieux working at modern sciences in accord with their appropriate methods."

Does this proposal imply a return to the premodern pretensions of universality, which, in Sarah Coakley's (2012, 17) terms, cling to "the belief in a shared 'flat plane' of universal reason, on which philosophers, scientists and theologians might meet to do genuine battle"? The answer would be yes only if the options were strictly dichotomous: universality versus historicism, or universal reason versus the Babel of incommensurable rationalities. However, in keeping with the Catholic tradition, Lonergan wants to affirm both/and: transcendental method *and* its specific determinations, particularity of cultures *and* the transcultural validity of cognitional performance.[20] His preference in later works, such as *Method in Theology* (Lonergan 2017, 125, see also 146n2), for the language of "comprehensive viewpoint" over the earlier "universal viewpoint" found in *Insight* underscores that, over time, this affirmation becomes more explicit. Yet even the earlier term does not assume a "flat plane"; rather, it refers to a heuristic structure of knowing—an anticipation of the "potential totality of genetically and dialectically ordered viewpoints" (Lonergan 1992, 587).[21]

Regarding the transcultural aspect of transcendental method, Lonergan (2017, 264) explains: "Transcendental method … is, in a sense, transcultural. Clearly it is not transcultural inasmuch as it is explicitly formulated. But it is transcultural in the realities to which the formulation refers, for these realities are not the product of any culture but, on the contrary, the principles that produce cultures, preserve them, develop them." This articulation underscores

that affirming a transcultural basis does not imply an a-historic account of rationality, for which postmodernity has little patience.[22] Lonergan clarifies this point further by situating transcendental method in relation to what he terms transcendental notions. He notes that his method is transcendental because the results envisaged "are not confined categorially to some particular field or subject, but regard any result that could be intended by the completely open transcendental notions" (Lonergan 2017, 17–18). These notions refer to humanity's innate "capacity for seeking and, when found, for recognizing instances of the intelligible, the true, the real, the good" (Lonergan 2017, 264). Transcendental notions make questions and answers possible, while categories render them determinate. As Lonergan (2017, 264) explains, "[a] question can be put differently with every cultural difference, but it is the same fundamental question that is arising." By the same token, transcendental notions are general, while categories are specific—not only to various cultures but to various fields of inquiry.

In other words, while the concrete ways of posing and answering questions are specific to each culture and context, the underlying wonder—the drive to seek understanding, judgment, and evaluation—as well as the resulting dynamic pattern of human cognition, is transcultural. Correspondingly, for Lonergan, the fourfold dynamic structure of human knowing—constituted by experience being sublated by understanding, understanding by judgment of truth, and judgment of truth by judgment of value—is invariant across both cultures and fields of inquiry. By contrast, the historicist alternative, which embraces a proliferation of incommensurate and localized rationalities, might appear compelling. Yet, consistent with its own principles, on what grounds could it justify such a stance?

Specific Methodologies, Common Norms

Endorsing cross-disciplinary engagement between science and theology on a transcendental basis necessitates affirming their relative methodological autonomy. As discussed earlier, Lonergan (2017, 264) asserts that "[w]hile the transcendental notions make questions and answers possible, categories make them determinate." Conceiving method concretely, therefore, does not mean reducing it to "principles and rules, but [seeing it] as a normative pattern of operations with cumulative and progressive results" that facilitate distinguishing "the methods appropriate to particular fields" (Lonergan 2017, 17n11).

Thus, transcendental method serves a heuristic function: it makes the known unknowns explicit. However, the transformation of the unknown into the known occurs only through the gradual accumulation of determinations specific to each discipline. This underscores that, in the common search for truth, the methodologies and concrete means of adjudicating conclusions will necessarily differ across fields. For example, both a theologian and a biologist might agree

that a theory of intelligent design is wrong. Yet, their justifications would differ: a theologian would argue from faith claims that give rise to the speculative affirmation of the noncompetitive character of divine action, while a biologist would rely on empirical evidence that refutes the examples (or gaps) intelligent-design theorists invoke. In other words, each would approach the same truth by employing methodologies, procedures, and specific norms appropriate to their fields. The adequate judges of their success will be those with expertise in the relevant domain, as special methods "derive their proper norms from the accumulated experience of investigators in their several separate fields" (Lonergan 2017, 369). Therefore, cross-disciplinarity depends on the condition of mutual engagement.

Such engagement proves fruitful to the extent that the transcultural normativity inherent in human cognition—at least implicitly—provides a foundation for negotiating real or apparent disagreements, addressing dialectical oppositions, and fostering practical cooperation. If Lonergan (2017, 361) is correct in asserting that "all special methods are adaptations and complications of the completely general pattern of transcendental method," then transcendental method should indeed facilitate cross-disciplinary collaboration. But how? Lonergan's (2017, 368) response grounds this facilitation in the transcultural normativity of what he calls transcendental precepts: "All special methods consist in making specific the transcendental precepts, Be attentive, Be intelligent, Be reasonable, Be responsible."[23] He elaborates: "However true it is that one attends, understands, judges, decides differently in the natural sciences, in the human sciences, and in theology, still these differences in no way imply or suggest a transition from attention to inattention, from intelligence to stupidity, from reasonableness to silliness, from responsibility to irresponsibility" (Lonergan 2017, 370).

The foregoing highlights that the normativity of transcendental precepts involves resisting the temptation to prematurely conclude one's inquiry, expanding one's horizon of knowing, uncovering biases, addressing distortions, and committing to causes that are genuinely worthwhile. Therefore, the transcendental precepts are not only meant to guide the development of methodologies specific to each field but also to facilitate cross-disciplinary dialogue.[24] Regarding "the foundational function" of transcendental method, Lonergan (2017, 369) observes:

> Besides the tasks of each field, there are interdisciplinary problems. Underneath the consent of men as scientists, there is their dissent on matters of ultimate significance and concern. It is in the measure that special methods acknowledge their common core in transcendental method that norms common to all the sciences will be acknowledged, that a secure basis will be attained for attacking interdisciplinary problems, and that the sciences will be mobilized within a higher unity.

As noted, Lonergan's advice for addressing interdisciplinary challenges—directed at both theologians and scientists—is to make their underlying philosophical commitments explicit.[25] One way to achieve this is by studying transcendental method, as unapologetically promoted in Lonergan's (2017, 371) own succinct endorsement: "To study transcendental method is not to study theology, or human science, or natural science. On the other hand, to study theology or human science or natural science is to use one's mind, and, if one is not merely to do so but also to know what one is doing, to know basically what others are doing in other fields, to be able to communicate with them, then one must study transcendental method."

To conclude this second part of the article, insofar as the unrestricted desire to know underlies all cognitional acts, truth remains the horizon toward which both the scientist and the theologian move. Lonergan is not unique in advocating for both the unity and relative autonomy of theology and science. Nor is he more eloquent than others in describing the implications of accepting that truth is one—despite being frequently distorted by our shortsightedness or culpable ignorance, and despite being apprehended through a multiplicity of concepts. Buckley (1998), among others, makes a very similar and perhaps even more compelling argument for the mutual engagement between religion and science as an intrinsic part of the mission of the church. Lonergan's unique contribution, however, lies in grounding the unity-in-distinction of theology and science in the unity of transcendental method, fully fleshing out the conditions for authentic knowing.

Conclusion

The engagement between theology and science seems to be entering a new era where science is, on the one hand, capable of pointing toward ultimate questions on an unprecedented scale and, on the other, assumes, whether tacitly or explicitly, a "flat plane" of rational interdisciplinary dialogue confined to reductive empiricism and physicalism. Theology, in turn, is equally affected by both the new possibilities and the threat of being subsumed by science as the first truth discourse. This may provoke—as seen in the radical orthodoxy approach—a reactive attempt to subordinate science to theology. Alternatively, as argued in the second part of this article, it may prompt an effort to explore human cognitional processes as transcultural and transdisciplinary, affirming both the unity and distinction of theology and science.

Such an effort provides rational—but not rationalist—avenues for rethinking the reasons why and how theology and science should cooperate on practical solutions to pressing challenges, such as the ecological crisis. Moreover, it enables a reimagining of the engagement between theology and science that respects the canons of each field, avoiding the quick condemnation or dismissal of the other. Most importantly, it prevents the premature closure of doors to

new insights that can only emerge through real dialogue. As genuinely, though provisionally, true—since new data will always raise further relevant questions—these insights can only be developed by applying the expertise of both fields.

As recently demonstrated by Coakley and Martin Novak, it is not only science that informs new understandings of the faith mysteries (Nowak and Coakley 2013). Christian ideas—perhaps no less, and perhaps even more—can expand the horizon of the known unknowns in science, prompting new scientific insights. For instance, I believe Coakley is right in asserting that it takes a Christian mindset to discern and be motivated to mathematically verify the possibility that costly cooperation (in the case of humans, altruism) is the third driving principle of evolution, alongside mutations and natural selection. She may be equally right in arguing that this does not mean subordinating science to theology, as evidenced by the fact that both the procedure and conclusions of Novak's work are approved by the scientific community, which does not necessarily share his Christian beliefs (Coakley 2012, 24–25). The implicit norm governing this approval is a tacit recognition of the internal integrity of an inquiry that asks and answers all relevant (and highly specialized) questions. In Lonergan's (2017, 368) terms, such integrity is the result of following the transcendental precepts: "Be attentive, Be intelligent, Be reasonable, Be responsible."

The unity of theology and science, as the papal magisterium discussed in the beginning of this article reminds us, cannot be an identity. This study focused on predominantly philosophical reasoning regarding the relative autonomy of the religious and the secular. However, there are equally important theological reasons for upholding such autonomy. In his essay on secularization, Lonergan (2018, 269) articulates these reasons by drawing on the mysteries of incarnation and redemption: in Christ, we see the unity of human and divine, the secular and the religious—the unity concretely manifested only dialectically in his death and resurrection. In his reflection on Elizabeth Johnson's *Ask the Beasts: Darwin and the God of Love*, Brian Robinette (2016, 475) offers another theological reason for the relative autonomy of theology and science. He reminds us that "at the heart of Christian faith itself is a caesura—an interruption or break that casts a radically new light upon what we take for granted about creatureliness." That caesura, as evidenced in Christ's resurrection, not only gives hope for "all the dead of Darwin's tree of life" (Robinette 2016, 478) but also cautions against indiscriminate accommodations in theology's engagement with science. In Robinette's (2016, 475) words, "[t]hat caesura is an eschatological perspective that a scientific account of life cannot provide."

However, unlike Karl Barth, these Catholic thinkers do not reject natural theology or the relative autonomy of science.[26] For Lonergan, the unification of all things in Christ is both continuous with and transformative of the emerging world order (Ryliškytė 2023, 386–438). For Robinette (2016, 478),

"the resurrection is not an explanation for anything, but it is a response"—the divine response that grounds eschatological hope for creation in the one who is "the firstborn *of* all the dead of Darwin's tree of life." In this way, science and theology—not unlike the natural and supernatural orders in the tradition they represent—maintain a relative autonomy that resists both separation and the subsumption of one by the other.

Notes

[1] I believe the critical interrogation of both science and theology in order to make explicit the liberating and oppressive capacities of both, undertaken by some scholars working with the critical theories lens, also falls under the category of "practical collaboration." For an example, see Myrna Perez Sheldon, Ahmed Ragab, and Terence Keel (2023).

[2] Because "science" here is used in the modern sense (i.e., natural sciences and, possibly, human sciences), this framing of the problem highlights a modern departure from the Aristotelian-Thomist understanding of science. It also raises the question of whether theology can still be considered "scientific" in some sense. Within the Aristotelian paradigm, St. Thomas Aquinas regarded theology as the highest science. However, with the shift to natural (physical) sciences as the paradigmatic form of science, theology came to be seen as distinct from "science." For an illuminating discussion of the Thomistic notion of theology as a science, see Bernard Lonergan (2005, 117–27). For contemporary insights into the conditions under which theology might still be conceived as a science, see David Piché (2010) and Olivier Boulnois (2011).

[3] For instance, see Jürgen Moltmann's (1991, 88) kenotic theology of creation. See also John Haught's (2007, 73) endorsement of this idea in proposing that the self-effacing of the Creator entails the "smallness" of divine omnipotence and omnipresence. For contemporary attempts to offer viable theologies of *kenosis* that reckon with the boundaries of Christian orthodoxy (broadly conceived), see C. Stephen Evans (2006).

[4] As later expounded by John B. Cobb and David Ray Griffin, the concept of the dipolar God originates with the process metaphysics of Alfred North Whitehead (1978) and Charles Hartshorne (1948). In his later rebuttal of criticisms that the necessary being cannot also be contingent, Hartshorne argues that "the apparent inconsistency disappears when one takes into account the distinction between the divine existence and the divine actuality" (Hartshorne and Hahn 1991, 619). To a classical theologian, this raises the question of how one can introduce potency into God's nature without undermining divine simplicity. In turn, without affirming divine simplicity, an argument for God as an uncaused cause seems to collapse, and one needs to posit an infinite recess of gods, none actually being God the Creator of all that exists (for this line of reasoning, see Aquinas, *Summa Theologiae*, I q. 3. aa. 1–8, esp. a. 7 co.). For more on the Thomistic reasons for affirming divine impassibility, see James Keating and Thomas Joseph White (2009).

[5] My engagement with Haught here also draws on Gloria Schaab's (2010) appraisal of his broader work.

[6] Gregersen's three varieties of panentheism include: soteriological panentheism (exemplified by John Zizioulas), expressivist panentheism (exemplified by Georg Wilhelm Friedrich Hegel and Friedrich Wilhelm Joseph von Schelling), and the dipolar panentheism (inspired by Whitehead and Hartshorne); see Gregersen (2004). For a helpful review and revision of Gregersen's position, see Jospeh A. Bracken (2014).

[7] To my mind, the primary issue with ontological monism—even Philip Clayton's (2000) emergentist monism—is that it upholds the unity of the universe at the cost of denying its spiritual (nonphysical) dimension. Without such a dimension, affirming divine causality in the world becomes either impossible (since God's immanence cannot be reduced to physical phenomena) or collapses into a physicalist reduction in which God is somehow present in all matter, whatever that presence might mean.

[8] Tyson (2022, 73) aligns with Michael Buckley's and Charles Taylor's analyses of secularization, claiming that "Christian theology largely produced its own demise as the West's primary truth discourse." His original contribution lies in attributing the blame to historical criticism: "It was not the Darwinian account of evolution that dealt a death blow to modern Western Christian theology; it was late eighteenth-century and early nineteenth-century historical-critical biblical scholarship that did it" (Tyson 2022, 143).

[9] For instance, he writes that theology should "treat 'science' as if it does not exist" (Tyson 2022, 90) and that the proponents of late nineteenth-century scientific naturalism "have killed and eaten" Christian theology (Tyson 2022, 131).

[10] In contrast, as explored in the second part of this article, Lonergan (1992, 22) clarifies that understanding is always constitutive of genuine knowing: for him, knowing is understanding correctly.

[11] Rather than providing general definitions of both terms, Tyson proposes two distinct types of knowledge and understanding, approximately describing the meaning of each type in relation to Plato's epistemological categories: Knowledge I (*eikasia* in Plato) pertains to sensory perception, while Knowledge II (*dianoia* in Plato) pertains to mathematical reasoning (both of which are "minimally theorized") (Tyson 2022, 119–20, 187). Meanwhile, Understanding I (*pistis* in Plato) is described as "existentially situated" and Understanding II (*noēsis* in Plato) as "essentially situated meaning, valuing, and purposeful understanding" (Tyson 2022, 192).

[12] Lonergan (2018, 264) distinguishes four possibilities: "(1) a sacralization to be dropped and (2) a sacralization to be fostered; (3) a secularization to be welcomed and (4) a secularization to be resisted."

[13] For example, interiorly differentiated consciousness enables the meta-thinking necessary to reconcile Eddington's two tables: "[T]he bulky, solid, colored desk at which he worked, and the manifold of colorless 'wavicles' so minute that the desk was mostly empty space" (Lonergan 2017, 81).

[14] In his 2009 Gifford Lectures, Fergusson argued that the postmodern condition leaves only two viable options for natural theology. Sarah Coakley (2012, 17) summarizes these as, on the one hand, what she terms "'the defeating the defeater' ploy," which challenges the background presuppositions of secularism (a strategy well illustrated, I believe, by Tyson), and, on the other hand, "the 'compossibility' option for 'natural theology,'" which asserts that there is no inherent logical failure in a personal Christian decision to interpret evolutionary history as the hand of God—"even though I dare not, or for Barthian reasons will not, attempt any evidential demonstration of such." See also Fergusson (2012, 78–95).

[15] For more on cognitional theory, or philosophy of self-appropriation, as his first philosophy, see Lonergan (2016, 232; 2018, 357).

[16] Lonergan terms this "critical realism," using "critical" in at least two senses: it serves as a critique of philosophies of knowing as well as affirms the role of reflective understanding and judgment as the final increment in the process of coming to know.

[17] Strictly speaking, Lonergan's (2017, 17 n11) method is transcendental in two senses: in the Scholastic sense, as opposed to categorial, and in the Kantian sense, as clarifying the conditions for the possibility of an a priori knowing. Lonergan appears to have returned to using "generalized empirical method" in at least some of his post-*Method* work. See, for instance, Lonergan 2018 (381) and Lonergan 2021 (171, 173).

[18] In Lonergan's technical formulation, self-appropriation entails applying operations as intentional (intending themselves as an object of inquiry) to the operations as conscious (given in the flow of waking consciousness): "To apply the operations as intentional to the operations as conscious is a fourfold matter of (1) experiencing one's experiencing, understanding, judging, and deciding, (2) understanding the unity and relations of one's experienced experiencing, understanding, judging, deciding, (3) affirming the reality of one's experienced and understood experiencing, understanding, judging, deciding, and (4) deciding to operate in accord with the norms immanent in the spontaneous relatedness of one's experienced, understood, affirmed experiencing, understanding, judging, and deciding" (Lonergan 2017, 18).

[19] The charge of naïve realism can be further supported by adverting to Polkinghorne's (2001, 102, 104) dismissal of Thomist creation metaphysics on the grounds of its alleged mysteriousness, even to the point of making God into a cause among other causes. What makes St. Thomas Aquinas's account of transcendent causality "too mysterious," Polkinghorne " (2001, 102) does not explain. However, one might suspect that his real concern is that a transcendent cause is unimaginable. But if unimaginable is taken to mean obscure or unintelligible and unreasonable, one cannot but conclude that knowing indeed means little more than taking a good look.

[20] For instance, see Lonergan's (2017, 3, 120, 281, 293, 307) discussion of the classicist and empirical notions of culture in *Method in Theology*.

[21] For more on the continuity and development between *Insight*'s notion of the universal viewpoint and *Method in Theology*'s comprehensive viewpoint, see Ivo Coelho (2001). Coelho (2001, 10) convincingly shows that in *Method in Theology*, "the functions of the universal viewpoint are taken over by transcendental method."

[22] According to postmodern anthropologies, rationality is so localized and historicized that the categories of other cultures are considered untranslatable. Alasdair C. MacIntyre (2020) suggests that the only possible way to "rationally" vindicate the truth of competing traditions of inquiry is by comparing "the adequacy and explanatory power" of their historical traditions. However, if MacIntyre (2020, 403) is correct that "there are no tradition-independent standards of argument," it becomes unclear on what basis this "adequacy" can be adjudicated and why one should regard the outcome of such adjudication as in any way superior to rival alternatives.

[23] In another passage, he adds the highest precept, "Be in love," which takes into account the en-graced transformation of human cognition and volition (Lonergan 2017, 252).

[24] A notable example of such facilitation is the interdisciplinary collaboration applying Lonergan's generalized empirical method at several universities in the United States, including Seton Hall and Boston College. Another compelling instance is the dialogue between environmental sciences and philosophy, as exemplified by Patrick H. Byrne's (2024) work in environmental ethics. Other notable contributions to Lonergan scholarship on the interaction between theology and science include works by Byrne (2005), Robert M. Doran (1971), Daniel A. Helminiak (1996, 1998), Neil Ormerod (2007, 2015), and Cyril Orji (2018).

[25] In line with Lonergan, the concrete implementation of this cross-disciplinary dialogue is something theology must address in relation to its functional specialties—a task that lies beyond the scope of this article.

[26] For an appraisal of Barth's approach to natural theology, see Andrew Torrance (2019). For a helpful account of Lonergan's views on natural theology, which also sheds light on their distinction from the Barthian position, see Ormerod (2015).

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An Introduction: Our Universe and Questions It Suggests

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This is a simple introduction for nonspecialists in astronomy, theology, or philosophy to set the scene for the thematic section "Theology and Philosophy Engage the New Cosmology." The objective of the section is to give an up-to-date account of a current understanding of the universe and its origin and to discuss theological and philosophical questions that arise from that scientific understanding. Three authors describe different aspects of astronomy, a further four describe related philosophical issues, and the final four authors focus on theological responses. This introduction presents a simple overview of the current scientific understanding of the origin of the universe and its evolution and nature. It also raises philosophical and theological questions of origin, purpose, and design, as well as putting forward the case for a retrieval of natural philosophy.

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Imagine lying on your back in a meadow on a crystal clear night, gazing up at the stars and noticing many more than you had ever seen before—jewels twinkling across eons of space, of diverse colors and distances, and grouped together in different ways. Maybe, as you look outwards, you are filled like me with a sense of wonder and mystery at the vastness and rich diversity of the universe. Questions may flood your mind about the nature of the cosmos and its origin, as well as the nature of strange objects such as red dwarfs, black holes, neutron stars, galaxies (Figure 1), and the Milky Way.

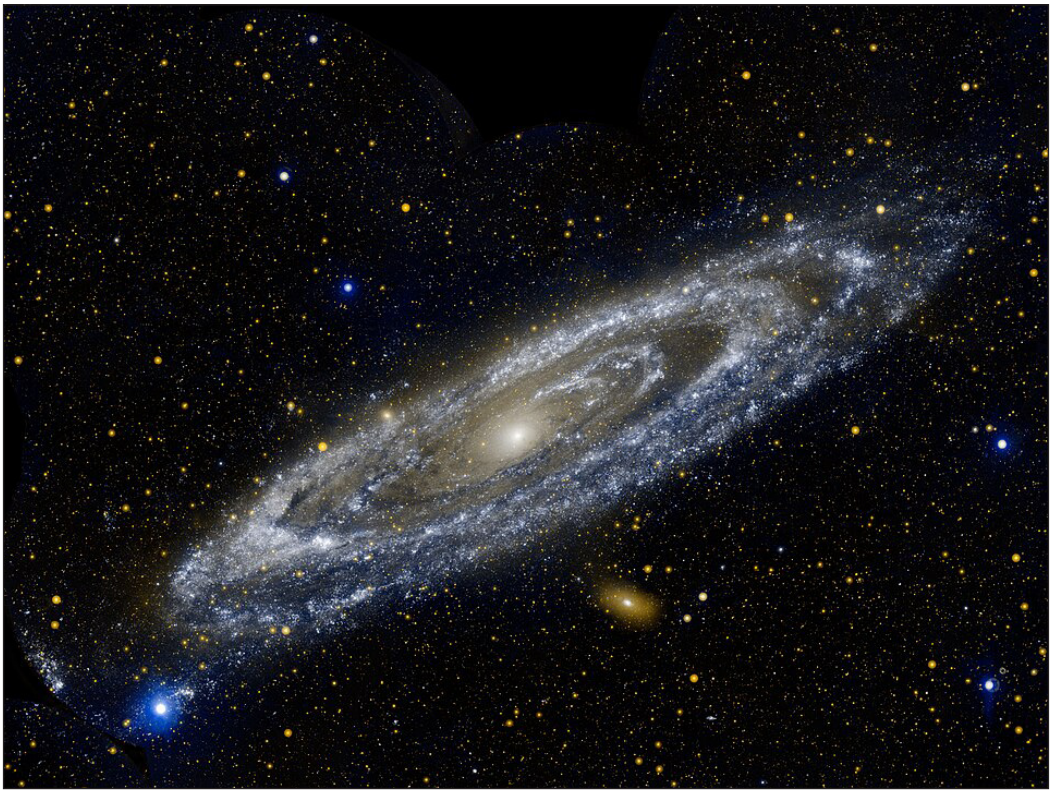

Figure 1: An image of the Andromeda galaxy containing a 100 billion (i.e., a hundred million million) stars (courtesy NASA, public domain).

Other thoughts may occur to you, including our insignificance on this tiny blue dot floating in space. Where is the God of Jews, Christians, and Muslims in all this? Is this God still necessary in our secular scientific world (Taylor 2007)? Do aspects of traditional belief need to change to accommodate the amazing advances of contemporary astronomy?

The aim then of addressing such questions in the present thematic section of *Zygon: Journal of Religion and Science* is twofold. One object is to give a simple, up-to-date account of our current understanding of the strange nature of the universe and how it came into being. Over the past twenty years, there has been a huge transformation in knowledge because of a feast of observations from space satellites and high-resolution telescopes atop distant mountains in Chile

or Hawai‘i. The second object is to go beyond a purely scientific description to raise questions and discuss related underlying theological and philosophical issues that naturally arise from these scientific advances, including questions of meaning, origin, purpose, and design. In this thematic section of *Zygon: Journal of Religion and Science*, a dozen of the world's top experts on these diverse fields come together to bring their complementary insights in a lively and fruitful exchange.

The purpose of this introductory article is to set the scene and introduce some of the exciting discoveries and challenges. The first three articles in the thematic section focus on astronomy, with John Peacock (2025) first describing the Standard Model of cosmology for an expanding and accelerating universe driven by dark energy, in which gravity causes the collapse of matter into stars and galaxies, 15% of the matter being normal matter and 85% dark matter. Then Bernard Schutz and coauthors Tsvi Piran and Patrick Sutton (Schutz, Piran, and Sutton 2025) describe the surprising importance of gravitational waves for the origin of life. The emission of such waves allows pairs of neutron stars spiraling around one another to merge into black holes while producing kilonova explosions in which most of the heavy elements above iron are manufactured. In particular, the decay of the radioactive isotopes ^{238}U and ^{232}Th of uranium and thorium produces heat, which helps maintain plate tectonics, and which in turn has been a major driver in human evolution, in particular human cognition. Jennifer Wiseman (2025) reviews the detection of planets orbiting stars outside our solar system and considers the possibility of life in many of the billions of such planets in our universe.

The next four articles consider philosophical aspects. Marcelo Gleiser (2025) responds to discoveries about exoplanets and the interconnectedness of life on Earth by presenting a biocentric worldview with an ethics of belonging that should help develop a sustainable future. Brian Pitts (2025) suggests that evidence for the existence of God does not necessarily follow from the presence of a Big Bang singularity. Adam Hincks (2025) and Chris Smeenk (2025) then give a theological and a philosophical reaction, respectively, to the amazing property of our universe of appearing "fine tuned," in the sense that, if the values of many properties, such as electricity and gravity, were only very slightly different, life as we know it would not have been able to evolve.

The final four articles present theological responses. Bernard Carr (2025) stresses that, historically, astronomy and theology have raised questions that have theological aspects, especially when developing an understanding of cosmology and black holes, together with the nature of time and singularities. Rodney Holder (2025) reflects further on the possible explanations for the very special properties possessed by our universe that have led to the evolution of intelligent life, while Nidhal Guessoum (2025) describes the main approaches of Muslim thinkers to cosmology and how they have evolved over time. Finally,

David Wilkinson (2025) rounds off the discussion by comparing scientific and Christian views on the likely future of the universe and humanity.

Background

For me personally, as a scientist, I am embarked on an open-ended venture in which ideas continually evolve and change, and a sense of creativity and of wonder are frequent. At any one time, I cannot *prove* the truth of one of my theories for, say, solar flares; rather, I can only say that it is *consistent* with current observations. In this way, I remain open to the possibility that future observations may show the theory to be limited or wrong. Similarly, as a person of faith, I cannot prove God's existence, but I can ask whether it is consistent or not with my experience and my current thinking. For the time being, it is consistent, so I am prepared to live my life under the assumption that God does indeed exist.

Furthermore, when discussing matters of science and faith, we all make background (or so-called "metaphysical") assumptions about the nature of reality (Ecklund 2017). According to a 2023 report by the Pew Research Center (Alper et al. 2023), 22% of Americans class themselves as "spiritual but not religious (SBNR)" in the sense of believing in a higher power or a deep sense of meaning beyond the material world but not attracted to organized religion. At the same time, 58% class themselves as religious, while 21% of Americans are neither religious nor spiritual. In the United Kingdom, while the 2021 census (Roskams 2022) did not consider the SBNR category, it did find that 46% of the population identified as Christian, a further 10% as belonging to other religions, and 37% as having no religion.

Many scientists separate questions of science from questions of theology and are so-called "metaphysical naturalists," i.e., they adopt the methods of science when studying scientific questions but recognize that there may be aspects of life that are outside the bounds of science, that are philosophical or religious, such as the nature of love and beauty or questions of purpose and meaning. However, another possibility is to work towards building a theology of science (McCleish 2019) or even a new unification of science and theology (e.g., Priest 2016; McGrath 2023).

A final background point concerns the extremely large and small numbers encountered in astronomy. We are all familiar with numbers as large as ten (10) or a hundred (100) or a thousand (1,000) or even a million (1,000,000), which scientists denote by the notations 10, 10^2, 10^3, and 10^6, since they have one, two, three, and six zeros, respectively. But in astronomy, much larger numbers are common, especially when describing enormous distances or numbers of stars. These include, for example, a billion (1,000,000,000, i.e., 10^9) or 10^{22}, which represents ten with twenty-two zeros after it! However, very small numbers also arise, especially when considering miniscule times after the Big Bang. For

example, a tenth ($\frac{1}{10}$) and a hundredth ($\frac{1}{100}$) are common in everyday life and are denoted mathematically by 10^{-1} and 10^{-2} or one divided by ten or a hundred, respectively. But the numbers we shall meet are very much smaller such as a billionth, represented by ($\frac{1}{1{,}000{,}000{,}000}$) or 10^{-9}, or even smaller.

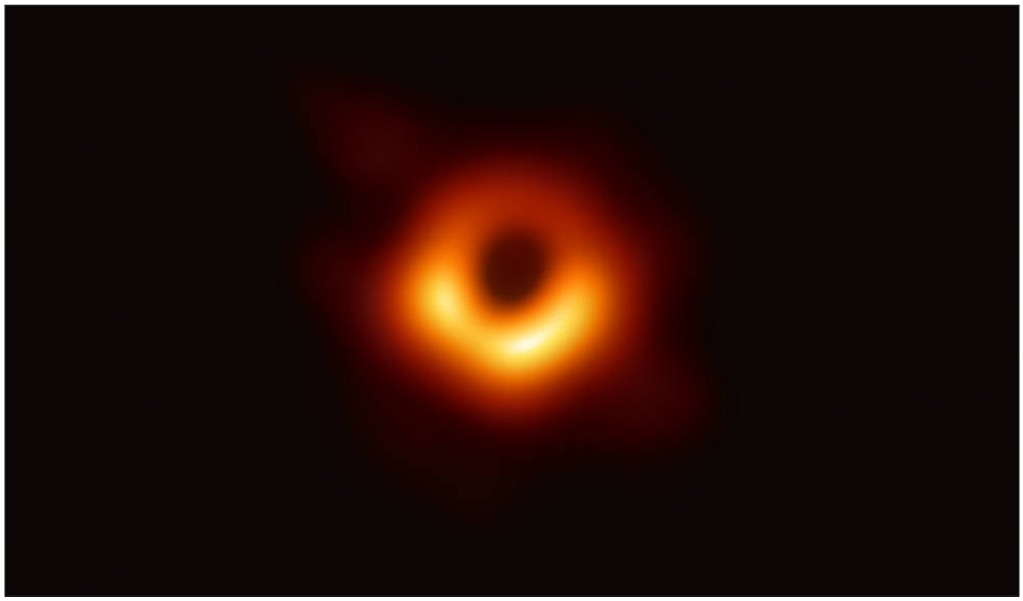

Figure 2: The first ever image of a black hole at the center of galaxy M87, in April 2019 (courtesy Event Horizon Telescope Collaboration).

Black Holes

A black hole is an incredibly dense object, so dense that its gravity is strong enough to prevent anything escaping it, even light. Only recently was it possible to image for the first time the gas swirling around a black hole (Figure 2).

In order to understand how black holes are formed, we first need to understand something of the nature of ordinary stars. In the center of a normal star, thermonuclear reactions fuse elements together to produce heat. For example, in our sun, hydrogen atoms combine to produce helium, but surprisingly, the mass of the resulting helium atom is less than the sum of the masses of the initial hydrogen atoms. What happens is that some of the initial mass is converted directly into energy, a process Einstein first described with his famous equation that implies that energy (E) and mass (m) are equivalent, that is, $E = m c^2$, where c is the speed of light.

Now, this release of energy creates a huge temperature and pressure in the core of the star, which in turn produces a strong outward pressure force (in the same way a region of high pressure in the Earth's atmosphere creates a force that drives winds towards low-pressure regions). Most of the time, however,

the star just remains calmly in equilibrium, since the outward pressure force is balanced by the enormous force of gravity attracting matter inwards towards the star's center.

When the thermonuclear fuel has been used up, however, a dramatic event occurs, as the high central temperature and pressure are no longer maintained. Since there is then no pressure force to oppose the inward force of gravity, the star rapidly collapses. The resulting final state depends on the initial mass of the star. When this mass is less than ten times the solar mass, it collapses to a so-called "white dwarf" of a typical radius equal to that of the Earth. When the initial mass lies between ten and thirty times the solar mass, the star collapses instead to a so-called "neutron star." However, when it exceeds thirty solar masses, the collapse continues all the way to a black hole.

Although suggested in the eighteenth century, the first model to use general relativity was proposed in 1916 by Karl Schwarzschild. Later, Stephen Hawking made several important discoveries about the nature of black holes. He used two fundamental theories about the nature of matter developed in the twentieth century that form the basis of much of modern physics. The first is Albert Einstein's theory of general relativity, which applies to matter moving at speeds near the speed of light. The second is quantum mechanics, which applies on extremely small scales, comparable with the size of an atom.

Working with Roger Penrose, Hawking used general relativity to understand the ways in which gravitation produces singularities such as black holes. It had been thought that nothing at all can escape from a black hole, but Hawking studied quantum effects near the surface of a black hole and discovered that they produce a new form of radiation called Hawking radiation, which implies they naturally tend to lose mass and energy.

Hawking also applied the ideas about black holes to the whole universe and so investigated the nature of the Big Bang, in which our universe is thought to have originated 13.8 billion years ago (see Peacock (2025) for details). Later, he argued that the universe has no boundary in space and time, so that, before the Big Bang, time did not exist and therefore the concept of a beginning for the universe is meaningless. What place then for a Creator? Later, in 2006, he suggested an even stranger idea, that the universe has many different initial states (called a multiverse), and so the present selects the past from a collection of different possible histories.

Black holes may have a wide range of masses and sizes. Those having a mass of a few solar masses form when very massive stars (bigger than thirty solar masses) collapse at the end of their life. After a black hole has formed, it can continue to grow by absorbing mass from its surroundings. By absorbing other stars and merging with other black holes, enormous so-called supermassive

black holes of millions of solar masses may also form, which are present in the centers of most galaxies.

Measurements of the orbits of stars around the center of a galaxy have been used to determine the presence of a black hole and the value of its mass. For example, astronomers have established that the radio source Sagittarius A*, at the core of the Milky Way galaxy, contains a supermassive black hole of about 4.3 million solar masses.

The radius of a black hole depends on its mass. A black hole of a mass ten times the sun has a radius of only thirty kilometers, whereas one of an intermediate mass of say a thousand times the mass of the sun has a radius equal to that of the Earth. On the other hand, "supermassive" black holes have masses between a hundred thousand and ten billion times the sun's mass and radii between 0.001 and 400 times the distance of the Earth from the sun.

Current Understanding of the Origin and Nature of Our Universe

Our universe is of course enormous and possesses an almost unbelievable number of stars and galaxies. Each galaxy, like the one in Figure 1, typically contains one hundred thousand million stars, but there are one hundred thousand million galaxies in the universe, giving a staggering total of ten thousand million million million stars (in other words, ten with twenty-two zeros after it). The sense of wonder arising from these numbers could remind one of the words of the psalmist:

> *When I look at your heavens, the work of your fingers,*
> *the moon and stars that you have established,*
> *what are humans that you are mindful of them?*

Evidence for the Big Bang

Carl Wilhelm Wirtz (1922) discovered that more distant galaxies are receding faster from us than closer ones. A Belgian priest called Georges Lemaître (1927) then concluded that the universe is expanding from an origin at a time now measured to be 13.8 billion years ago. He estimated a value for the ratio between the recessional speed of galaxies and their distance and connected this law with a solution to the Einstein field equations in general relativity for a homogeneous isotropic universe. Two years later, American astronomer Edwin Hubble (1929) calculated a more accurate value for this speed–distance ratio. The observation that galaxies are moving away from us at speeds proportional to their distance is now known as the Hubble-Lemaître law. Twenty years later in a radio broadcast, British astronomer Fred Hoyle christened this origin and expansion of the universe "the Big Bang."

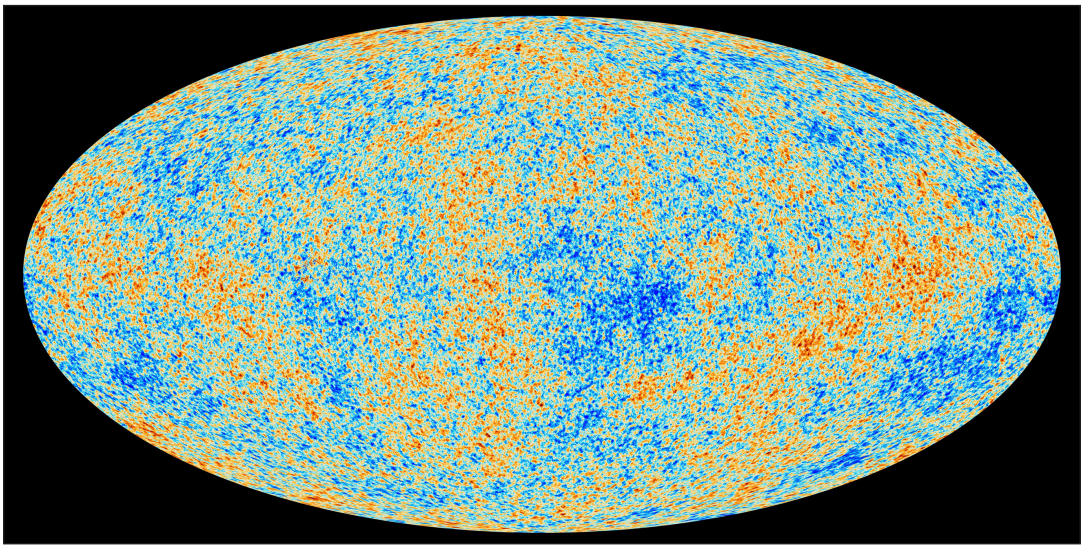

Figure 3: Fluctuations in the glow emitted less than half a million years after the Big Bang, showing patches that are slightly hotter (red) or colder (blue) than normal (courtesy the Planck collaboration and European Space Agency).

In recent years, much additional evidence has emerged for the Big Bang. First, in 1964, two American radio astronomers, Arno Penzias and Robert Wilson (1965), were measuring microwaves and discovered a strange hiss, which they soon realized represented the glow from the Big Bang. It led to them being awarded the Nobel Prize. More recently, the fluctuations in the glow, called the cosmic microwave background, which were formed very soon after the initiation of the Big Bang, have been measured and are shown in Figure 3.

Second, Big Bang theory predicts the amount of hydrogen and helium created during the early stages of the Big Bang, and the observed ratio of these amounts agrees with the prediction. This is important, since most of the hydrogen and helium in the universe is thought to have been created during the Big Bang. Small changes in these amounts are occurring in small stars such as the sun, where hydrogen is being combined (by thermonuclear fusion) into helium. But many of the other common elements have been created in stars more massive than the sun. For example, when atoms of helium are fused together, they can produce oxygen and carbon, or in even hotter stars, carbon can be fused to produce neon, sodium, oxygen, and magnesium, and so on up to the element iron. Many elements heavier than iron were thought to form when stars explode as so-called "supernovae," but now "kilonova explosions" are regarded as the main source of elements more massive than iron (Schutz et al. 2025).

What Happened after the Big Bang?

When observing distant objects, we are looking back in time, since the light that comes to us travels at the speed of light. Indeed, we often measure distances in

so-called "light years," where one light year is the distance light travels in a year. At 186,000 miles every second (the speed of light), this is six trillion (i.e., six million million) miles. Thus, light from the sun takes eight minutes to reach us, and so, when we observe the sun now, we are really seeing what it was like eight minutes ago. Again, the nearest star is four light years away, since its light takes four years to reach us. Even more distant, the center of the Milky Way galaxy is 25,000 light years away, and the Andromeda galaxy (Figure 1) is two million light years. On the other hand, the edge of the visible universe is very much further, namely, over thirteen billion light years.

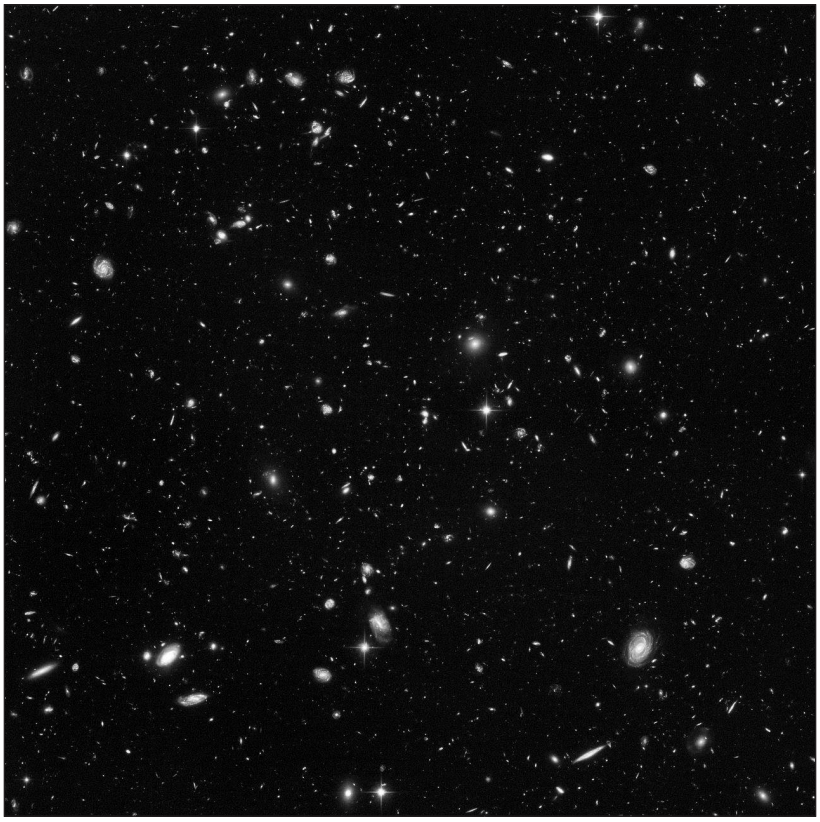

Figure 4: An image of nearly 10,000 galaxies at the edge of the visible universe from the Hubble Space Telescope (courtesy NASA, European Space Agency, and S. Beckwith (STScI) and the Hubble Ultra Deep Field team).

The most distant image we have yet obtained in normal light of the universe has come from the Hubble Space Telescope (Figure 4). It was formed a few hundred million years after the Big Bang, but our mainstream understanding of the evolution of the universe goes back much further than this. We do not know what happened exactly at the Big Bang, since near that time our theories of general relativity and quantum mechanics both fail and we have not yet discovered a theory to replace them, despite nearly a century of trying by the finest physics minds in the world. However, we do have a reasonable

understanding of what was happening within an incredibly tiny fraction of a second after the Big Bang, as follows.

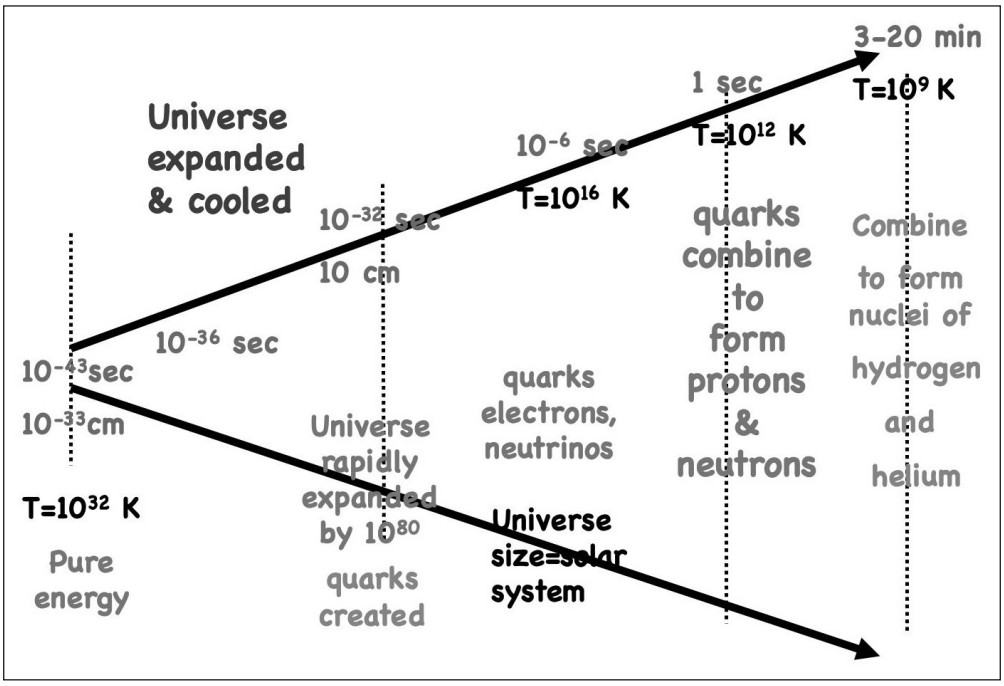

Figure 5: The initial expansion of the universe up until ten minutes after the Big Bang.

Our knowledge surprisingly goes back to 10^{-43} seconds (i.e., one divided by ten with forty-three zeros after it, or one tenth of a millionth of a millionth of a millionth of a millionth of a millionth of a millionth of a millionth of a millionth of a second) after the Big Bang. Big Bang theory describes how the universe expanded and cooled, how the elements of which we are all composed began to be created, and how the four fundamental forces that surround us today and are familiar to modern physics were fashioned. These are gravity, the strong nuclear force (which binds the cores of atoms together), the weak nuclear force (responsible for radioactivity), and the electromagnetic force (which produces electric and magnetic fields and light waves).

At 10^{-43} seconds, the size of the universe was only 10^{-33} centimeters (i.e., one thousandth of a millionth of a millionth of a millionth of a millionth of a millionth of a millionth of a centimeter), there was one unified force and pure energy. As the universe expanded (shown in diagrammatic form in Figure 5), it became less dense and cooled. By 10^{-12} seconds, the temperature had cooled to 10^{16} K, and the universe had expanded to a size equal to that of today's solar system. After 10^{-6} seconds, the unified force separated out into the four fundamental forces. By one second, the universe was made up of energy and particles called quarks,

electrons, and neutrinos. The particles then combined to form the building blocks of atoms, known as protons and neutrons, and by three seconds these had combined to make the cores (or nuclei) of hydrogen and helium.

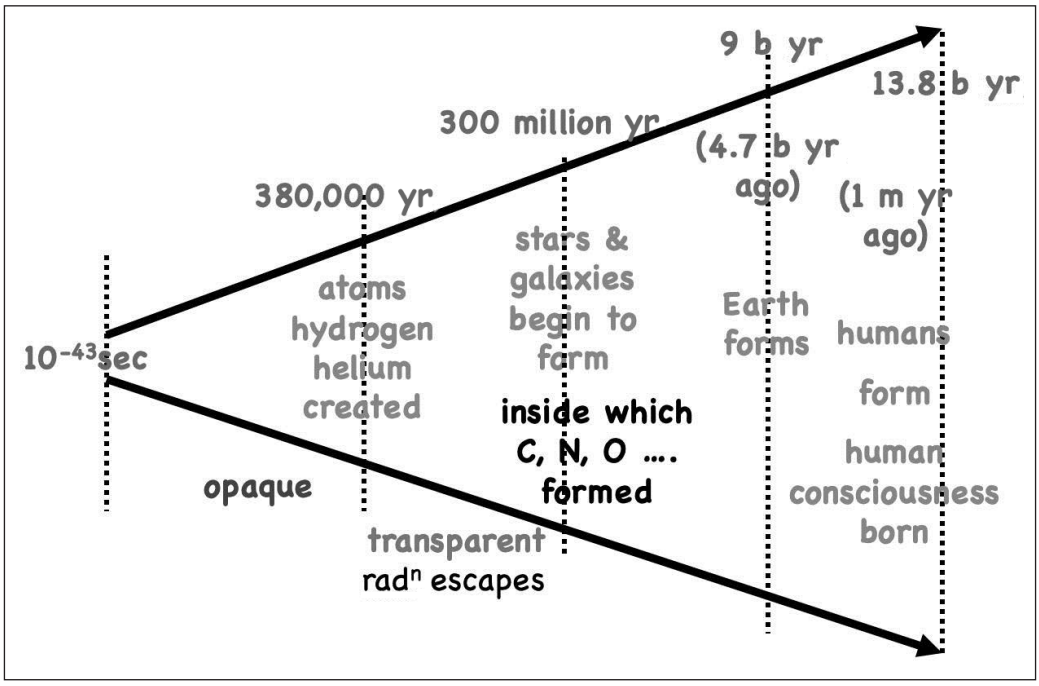

Figure 6: The later expansion of the universe up to the present day.

At this stage the universe was opaque, but after 380,000 years, it became transparent when nuclei of hydrogen and helium joined with electrons to form atoms (Figure 6). At this point, radiation could start to escape. Indeed, it is the surface of this expanding, cooling ball we see when we look back in time to the cosmic microwave background glowing at a temperature of 2.7 K (Figure 3).

After a few hundred million years, the first stars and galaxies formed, inside which carbon, nitrogen, oxygen, and so on formed by fusion. Then, after nine billion years (i.e., 4.7 billion years ago), the Earth formed. Finally, very recently in cosmic time, only a few hundred thousand years ago, humans formed, and human consciousness was born.

A key aspect of modern cosmology is the idea of so-called "cosmic inflation" proposed by Alan Guth (1980) to solve many puzzles about the nature of the universe. He suggested that at 10^{-35} seconds, the universe expanded incredibly rapidly by a factor of 10^{80} in a tiny fraction of a second. The quantum fluctuations present at the time ultimately became galaxies, and indeed it is the seeds of clusters of galaxies that can be seen in the cosmic microwave background (Figure 4).

Questions about the Big Bang?

The theory for the Big Bang is based on general relativity and suggests that initially space and time were created from nothing, from quantum fluctuations in a vacuum. But general relativity and quantum mechanics break down before 10^{-43} seconds. So, a key question is what happened before this time. And how can quantum theory and general relativity be combined to answer it?

There are two main candidates at the moment for trying to unite general relativity and quantum mechanics. The first is superstring theory, in which elementary particles are tiny strings (rather than point-like particles) and space has seven extra dimensions. The second is loop quantum gravity, in which space and time are granular rather than continuous.

Was the Big Bang really the beginning, as Big Bang theory suggests, or is a big bounce or an oscillating universe more likely, as some people would prefer?

Is there just one universe or are there many universes (a collection called a multiverse)? Could these other universes be spawned inside black holes or quantum fluctuations?

All of these proposals are highly speculative, with no evidence yet of any of them, but in future, they may be ruled out or perhaps become part of mainstream thought.

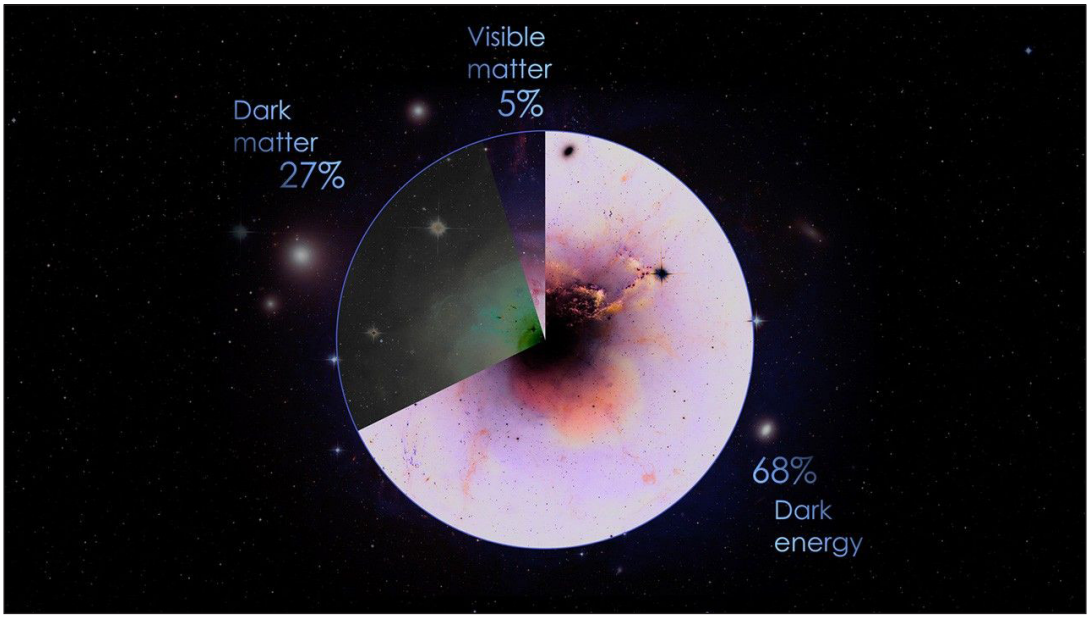

Figure 7: The proportions of dark matter, dark energy, and ordinary matter in the universe according to the Planck probe measurements, March 2013 (courtesy NASA's Goddard Space Flight Center).

What Is the Universe Made Of?

The proportions of different kinds of matter in the universe have been measured by instruments on board a series of spacecraft. For example, the Planck Mission

is a European Space Agency satellite launched in 2009. It has shown that only 5% of the universe is normal matter, but 27% is dark matter and 68% is dark energy (Figure 7).

Something, which we call "dark matter," is making galaxies rotate more rapidly than we expect and preventing galaxies flying apart. There are several candidates for dark matter, including WIMPs (weakly interacting massive particles), axions, and primordial black holes, but as yet, no general agreements of definitive data have emerged on what it might be. Also, it is natural to expect gravity to slow down the outward motion of the universe as it expands, but a big surprise in 1998 was the discovery by Adam Riess and Saul Perlmutter that the expansion is instead accelerating. Again, the cause is as yet unknown, but it has been christened "dark energy."

Figure 8: The northern arm of the Laser Interferometer Gravitational-Wave Observatory interferometer on the Hanford reservation, which produced the first direct detection of a gravitational wave (public domain).

Gravitational Waves

These are disturbances in the very fabric of space and time, proposed by Einstein (1916) as a consequence of his general theory of relativity. When a body accelerates rapidly, provided it is not highly symmetric, it generate changes in space and time that propagate at the speed of light. Examples include coalescing black holes or neutron stars.

Teams of international scientists had been setting up unbelievably sensitive instruments for fifty years to try and detect such waves, and I for one was certainly expecting such a first detection to be marginal, barely poking up above the background noise and not producing much astronomical information. However, the first detection when it came was stunning and far exceeded expectations—the discovery of the century. It was announced on February 11, 2016 when the LIGO (Laser Interferometer Gravitational-Wave Observatory) Collaboration (Figure 8), using the Advanced LIGO detectors, observed gravitational waves coming from a pair of black holes that were spiraling inwards and merging to form a single black hole (Figure 9). The black holes were located 1.4 billion light years away and possessed masses of thirty-six and twenty-nine solar masses. The resulting coalesced black hole was only sixty-two solar masses, so three solar masses had been converted into the energy of outwardly propagating gravitational waves. More on the importance and consequences of gravitational waves is described in the article in this section by one the leaders in the field, Bernard Schutz, together with two coauthors, Tsvi Piran and Patrick J. Sutton (Schutz, Piran, and Sutton 2025).

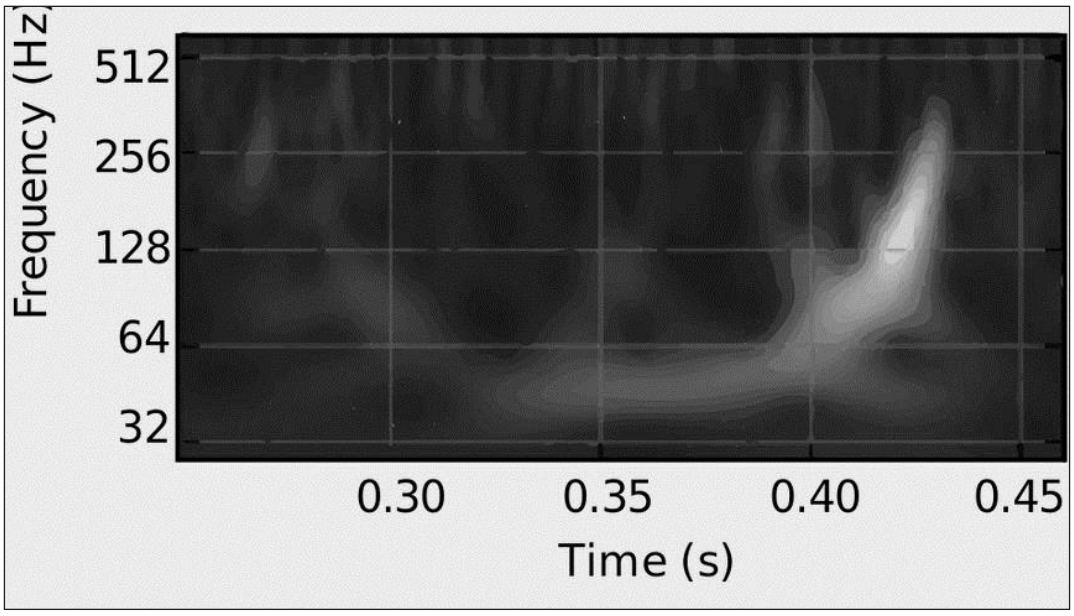

Figure 9: The first detection of gravitational waves by the Laser Interferometer Gravitational-Wave Observatory, showing how the frequency of the waves increased in time as the black holes spiraled inwards (courtesy United States National Science Foundation).

The event lasted 0.2 seconds, and the waves reached Earth as a ripple in space-time that changed the length of a four-kilometer LIGO arm by a thousandth of the width of a proton, equivalent to changing the distance (four light years) to the nearest star by one hair's width. The energy carried by the waves was

immense, equivalent to the energy of the three lost solar masses, and, in the final twenty milliseconds, reaching a power fifty times greater than the light radiated by all the stars in the observable universe.

By March 2025, 290 gravitational wave events had been observed, most of which originated from collisions of black holes, whereas others involved neutron star collisions or collisions of neutron stars with black holes. For this amazing discovery, the 2017 Nobel Prize in Physics was awarded to Rainer Weiss, Kip Thorne, and Barry Barish.

Philosophical and Theological Questions of Origin, Purpose, and Design

I begin by describing the arguments Alister McGrath (2023) has presented for a retrieval of the ancient ideas of natural philosophy before focusing in the following subsections on particular issues that arise in astronomy.

A Retrieval of Natural Philosophy

In his book on *Natural Philosophy,* McGrath (2023) first describes the history of the development of the idea of natural philosophy and its disintegration in the nineteenth century and then gives reasons for a retrieval of the concept.

The Tradition of Natural Philosophy

As far as its origins are concerned, natural philosophy emerged in Greece in the fourth century BCE with Aristotle's observations of fish and his explanation of their migratory patterns. It was regarded as a systematic inquiry about nature that led to an understanding of causes and relations different from simple knowledge. Here, *theoria* was a mental viewing of the natural world by philosophers Plato regarded as intellectual ambassadors who journey to seek truth in a divine world. Aristotle attentively observed plants, animals, and stars with the aim of identifying *arche*, the first principles behind nature, so that science mirrors reality and theory coheres with observations. In particular, Aristotle used a process of induction, whereby particular observations led to general principles. These ideas were absorbed and developed by the Islamic world and later rediscovered in Western Europe.

During the Middle Ages from the thirteenth to the sixteenth centuries, Aristotle's natural philosophy dominated Western attempts to make sense of the world. However, the foundation of universities meant a relocation of theology from monasteries, so it was no longer under church control. Furthermore, this involved a separation into faculties of philosophy and theology in medieval universities such as Paris. For example, the Parisian theologian Albertus Magnus distinguished realms that are natural (for natural philosophy) from those that are supernatural (for theology). His successor, Thomas Aquinas, regarded these realms as using different methods and norms but reaching similar conclusions. In the twelfth century, Hugh of St. Victor had regarded nature and the Bible as

God's two books for understanding and wisdom. The fifteenth and sixteenth centuries saw a decline of Aristotelian natural philosophy as voyages across the world displayed its limitations. The sixteenth century also brought new empirical approaches and an experimental method, which loosened the connections to Aristotle and led to a golden age of natural philosophy beginning with Kepler, in which making more accurate observations was seen as a way of expanding knowledge empirically.

Ptolemy in Alexandria had suggested in the second century that the observed motions of planets could be explained as a set of nested circular orbits around the Earth. In 1543, Copernicus reevaluated the data on planetary motions and suggested instead that the sun is stationary while the Earth and the other five known planets move around it. Then, in 1572, Tycho Brahe observed a new star in Cassiopeia, which cast doubt on Aristotle's claim that the "fixed" stars are perfect. He made many new observations that improved the accuracy of calculations of planetary positions, especially Mars, and moved to Prague, where he was joined by a young Kepler. After Tycho's death in 1601, Kepler used Tycho's observations to suggest that Mars orbits the sun in an ellipse rather than a circle due to a force of some kind from the sun. He later proposed three laws of planetary motion: all the planets move in elliptical orbits with the sun at a focus; the line joining the sun and a planet moves at such a speed that it sweeps out equal areas in equal times; the square of the orbital period is proportional to the cube of the orbital semi-major axis. Kepler regarded God as the source of the harmony present in music, mathematics, and astronomy and thought that, since the human mind is the image of God, it is sensitive to patterns in creation.

A key effect of the Reformation in Europe was that both Lutheranism and Calvinism were hospitable to Kepler's natural philosophy. For example, Calvinists distinguished between natural knowledge and revealed knowledge, both being from God, while Lutherans such as Melanchthon distinguished between truths from revelation and those from natural inquiry. After the Dutch invention of telescopes, Galileo made his own in 1620 and observed that the surface of the Moon is rough, that Jupiter possesses four orbiting moons, and that Venus has changing phases that imply an orbit around the sun. Like Kepler, Galileo felt the book of scripture is open to anyone, but understanding the book of nature is open only to those who are mathematically literate, since mathematics is the language of nature.

The seventeenth century was a golden age for the experimental natural philosophy that emerged in England with the work of Francis Bacon, Robert Boyle, and Isaac Newton. Dominant was a belief in God as creator of an ordered universe, which the human mind can grasp and so gain understanding as well as make moral and spiritual advances. After the Civil War, Charles II inaugurated a new era of intellectual progress, with, for example, a charter being

granted in 1660 to the Royal Society, whose aim was to employ the new physico-mathematical experimental natural philosophy proposed by Bacon. For Bacon, understanding natural processes could lead to human improvement, but natural philosophy and religion are complementary and so should be kept separate. His natural philosophy involved using particular observations and experiments to produce general explanations for nature's patterns by a process of induction, in which the explanations then led to new experiments to confirm or develop the understanding. Some experiments were aimed at understanding causes, while others yielded practical outcomes.

Boyle helped gradually replace Aristotle's ideas with a mechanical natural philosophy for the motion of particles, in which careful and detailed observations were more important than preconceived interpretations and the world is God's creation and so a worthy object of scientific study. For Boyle, it was important to tolerate disagreement and favor human reason over the ambiguities of biblical interpretation. He felt an empirical understanding of God's world would reveal God's purposes and transcend sectarianism. Applying the methods of natural philosophy to theology was described from about 1690 as "physico-theology." Boyle marked a transition from a view that the natural world was created for human benefit to one in which a realization of the vastness of the universe offered a more expansive view of God's works.

Newton further developed natural philosophy in his *Principia Mathematica* by emphasizing the role of mathematics. He preferred experimental natural philosophy to speculative ideas such as René Descartes's vortex theory for planetary motion, which was not grounded in observation. Robert Hooke had begun to describe elliptical orbits in terms of inertia and gravity, but Newton's theory of the motion of bodies under the inverse square law of universal gravitational attraction was expressed mathematically and explained the origin of Kepler's three laws. He also extended the scope of his theory for the motion of bodies under gravitation by suggesting they applied throughout the universe of his day. His emphasis on regularity and order was later misinterpreted as producing a clockwork universe with God as the watchmaker.

Physico-theology with its clear connection between nature and religion gave a motivation for study, and the natural philosopher was privileged to observe the beauty and complexity of the universe, which led to reverence and respect. In comparison, deism (which came later) focuses on God as creator and lawgiver, but it arose from rationalism rather than natural philosophy. Newton's approach allowed us to see harmony and order beneath the surface, which restored coherence to a world John Donne had seen as in disarray in 1611. By the end of the eighteenth century, however, Newton's universe seemed to be autonomous, with no need for God. Indeed, the Newton–Boyle synthesis had begun to fragment in the eighteenth century and fall apart completely in the nineteenth.

The nineteenth century saw a move away from theistic approaches to nature and a bifurcation of natural philosophy into science and philosophy, with a loss of moral focus. William Whewell suggested the term "natural philosopher" be replaced by "scientist." Also, during the Enlightenment, David Hume criticized natural theology and distinguished fact from value, claiming that studying the natural world cannot generate moral values. Others referred to science in the singular as a field that employed a "scientific method," overlooking the existence of many sciences that have their own methods. Newton began to be seen as the founder of a secular scientific modernity, while Blake believed the natural world had been impoverished by what he saw as a reductionist agenda and a mechanical world view. John Ruskin criticized a cold materialistic science in which objectivity had produced a disengaged account of nature. These moves stimulated a transition from theistic science, in which nature was grounded in a divine act of creation, to a naturalistic approach to science, such as Darwinism.

In the latter part of the nineteenth century, natural philosophy came to be regarded as outdated and faded into obscurity, as distinct sciences evolved and became professionalized. An agnostic Thomas Huxley made a clear distinction between philosophy and science, the former addressing the question "what can I know?" and the latter addressing "what do I know?"

Retrieving the Concept of Natural Philosophy

McGrath (2023) suggests there is a need to reconceive natural philosophy in ways that link attentiveness to the natural world with quests for understanding, wisdom, and wellbeing. This would respond to an instinct to preserve, respect, and appreciate the complexity of nature by assessing what was important in the concept of natural philosophy in the past and seeking a holistic view of science rather than being trapped in its current artificial divisions.

There are several reasons for a need to retrieve natural philosophy. First, in early modern times, it had a moral dimension that is currently absent from science but was in harmony with nature and focused on the art of living well. Second, engaging with the natural world corrects limitations in the philosophy of human reason; thus, Bacon suggested that collecting observations can counter human errors and lead to an awareness of the beauty of nature. Third, it used to enable humans to flourish in the world and respect nature; Boyle regarded the natural philosopher as a priest in the temple of nature, while American wilderness authors such as Ralph Waldo Emerson and Henry David Thoreau instilled a holistic view of humanity's relation with nature. Fourth, an urge to understand is often an urge for unity; the poet William Allingham compares a cold scientific mentality that breaks a whole into pieces with poetic imagination that reconstructs and reveals completeness and beauty. Finally, there is a need for a fresh relationship between philosophy and natural science in which, like for Kepler and Newton, the universe can be regarded as a coherent whole.

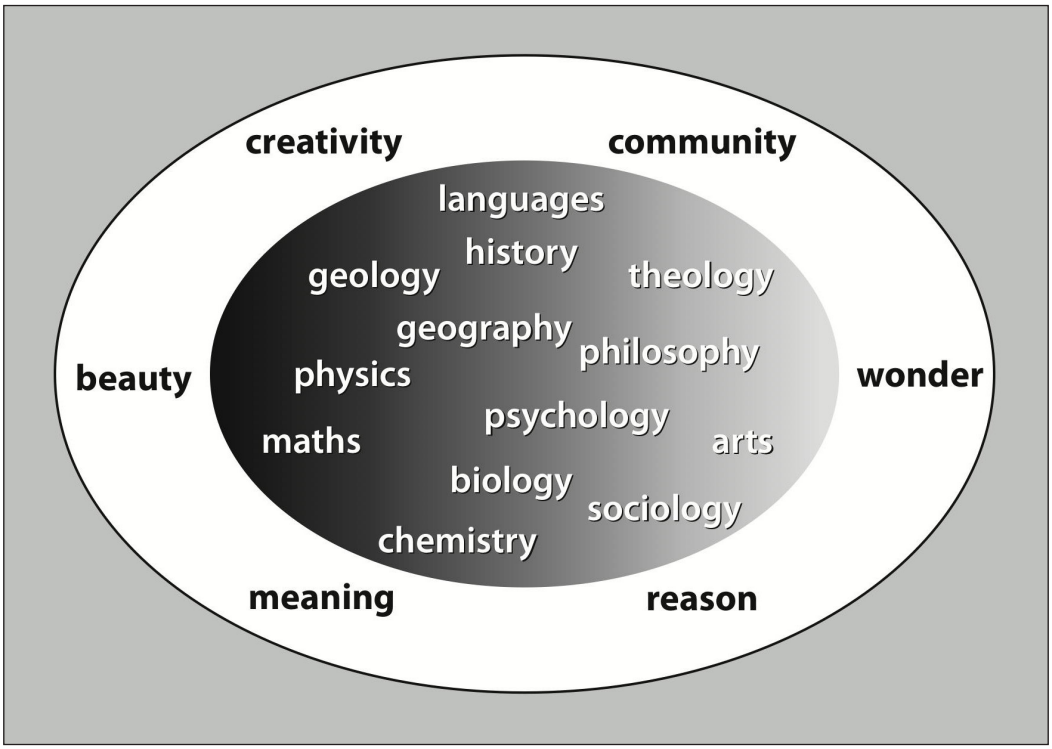

Figure 10: An integrated view of the sciences and humanities as a mixture of subjects (greys) that merge continuously into one another (Priest 2016).

The development of discipline specialties has led to a fragmentation of knowledge and an impoverished compartmentalization with a layer-cake model of reality, which is not held together in a broad vision. By comparison, Stephen Jay Gould (2003) feels the many disciplines in the sciences and humanities should all be respected and valued and proposes they be "quilted together to produce a beautiful and integrated coat of many colors." In a similar way, I have put forward an integrated view of the sciences and humanities as fields that merge into one another and are part of a whole in which wonder, reason, meaning, beauty, and creativity all play a role (Priest 2016; Figure 10).

Mary Midgley (2005) suggests that the complexity of the world can be addressed with multiple maps having their own methods, so that natural philosophy can superimpose or weave together these interconnected maps to create a unity. On the other hand, Karl Popper (1968) conceives of three worlds, namely, of physical objects, of subjective mental states, and of creative thought, which can be held together and help create a retrieved natural philosophy.

McGrath (2023) emphasizes that an important aspect of this retrieval is found in the original Greek term *theoria*, which included the sense of gaining a deeper understanding by contemplating the natural world, and which C. P. Snow (1965) feels could lead to a sense of coherence and beauty, while Iris Murdoch (1992) shows how what initially seems to be disconnected can often be recognized as correlated and unified. Furthermore, the current conflicting

approaches to nature given by the sciences and humanities can be reconciled by seeing the world and interpreting it in new ways that unify the modern separation of theory and observation (Gadamer 1998).

For McGrath, the new natural philosophy is a disciplinary "imaginary" that achieves an integration of apparently disconnected experiences (Licitra Rosa 2021). Thus, new imaginaries can be built and inhabited that offer a framework for organizing our experience of the world and that constitute a domain extending across present disciplinary boundaries (Taylor 2004; Lennon 2015). In other words, Popper's world three is able to connect his worlds one and two.

In Popper's world one, the quest for objectivity is a central aspect of contemporary sciences, since it points to knowledge that is universal and independent of culture or personal opinion. Bacon regarded experiments as a gateway to objectivity, but for Boyle and Newton, experimental results are provisional. However, the division between the objective and subjective is artificial, since scientific discoveries often use imagination to propose hypotheses, as well as invoke beauty to decide between competing theories. Thus, wonder is often what starts a journey of discovery. Thomas Nagel (1986) has discussed the limits of objectivity, emphasizing that a human quest for reality involves both objective and subjective paths, with a subjective view being inevitable, since the world appears different to different people and there is a cultural element to thinking.

Popper's world two acknowledges the importance of subjective accounts of human experience, which go beyond objective notions of space and time to include history, memory, and belonging, so that the subjective and objective need to be integrated to give a deeper understanding of our world. Indeed, wonder draws us into the beauty of nature to experience a new way of seeing and valuing it. Paul Dirac (1954), for instance, stresses the need for a physical theory to be beautiful. Although objective accounts may be expressed in the language of poetry, subjective descriptions may be helped by poetry, and these may be woven together to help see the whole (McGilchrist 2012; McLeish 2019).

The new vision for reimagining natural philosophy proposed by McGrath (2023) involves weaving Popper's three worlds into a coherent whole. The Enlightenment aim of intellectual unity failed due to the fragmentation of disciplines, while biologist Curtis Wilson's (1968) manifesto for unity suffers from an unsatisfactory reduction of all knowledge to physics. Instead, McGrath seeks a voluntary confederation of disciplines that work together to understand human interaction with the world cognitively, emotionally, aesthetically, and morally.

The notion of a disciplinary imaginary can hold together the multilayered nature of reality revealed by a variety of disciplines, which represent different lenses on the natural world, namely: an impersonal scientific eye that concerns the laws of nature; an aesthetic eye that appreciates beauty and wonder; an ethical

eye that seeks moral responsibility; and a spiritual eye that offers a religious perspective. One approach to retrieving natural philosophy is by recovering the approach of a polymath who holds the views from multiple windows together in a coherent unity (Lewis 1992). Another is a communal approach in which wisdom is shared across interconnected disciplinary boundaries so that the whole is seen and a grander vision revealed by transcending the parts.

Particularly important is attentiveness towards nature in which complexity and beauty are appreciated. Examples of writers who exemplify this approach are Henry Miller (1964), who said, "The moment one gives close attention to anything, it becomes a mysterious, awesome, indescribably magnificent world in itself," and Iris Murdoch (1970), who describes how great art can enable such attentiveness. In addition, there is a moral dimension to our proper respectfulness for nature (Murdoch 1992). Arising from this is a sense of humanity being responsible for preserving and valuing nature, not in order to serve human needs but rather as an object of beauty and harmony in its own right.

In his conclusion, McGrath stresses that Aristotle was key in promoting an engagement with nature that evolved into "natural philosophy" and that Kepler and Newton encouraged the cultivation of understanding by mathematically demonstrating the coherence of the world. We also need wisdom in discerning the place and responsibility of humanity within nature. A new vision of natural philosophy will include precision and objectivity as well as the delight and joy that come from an expanded encounter with nature while attending to the ultimate questions embedded in our lives.

Astronomy and Theology

When comparing astronomy and religion, many questions arise. These are discussed in detail in the articles that follow, and so I only touch on some of them briefly here.

- What is the relation between a theological and a scientific account of the origin of the universe?
- Does modern astronomical cosmology support a religious doctrine of creation out of nothing (or *Creation ex Nihilo*)?
- Does the Big Bang prove or disprove the existence of God?
- Is Hawking correct that "physics alone created the universe, so the existence of God is not necessary" and that "when we have a unified theory of quantum and gravitational effects, we shall know the mind of God"?
- Should the theology of creation be updated to take account of modern scientific advances?

Cosmology, the science of the origin and development of the universe, has a long history as part of Judaism, Christianity, and Islam, but relatively recently, it

has also become part of modern science (essentially since 1929, when Hubble discovered the universe is expanding). But questions about the beginning and end of the universe, the existence of intelligent life, and why there is a cosmos were familiar to medieval theologians and philosophers.

Does modern astronomical cosmology support a traditional religious doctrine of creation out of nothing (or *Creation ex Nihilo*)? Clearly, the Big Bang is consistent with the theological idea, but it does not prove the existence of God. Indeed, in general, we need to beware of the danger of a so-called "God of the gaps," in which God is invoked to explain any currently unexplained scientific fact, since a future scientific explanation may appear, making God redundant.

However, talk of "creation out of nothing" raises other questions. For example, how can we make sense of this phrase, since "nothing" may imply that before the act of creation there was no space and no time, when creation is normally a process in time? Again, what is the difference between a scientific notion of causality (of one event causing another) in the early universe and a theological view of causality in the doctrine of creation?

The belief (of Newton, for example) that the laws of physics govern the universe led to a growth of deism, with God creating the universe and then leaving it to its own devices, but this is not what is commonly meant by a Christian God. The Judeo-Christian God creates from nothing but also sustains the universe in being, supporting and caring for life by providence (benevolent intervention, such as acts of guidance and miracles). Indeed, in my view, God may well be at the root of all creative acts, whether recognized or not.

With a complete theory for the Big Bang, we would certainly have great insights into the nature of the universe God has created and how this occurred, but God is very much greater than that, and so we certainly would not know, in my view, the mind of God. Tiny glimpses of God are so much greater and more mysterious than the concept Hawking appears to have.

The complementary nature of different questions, in particular the difference between "how?" and "why?", are important here. If the development Hawking advocates does indeed turn out to lead to a unified theory of relativity and quantum theory, scientists may be able in future to say how the universe started, but they still will not be able to answer why. It is possible God sets up and maintains all the laws of physics, including gravity, and allows them to work in such a way that the Big Bang occurs spontaneously and, ultimately, life is created. In other words, explaining the Big Bang in terms of physics is not inconsistent with there being a role for God.

Many of the questions most crucial to us as human beings are not addressed adequately by science, such as the nature of beauty and love and how to live one's life—often, philosophy or history or theology are better suited to help

answer them, which is why we have gathered the group of international experts in astronomy, philosophy, and theology to contribute to this interdisciplinary section of *Zygon: Journal of Religion and Science*.

Compare an atheistic world view with a religious one. If there were no God, it would be difficult to account for moral realism, free will, rationality, and fine tuning. If, on the other hand there were a God, it would not be surprising to find a universe fine-tuned for life, containing free, rational, and moral creatures with a sense of the divine.

Fine Tuning

Martin Rees (2000) in his book *Just Six Numbers* proposes that six of the fundamental physical constants that are a key part of modern physics could in principle have a wide range of values, but extremely small changes in the values they possess would mean there could be no life as we know it. In other words, our universe is fine-tuned for the building blocks of life to be present.

Two of those constants determine the fundamental interactions of physics. One is the ratio of the size of electrical to gravitational forces. If this ratio were only 1% larger, the sun would have exploded and so life on Earth would not have evolved. Another constant is the fraction of mass converted to energy when hydrogen fuses to form helium. If thiswere 2% bigger, all the hydrogen in the universe would have been used up within a few minutes of the Big Bang. Another constant is the ratio of the mass of a neutron to that of a proton. If it were different, then carbon, nitrogen, and oxygen would never have been created. A fourth constant is the number of spatial dimensions in our world, namely, three. The final constants determine the size, age, and expansion of the universe and include the density of the universe and the nature of a vacuum.

In their accompanying articles here, Chris Smeenk (2025) and Adam Hincks (2025) address philosophical and theological implications of fine tuning. The fundamental constants are just right for life. So, is this a proof of God? Certainly not, but it is consistent with God's existence as creator in some sense.

We have four choices in response to the existence of fine tuning:

1. One is to follow Hawking (1988) and say that it is just happenstance—there is no need for a Creator, since there is nothing for him to do.
2. Another is to say that it is an expression of our ignorance, that in future we may develop a theory that naturally produces the fine-tuning values.
3. A third possibility is that it is the workings of providence, of God, and that it is consistent with God's work as designer and creator.
4. A final possibility is that our universe is part of a vaster multiverse of unconnected universes, spontaneously created out of nothing, containing

different sets of laws of physics, such that we exist in the one universe with the right combination of fundamental constants for life.

A Universe or a Multiverse?

Is there likely to be a single universe? If so, we need an explanation for fine tuning. Or is there, on the other hand, a multiverse of unconnected universes? These would be spontaneously created out of nothing and contain different sets of laws of physics and the different logically possible combinations of fundamental constants, such that we exist in the universe that has the right combination for life.

Is the existence of a multiverse scientifically provable or does it lie more in the realm of philosophy as an alternative hypothesis to God? Some have suggested the idea of a multiverse is unscientific, since there is unlikely to be observational evidence for or against it. The existence of a multiverse, however, does not rule out the need for God to exist.

Where Did the Laws of Physics Come From?

Religion and science use different types of explanations. The sciences use the laws of physics, chemistry, biology, psychology, and so on to provide explanations at different levels. Perhaps all these levels, together with philosophy and theology, are needed for a complete explanation?

However, what is the origin of the laws of physics? Why is there something rather than nothing? Why is the world intelligible? According to Einstein, "the most incomprehensible thing about the universe is that it is comprehensible."

Is there meaning and purpose in the universe? Is the universe divinely determined? For the Hebrew Bible, everything comes from God's will to create; it is good in His eyes. But is this consistent with a scientific approach?

Mathematics

The universe is incredibly structured, ordered, and beautiful, with a uniformity, regularity, and intelligibility characterized by mathematical simplicity and elegance. Thus, the symmetry and elegance of mathematics appear to underpin the universe. Mathematics has an uncanny ability to mirror the patterns of nature.

Mathematical truth, however, is not human invention at all; rather, it is there, and its existence is gradually uncovered. Mathematics describes the deep reality behind the world. So, does this reflect the divine mind? It certainly seems consistent with a divine creator and a rational heart to the universe.

Why then are there mathematical laws at all? Why does mathematics describe world?

Perhaps because it taps into the mind that made it all.

The Nature of Space, Time, and Matter

Space and time may be much stranger than we think (Rovelli 2018; Hobson 2017). We feel time is flowing in space and that space and time are continuous, with events in space determined in time.

In the seventeenth century, the idea of a clockwork, mechanistic universe was in vogue. Once it was set up, all subsequent behavior seemed to be determined. Now, however, we realize the universe is highly complex, changing, and evolving, and that there is a mixture of smooth and random behavior. On a quantum level, reality has a statistical nature, but on large scales we find chaotic and turbulent behavior, so that, for example, we are unlikely to ever be able to predict the weather for more than a week or so ahead.

Quantum mechanics is used by physicists in a highly effective manner to solve practical problems, but its implications about the underlying nature of reality are not well understood. Perhaps reality does not consist of things located continuously in space and time, as we tend to believe, but all physical reality consists of quantum waves, with space and time emerging in a granular manner out of a deeper reality. These are tricky aspects currently being tackled by theoretical physicists.

The Relationship between God and the Universe?

This leads on to related theological questions concerning the relationship between God and the universe. Saint Augustine (400) realized that God is outside time and so thought that we cannot speak of a time before Creation. Time is likely, therefore, to be contingent, i.e., to depend on God. It is also irreversible, since it appears to flow forwards, for several reasons, one of which concerns the physics of thermodynamics and its claim that disorder increases in time.

If God is outside time, how does God interact with it? What about free will? Is God partly in and partly outside time? Does God exist in other dimensions of time? Does God know the general trends of the future but not the details?

What is our role in Creation? Is it as co-creators? Is it to care for, conserve, and develop God's creation? Is it to appreciate the beauty and wonder all around us?

What Future Can We Predict for Humanity and for the Universe?

Rees (2018) in his book entitled *On the Future: Prospects for Humanity* stresses that the world is unsettled, rapidly changing, and facing global problems, such as climate change, mass loss of species, forest felling, and the acidification of oceans. Since 1950, the number of floods across the world has increased by fifteen times, extreme temperature events by twenty times, and wildfires seven-fold. Topsoil is being lost ten to forty times faster than it is being replenished by

natural processes. However, our approach to the future is often characterized by short-term thinking, polarizing debates, alarmist rhetoric, and pessimism. A very different approach is needed from now on if we are to halt these trends.

Rees points out that this century is special, since it is the first one when our species is so empowered that it has the planet's future in its hands. He suggests we can harness science and technology to address the challenges, provided we think rationally, globally, collectively, and optimistically. If advances in biotechnology, cybertechnology, robotics, and artificial intelligence are applied wisely, they could overcome the threats to humanity from climate change, poverty, disease, and nuclear war.

In the long term, however, a scientific view of the future of the solar system is bleak. Radiation from the sun will steadily increase, so that after about 600 million years, all plant life and most animal life will have died away due to a fall in carbon dioxide. After four billion (10^9) years, the Earth's surface will melt, and all life will cease. After about five billion years, the sun will run out of hydrogen and grow into a red giant star, whose radius will stretch right out to the Earth, which will be absorbed by the sun. Later, the sun will collapse to a tiny star, called a white dwarf. By that time, some form of intelligence may possibly have spread from Earth far out into the Milky Way galaxy, or even to other galaxies.

In the much more distant future, when the universe is 10^{12} years old, there will be no hydrogen left, stars will cease to form, and all massive stars will have become neutron stars and black holes. After 10^{14} years, small stars will have become white dwarfs, and the universe will be a cold, uninteresting place composed of dead stars and black holes.

Theologian David Wilkinson (2025), however, brings biblical themes into dialogue with scientific insights and draws a connection between physical and biblical ideas about the end of time. For the Christian who believes in a Creator God of Love, there is hope in the return of Christ to inaugurate a new creation, a new heaven, and a new Earth. The idea of God as Creator, not just at the Big Bang but continually at work, is another source of hope. When we adopt a model of God's guidance that unites Creation and new creation, it gives a different perspective on time and the end of the story.

Conclusion

The sense of wonder and humility that comes from gazing at the stars is a common response to pondering the amazingly beautiful and surprising nature of modern science and its unexpected discoveries. Indeed, creativity, imagination, and a feeling of being carried along on a voyage of discovery are central to what it means to be a scientist—they lie right at the core of scientific thought and are much more akin than most people realize to creative acts in the arts, when composing a piece of music, say, or painting a landscape.

One could go further and say that such an open attitude to being led into new directions in a non-judgmental and welcoming manner is central to being a human person, whether talking about our relationships with each other or about a being engaged on a scientific or artistic venture. But both rationality and creativity are needed, since, without rationality the danger is to lose touch with reality, whereas, without creativity, the path of discovery soon grinds to a halt.

There are clear parallels here with an open attitude to religious experience and theological thought, where opening ourselves in wonder and humility characterize much religious worship, and are also central to meditation and thought on Holy Scriptures. These common aspects of the sciences, the arts and theology in turn suggest that the common polarized, divisive approach of the past 150 years to science, arts, and faith is a misguided aberration and that we should seek to build a more unified approach. What can unite this approach is the central common role of a search for understanding that combines reason and imagination.

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Dark Cosmology and Its Origins

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This article reviews the standard model of cosmology: an expanding universe whose expansion is now accelerating, driven by dark energy (equivalent in practice to endowing the vacuum with a constant uniform energy density). Structure in the universe is generated by the matter that can clump, where gravity causes density enhancements to collapse and generate galaxies and their large-scale clustering patterns. This matter is about 15% normal gas, but the remainder is collisionless, interacting only through gravity and not supporting sound waves, nor scattering electromagnetic radiation. The nature of these dark constituents, as well as the origin of the fluctuations that seeded cosmological structure, is most probably connected to physical processes at early times. Thus, observations of dark cosmological structure give us a window into the origin of the universe. The aim here is to give an overview of the development and successes of this model, together with the outstanding fundamental puzzles in our understanding of cosmology.

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Galaxies and the Universe

The visible universe contains very roughly 10^{11} galaxies, of which the Milky Way is a relatively typical specimen. All of these make up a uniformly expanding system, so that a pair of galaxies separated by a distance D will recede from each other with a velocity of $v = H D$, where H is Hubble's constant. This means galaxies were closer together in the past, and that the universe was denser at early times. The density of the universe is important because its gravitational effects have an impact on how the size of the universe changes with time, and we can claim to know rather accurately what this density is: about 9.2×10^{-27} kg m^{-3} at the present day. We also know this figure is made up of a number of different constituents, which can be listed in descending order of abundance:

1. Dark energy (70%). A uniform substance that does not clump, effectively endowing the "empty" space between particles with weight. It also has negative gravitational properties and causes the expansion of the universe to speed up.
2. Dark matter (25%). Material that can clump but is collisionless: it interacts with other matter only via gravity and does not support sound waves. It is commonly conjectured to consist of an exotic elementary particle.
3. Ordinary or "baryonic" matter (4.5%). The component of the universe that enables stars, planets, and life.
4. Neutrinos (0.13%). Once thought to be massless, these light elementary particles show that relic particles can contribute to the store of dark matter.
5. Electromagnetic radiation (0.0051%). The cosmic microwave background (CMB). As the universe expands, its temperature changes, being inversely proportional to the size of the universe. The current temperature is 2.725 K, but once was above 10^4 K, at which point the energy density of radiation dominates over all other constituents.

The level of detail in this picture is remarkable, especially so when we realize that all our current cosmological ideas were developed during a single human lifespan. The observational discovery of the expanding universe was due to Vesto Slipher (1875–1969), who performed spectroscopy over the years from 1912. By 1917, he had demonstrated that galaxies on average show a positive Doppler shift (see, e.g., Peacock 2013). Today, we view these redshifts as giving us information on the size of the universe, $R(t)$, as compared with its value at the time, t_{emit}, when the radiation we now see was emitted: $1+z = R(now) \,/\, R(t_{emit})$, where z is the redshift, that is, the fractional increase in observed wavelength of radiation.

Other selected milestones on this journey were the discovery of the CMB (1965) and the acceptance that the cosmic expansion was accelerating

(progressive evidence through the 1990s). Definitive evidence for neutrino mass was assembled in the period 1998–2001. The existence of dark matter dates back to the 1930s, but the installation of non-baryonic DM as part of the standard cosmological model only came about in the early 1980s, and direct proof that the dark matter was collisionless was only obtained from detailed mapping of CMB fluctuations and large-scale structure in the galaxy distribution at the start of this century. All these developments are expanded upon later; a more detailed history is given by Gianfranco Bertone and Dan Hooper (2018).

Thus, for the best part of a quarter century, we have had a well-established cosmological model that has continued to account for cosmological data during a period where measurements have improved in precision by several orders of magnitude. This success requires the specification of just five fundamental parameters: the densities of dark energy, dark matter, and baryons (which together determine the value of the Hubble constant), plus the amplitude and slope of primordial fluctuations, as discussed later. Nevertheless, there are many reasons for dissatisfaction. Most fundamentally, the dynamics of a radiation-dominated universe require a singularity: about 13.8 billion years ago, the energy density of the universe diverged at the point traditionally named the Big Bang. Key aspects of cosmology, in particular the density fluctuations that seed the subsequent formation of astronomical structures, had to be taken as unexplained initial conditions set down at this moment of creation. But around 1980, a set of ideas emerged that offered an alternative in which the Big Bang singularity was either disposed of entirely or pushed to some indeterminate earlier time. This is the framework of inflation, discussed later. Inflation has not yet been fully verified as the correct theory of cosmic initial conditions, but almost all cosmologists agree it is more plausible than the traditional Big Bang. Yet, remarkably few popular accounts of cosmology highlight this dethroning of the old initial instant of creation—perhaps because it is a philosophically attractive idea for many. Confusingly, modern literature continues to use the term "big bang," but this now refers to processes occurring when the universe was hot and dense (e.g., the generation of light elements such as helium through nuclear reactions at temperatures around 10^{10} K) and does not have its original implication of an initial singularity.

Beyond the issues with initial conditions, the physical contents of the universe raise major unanswered questions. What is dark matter? In particular, is it an elementary particle? Is dark energy truly a density of the vacuum, or is it something that evolves? Why is the baryonic material matter rather than antimatter? This article reviews some of the suggested answers to these questions and takes stock of the scope for progress in improving our understanding of the cosmological model.

Large-Scale Structure

Cosmologists are able to ask questions about the universe only because it contains structure, that is, galaxies, and within them, stars and planets to host life. We can see new stars being created today as clouds of gas collapse under their own gravity, and it is a natural assumption that galaxies formed in an analogous way. This speculation became more plausible with the discovery of large-scale structure: the fact that galaxies are not distributed at random in space but clump together in clusters, with the clusters themselves congregating in superclusters.

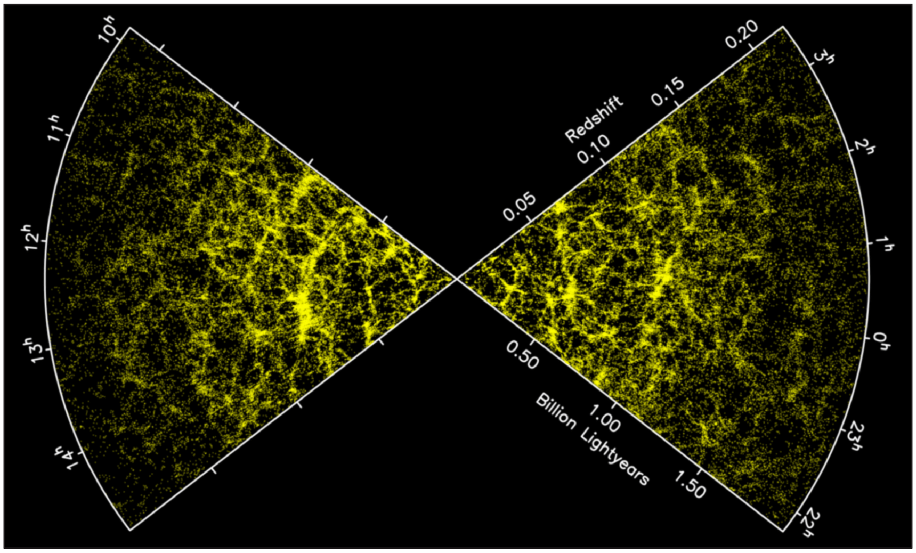

Figure 1: The large-scale structure in the galaxy distribution as mapped with approximately 250,000 redshifts from the 2-degree Field Galaxy Redshift Survey. Each yellow dot is a separate galaxy. We are located at the center of the picture.

Our knowledge of this structure came into focus slowly. For many years, data were two-dimensional, showing only the projected positions of galaxies in the sky. But starting around 1980, these studies moved into the realm of 3D with the advent of redshift surveys. Here, we exploit the expansion of the universe, where Hubble's law says that the recessional velocity is $v = H_0 D$, where D is distance and H_0 is Hubble's constant at the present day. The velocity causes a Doppler shift of spectral features to lower frequencies: the fractional shift is called the redshift, z, and $z = v/c$ for small velocities. Therefore, $D = cz/H_0$ (at least, while z is small), and so spectroscopy gives us the distance to a given galaxy. For larger redshifts, $D = c/H_0$ times a function of redshift that depends on the matter content, reflecting the fact that H varies with cosmic epoch. Measuring $D(z)$ then—which can be done using the apparent fluxes of objects of standard luminosity, or the angular size of objects of standard size—allows us to measure the contents of the universe.

By the mid-1970s, redshifts existed for only a few thousand galaxies, but the arrival of electronic detectors and computers to process spectra allowed much more rapid progress. By 1990, the Center for Astrophysics surveys had accumulated around 10,000 redshifts, increasing to about 0.25 million by 2000 through the 2-degree Field Galaxy Redshift Survey (www.2dfgrs.net). The 2dFGRS was the first survey that allowed the large-scale structure to be seen in full detail over a cosmologically representative volume, yielding the iconic image shown in Figure 1. This was taken forward though the million-redshift barrier by the Sloan Digital Sky Survey project, which pioneered the idea of mapping larger volumes of space by preselecting only particular classes of galaxy—especially luminous red galaxies. Today, the Dark Energy Spectroscopic Instrument project has taken this total to over ten million redshifts (desi.lbl.gov).

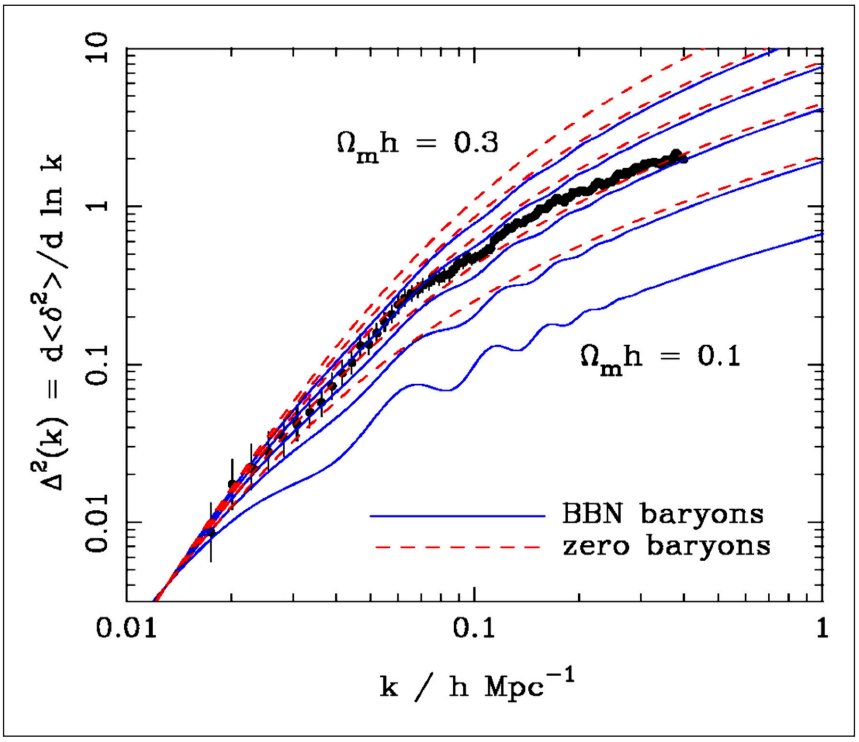

Figure 2: The power spectrum of the galaxy distribution, as measured by the 2-degree Field Galaxy Redshift Survey in 2001. The quantity Δ^2 gives the contribution to the fractional variance in density from fluctuations in a unit logarithmic range of scales. The wavenumber, k, is $2\pi/\lambda$, where λ is the wavelength of a given fluctuation. The symbol Ω_m is the "matter density parameter": the contribution of matter (dark plus baryonic) to the density of the universe, in units of the critical value needed to curve space-time sufficiently to make the universe "closed" with finite volume (about 10^{-26} kg m^{-3}). The parameter h is a number proportional to the Hubble constant, now known to take a value close to $h = 0.7$.

With these studies, we are able to measure with great precision the statistical properties of the galaxy distribution. These can be used as a probe of the distribution of mass in the universe—but first we need to allow for the fact that the formation of galaxies is complicated so that we do not expect a simple proportionality between the density of matter and that of galaxies. But, naturally, regions containing more mass will form more galaxies: so, if the matter density is raised by a factor $1+\delta$, we expect a change $1+b\delta$ in the galaxy density, where b is a bias parameter. With this assumption, galaxies can be used to map the form of fluctuations in density and how they depend on scale. The mathematical tool of interest here is Fourier analysis: we imagine the 3D density fluctuation field as a superposition of terms that oscillate with different wavelengths, λ, usually expressed as the wavenumber $k = 2\pi/\lambda$. The key quantity that characterizes the fluctuations is the power spectrum, which gives the contribution to the fractional variance in density that arises from modes in a given range of wavenumber. This is plotted in Figure 2, where we see that the galaxy measurements are closely matched by a smoothly varying theoretical model. As explained in more detail later, these results provide direct evidence that the matter content of the universe is dominated by some form of dark matter that interacts only through gravity. If the universe instead contained only "baryonic" material (the same kind of atomic gas from which the stars are assembled), then the galaxy power spectrum would show clear oscillatory features, reflecting the fact that such gas can support sound waves. But only very weak imprints of the so-called baryon acoustic oscillations (BAO) are seen.

The Cosmic Microwave Background

The simplest hypothesis for the existence of large-scale structure is that it reflects the operation of gravitational instability: regions with an above-average density will suck in more matter and increase their fractional fluctuation away from the mean density. When the fluctuations are small, the fractional density perturbation, δ, grows almost in proportion to the size of the expanding universe. If we measured density fluctuations at some early time and found them to be much smaller than at present, that would give direct evidence for this picture.

We can carry out this test using the CMB. The existence of this radiation was predicted in the 1940s on the basis that the universe once must have been hot enough to allow nuclear reactions that would build up light elements such as He^4. At such extreme conditions, baryonic matter would be fully ionized and "glued" together via Compton scattering with the black-body radiation associated with the temperatures at that time. But as the universe expanded, the radiation cooled: eventually, a temperature of $< 10{,}000$ K was reached, at which point the matter underwent recombination and became neutral. Then, the

radiation could travel freely: there was an era of "last scattering," and the CMB photons we detect today come to us from a surface at a large distance (a redshift of approximately $z = 1100$). The radiation was compressed or expanded by the density fluctuations of that time, as well as influenced by the gravitational potential and the velocity of the scattering plasma. Almost as soon as the CMB was first detected in 1965, it was predicted on this basis that the CMB radiation should contain small anisotropies. The detection of these fluctuations, which are approximately one part in 100,000, was first made by the Cosmic Background Explorer satellite in 1992, followed by Wilkinson Microwave Anisotropy Probe in 2003 and Planck in 2013, yielding the beautiful map shown in Figure 3. For more on this history, see Ruth Durrer (2015).

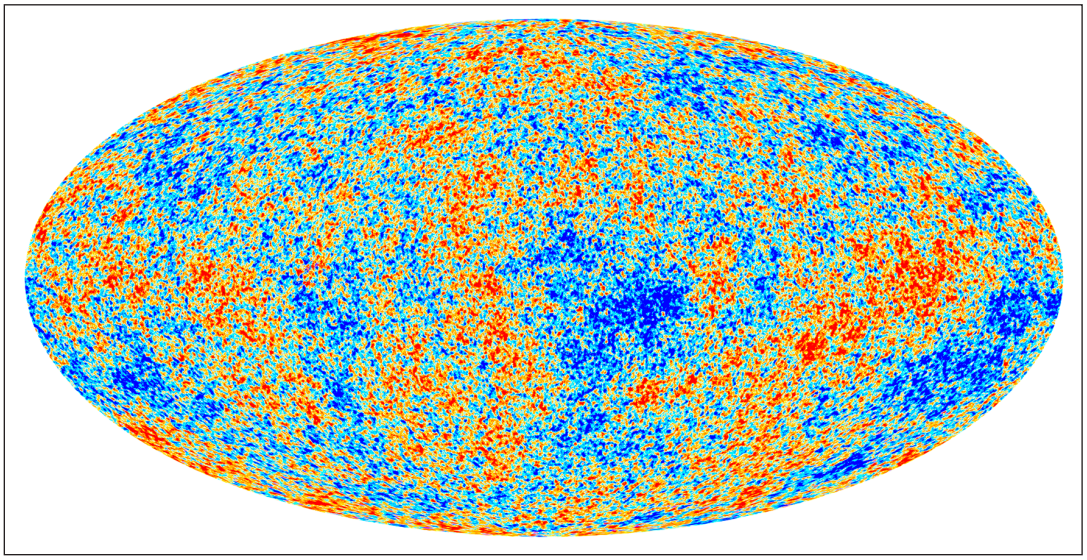

Figure 3: A map of the temperature fluctuations in the CMB as measured in 2013 by the European Planck satellite. The pattern is dominated by hot (red) and cold (blue) spots of approximately one degree in angular extent. These fluctuations are very small, typically one part in 100,000 of the mean CMB temperature of 2.725 K. What we see here represents the primordial seeds of future large-scale structure, which will amplify these early fluctuations (seen when the universe was about 380,000 years old, or 1/1100 of its current size) by means of gravitational collapse.

As with density fluctuations, the CMB temperature can be decomposed into modes of different scales, allowing the computation of the power spectrum of temperature fluctuations, shown in Figure 4. This striking difference between the forms of the CMB and the galaxy power spectra is a vivid illustration of the role of dark matter. With the CMB, we see photons that have been tightly bound to the baryonic component by Thompson scattering, so the temperature fluctuations are very largely determined by the density fluctuations in the baryonic

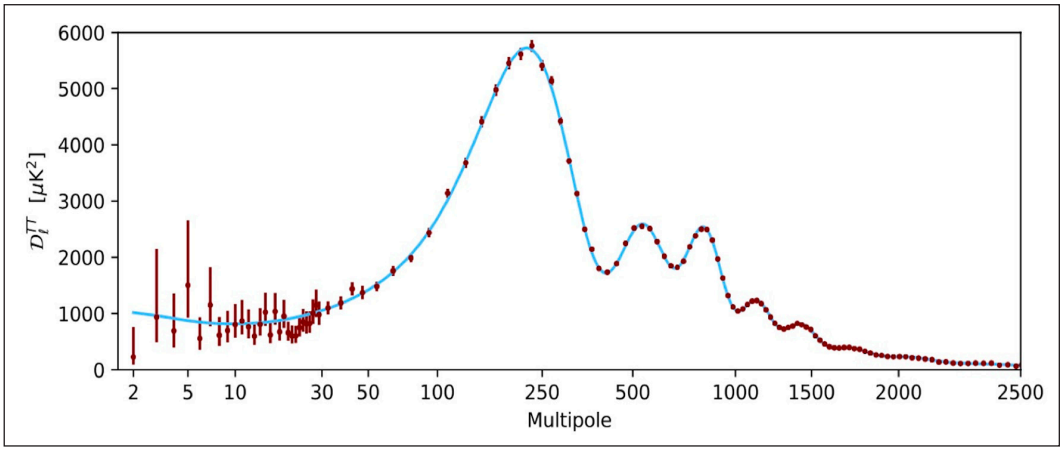

Figure 4: The angular power spectrum of the CMB temperature fluctuations (Planck Consortium 2020). The multipole is 360 divided by the angular wavelength in degrees. The vertical scale is the contribution to the temperature variance per log angular scale. We see that the signal is dominated by an acoustic peak of about one degree scale followed by harmonics—beautifully matched by theory (blue line).

component. For perturbations of small spatial wavelength, pressure forces dominate over gravity; so, the baryon fluctuations oscillate as acoustic standing waves: a region that was once denser than average will in due course become underdense and (if seen at the right time) pass through the mean density. This is why the CMB power spectrum contains peaks at particular scales, with much reduced signal in between. There is a dominant peak at the "acoustic horizon": an angle of around one degree, which is the maximum distance sound waves can propagate before the decoupling of photons and baryons (close to 150 Mpc), seen at the distance to the last scattering of CMB photons. In contrast, the density spectrum shows much weaker oscillations of the same kind, diluted by the dark matter contribution. From such measurements, we learn that dark matter outweighs normal matter in the universe by a factor of 5.36 ± 0.05.

Dark Matter in Galaxies

These arguments from cosmic structure have been presented somewhat anachronistically: historically, the need for dark matter in cosmology was established by very different arguments, with a close interaction of observation and theory. One common key argument relates to galaxy rotation curves. These have been measured going back to Slipher's work around 1914: spectroscopy of galaxies is able to establish that different sides of a galaxy have spectral features located at different wavelengths, indicating the presence of a Doppler shift arising from the bulk velocities of the stars in the galaxy. This rotation is usually a few hundred km s^{-1} (220 km s^{-1} for the Milky Way). Stars are maintained in approximately circular orbits by the gravitational attraction of the mass in the

object. For the simple case of a spherically symmetric galaxy, the centripetal acceleration balances the gravitational attraction if $V^2 = GM/r$, where V is the rotational velocity and M is the mass enclosed within a radius r.

From this equation, we can see that the rotation velocity should fall at large radii once we pass beyond the edge of a galaxy's mass distribution. But there is good evidence that, in many cases, this fails to happen: often, the rotation curve will remain flat to the largest measured radii, indicating an enclosed mass that grows linearly with radius, which corresponds to an extended "halo" with a density falling in proportion to $1/r^2$. Thus, there is a need for dark matter, since a galaxy's mass continues to grow beyond the point where the distribution of visible stars cuts off. But how could this ever be established, since surely stars are needed to measure the Doppler shifts? This was indeed an issue with one of the early studies that is often pointed to as contributing to the discovery of dark matter: Vera C. Rubin and W. Kent Ford Jr. (1970). This optical study showed that the mass of M31 continued to increase right to the boundary of the stellar distribution, but no clear claims for a halo of dark matter were made. What took such studies into a new regime was the use of radio astronomy. Neutral hydrogen gas emits a characteristic spectral line at twenty-one cm wavelength, and many galaxies contain discs of this cold gas that extend very far beyond the visible body of the galaxy, by perhaps a factor of three or more in radius. The amount of emitting gas is very small, so we can be sure the density of matter at large radii greatly exceeds the density of stars and gas at that point. M.S. Roberts and Arnold H. Rots (1973) published one of the important first papers to demonstrate this.

But at almost the same time, a completely different argument appeared, given by Jeremiah P Ostriker., P. J. E. Peebles, and Amos Yahil (1974). They had been involved in simulations of idealized galaxies, following numerically the trajectories of many stars that orbited under their mutual gravitational attraction. Their conclusion was that discs of stars are unstable and should form linear structures called "bars." The only way they could see of suppressing this instability was to assume galaxies are embedded in invisible, spherical mass distributions, so that gravity is dominated by that dark halo rather than the mass of stars. This paper was hugely influential and led cosmologists to interpret the emerging galaxy rotation curve data through a prejudice in favor of dark halos, even before the observational situation had become definitive. Ironically, the original argument about bars was misleading to an extent, since bars are now known to be much more common in galaxies (including one in the Milky Way) than was appreciated in the 1970s.

Non-Baryonic Matter

Demonstrating that dark matter exists through its gravitational effects is all very well, but far from telling us very much about what it might be. Empirical

properties are commonly summarized terms of the ratio between mass and visible luminosity. Typical figures are several hundred to over 1000 (in units where the sun has a figure of unity), depending on the waveband in which any visible emission is measured. Achieving such figures is not as difficult as might be supposed: planets and comets are much darker than this, as indeed are low-mass dwarf stars. Therefore, it initially seemed reasonable that the darkness of dark matter simply reflected an absence of heavier and more luminous stars. Perhaps star formation in the very different physical environments of the outskirts of galaxies favored the formation of dwarf stars, or perhaps there was much ionized or molecular gas that was not registered by neutral hydrogen observations?

But such a possibility came under increased pressure in the 1970s through an argument that reached back into the very early universe: primordial nucleosynthesis. It had been appreciated through the insight of George Gamow and the subsequent detailed calculations of Ralph A. Alpher and Robert C. Herman (1950) that the light chemical elements could be generated by nuclear reactions in the early universe. A side product of these calculations was a prediction of relic thermal radiation with a temperature of order 10 K. Given the subsequent importance of the CMB, it now seems a little strange that this prediction was not more widely known, and that it did not provoke any observational searches for many years. Such calculations became particularly important in the 1970s with the first observational determination of the abundance of Deuterium in the interstellar medium. This element turns out to be rather sensitive to the balance between matter and radiation, and it allows an estimate of the present density of normal baryonic matter. A modern determination suggests the baryon density is about 4.5% the total density in the universe (including dark energy). Thus, if we measure the density of the universe as a whole to exceed this figure, as we do, then the dark matter cannot be in the form of baryons.

In that case, what are the options? We have rather limited constraints: we know the amount of dark matter, and we know it appears to interact only by gravity. So, we are looking for something that consists of compact clumps of matter, and there are two options: black holes or weakly interacting elementary particles. Black holes can only grow by accreting baryonic material. Gas dissipation processes are required to remove angular momentum and allow material to funnel down to the scales of the black-hole horizon. But it seems implausible that such processes could ever be so efficient as to sequester the majority of the baryons—rather, indications from measuring the supermassive black holes in the centers of galaxies are that the efficiency of the incorporation of baryons into black holes is more like 0.1%. For black holes to make up the dark matter, we must therefore speculate there is a population of primordial black holes. It is possible in principle that conditions on small scales in the

very early universe were sufficiently violent that formation of black holes could be very efficient. However, we can be fairly sure that the majority of the dark matter is not in black holes of astrophysical sizes. These objects would reveal themselves via gravitational lensing, causing characteristic spikes in the brightness of stars when a primordial black holes passes along the line of sight. As a result, the dark matter can only consist of primordial black holes if they lie in the mass range 10^{14}–10^{19} kg (the mass of a small asteroid) (see B. J. Carr and A. M. Green (2024)).

But most speculation about the identity of dark matter involves the possibility of exotic elementary particles that remain as relics of the early phases of the universe. The physical basis of this mechanism is straightforward, based on the thermodynamics of the early phases of the Big Bang. Although rapidly expanding, the early universe is so dense that thermal equilibrium is a good approximation; this means that at temperatures $kT > m\,c^2$, particles and antiparticles of mass m will exist in similar numbers to photons. But once the temperature falls below the rest-mass threshold, the particles will tend to annihilate. However, the time needed to find an annihilating partner eventually exceeds the age of the universe. This is the process of "freezeout," and the ratio of dark matter particles to photons will remain constant beyond this point. We can be sure this mechanism works, since it predicts the universe contains a density in relic neutrinos that is 68% that in photons; this extra density speeds the expansion of the universe, and its influence can be detected in the pattern of CMB fluctuations. Might the dark matter therefore be the frozen-out relic of some other particle?

However, it was neutrinos that first stimulated our current ideas on particle dark matter. We know of three distinct types of neutrinos: those partners to the electron, muon neutrinos, and tau lepton neutrinos. If they have different masses, this opens the door to "neutrino oscillations," in which neutrinos of one type transform to another. In 1980, it was reported this phenomenon had been detected, implying a characteristic neutrino mass of around ten eV, which was sufficiently large that relic neutrinos could make up all the dark matter. This idea was tremendously exciting but quickly proved problematic, as neutrinos would constitute "hot dark matter," meaning they retained substantial random velocities from their thermal origin. Massive neutrinos would move too quickly to remain in galaxy halos, and indeed their motions would erase primordial fluctuations up to supercluster scales. In fact, it was not long before the original massive neutrino experiment proved to be in error; we now know that neutrinos do indeed have mass, but at the much lower level of around 0.1 eV, meaning neutrinos are a form of particle dark matter but only contribute perhaps 0.5% of the total amount—what is the rest?

The most natural answer to this question was first proposed by Peebles (1982): "Cold dark matter." Here, we consider a particle much more massive

than the neutrino, but which freezes out its abundance when nonrelativistic so that it has a much smaller number density. Such candidates are referred to as WIMPs (weakly interacting massive particles). Because the freezeout is very early, random velocities are negligible, and density fluctuations are preserved on all scales. The relic abundance turns out to depend only on the strength of the annihilation interaction; this is a neat result but means a wide range of masses is possible. There is a tendency to think the hypothetical particles may be very heavy, above 1 TeV in energy scale, to explain why they have not been observed in production at the Large Hadron Collider. But lower masses are possible. Very light particles tend to damp cosmic structures, as we saw with neutrinos, and masses below a few keV can be ruled out on the grounds that they would interfere with the formation of dwarf galaxies and observed structures in the intergalactic medium. However, even this limit can be evaded if the particles interact sufficiently weakly that they are not initially in thermal equilibrium. In this case, the mass limit is set by the point at which quantum wave effects become important: a mass as tiny as 10^{-23} eV.

If the dark matter is in particle form, then the only way to settle the question of its mass is by experimental detection, and there are two routes: direct and indirect. The indirect route is astrophysical and depends on the fact that particle dark matter is presumed to be composed of an equal number of particles and antiparticles. Thus, annihilation still proceeds at some level within dark matter halos, producing energetic photons. Indeed, there have been claims that anomalous gamma-ray emission from galaxies may derive from this mechanism. But it is rather hard to rule out more prosaic astrophysical origins for energetic photons, especially given the uncertainty over the particle mass, plus the complication that energetic photons will probably be reprocessed rather than travel cleanly to us to be detected.

Thus, most attention has been devoted to direct detection experiments. These tend to be carried out in laboratories deep underground using cryogenic detectors. The hope is that a rare interaction between a dark matter particle and a nucleus in the target will cause energy transfer to the nucleus that can be detected using particle physics detector technology. Deep mines are needed to reduce the background from cosmic-ray particles, and such experiments aim for exquisite efficiency in this respect, so that even a single detected event could provide evidence for dark matter. But shielding cannot be perfect: neutrinos pierce the Earth with ease, and indeed, current experiments are approaching the limit set by the expected event rate from solar neutrinos. So far, there has been no detection, and this is causing some to question whether WIMPs are the correct explanation for dark matter. Possibly this is premature, though even if there is no detection before the neutrino limit is reached, it is still quite possible to imagine particles whose interaction strength lies below this threshold. In this case, the dark matter puzzle could only be solved via the direct production of

these particles in accelerators. In the meantime, alternative explanations will continue to be pursued. For a detailed review of experimental searches for dark matter, see Marcin Misiaszek and Nicola Rossi (2024).

The Cosmological Constant and Dark Energy

Throughout the 1980s, the idea of a universe dominated by dark matter was considered well established, and the only question seemed to be how much of it there was. Could there be a critical density, so that the universe was almost closed, with a finite volume ($\Omega = 1$, where Ω is the density parameter)? The simplest means of estimating the density relied on measuring the masses of individual self-gravitating systems, especially clusters of galaxies, which could be done by measuring the orbital velocities of the galaxies within them. Indeed, this was how the first detection of dark matter was made (Zwicky 1933). Counting up the stellar emission of the galaxies yielded a mass-to-light ratio, M/L, which could be applied to the mean density of light as measured in large galaxy surveys to estimate the mean matter density. Such methods tended to yield a lower matter density, $\Omega_m = 0.2–0.3$, indicating the universe was of infinite extent and would expand forever.

However, this conclusion neglected a component of the universe that had been hypothesized from the earliest days of cosmology. Having written down the relativistic field equations of gravity in 1915, AlbertEinstein set out in 1917 to answer a question that had stumped Isaac Newton: What does gravity predict for an infinite uniform mass distribution? Both Newton and Einstein assumed without question that the situation must remain static (ironically, Einstein was unaware of Slipher's evidence to the contrary, published the same year). But Einstein showed transparently that this only could be so if the equations of both Newtonian and relativistic gravity were modified. A large-scale repulsion had to be introduced to counteract the attraction of matter to itself. The magnitude of this repulsion was controlled by a new fundamental parameter, Λ: the "cosmological constant." Einstein saw this as determining the curvature of space-time in the absence of matter, but subsequent work (especially by Andrei Sakharov and by Yakov Zeldovich in the 1960s) proposed an alternative interpretation: that Λ represented the energy density of the vacuum. Although such a concept may sound self-contradictory, it is inevitable from the point of view of quantum mechanics. A completely empty vacuum would constitute perfect knowledge and violate the uncertainty principle. The vacuum density can be estimated by adding up the zero-point energy of wave modes of the electromagnetic field—but the result is infinite, and a finite calculation arises only if the sum is truncated at some maximum frequency. But to avoid exceeding even the rather rough upper limits that could be estimated with 1960s data, this cutoff frequency needed to be somewhere in the infrared, which makes no sense. Assigning the cutoff to new physics that lurks beyond the energy scale of the largest particle accelerator yields an estimate that exceeds the limits by

roughly sixty powers of ten. Faced with this grotesque failure, the reaction of most cosmologists was to assume that some yet-to-be discovered argument would cancel such contributions, so that $\Lambda = 0$.

But during the 1990s, a string of evidence accumulated to suggest that a nonzero Λ might be required. The most simple and powerful evidence came from the CMB. If the universe is open, with negative spatial curvature, structures at the CMB scattering surface will subtend smaller angles (the opposite of the effect we see on the surface of a sphere, where light rays that follow great circles all converge at the poles). The one-degree peak in the CMB and its harmonics would then move to smaller scales. Keeping the CMB fluctuations on degree scales requires a density close to critical, meaning that $\Omega_m + \Omega_L$ would be close to unity. Since a range of arguments favored $\Omega_m = 0.2$–0.3, as described earlier, a nonzero Λ seemed to be required. All this was set out clearly by G. Efstathiou, W. J. Sutherland, and S. J. Maddox (1990), but somehow their prescient paper failed to convince the community. This is perhaps not so unreasonable, since it is a huge leap for physics to accept the vacuum has weight; "extraordinary claims require extraordinary evidence." Enough straws to break the camel's back and cause widespread acceptance of Λ as part of standard cosmology only accumulated by the end of the 1990s, with results from the study of supernovae proving critical. It was established that supernovae of type Ia (lacking hydrogen emission lines and presumed to be connected to white dwarf stars) were objects of a relatively standard peak luminosity, if corrections were made depending on the durations of different supernova explosions. By using their observed light curves, relative distances could then be inferred with about 5% precision. Thus, the distance–redshift relation could be measured empirically with high accuracy, and this allows a determination of changes in the expansion rate over time. In a matter-only universe, the cosmic expansion should decelerate; but if Λ dominates, then the expansion would accelerate, with the size of the universe increasing exponentially with time. In 1998 and 1999, two groups reported evidence for cosmic acceleration in this way. As explained, this was far from the first observational evidence for Λ, but it was a particularly direct route. As a result, the cosmological community accepted the reality of Λ virtually overnight.

But then the difficulties in understanding the level of the vacuum density became more critical. Clearly, there was no grand symmetry that guaranteed $\Lambda = 0$, but how could such a small nonzero value make sense? The most likely answer seemed to be evolutionary. Perhaps Λ was declining towards zero, and we happen to see it in the late stages of this history. The term given to this evolving Λ is not a good one, but it now seems impossible to change it: dark energy. Anyone who has heard of $E = m c^2$ might well think this term is synonymous with "dark matter," and they would be right. In practice, the distinction is that dark matter clumps under gravity, whereas dark energy is spread uniformly (or very nearly so) throughout space. A more physical distinction is in terms

of pressure, which is zero for cold dark matter but negative for dark energy. This is necessary if dark energy is to behave like Λ and stay constant as the universe expands. Dark matter certainly does not do this: its density falls as the universe expands. If we express the relative size of the expanding universe as a function of time as $a(t)$, then the density of matter scales as $1/a(t)^3$. Why should Λ not become diluted in the same way? When a gas expands, its pressure does work and reduces the total internal energy of the gas (or vice versa; this is why a bicycle pump becomes hot). But we want to increase the total amount of energy from Λ in a given volume as that volume increases, so the pressure must be negative. We therefore characterize the properties of dark energy via an equation of state parameter, w, which is the ratio of the pressure to the energy density. For a perfect cosmological constant, $w = -1$ exactly. The effective vacuum density then changes with the cosmic scale factor as $a^{-3(1+w)}$, if w is a constant—which in general it may not be. So, for example, if $w = -0.95$, the vacuum density would have declined by 10% since the time the universe was half its present size. Such a variation is about at the limit of what is detectable by current data.

The way we are able to probe the evolution of dark energy is by its impact on the expansion of the universe. If the dark energy density is higher, the rate of expansion increases, and so the distance corresponding to a given redshift goes up. In fact, the distance to a given redshift is affected by the expansion rate at all points on a photon's trajectory; thus, the angular size of features in the CMB (originating at roughly $z = 1{,}100$) is affected by the accelerating effects of dark energy at low redshifts. We can measure the expansion rate during the late-time vacuum-dominated phase by studying the distance–redshift relation for redshifts up to 1–2, which can be done by using either the standard candles of type Ia supernovae or the baryon acoustic oscillations standard ruler. Based on these studies of the distance–redshift relation, we can say that the equation of state of dark energy is consistent with the unevolving $w = -1$ to a tolerance of about 5%. Future studies aim to reduce this precision to under 1%, particularly using results from new redshift surveys such as the Dark Energy Spectroscopic Instrument (www.desi.lbl.gov), which aims to amass about fifty million redshifts, or those from measurements of gravitational lensing made by the Euclid satellite (www.euclid-ec.org).

If dark energy turns out to evolve, a variety of models exist for how this could happen. The simplest is to assume the dark energy is generated by a scalar field of some kind. To explain what this is, consider the example of the electromagnetic field: something that fills space and whose strength determines forces acting on charged particles (strictly, this is what the electromagnetic field does rather than what it is—a philosophical distinction that was of greater concern to James Clerk Maxwell's generation than it is today). A field such as this is associated with a particle that is the quantum of the field: the photon in

the case of electromagnetism. Similarly, a scalar field has an associated quantum that has zero spin; the Higgs boson is the only known example. The detection of the Higgs boson in effect shows that the Higgs field exists and can change with time; dark energy models appeal to the identical dynamical equations that describe the Higgs field, but with the key proviso that we are dealing with a new scalar field (named the "inflaton") and that this is homogeneous and follows the same time dependence at all points in the universe. This time-varying scalar field can then produce a time-varying energy density that is spread uniformly. A useful picture is to imagine the dynamics of a scalar field as being like that of a ball rolling down a hill. If the ball stays at the top of the hill, this generates a cosmological constant: an energy density with $w = -1$. But if the ball is free to move, then it rolls "downhill," and the density of dark energy decays with time. The fact that w is close to -1 tells us that the "hill" of energy density as a function of field value is fairly flat at the top, but there seems to be no need for it to be perfectly flat.

However, such models have a problem to overcome. Recall that simple quantum arguments seem to indicate a natural level for the dark energy density that is at least sixty powers of ten larger than observed. So, the hilltop has to be very low if the field is not rolling rapidly. And if the field is rolling downhill, is this towards a plateau at zero density? The scalar field dynamics are the same if the whole hill sits on a plateau of arbitrary height. Therefore, dynamical models quickly end up having to contend with the original problem they were designed to solve: Why should the dark energy density be small and nonzero? From this argument, and given the lack of any sign of evidence for evolution to date, we may suspect we are indeed dealing with a cosmological constant.

A very different way of approaching this problem was set out by Steven Weinberg in 1989. He noted that cosmological gravitational instability is suppressed once dark energy comes to dominate and the universe expands exponentially. Thus, if the cosmological constant had been very much larger, the growth of cosmic structure would have ceased before galaxies ever formed. We will never measure this high value because there would be no observers to experience it. This is called the "anthropic" explanation for the level of the cosmological constant, but this is a misleading term. Observers are needed to measure a given level of the vacuum density, but they do not need to be human, or even based on carbon. Also, this name obscures the fact that the anthropic approach requires a multiverse: many copies of our observed universe, but each with different levels of vacuum energy. Otherwise, it is almost certain the level would be high, so that there would never be any observers. But we do exist, and this only makes sense in a multiverse, as there will always be some rare member of the ensemble that wins the ultimate cosmic lottery, emerging as an observed universe with a low vacuum density. This line of reasoning

works with planets: the Earth is extremely well suited in its properties to the existence of water and hence life. It seems highly likely that this situation arose because billions of planets exist, most of which are too hot or too cold. But with a large enough supply of possibilities, we are bound to find one that works. The direct detection of exoplanets is of course an astronomical triumph, but anthropic reasoning allowed us to be confident of their presence without the need for telescopes.

Modifying Gravity

We should be clearly aware that the evidence for dark matter and dark energy is purely gravitational. We measure orbital velocities in galaxy halos or within clusters that exceed what can be bound by forces from visible matter, and on a global scale, the acceleration of the cosmic expansion requires the effect of dark energy to balance the deceleration from dark matter. It is then reasonable to wonder whether dark matter and dark energy genuinely exist as physical substances or whether we infer their existence erroneously because gravity does not operate as assumed.

Regarding dark matter, there has been much exploration of the idea of modified Newtonian dynamics (MOND), invented by Mordehai Milgrom (1983). Milgrom notes that the evidence for dark matter in galaxy rotation curves arose only at large radii, where the stellar mass density tended to zero. At this point, the gravitational field is very weak, and the resulting acceleration predicted by $F = ma$ is well below the point at which this relation could ever be tested in a laboratory. If there is some critical acceleration, a_0, below which the relation of force and acceleration becomes $F = m\,a^2/a_0$, then the appearance of dark matter naturally arises, even though the gravitational force is generated only by the stars in the galaxy. This is an attractively simple hypothesis, and it has been shown to account well for a range of data on the internal dynamics of galaxies (e.g., McGaugh 2012).

Nevertheless, the idea of MOND has generally not taken root. Initially this was because the key equation was purely ad hoc—though Jacob Bekenstein subsequently attempted to derive modified dynamics from more fundamental principles. However, the general belief in the reality of dark matter as a physical substance stems from the data on larger than galaxy scales. Particularly, the small amplitude of baryon oscillations in superclustering argues for a dominant component that does not support sound waves. The fact that the dark matter is collisionless is also illustrated rather directly in a single system called the "Bullet Cluster," where two clusters of galaxies have recently merged (see Figure 5). The intracluster gas (which dominates the baryon content) is sandwiched between the two clusters, whereas gravitational lensing shows that the mass remains concentrated with the two sets of

galaxies. So, the appearance of dark matter is not because the gravitational effect of the baryons is nonstandard.

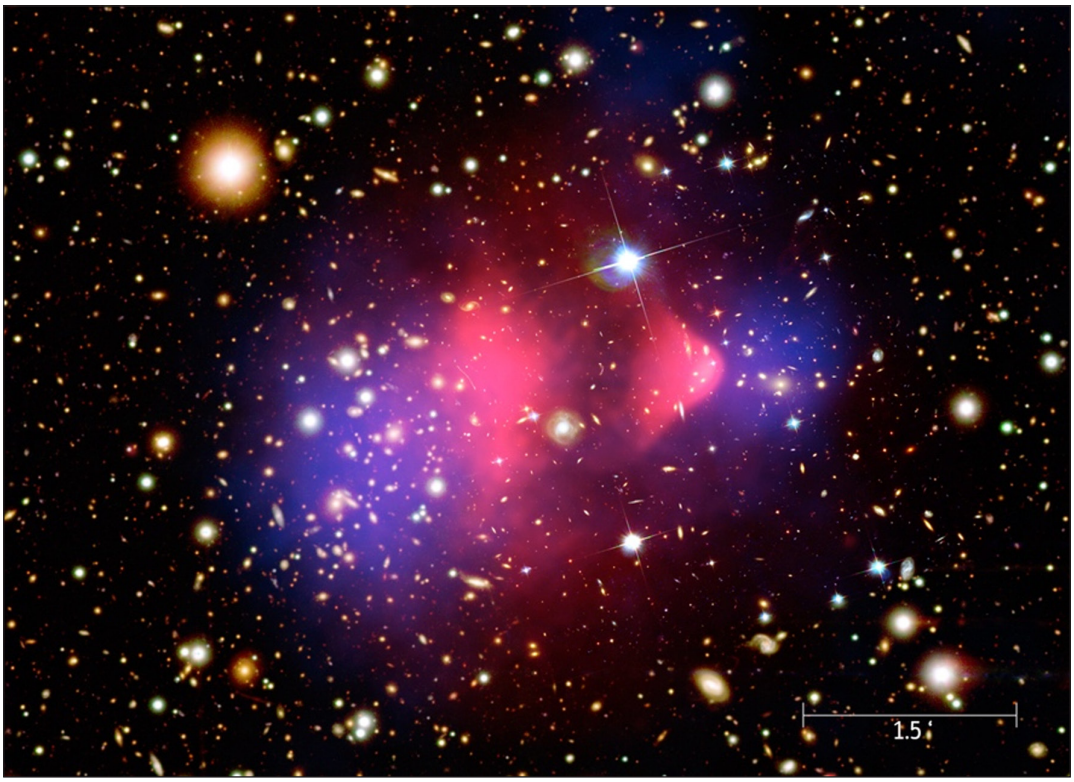

Figure 5: The Bullet Cluster (Clowe, Gonzalez, and Markevitch 2004). X-rays from diffuse gas (red) are in different locations to the dark matter inferred from gravitational lensing (blue). It can be seen directly that the dark matter is collisionless and cannot be an artefact of the gravitational field generated by the baryons.

But although we can be relatively sure dark matter exists as a physical substance, the same cannot be said of dark energy. This can only be investigated on the scale of the entire expanding universe, leaving open the question of whether gravity operates on such scales exactly as specified by Einstein's original 1915 relativistic theory. It is certainly easy to generalize Einstein's theory to more complicated alternatives—though none of these have the same aesthetic appeal. One way we can attempt to tell the difference is by the operation of gravity on the largest-scale fluctuations: Does superclustering grow in amplitude at the rate we would expect in a standard ΛCDM model? This question can be addressed using the new generations of redshift surveys, from which we can infer that the strength of gravity on supercluster scales is within 10% of the standard prediction. But attempts to improve this tolerance will continue, since even a 1% deviation would confirm that dark energy cannot be understood without revising the theory of gravity.

Inflation and Initial Conditions

The earlier discussion of scalar fields contributing an effective Λ does not follow the actual progress of history, and the idea actually arose at the opposite end of time as an explanation for cosmological initial conditions. Relativistic cosmology as it arose in the first half of the twentieth century was deeply unsatisfactory in a number of respects. First, it contained a singularity: integration of the equations of motion for the cosmic expansion showed that the energy density diverged about ten billion years ago. This "big bang" (a term coined by Fred Hoyle to express his criticism of the theory) conventionally forms the origin of cosmic time; because the equations being integrated break down, it is impossible to say what happened before $t = 0$. Worse, certain key properties of the universe apparently have to be set as initial conditions at this singularity: the ratio of photons to baryons, the amplitude of the fluctuations in space-time that seed cosmic structure, the curvature of the universe. All of these cry out for some theory of what happened before $t = 0$.

A first step towards meeting this challenge was given in a prescient and underappreciated paper by E. B. Gliner and I. G. Dymnikova (1975). They noted that the conventional cosmological models were radiation dominated at early times, with a scale factor $a(t)$ proportional to $t^{1/2}$. In contrast, a universe dominated by a cosmological constant has an exponential dependence, $exp[Ht]$, where H is a constant. Gliner and Dymnikova conjectured that the equation of state might have changed at early times, switching from radiation dominated to vacuum dominated prior to some critical time near $t = 0$. The early-time behavior will then no longer go to zero size at $t = 0$ but rather be followed to infinitely early times without a singularity. In this picture, the standard big bang singularity at $t = 0$ is an incorrect inference that arises from the wrong extrapolation back in time of the late-time expansion. This behavior is illustrated in Figure 6.

The key question with this picture, of course, is how and why the equation of state should vary. This received an answer in Alan H. Guth (1981), who was considering the cosmological implications of the Grand Unified Theories of particle physics. These contain scalar fields that play an analogous role to that of the Higgs field in the standard model. If the field has a potential energy function, evolution of the field is then accompanied by a change in the effective energy density of the vacuum. Guth realized that it was then quite possible to start with a high "false vacuum" density that behaved effectively just as a large cosmological constant but would lower itself by self-consistent dynamics. If the field couples to light at all, then this process can be accompanied by "reheating," in which the change in scalar field energy density is transmuted to radiation. At the end of the process, we have a radiation-dominated universe that looks as though it emerged from a big-bang singularity at $t = 0$—but this is an illusion.

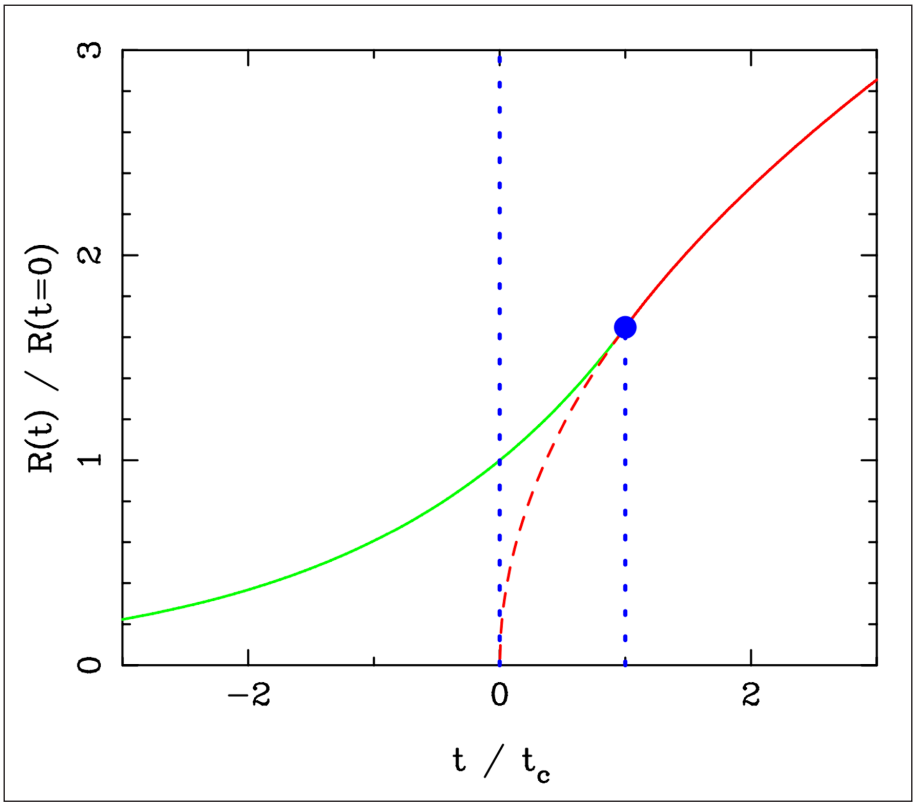

Figure 6: The "inflationary" history of the expanding universe, as first conjectured by Gliner and Dymnikova (1975). The quantity $R(t)$ is the cosmic scale factor, which is expected to scale in proportion to $t^{1/2}$ at early times when the universe is radiation dominated. The expansion then follows the red track, reaching $R = 0$ at $t = 0$, an infinite-density "big bang" singularity, preventing any integration of the cosmic equations of motion to earlier times. But suppose a large cosmological constant existed prior to some critical time t_c: in that case, the expansion would actually have followed the green track and need never have been singular. The blue dot marks the transition point. This is the modern picture of "inflationary" cosmology, which replaces the classical big bang. The inflationary phase itself may have started following a true initial singularity at some time well before $t = 0$, but the occurrence of any such singularity leaves no observable signature if inflation continues for sufficiently long.

These are attractive ideas, but may well seem rather speculative. How are they to be tested if the inflationary era is confined to setting up the initial expansion? One reason inflation captured the attention of the cosmology community is that it was quickly found to have an unexpected consequence for structure formation. The inflationary universe is extremely small. Everything we can now see over billions of light years was contained in a region perhaps just a few centimeters across when inflation ended, so that earlier in the process, we might well be dealing with dimensions smaller than an atomic nucleus, a scale at which quantum mechanics cannot be neglected. In an astonishing outburst

of creativity, which brings to mind the quantum revolution of the 1920s, this basic idea was fleshed out by 1982 into a full theory of how these early quantum fluctuations could seed primordial density fluctuations that would serve as the seeds of the subsequent formation of structure in the universe. If true, this is one of the most audacious ideas in physics: that galaxies, planets, and people have their ultimate origins in the same physics that controls the structure of atoms. The fact that inflation was not originally developed with any aim of achieving this is what makes it a very plausible picture for the earliest phases of the expanding universe.

Outlook

This brief overview has set out some of the historical development of the current ΛCDM cosmological model. This is commonly known as the "standard model," with some justice: its theoretical development was complete forty years ago, and it has been the preferred alternative in matching a wide range of cosmological data for at least twenty-five years. This is a deeply impressive achievement, but the model leaves open a number of fundamental questions:

1. Did inflation happen? Inflation is rather good at covering its tracks, and the only relic from what happened during the period of inflation is the spectrum of density fluctuations. The simplest generic character these could have is to be "scale invariant," meaning the gravitational potential field has a fractal character whose appearance is unchanged under magnification. But inflation predicted the fluctuations would have a small "red tilt," with a slight reduction in fluctuation on small scales—and this was detected by NASA's Wilkinson Microwave Anisotropy Probe satellite in 2006. A further test would be that the same mechanism of quantum fluctuations should also generate relic gravitational waves. Seeing these in addition to tilt would constitute proof beyond reasonable doubt that inflation did occur. In 2014, there were briefly claims of such a signal, but these turned out to be due to foreground emission from the Milky Way (see Ade et al. 2015). The search for primordial gravitational waves remains one of the core aims of future cosmology experiments. Even if detection was achieved, however, it would still leave major questions. In particular, what is the scalar field that drives inflation? At present, any well-formed relation between inflation and the phenomenology of particle physics is lacking.
2. What is the dark matter? We know it has several constituents. At least 0.5% comes from massive neutrinos, but what is the rest—is it a single constituent, or more than one? For many years, the simplest alternative was seen to be a new massive particle, and this is probably still true. But the lack of any sign of such a particle, either from direct relic detection in

underground experiments or the generation of new particles in the Large Hadron Collider, has weakened confidence in this model. Certainly there is no shortage of very different alternatives, from ultra-light scalar fields to primordial black holes. From an astrophysical point of view, this is problematic. The process of galaxy formation and clustering will proceed identically with almost all these alternatives, and so survey astronomy offers no way forward in answering this question. Apart from laboratory detection of dark matter particles, the only way in which astronomy can bear on the question of particle dark matter is via indirect signatures of particle decay or annihilation. But high-energy photon emission can arise in a number of purely astrophysical ways, so interpreting this evidence is not straightforward.

3. Is dark energy dynamical, or is it truly a cosmological constant? As we have seen, the current evidence is that dark energy is close to an unevolving vacuum density, changing by at most a few percent when the size of the universe doubles. In a picture where dark energy arises from scalar field dynamics, this is not so hard to achieve. All we need is for the field potential function to be sufficiently flat so that the field is "frozen" in practice, even though it is free to evolve. There is no natural prediction for how large this evolution could be, and it could easily be undetectably small. In any case, the need for fine tuning to reduce the effective Λ to a tiny fraction of the expected quantum vacuum density indicates there is still much to be understood. Detecting evolution requires rather small discrepancies with the ΛCDM model to be taken as real effects that indicate new physics. An example might be the Hubble tension, in which the value of H_0 inferred using the ΛCDM model is 5–10% lower than attempted direct measurements (Di Valentino et al. 2021). Most cosmologists (including this author) think it more likely that this discrepancy arises from unidentified systematics. Nevertheless, it was claimed in early 2025 on the basis of baryon acoustic oscillation measurements of the expansion history that dark energy has altered in value by roughly 10% during the time since redshift 1 (Abdul-Karim et al. 2025). If these claims are confirmed, it will be a revolution in cosmology.

These questions will continue to motivate new cosmological experiments. There will be redshift surveys of a good fraction of a billion galaxies. Maps of the CMB will be made with ever increasing resolution and sensitivity. But the chance must be accepted that once these next generation projects are complete, near the middle of this century, the ΛCDM model will still account for everything we see—and also that we may be no closer to knowing what the dark matter and dark energy actually are.

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Evolution of Human Cognition Required Einstein's Gravitational Waves

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This article describes an unexpected anthropic fine-tuning of gravity: human cognition arose on Earth only because the laws of gravity included gravitational waves. Their link is the heat from decays of the radioactive isotopes ^{238}U and ^{232}Th, which were synthesized mainly in rare explosive mergers of binary neutron stars, brought about by the loss of orbital energy to gravitational radiation. This heat, released in Earth's interior, has (1) maintained plate tectonics and (2) likely helped keep Earth's iron core molten. The core's magnetic field has protected all life from annihilation by the solar wind. More surprisingly, relative brain size, a proxy for cognition, has seen two sharp increases, first for mammals and then for humans, both attributed by evolutionary biologists to adaptations to major climatic changes caused by specific tectonic events. After the second event, the joining of North and South America, human brain size grew from chimpanzee levels to modern human ones. If the laws of gravity had not included gravitational waves, humans would not be capable of studying the laws of gravity.

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A Cognition That Can Understand Its Own Evolution

Humans appear to be the only animals that attempt to understand their own cognition and its origins. The ability to do this is often referred to as the mystery of human intelligence, but in this article, we avoid the ambiguous term "intelligence" and simply address cognition generally. Humans' uniqueness and success is in any case more than what is normally meant by individual intelligence: humans are able to solve complex problems only because we have cumulative culture and sophisticated communication. We use our intelligence to build on what previous generations have accomplished and then pass even more knowledge on to the next generation. This is as much a social activity as an intellectual one. Humans' social behaviors coevolved with our brain size and analytic capabilities, so it is artificial to separate them when discussing the evolution of these unique capabilities. The left and right brains have both been essential for human success. So, it is more appropriate here to speak of the mystery of human cognition as a whole rather than just of our intelligence. This cognition arose through Darwinian evolution because it gave our ancestors the ability to survive in changing and challenging environments.

In this article, we describe how some of the most important challenges for the evolution of our cognition had a surprising origin. One particular aspect of the laws of physics, Albert Einstein's (1915, 1918) gravitational waves, contributed in an essential way to one of the most formative evolutionary challenges humans experienced, a challenge believed to have driven human cognition to develop from something similar to that of chimpanzees to its present capabilities. This is by itself a remarkable association. But it is more. It goes to the heart of the philosophical issue of the "fine-tuning" of the laws of physics and what is known as the anthropic principle (Carter 1974).

The attempt to understand "how we got here" over the cosmic timescale since the Big Bang has led to a long-running discussion of the multitude of ways in which the laws of physics and the values of the fundamental constants of nature seem to be fine-tuned, that is, have relationships necessary for humans to have evolved. As a simple example, consider the elementary fact that electrons are much less massive than protons. This leads to atoms with electrons orbiting far from the nucleus, when compared to the size of the nucleus. When such atoms are packed in against one another, the electrons can readily interact with other nearby nuclei and the electrons that orbit them. This is what gives us chemistry, solid materials, and the huge variety of substances in our world. If electrons and protons had the same mass, electrons' orbits would be tightly bound to their nuclei, chemistry would simply never have happened, and there would be no life. This then seems puzzling: why should the universe have lightweight electrons? Is that an argument for intelligent creation? Not if we understand the weak anthropic principle: if, in a hypothetical universe, electrons and protons did have the same mass, and chemistry therefore had

not happened, humans could not be there to puzzle over it. Only if life were possible would there be anyone to ask the question. Since we are asking it, we should not be surprised the universe has enough fine-tuning to produce us.

Most of the fine-tuning scientists have discussed is about the fundamental properties that make life possible, but these do not directly say anything about the evolution of a cognition sophisticated enough to ask questions about fine-tuning. In this article, we discuss a surprising type of fine-tuning that is directly related to the evolution of human cognition: gravity must allow gravitational waves. We provide evidence to support the following chain of deductions that leads to that conclusion.

1. Gravitational waves carry energy away from binary star systems, thereby bringing the stars closer together. One consequence is that the there are occasional (explosive) mergers of neutron stars (themselves the collapsed cores of dead massive stars), producing short-lived optical events we call kilonovas (Metzger 2020). ("Macronova" is also used in the literature.) Without gravitational waves, there would be no kilonovas.
2. Kilonova explosions have been the principal source of the elements in the periodic table above iron (Lattimer and Schramm 1974; Eichler et al. 1989; Hotokezaka et al. 2018). These include uranium and thorium, whose radioactive isotopes ^{238}U and ^{232}Th are distributed throughout Earth's interior. Without kilonovas, the amount of these isotopes would be much smaller, or even zero.
3. The heat generated inside Earth by decays of these very long-lived isotopes contributes to keeping Earth's core molten and therefore to sustaining Earth's magnetic field. Without this field, Earth would look like Mars: the solar wind would have blown away the atmosphere and oceans.
4. Additionally, this heat is believed by geophysicists to be essential to maintaining plate tectonic activity today. Without this heat, the continents would likely have frozen in place a billion or more years ago.
5. Plate tectonics has been a major driver of evolution, in particular cognitive evolution. The merger of North and South America to produce the Isthmus of Panama three million years ago created climate changes in Africa that sparked the enlargement of the human brain from chimpanzee-size to its present size. If continents had frozen in place before this, all African primates would probably have remained small brained. Or, primates might not even have evolved, because the earlier tectonic event of the splitting of Australia from Antarctica about forty million years ago seems to have produced a rapid increase in mammalian brain size generally. Without that event, mammals might never even have reached the intelligence of primates.

The fact that Earth has creatures who can understand Einstein's general relativity depends on the very existence of the gravitational waves of general

relativity. Gravitational waves were not necessary for the evolution of life, nor possibly even for the evolution of mammalian life, although a case has been made for the possibility that kilonova-produced iodine was indeed necessary for life on Earth, at least as we know it (Ellis et al. 2024). But we show here that gravitational waves were part of the causal chain for the final step: making humans bright enough to start understanding our own cognition.

Gravity the Outlier

Let us begin with the unusual nature of gravity. Gravity is an outlier. Unlike the electromagnetic interaction, in which opposite charges attract but like charges repel, gravity normally does only one thing: it attracts everything. The other two fundamental forces of physics (called the strong and weak interactions) are also normally attractive, but they act only between specific kinds of particles and only over very short ranges, making them important in the atomic nucleus but negligible over a distance as small as the size of an ordinary atom. So, over macroscopic distances, only gravity and electromagnetism are important, both getting weaker with increasing distance as $1/r^2$.

Moreover, only gravity attracts everything. All other particles are selective in what they interact with. Protons, for example, interact electromagnetically with other charged particles but not with neutral ones. But, because of the equivalence of mass with energy, any form of energy has its own gravitational attraction. Every particle and every field have energy, so gravity is the only universal interaction.

Inherently, gravity is much weaker than the other forces (far weaker even than the "weak" interaction). But its universal attraction allows it to become competitive with the others if there is enough matter in a small enough region. It turns out that if an object is made of "ordinary" material (like rocks or solid iron), and if its mass is larger than about 3×10^{21} kilograms (about 5% of the mass of our moon), then gravity will be more important than the other forces in shaping the object's form (Schutz 2003, 91). This is the reason planets and large moons are smooth and round, while smaller objects like asteroids, comets, and even small moons such as Mars's Phobos are irregularly shaped.

Typical objects in our day-to-day experience are so small that their mutual gravity does not matter at all. The only gravity we normally have to deal with in everyday life is that of Earth itself. However, where gravity is dominant, able to overwhelm electromagnetic forces, its relentless pull knows no way of stopping. Gravity by itself can achieve no equilibrium. Equilibrium requires a balance between attraction and repulsion. This one-way feature of gravity has shaped our universe, leading to the formation of planets, stars, galaxies, and ultimately, black holes.

Normal chemical matter, by contrast, is ruled by the electromagnetic interaction, whose combination of attraction and repulsion allows it to achieve equilibrium in countless different forms. The attraction of opposite

charges is balanced by the repulsion of like charges, and since they come in equal numbers, they can (with the help of the exclusion principle of quantum mechanics) reach stable arrangements for a huge variety of solid materials. In empty space, countless rocky asteroids and icy comets smaller than our moon have reached equilibrium with very irregular shapes. Unless they are unlucky enough to encounter the sun or a planet or another rock, they will just retain their form essentially forever.

The atomic nucleus is also in equilibrium if the number of protons and neutrons is right. The protons, all having the same electric charge, repel each other very strongly at these small distances. But the strong interaction acts attractively among all the protons and neutrons together. If there are enough neutrons, the strong interaction will hold the nucleus together, just balancing the electromagnetic repulsion. If these particles are pushed too close together, the electric repulsion will get stronger and push the nuclear structure back to its equilibrium configuration. This is how all the stable nuclei in the periodic table maintain their equilibrium.

Since the nuclear force is short range (attracting basically only the nearest neighbor protons and neutrons) while the electromagnetic repulsion is long range (every proton in the nucleus pushing itself away from every other one), this balance only works for small numbers of particles. The more protons there are (in other words, the higher we go in the periodic table), the higher the neutron fraction has to be in order to achieve balance., There are no stable nuclei, apart from the smallest, whose neutron number is much smaller than its proton number. (Stability is actually more complicated than this, since the particles have an exclusion principle with other particles of their own type. But we do not need this level of detail for our purposes here.)

Unstable nuclei might split, some of them emitting a ^{4}He nucleus consisting of two protons and two neutrons, a process called alpha decay. Others might fragment into two pieces more similar in size, a process called fission. In yet others where the number of neutrons is a bit larger than actually needed for counteracting the repulsion of the protons, one neutron might disintegrate, leaving a proton behind in the nucleus and expelling an electron and a neutrino. This is called beta decay. The result of all these competing forces and processes is that, beyond uranium in the periodic table, there are simply no stable nuclei. As discussed in the following section, we found a need to pay attention to the stability and instability of nuclei when looking at how uranium and thorium are created in the first place, in collisions between neutron stars that lead to kilonova explosions.

On its own, a neutron is not actually itself in equilibrium. It is an unstable particle, and this is why beta decay is available to slightly unstable nuclei. The instability of the neutron arises because the weak interaction—which is weaker than the strong one but still very much stronger than gravity—is repulsive at this scale. It prefers to split the neutron apart, creating a trio of free particles—one proton, one electron, and one antineutrino—with a big enough kick that

the proton and electron escape from each other by shooting off in different directions despite their natural electromagnetic attraction to one another. The only reason a neutron does not always do this when it is being used to glue nuclei together is that the proton it would create would still be stuck in the nucleus, bound by the strong interaction, and its mutual electric repulsion of other protons would require more energy to create than is available from the decay of the neutron. Beta decay happens when there are still enough remaining neutrons that the proton left behind is bound despite the repulsion of the other protons.

The large variety of ways in which all three interactions (excluding gravity) work together, as hinted earlier, ensures equilibrium of matter is possible in a wide variety of forms and circumstances. Our material world is made of such stable equilibrium structures. Stability implies that these structures are in a state of minimum energy: at least for small disturbances, disturbing equilibrium requires energy input. A nudge to an equilibrium system, adding energy to it, typically leads to small extra motions, increasing the system's temperature. Such equilibria are said to have positive specific heat: the temperature goes up when energy is added.

That may sound like it should always happen, but gravity is just the opposite! If energy is added to a satellite in orbit around Earth, say by firing its rockets to give it a forward push, it will move further from the planet and slow down. If energy is added to the atmosphere of a star, it will expand so that its outer regions actually get cooler. Systems controlled by their internal gravity have negative specific heat.

Anything big enough for gravity to dominate its structure is called self-gravitating, and such bodies exist in an uneasy balance between the equilibrium-seeking of the three other interactions and the persistence of gravity in destroying the equilibrium. If a system's energy keeps decreasing (e.g., when a star radiates light), the equilibrium between gravity and other forces may keep readjusting and persist for a long time, but the continued contraction of the system and concomitant strengthening of its self-gravity can ultimately lead to catastrophe.

Of course, reassuring as it is to be surrounded by structures in equilibrium, our own biological existence is not an equilibrium state. At the individual organism level, life is a process of development and change and renewal, ultimately followed by disintegration. At the species level, Darwinian evolution can sometimes come to an equilibrium when averaged over the fates of many individuals, provided its ecological niche is itself stable over time. But if conditions change enough, then such a quasi-equilibrium can give way to cutthroat competition for survival. We come back to this later when considering the evolution of higher cognition.

Now, if life and its evolution require disequilibrium, then this can only have happened through the influence of gravity. To understand the importance of gravity, let us indulge in a fantasy. Imagine a Big Bang like ours, only without

gravity: everything shoots out from the initial singularity, expanding rapidly, cooling, forming the elementary particles. The expanding cloud of gas would, as in our real world, consist mainly of what we call dark matter. The normal (non-dark) matter in this still very hot cloud would—via the nuclear interactions—form helium nuclei and traces of lithium (the third element in the periodic table). No bigger nuclei would have enough time to form as the gas expanded and cooled.

So far everything in this fantasy universe is the same as in our real one. But, in the absence of gravity, after these light nuclei had formed, nothing more would happen. No cosmic structures, no planets, no DNA. Just a cloud of simple elements expanding, getting colder and colder. The dark matter would have had small density irregularities, but these would have made no difference, since dark matter does not interact with normal matter in any way in this gravity-free Big Bang.

So, the immense diversity and complexity of our universe is owed to gravity, but not to the overall smooth gravity of cosmology, which determines the slowing down or speeding up of the expansion of the universe on the largest scales. Where gravity started to be important for structure was in the small random density fluctuations in the dark matter that emerged from the Big Bang, where regions of larger density had stronger gravity that was sometimes strong enough to reverse the overall cosmic expansion in that region. Since there is ten times as much dark matter as ordinary matter, the extra gravity of the dark matter managed to put the brakes on the expansion of everything in many local regions, slowing these regions down until they re-collapsed in on themselves. Given gravity's inability to find an equilibrium all by itself, and the way it gets stronger and stronger as matter gets more and more dense, the formation of complex hierarchical structures was then inevitable.

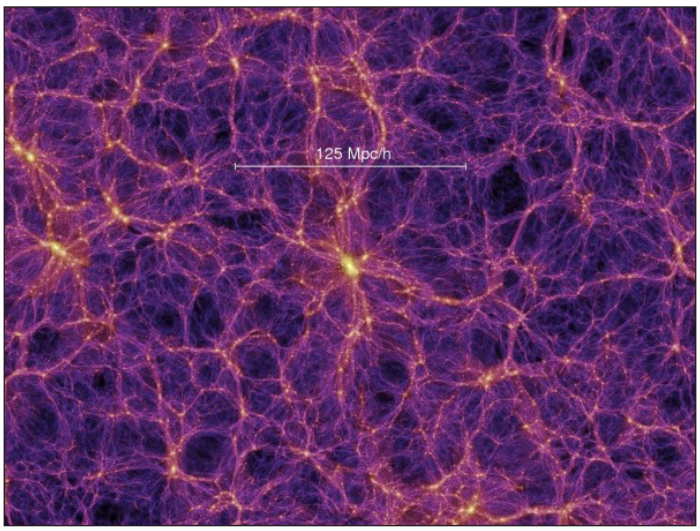

Figure 1: The cosmic web: a supercomputer simulation of the formation of structure in the early expanding universe. The bright spots are groups of galaxies, not stars. Credit: Volker Springel and the Virgo Consortium.

In a process astrophysicists have now been able to simulate on supercomputers, filaments of gas began to get denser and denser, woven together into what we call the cosmic web (Figure 1). Within these filaments, giant clouds formed, and out of these clouds condensed the galaxies that dominate our photos of the very distant universe. And within these galaxies, the still-collapsing gas got dense enough and hot enough for stars to form and eventually to halt the collapse by igniting nuclear reactions in their cores. The road to the evolution of life had opened up.

Gravity the Midwife

The story so far needs only what we call Newtonian gravity, the form of gravity that adequately explains our solar system's planetary orbits. As described earlier, Newton's law of universal gravitation states that every body in the universe attracts every other body with a force proportional to the inverse square of the distance between them. But Newton had no proposal for the mechanism by which this force acts; physicists refer to it as "spooky action at a distance," and it was criticized from the start for that reason.

The most revolutionary idea in Einstein's theory of gravity (known as the general theory of relativity) was the proposal that gravity can be viewed not as a force that acts mysteriously across empty space but rather as an inherent property of space (or, more correctly, of space and time). Specifically, in Einstein's theory, a massive object such as the sun warps the space-time around it, as illustrated in the left panel of Figure 2. This warping causes other objects moving through that space-time to follow trajectories we perceive as curved, such as the Earth orbiting the sun. A smaller body such as Earth generates its own smaller warping of space-time, which is responsible for the gravity that keeps us on the ground. In the most extreme case, black holes, the curvature becomes so strong that not even light itself can escape from the surface of the object.

Space-time curvature also opens the possibility of waves in space-time. The most important example for our purposes is a close binary of two compact objects such as black holes or neutron stars, as illustrated in the right panel of Figure 2. As the two objects orbit each other, the constantly changing curvature of space-time they produce causes waves in space-time that radiate out from the binary at the speed of light. These gravitational waves carry energy away from the binary, causing the two objects to approach each other, slowly at first, but getting ever faster as they get closer.

Because these changes from Newton's gravity to Einstein's are part of relativity, they become more important when speeds get closer to the speed of light. That is why Newtonian gravity works fine in our solar system. We need to add the complications of Einstein's gravity only when gravity gets strong enough to raise the typical speeds to a good fraction of the speed of light. So, we

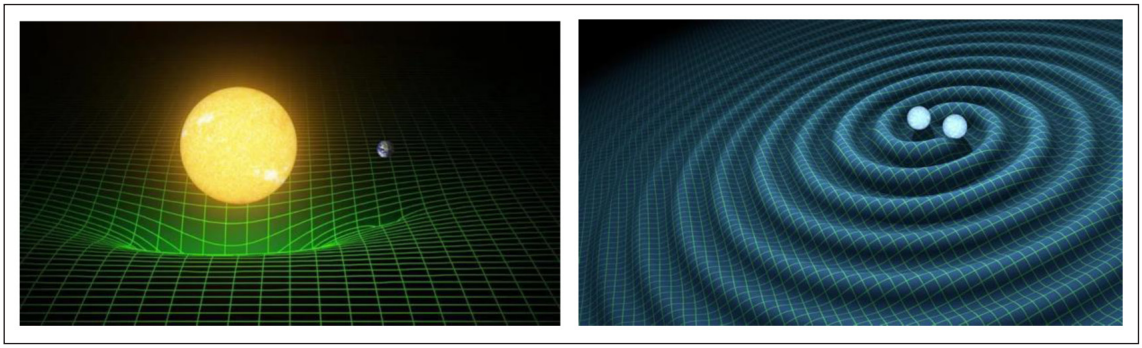

Figure 2: Left panel: the sun changes the local geometry in such a way that Earth is trapped in a nearly circular orbit around it. To get away, the planet would need a higher velocity, called the escape velocity. Credit: T. Pyle/Caltech/MIT/LIGO Lab. Right panel: two objects in orbit around one another disturb the local geometry in a way that sends out ripples of geometry at the speed of light. These gravitational waves disturb the local gravity wherever they pass, which is how our detectors sense them. They also carry energy away, causing the objects to spiral gradually together. Credit: LIGO Scientific Collaboration.

need Einstein in order to understand the universe right when it was beginning, but by the time dark matter started forming structure, the temperature of the expanding gas was low enough that the random speeds of particles were non-relativistic. Therefore, as the discussion in the previous section demonstrates, the Newtonian aspect of gravity was necessary for life to evolve.

Necessary, but clearly not sufficient: the process of forming life was extremely complex and involved all the forces of nature, not just gravity. Many other ingredients went into the mix that is our universe, and some of them also look like they were finely tuned in order to allow a universe with life. But our point here is to recognize that gravity was certainly necessary. Gravity in its Newtonian form has partnered with the strong and electromagnetic interactions to enable almost every stage of the path evolution took, as far as we can discern it. The cosmic web formed large and small condensations of gas, and the small ones usually got trapped by the gravity of the large ones. While stars began to form in all these blobs of gas, the gas blobs themselves were also busily merging. Most galaxies are formed by mergers of small galaxies falling into big ones, and sometimes by the merger of two big ones.

Let us focus our attention on our own galaxy, the Milky Way. Observations by the recent European Space Agency mission Gaia have begun to trace its merger history (Gaia Collaboration 2018). Over time, the Milky Way has cleared out its near neighborhood, so that only a few small assemblages of stars remain to be incorporated. The Small and Large Magellanic Clouds are chief among them, and these are on a trajectory to merge into the Milky Way in, say, a hundred million years. A mighty collision with the Andromeda Galaxy, M31, is also in the cards, but many billions of years away.

The first Milky Way stars that condensed out of the gas of our galaxy as it got denser and denser were not suitable hosts for life, because they just consisted of the primordial elements, hydrogen and helium. No rocky planets or moons could have formed around them. The gas cloud that formed each first-generation star contracted under the pull of its own gravity, got hotter (because of its negative specific heat), and eventually ignited nuclear reactions deep down in its center. The stars became meta-stable, the energy released by the reactions providing the pressure to stop further collapse. These reactions mainly created more helium by using the hydrogen as fuel. A core of helium "ash" built up inside, and as more ash was added, it got denser and hotter until (helped by gravity's inward pull) the central temperature was hot enough to begin nuclear reactions between the helium nuclei too, allowing some of them to fuse into carbon and even heavier elements. For the first time, elements heavier than lithium began to appear in the Milky Way.

These first stars were more massive than typical stars today, which means they evolved much more quickly. Many of them eventually ran out of fuel and just collapsed in on themselves, forming black holes. But some of them exploded to become the first generation of supernovas, blowing off at least some of their newly manufactured elements. Other clouds of primeval gas in our galaxy that had not yet formed stars were essentially polluted by this stuff. For the first time, chemistry became possible in the Milky Way. Because we are made of these elements, astronomers do not call this pollution but "enrichment."

The next generation of stars formed from the newly enriched gas, some of them possibly triggered to collapse by the impacts of the first supernova explosions. These did the same sorts of things as the earlier generation, but because they had the extra elements, they were typically less massive (and hence longer lived). They now had two ways of expelling some of the elements they had cooked up in their interiors: the more massive of them exploded as supernovas, and many of the less massive stars expanded their outer regions as "planetary nebulas" or "red giants," eventually blowing off their exteriors and settling down into long-lived white dwarf stars. The material blown away in this way contains elements synthesized during the lifetime of the star. Supernovas, on the other hand, blow out elements created even deeper inside the stars and then synthesize even heavier elements through the nuclear reactions that happen in the dense gas during the initial phase of the explosion. All of this synthesis happens via fusion: helium nuclei encounter existing nuclei and merge with them to make heavier ones. The most common basic elements were synthesized in this way: carbon, oxygen, silicon, iron, etc. The stellar winds and supernova explosions pushed them out through the galaxy, increasingly enriching the remaining gas in the Milky Way. If rocky planets had not been possible for this second generation of stars, they were certainly possible for the third.

The supernovas we have been describing are actually called Type II supernovas. There is another important type, Type Ia. These are explosions of white dwarfs, the kind of star our sun will eventually turn into. With Type Ia supernovas, we get our first glimpse of the influence of gravitational waves on nucleosynthesis. If a white dwarf forms in a binary system with another star, and if their orbital separation is close enough, then over billions of years the regular changes their orbital motions make in the local gravitational field send out Einstein's gravitational waves, which carry energy away. The stars get closer together and eventually merge, and that merger produces the Type Ia supernova explosion. The elements synthesized are similar to those in Type II supernovas; in fact, they may have been the source of most of Earth's iron. They therefore contribute to the variety of chemistry on our planet, but they do not produce the special things the elements produced by analogous mergers of neutron stars do, as will be shown later.

At first, scientists assumed all the elements of the periodic table were formed this way, by fusion inside stars or in supernovas. But computer simulations have shown this is not possible. For one thing, ^{56}Fe is the most stable element, so adding a helium nucleus to it would require considerable input energy, which is not readily available inside stars. It is available in supernova explosions, but therein the process of combining elements to make heavier ones stops when the expanding gas of the supernova gets too thin, after which the existing nuclei do not have much likelihood of colliding with others. Fusion like this synthesizes elements in the periodic table up to iron, but not much beyond. Newtonian gravity, therefore, with a bit of assistance from gravitational waves, sufficed to midwife the lower half of the periodic table. Had there been no gravitational waves, the relative abundance of various elements would have been different, but life surely still would have been possible.

In the next section, we explain that the heavier elements (including gold, silver, iodine, uranium, etc.) could not have formed from any process regulated just by Newtonian gravity and that gravitational radiation was essential to their formation. But to understand the implications of that, we need first to continue with the story of how our solar system provided the nursery for the evolution of life.

Our sun is a late-generation star whose progenitor gas cloud was richly seeded with all the elements heavier than lithium. The inner planets of our solar system were hot enough to have boiled off almost all the hydrogen and helium that still bulk up Jupiter and the other outer planets. By chance, Earth found itself in the habitable zone, at a distance from the sun where water can remain liquid, with plenty of surface water. Somehow, whether through early electrical storms, from cometary seeds, or from the Mars-size planet that collided with Earth early on and threw off the stuff that formed our moon (Young et al. 2016),

Earth's oceans got a good dose of amino acids. Life started—that much we know. How? That we do not.

Once life started, however, Darwinian evolution took over, and complex multicellular organisms eventually appeared. During this whole amazing story, Newtonian gravity did more than just hold the oceans onto the planet and keep our planet at just the right distance from the sun. It also held the sun together as a nuclear fusion furnace, providing a steady and gradually brightening flux of energy to keep the oceans liquid, and later to power photosynthesis.

At every stage of the story so far, Newton's gravity has been present, acting as a kind of midwife to the birth of life. Now it is time to turn to the issue of why this was not actually enough to ensure life prospered on Earth and did not later die out, and enough to explain why higher cognition, using bigger and more energy-expensive brains, was needed by some animals to pass the test of natural selection. It is time to start explaining the unique and unexpected role of Einstein's general relativity in the story of life on Earth.

The Gravity That Enabled Production of the Heaviest Elements

Astrophysicists only have come to realize fairly recently that black holes and gravitational waves are not just Einsteinian exotica; in fact, they play an important role in many of the aspects of the development of the universe we have outlined. Importantly for evolution, without gravitational waves, the elements in the heavier half of the periodic table would never have been created in anything like their observed abundances. After explaining why, we argue that without the particular elements uranium and thorium, it seems unlikely cognition as advanced as that of humans would have evolved, and it is very possible all life would have died out by now. We begin by looking at what links black holes, neutron stars, and gravitational waves with the synthesis of the heaviest elements.

Our earlier outline of how stars form and die in supernova explosions ignored what happens to the stars after they explode. We saved that part of the story for here because it cannot be understood without Einstein's gravity. Typically, the star does not completely disintegrate in the explosion. That is because the source of the energy of the explosion is gravitational, not nuclear. Before the explosion, the star was in equilibrium between gravity and the nuclear processes: gravity pulled inward and the energy released by nuclear fusion reactions was carried by photons that pushed outwards. The equilibrium failed when the nuclear fuel started running out. The result was that the innermost core of the star, which was the only region hot enough for the nuclear reactions to take place, had difficulty supporting itself against the weight of the rest of the star. So, it started to contract. To make a (very) long story short, at some point the core could no longer generate enough energy to support the rest of the star, and it collapsed inwards, pretty much in free fall.

Although the stars that make supernovas are typically very massive, more than ten time our sun's mass, the core when it collapses is only a bit more massive than our sun. It turns out, quite remarkably, that when the free-falling collapsing core reaches nuclear density, it can again develop enough pressure to stop its collapse. This is an unheard-of density: the whole solar mass of material turns into one large nucleus. Our discussion earlier of nuclear stability suggests this would be wildly unstable, but in this case, there is an added factor: gravity. The size of this core is only ten to fifteen kilometers in radius, and therefore gravity is highly relativistic. The escape speed from such a body would be close to the speed of light. The collapse has happened at close to the speed of light, leaving the outer part of the star behind. The high escape speed means that each nuclear particle is tightly bound by gravity, because to get away at close to the speed of light, it would need kinetic energy that is a good fraction of its entire rest-mass energy. Because that much energy is not available, the core is now a stable body. We call it a neutron star, because almost all the electrons in the collapsing core have been pushed into merger with the protons, forming neutrons that remain stable in this strong gravitational field.

Now, the collapse of this much mass into a stable configuration that is so much smaller releases a huge amount of energy, something like 10% of the rest mass-energy of the material in the core. A tiny amount of this energy is carried away from the core by the elusive particles we call neutrinos, which are emitted when electrons and protons combine to make the neutrons. These particles have a tiny rest mass, and the amount of energy they get when emitted by this reaction is far more than their rest-mass energy, which means they will escape the core's gravity. But most of the energy is just the gravitational energy released by the collapse of the core, and that becomes thermal energy in the hot cloud of gas just outside the neutron star. This gas consists mostly of neutrinos and their anti-particle companions, antineutrinos, which are created in pairs when very energetic photons (hyper-energetic gamma rays) collide with one another. This turbulent soup of photons and neutrinos has a huge pressure that pushes outwards, encountering the remainder of the star, which is starting to collapse inwards as well. This remainder is called the "envelope" of the star. At the inner edge of the envelope, a shock develops. What happens next depends on how massive the original star was.

In most of the stars that started out with enough mass to collapse, the envelope (which contains 90% or more of the star's original mass) is simply blown away by all the energy released in the collapse. That is the classic supernova explosion, called a Type II supernova. The inner part of the envelope had already gotten very dense before encountering the neutrino gas pushing outwards, so the neutrinos and the high density and temperature there induce nuclear reactions that fuse the existing elements into even heavier ones, up to iron. All of this is blown out through the galaxy, mixing into the clouds of

hydrogen that have not yet formed stars. Left behind is a neutron star, initially very hot, with a mass a bit larger than that of the sun, crammed into a sphere that is only the size of a big city.

It should not be surprising that some stars are too heavy for this scenario: the inner envelope can be too massive to be fully blown away, so some of it falls back onto the neutron star core. If the core then grows much bigger than about twice the sun's mass, the nuclear forces will not be able to support the core against the increased gravity, and the core will collapse. There is no further stopping point after that: the core collapses to a black hole. The hole really is a hole: there is no longer any outward pressure on the envelope from neutrinos and the hot γ- and X-rays that were given off by the core, so now matter just falls in. The outer part of the envelope was still blown away by the neutrinos, creating a supernova explosion, but the central remnant is now a black hole with a mass much larger than that of the sun.

Fascinating as black holes are, they do not play a central role in our story. They are dead, unable to participate further in processes like nuclear physics. But neutron stars are just enormous nuclei. These remnants of the smaller supernovas turn out to be ingredients in the recipe for the synthesis of the heavier elements and the evolution of human cognition.

It is time now to explain more completely our story's final ingredient: Einstein's gravitational waves. The LIGO Scientific Collaboration, an international collaboration with two detectors in the United States, made the first direct detection of gravitational waves on September 14, 2015 (Abbott et al. 2016). The waves had been emitted a billion years ago by two very distant black holes. The holes, each around thirty times the mass of our sun, had found themselves in a tight orbit around one another, maybe as a result of supernova explosions of both stars in a binary system. Their orbit was in fact a doomed death spiral: their motion emitted gravitational waves, which carried energy away, which slowly but surely brought the holes closer and closer to each other. In fact, because of gravity's negative specific heat, the more energy the orbit lost, the faster the black holes moved in their orbits and the stronger the waves they radiated, which accelerated them to spiral in even faster. Such a dance can only end in catastrophe, and for these holes that happened when, after possibly several billions of years in orbit, they reached their last few orbits at exactly the right moment for their final radiated waves to travel a billion light-years and pass through the freshly upgraded LIGO detectors when they were in observation mode. LIGO's event, called GW150914, only told us about the final 0.2 seconds of this drama, as the holes made their last couple of orbits, merged to form a single much larger black hole, and then settled down into an eternally quiet state (left panel of Figure 3). The next big thing to happen to this hole likely will be its final evaporation through the emission of Hawking radiation, some 5×10^{72} years from now.

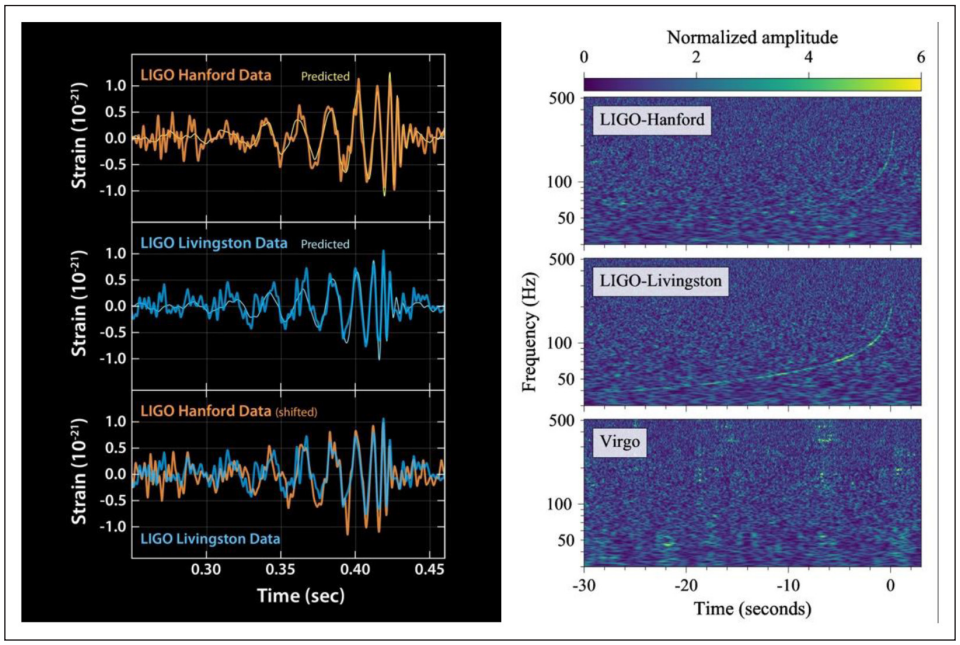

Figure 3: Left panel: The signal received by the two LIGO detectors on September 14, 2015 (top two panels), and the two signals superimposed with a slight shift in time because the signal arrived at one detector before the other. Right panel: The signal in LIGO and Virgo detectors of the binary neutron star merger GW170817. Since the signal was too weak to see the raw waveform clearly in a time series like the one on the left, this panel shows the loudness of the signal as it would be heard by the ear, plotted against time. The pitch is plotted vertically, and loudness is indicated by the color. It was weak in Virgo because its location in the sky happened to be in a direction to which Virgo had very low sensitivity. Notice the very big difference in the timescale of the signals, as indicated on the horizontal axes. Credit: LIGO Scientific Collaboration.

LIGO and its partner, the European Virgo detector near Pisa, have so far detected almost 300 further black-hole mergers. But these events are not the ones that have played a role in the evolution of life. That distinction belongs to neutron-star mergers like GW170817 (right panel of Figure 3). Long ago, the supernovas of both stars in a binary system led to two neutron stars in a tight orbit, and they reached the merger stage a mere 120 million years ago. Because their masses were much smaller than those of the black holes in GW150914, their orbit evolved more slowly, and the gravitational wave signal entered the observational frequency band of LIGO and Virgo a couple of minutes before they merged, not fractions of a second. The merger produced a huge kilonova explosion observed by astronomers around the world and across the electromagnetic spectrum: γ-rays, X-rays, visible light, infrared light, radio waves. Most of the neutron-star material was not ejected but rather merged into a single very massive neutron star and almost certainly collapsed into a black hole within a second or two. But the fraction that did get caught up in the

explosion was blown away. What the astronomers' detailed observations have told us is that this exploding cloud of neutron-star material went through a sequence of nuclear processes that transformed it into an expanding cloud of the heaviest elements of the periodic table.

Our earlier discussion of nuclear stability is useful now in helping us understand why this was so. The material blown off from the two stars started out as pretty much pure neutrons. Once free of the gravity that had stabilized them inside the neutron star, the neutrons began to beta decay back into protons and electrons, and the protons' mutual repulsion began to break the material up, creating fission on a grand scale. The fragments were basically enormous neutron-rich clumps. But we know that no such "clump" can be stable if it has more particles than the biggest (nearly) stable nucleus, ^{238}U. So, these clumps kept breaking down hierarchically into smaller ones, a process that continued until the clumps were actually the nuclei we know from the periodic table. That is when the fragmentation stopped, because the nuclei were stable. It would not have gone to nuclei lower than ^{56}Fe, because this is the most stable of all nuclei.

Each fission event released a significant amount of energy in light particles, like neutrinos, photons, electrons, and individual protons and electrons. And all of this energy from the nucleosynthesis was released in a mere fraction of a second. This energy made the explosion cloud start to expand at very high velocities, and after a few hours it was big enough and bright enough for astronomers to be able to see it. The spectra they recorded were consistent with the expectation that the cloud contained these heavy elements (Abbott et al. 2017). It was our first glimpse of the synthesis of the upper half of the periodic table.

A kilonova like this is a rare event: it may occur in the Milky Way only once every 100,000 years or so. Supernovas, by contrast, happen at least once a century. The expanding kilonova cloud enriches the gas clouds significantly only in its near neighborhood in the galaxy. The heavy elements in the primordial gas cloud from which the sun eventually collapsed were therefore contributed by many infrequent events over a long period of time. The remaining abundances of some of the relatively short-lived radioactive isotopes among these elements tell us that the last time our primordial cloud was "seeded" was about 100 million years before the solar system formed from it. By contrast, its last enrichment by a supernova may have been about thirty million years before the sun began to form (O'Neill et al. 2020). In fact, even shorter-lived isotopes, whose initial supply in the solar system would by now have completely decayed, continue to arrive at Earth in small quantities from distant and more recent kilonovas, and this can be used to confirm the kilonova rate in the galaxy we quoted earlier (Hotokezaka et al. 2015). But our primordial cloud's abundances of all the stable elements in the periodic table, plus those of very long-lived radioactive isotopes like the ones of interest here, ^{238}U and ^{232}Th), had been

growing for many billions of years before the solar system formed, as each nearby supernova or kilonova added more to the cloud. See Figure 4.

Of course, it is important to ask whether there may also be other places where the heavier elements are synthesized. Figure 4 gives an overview of how this works out for all the elements. One possibility for the heavier elements is a binary merger between a neutron star and a black hole. If the hole is not too massive, the star may get shredded by the black hole's strong gravity before it enters the hole, and a similar process to the one just described would likely happen, also requiring gravitational waves. Other sources that do not require gravitational waves have been suggested, but they appear to contribute only a small fraction of the amount produced in mergers (Hotokezaka et al. 2018).

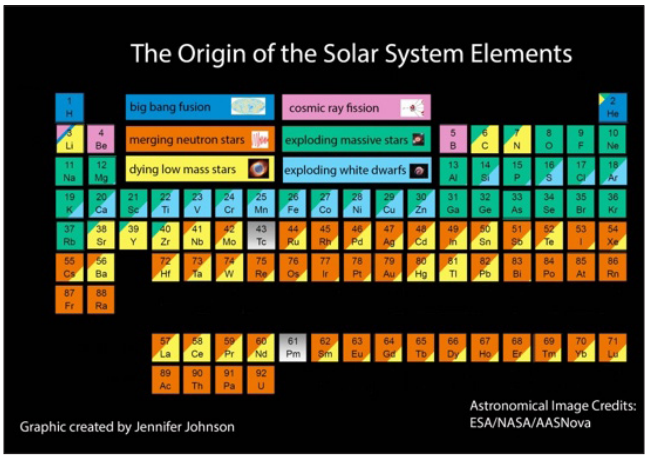

Figure 4: The principal sources of the elements. Credit: J Johnson, ESA/NASA/AASNova.

Animal Evolution in an Unstable Environment

We are now ready to ask and answer the question "so what?" What do we humans need these elements for? Well, of course, our bodies use iodine, and this has led to the suggestion that gravitational waves were indeed necessary for life itself (Ellis et al. 2024). But it is hard to be sure nature would not have found a different way to do what we need iodine for if there had been no iodine on Earth. Central to human culture is our love of silver and gold jewelry; however, these elements are surely not essential for life. Nuclear reactors use uranium, but they are also not essential for life. What is often ignored is how important thorium and uranium have been for the preservation of life on Earth and the evolution of advanced cognition in life on land (Schutz 2018; Piran 2019; Ellis et al. 2024).

These elements have influenced evolution through their importance in Earth's internal heat budget. At least half of the heat flowing out of Earth is generated by the decay of uranium and thorium (KamLAND Collaboration 2011; O'Neill et al. 2020). Another important long-lived isotope is ^{40}K, which was made by

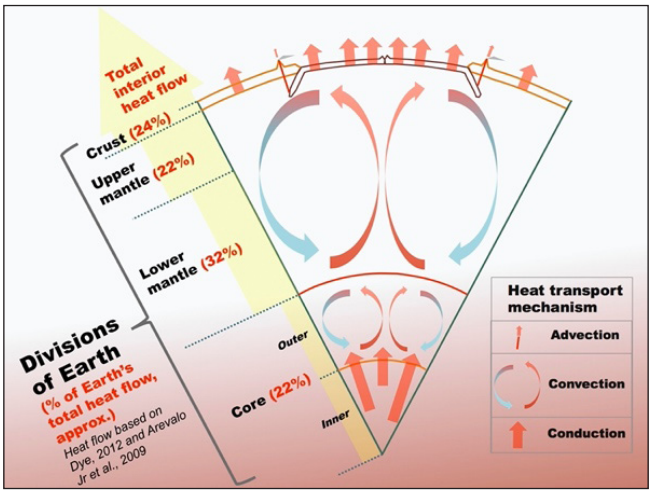

Figure 5: Schematic of Earth's heat flow. The main divisions of the Earth are shown together with their relative contributions to the total heat flow to the surface and the main transport mechanisms. Credit: Wikipedia, "Earth's internal heat budget."

stellar processes that only required Newtonian gravity. Its decays at present contribute perhaps another 10% (O'Neill et al. 2020). The fraction of the total heat flow that comes from radioactive decays is called the Urey ratio, which for Earth is therefore at least 0.6. The rest of the heat flow is primordial, just the slow cooling of our planet that has been going on since it was formed. What is more, it appears that the lower mantle generates significantly more heat than the upper mantle; this is the only reasonable explanation for the mantle convection that drives plate tectonics (Figure 5). This extra heat must be radiogenic, since the primordial heat would have been more uniformly distributed. Geologists believe this radiogenic contribution is vital, that if only 40% (or less) of heat came from cooling the interior, it would likely not be enough to drive plate tectonics. The history of the movement of our continents, at least during the last one billion years, is due to the excess heat released deep in the mantle by ^{238}U and ^{232}Th, elements created by neutron stars brought into collision by their radiation of gravitational waves.

Tectonics is not the only effect this heat flow has on our planet. The temperature of Earth's core is high enough to keep iron molten, and Earth's rotation stirs up the liquid iron. This creates electric currents through the iron that generate Earth's magnetic field. If the core cools too much as the planet ages, then the iron could solidify, quenching the magnetic field. As we discuss later, if this had happened to Earth, it would have had devastating consequences for life. This may in fact have happened on Mars. There is evidence there of a primordial magnetic field that no longer exists (Acuña et al. 1999).

For the purpose of understanding the importance of gravitational-wave midwifed elements for life on Earth, the question is whether radioactive

elements have helped keep the iron core molten. The Urey ratio, measured at Earth's surface, does not necessarily constrain the ratio of heat sources in the core, since geochemistry suggests uranium and thorium may be under-abundant there, while potassium might be present in larger abundances (O'Neill et al. 2020). So, at present, there is not enough evidence to make the case one way or the other that radioactive uranium and thorium are keeping Earth's magnetic field strong. Since the question is open, we first briefly explain why the magnetic field is so important for life on Earth, after which we turn our attention to the issue of plate tectonics, where the importance of ^{238}U and ^{232}Th seems to be much clearer.

Earth's Magnetic Field and the Persistence of Life

For the last four billion years, Mars has had no large-scale planetary magnetic field (Acuña et al. 1999). Mars is also a barren planet with almost no atmosphere. These two facts are related. Earth's magnetic field shields our planet from the continuous stream of charged particles called the solar wind. The sun's complex surface magnetic field—which is responsible for sunspots, solar prominences, and solar storms—also constantly pushes away the outermost part of the solar atmosphere. Because of the high temperature of this gas, its particles are all ionized. We call this a plasma. When this plasma encounters Earth's magnetic field, the charged particles follow the field lines, so most of it is deflected by the field past the planet, while some is caught by the magnetic field lines and channeled toward the magnetic poles, occasionally creating auroras at lower latitudes.

If Earth had no magnetic field, the plasma would simply plow into its atmosphere over the course of billions of years, gradually stripping away not only the atmosphere but also the water in all the oceans. If, as seems possible, Mars was formed with an atmosphere similar to Earth's, then its initial magnetic field would have been a similar shield. But after the magnetic field died, the atmosphere and any surface water were blown away. If life had evolved in the watery regions of Mars in its early years, it would not have survived once the magnetic field disappeared, at least not on Mars's surface. That is why the next searches for whatever may have passed for life on Mars will need to drill down deeper. The discovery of a thriving biosphere full of microbial life at depths of a few hundred meters on Earth (Magnabosco et al. 2018) have added hope that something similar may still be present on Mars.

It seems likely that without radioactive potassium, and also possibly the uranium and thorium whose synthesis was enabled by gravitational waves, Earth might well no longer have a magnetic field, an atmosphere, or liquid oceans. Absent the warming effect the CO_2 our atmosphere has always carried, Earth's mean temperature would be below freezing. Terrestrial and oceanic life as we know it would eventually have been annihilated, if it had had a chance to start at

all, and it is possible no form of life would have survived, even underground. To make this association with gravitational waves clearer, however, better estimates of the amount of uranium and thorium in the deep core will be needed.

Plate Tectonics and the Evolution of Higher Cognition

Given the uncertainty about what keeps Earth's magnetic field strong, it is possible that an Earth with no uranium and thorium might still have maintained a thriving community of life, but on continents no longer moving around. What might evolution have looked like on such a geologically quiet planet? To answer that hypothetical question, we first make a brief sketch of what is known about the four billion years of evolution on Earth as it really is, with those radioactive elements distributed through its body.

Earth formed about 4.6 billion years ago, and the first living cells seem to have appeared only 600 million years later. At that early time, Earth's interior was still very warm, both from its formation and then from the reheating caused by the impact 4.5 billion years ago of a Mars-sized planet, which led to the formation of the moon from the debris (Young et al. 2016). The radioactive isotopes would at that time have contributed only a small fraction of Earth's heat flow, so life would have formed whether the isotopes were there or not.

As Earth gradually cooled, continents formed, and continental plates began moving. This is thought to have started sometime between three and one billion years ago. In the interval between four and one billion years ago, evolution created photosynthesis, eukaryotic cells (cells with a membrane-bound nucleus), and mitochondria (which seem to have been essential for the later development of multicellular organisms). Earth's atmosphere became oxygenated as a result of photosynthesis around 2.5 billion years ago. By one billion years ago, multicellular life had appeared. Importantly, by that time, the isotopes of uranium and thorium were already contributing the largest part of Earth's outward heat flow and had become essential for maintaining the motions of the continents and for continued volcanism (O'Neill et al. 2020). The whole subsequent evolution of complex plants and animals occurred in an era in which geologic instability was driven by the heat released by the decay of isotopes whose synthesis had been brought on by gravitational radiation.

However, plate tectonics and volcanism have a much greater effect on terrestrial life and life in the shallows of continental margins than they do on life in the body of the oceans. While the continents move (very slowly), the oceans remain one connected system that allows living things to relocate in response to this motion, to remain as much as possible in the environmental niche in which they evolved. It is therefore reasonable to think that, if gravity had been purely Newtonian, Earth would still have evolved its full complement of nonmammalian sea life. But, possibly apart from the octopus, none of this life has cognition approaching that of mammals. The most advanced

ocean-dwelling animals are the cetacean mammals whose ancestors adapted to the sea after evolving on land.

The oceans provided the nursery for all animal life until the amphibians appeared 360 million years ago. The land animals that evolved after that did not experience a more nourishing or supportive environment than fish have had. On the contrary, the air they lived in exposed them to the full impact of the environmental changes created by volcanoes, earthquakes, meteorite and asteroid impacts, mountain-building, continental collisions, and periods of extreme climate change. Challenges such as these force organisms to keep evolving and often drive them into new behaviors that are more sophisticated and adaptive.

It therefore seems reasonable to ask whether the challenges of an unstable geology were the main reason cognition developed further on land than in the seas. Other occasional events, such as the famous impact of the asteroid that brought about the extinction of dinosaurs, should certainly be considered, but as we show, the evidence is that their influence on the development of cognition were unimportant compared to that of tectonics.

We show that to understand human cognitive evolution, we need to consider one further recurrent cause of changes in climate: the cycle of ice ages. For the past 2.6 million years, these have come and gone with the regular changes in Earth's orbit that arise from Earth's gravitational interactions with the moon and other planets. These orbital variations have of course been present for Earth's entire 4.6-billion-year history, so by themselves they do not explain these relatively recent ice ages. What has changed in the last few million years is that Earth is globally significantly cooler than earlier, so that the small changes in insolation that the orbital variations cause have been able to just tip the planet into and out of periods of substantial ice cover. Now, Earth's overall global temperature during the past few million years has been affected mostly by the tectonic motions of the plates. These change global oceanic circulation patterns, which redistribute the sun's heat and move land masses toward or away from the poles, making it easier or harder to form ice sheets. Tectonics has put Earth into its current marginal temperature range, where ice ages can happen.

Having surveyed the main epochs of evolution, we turn now to the specific impact of these evolutionary pressures on cognition. The group of animals with the most advanced cognition are the mammals. It is known that mammalian brains have a special feature. Experiments show that even simple mammals like rats are able to make decisions by considering alternatives based on their prior experiences. They appear to be able to imagine the consequences of pursuing each alternative available to them and, after a pause, choose the one likely to provide the best outcome. In other words, they are able to consider before they act (Bennett 2023). Amphibians and reptiles, by contrast, also learn from experience but basically use this learning to guide immediate instinctive reactions to changing situations.

It is not known when or why mammals developed this widely shared capability, but by itself it would not qualify mammals to be exceptionally intelligent. The size of the brain matters: the brain has to be able to remember enough relevant past experiences in order to use them to make good decisions as and when similar situations arise. And brain size in mammals appears to have been more influenced by tectonic activity than by isolated events like the asteroid.

Mammals have been around for about 180 million years, but they got their chance to take over terrestrial habitats when the Chicxulub asteroid wiped out the dinosaurs sixty-six million years ago. At that time, they were not particularly advanced cognitively, if we judge cognition by the ratio of brain size to body size (an admittedly crude criterion). Brains are energetically expensive organs to run, so an animal that puts only a small fraction of its body's energy budget into the brain is generally not going to get much out of it. At 100 million years ago, the typical mammalian brain-to-body-size ratios were quite small, but they started to increase slowly around eighty million years ago, long before the asteroid arrived.

What happened next is most clearly shown not by looking at the simple and crude brain-to-body-size ratio but at the so-called PEQ, or phylogenetic encephalization quotient, which is the quotient of the actual brain-to-body-size ratio to that expected from a fit to the distribution of this ratio among closely related species, normalized to a particular epoch (Bertrand et al. 2022). This is believed to be much more closely related to relative cognitive improvements than the simple size ratio. The data gathered by Ornella C. Bertrand et al. (2022) for the average of a very large sampling of mammals are shown in Figure 6. This plots the rate of change of the PEQ vertically (in units of ten million years) against the look-back time from the present, plotted horizontally (in units of millions of years).

From about eighty million years ago, average mammalian PEQ continued to slowly increase at a gradual rate for a long period. This slow acceleration in brain size began long before the asteroid event at sixty-six million years ago. Before this time, mammals were small tree dwellers. But around eighty million years ago, the forest floor and open grassland began to be populated by flowering bushes, and this more easily obtainable food may have drawn mammals down from the trees (Janis et al. 2025); after this, they became burrow dwellers. This big change in their environmental niche may account for the need to increase their brain size in order to take advantage of the new foods and—for the mammals that left the forest—avoid falling victim to the dominant dinosaurs.

It is striking, however, that Figure 6 shows no particular change in the acceleration rate of brain size at the asteroid event. What apparently did change rapidly after the asteroid was mammalian body size (not shown in this plot), as mammals quickly filled the empty habitats once dominated by dinosaurs. But apparently their brain size simply kept up with their body size. The African

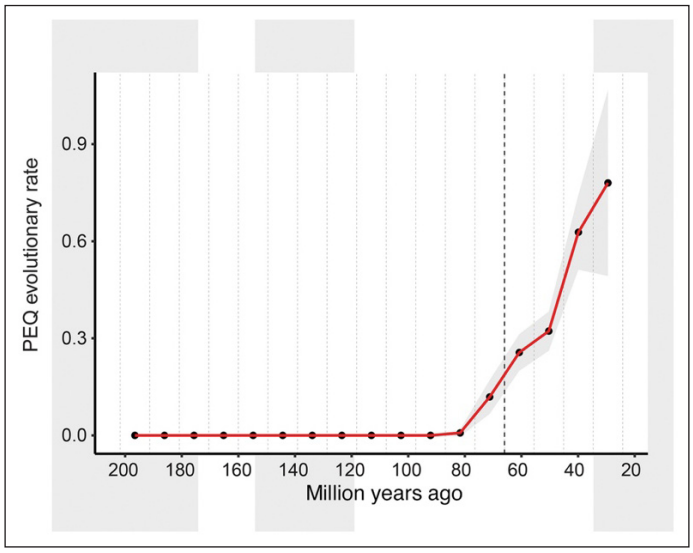

Figure 6: Rate of increase, per ten million years, in the phylogenic encephalization quotient (see text for definition) of all mammals, plotted against time before present (in millions of years). The vertical dashed line marks the epoch of the asteroid impact. Credit: Bertrand et al. (2022).

climate then was much warmer than today's and remained very stable over tens of millions of years. Presumably, adapting to empty niches in these favorable conditions did not require rapid changes in cognition.

But then, at forty million years ago, the average mammalian PEQ rate of change increased sharply, going even higher by thirty million years ago. This was toward the end of the Eocene, when global temperatures took a sharp drop. In Africa, open savannas replaced dense tropical forests. These changes in the African climate were caused by complex changes in the oceanic circulation, which in turn seem to have been initiated by a major tectonic event: the slow separation of Antarctica from Australia was completed around thirty million years ago. Before separation, the changing shape of this land mass would already have changed oceanic circulation, but full separation allowed water to flow between them, creating a rather rapid change in circulation and global climate. After that, the icing up of Antarctica continued the cooling trend. It would appear from Figure 6 that this dramatic change in climate forced mammals in Africa to adapt in a major way to the changed habitat, and the ones who survived tended to have significantly bigger brains. This correlation between the inferred increase in mammalian cognition and tectonic activity is striking, even more so given the absence of a correlation between cognition changes and the impact of the asteroid.

The humans' evolution of special cognition also seems to have been driven by tectonic changes. Human cognition is built on that of primates, whose cognition had already increased more rapidly than most other mammals as they adapted to the stresses described. Humans separated from their last common primate ancestor around seven million years ago. For the next four million years

or so, our hominin ancestors remained rather small creatures with chimpanzee-sized brains, living on the margins of forests. But between three and two million years ago, the more primitive *Australopithecus hominins* gave way to those of the new genus *Homo*. The earliest of these, *Homo habilis*, had a transitional form, with a slightly larger brain and a flatter face. This is also when the first systematic manufacturing of stone tools, the Oldowan tool culture, began. By two million years ago, with the evolution of *Homo erectus*, our ancestors began to look more familiar: the brain size had almost doubled, the individuals were walking fully erect, and the tool culture (called Acheulean) had become more sophisticated, needing considerable practice to achieve proficiency in the making of tools. If you met a group of *Homo erectus* individuals walking down the street, you would recognize them as human. In fact, *Homo erectus* became the longest-lived human species of all time, lasting over a million years and spreading right across Africa and Eurasia.

It is believed by specialists (e.g., Stanley 1998) that these evolutionary changes were driven, as before, by environmental changes. A long period of further cooling and drying had set in between three and two million years ago, in which savanna replaced much of the forest that *Australopithecus* had used for shelter. This change was accompanied by another: the climate became more unstable than before, with warmer wetter periods alternating with cooler dry periods, for example as indicated by lakes that come and go repeatedly in the geological record. These environmental stresses likely drove the rapid and steady increase in brain size, and hence in cognition, that has accompanied human evolution from the time of *Homo habilis* through *Homo erectus* and to the eventual appearance of *Homo sapiens* about 300,000 years ago.

What caused these more recent environmental changes? The joining of North and South America culminated around three million years ago with the raising of the Isthmus of Panama, blocking oceanic currents that had previously flowed between the two continents. This resulted in part in a new circulation pattern east of Africa that was responsible for the major cooling of the continent. This pattern, still in place today, also brings regular monsoons to India, and drives the El Niño–Southern Oscillation. The cooling also tipped the temperature balance in the Northern Hemisphere so that the periodic changes in Earth's orbit due to the moon and planets began to create alternating glacial and glacier-free epochs. It was these alternations that in turn caused the increased instability of Africa's climate.

It is difficult to escape the conclusion that these tectonic events—the separation of Australia from Antarctica and then the joining of North and South America—were responsible for major environmental stresses in Africa that initiated the evolution of, first, mammalian cognition to the general level at which we see it today, and then human cognition. The details of these evolutionary processes were of course both very complex, but it seems unlikely they would

have happened at all if the motions of continents had not produced major changes in Earth's climate. This cognition is therefore another consequence of the heat released by the unstable isotopes of uranium and thorium, whose synthesis required the physics of gravity include gravitational radiation.

Perspective

The production of ^{238}U and ^{232}Th in multiple kilonova explosions at the end of the gravitational-wave driven inspiral of two neutron stars or of a neutron star and a black hole eventually had surprising consequences for life on Earth. Once incorporated in the body of the young planet, the isotopes provided a steady supply of heat from their radioactive decay. This heat is now helping keep Earth's iron core molten, which helps sustain the protection Earth's magnetic field gives from the solar wind.

Today, the heat from these isotopes accounts for more than 50% of Earth's heat flow. This appears to be essential for sustaining plate tectonics and the other geological processes driven by mantle convection during the epoch of terrestrial life on Earth, all of which have cumulatively pushed mammals and specifically humans to the highest levels of cognition in the animal kingdom. Other environmental stresses, such as the comet impact sixty-six million years ago, have had major effects on evolution, but apparently not particularly on cognition. If Earth had cooled enough so that, even by as recently as fifty million years ago, the continents had frozen into some fixed configuration, terrestrial life could probably still have developed a higher level of cognition than that found in fish. However, the level of cognition would not have reached that of the average mammal today, to say nothing of the level evolved in humans.

This is an exceptional instance of the fine-tuning of the laws of physics, because without gravitational waves, there would be life—probably even some form of mammalian life—but no humans cognitively advanced enough to understand the fine-tuning. Without Einstein's gravitational waves, we would not have had Einstein.

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Planets and the Possibility of Life beyond Earth

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The question of whether life exists beyond Earth has intrigued humans throughout history. Millennia of speculation have fueled both philosophy and theology, with contemplations of the spiritual state of alien beings shedding new light on that state of our own species. The relatively recent first scientific detections of planets outside our solar system, followed by a surge in further exoplanet discoveries and study, are reinvigorating these ancient questions of life beyond Earth. Although extraterrestrial life has not yet been found, astronomy and cosmology are revealing a universe intrinsically connected to life, as stars generate the chemical building blocks needed for planets to form and for life to thrive. This article summarizes new scientific advances in the discoveries of exoplanets, the search for life beyond Earth, and evolving habitability in the universe, setting the stage for fresh consideration by others of the rich theological implications.

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Introduction: Contemplating Alien Worlds and Life Throughout Human History

The question of whether life exists beyond Earth is an old one. Long before the modern development of astrophysics and astrobiology, human imagination envisioned alien worlds and life. Even in antiquity, Epicurus wrote that "there are infinite worlds both like and unlike this world of ours … Furthermore, we must believe that in all worlds there are living creatures and plants and other things we see in this world" (Bailey 1926). "Worlds" for Epicurus are what we would more likely call "universes," but even so we can see in his words the vision of life flourishing beyond Earth. Such envisioned life from antiquity (and today) also includes nonphysical spiritual beings such as angels who can navigate seamlessly across space and time, at times becoming apparent on Earth to interact with humans. More recent science fiction has proposed the idea of life unattached to a particular locality. The television series *Star Trek: The Next Generation* (Paramount Television 1987–94), for example, introduced "Q" as a manipulative and powerful character freely navigating across and between dimensions, appearing in any desired form and place.

Most speculation of extraterrestrial life in recent centuries, however, involves planets and moons, with physical life living on, or at least originating from, particular planetary locales. The Copernican revolution energized a new era of speculation about the possibilities of other inhabited worlds, including the inherent theological and philosophical challenges these present. In literature, life has been imagined on every planet in the solar system as well as Earth's moon. In the nineteenth and early twentieth centuries, now-debunked "observations" of extraterrestrial life—from the "Great Moon Hoax" published in the *New York Sun* falsely ascribing observations of diverse lunar life to astronomer Sir John Herschel (Figure 1), to the infamous *canali* (channels) on Mars described by astronomer Percival Lowell as bands of planted vegetation—built upon societal openness to the possibility of life thriving on other worlds. Thomas Dick, a minister and popular writer on Christianity, philosophy, and astronomy wrote in 1838 that "the Moon is inhabited by rational creatures, and . . . its surface is more or less covered with vegetation not dissimilar to our own Earth."

The idea of life beyond Earth has also inspired theological reflection for centuries, spawning multiple profound questions: If life exists beyond Earth, was it created by the same Creator as life on Earth? Were the same processes for life creation and diversification used, e.g., instant appearance or long-term evolution through natural selection? How did God relate to these creatures, and vice versa? Do they have a sense of morality, and do they have moral failings? Do they understand good and evil? For Christians, the issues take on more intensity due to the centrality of Jesus Christ to their faith—a God who came in human form to planet Earth. Would the redemption of humanity from the ramification of their sin, provided through the life, death, and resurrection of

Figure 1: Lunar animals, as falsely reported to be observed by astronomer Sir John Herschel. Alien worlds imagined to host life can be as close as the moon. (From the Finding our Place in the Cosmos collection, Library of Congress 2025.)

Jesus, extend to morally culpable beings beyond Earth? Would the promised return of Jesus and a new, or renewed, "heaven and earth" have any meaning for beings and civilizations on other planets? Had God become incarnate in other forms for other worlds (Crowe 1986, 2008)?[1] Musings on the spiritual state of life beyond Earth extend into science fiction. The famous space trilogy of C. S. Lewis (2011), for example, considers the moral state of, and role of Christ in the lives of, imagined beings on other planets in the solar system as a comparative lens through which to view the workings of God through Jesus Christ on planet Earth.

Then there are the fantastical imaginings of intelligent aliens from other planets visiting Earth. Science fiction films and books vividly portray both positive and dangerous possibilities of such encounters. Personal encounters with alien beings and sightings of unearthly spacecraft are claimed by people around the world, usually through sensationalist media and without mainstream credibility. Official studies of (mostly aerial) sightings are beginning to take place in a more public and scientific fashion. NASA (2023), for example, recently established an Unidentified Anomalous Phenomena Independent Study Team to recommend scientific approaches and data handling for reports of unusual sightings. It is important to note that most unidentified anomalous phenomena can be traced to a non-alien cause, such as human activity or atmospheric physics.

Exploring Planets and Looking for Life in our Own Solar System

Speculation about imagined life on other worlds was the only option until scientific space exploration became a reality. Exploiting the new technology of the telescope, Galileo Galilei set his sights on the moon, Venus, and Jupiter, recording systematic observations that were good enough to explain what had hitherto been mysteries and even challenge long-held paradigms about cosmology. As optics improved in subsequent centuries, observations of planets and the moon only fueled curiosity about the possibility of life beyond Earth.

The dawning of the space age in the twentieth century began a new chapter in looking for life. Finally, humans could actually send probes, and sometimes themselves, to investigate alien worlds. Early probes to the moon sent back close-up photos, with subsequent human missions investigating, and even returning, moon dust and rocks. The moon turned out to be a dusty, lifeless world with no atmosphere. In more recent years, interest in the moon as a place that could support life has been re-fertilized by the detection of water in molecules across its surface and in ice reservoirs at its shaded poles. The question now is not whether life exists on the moon but rather whether human life from Earth could be sustained there for a time using lunar water resources.

The 1960s and 1970s saw the first mechanical probes sent to study other planetary bodies. Of these, perhaps most famous are the *Viking* missions to Mars and the *Voyager* probes to the outer planets. These were joined and followed by hundreds of missions designed to study something of the character of solar system bodies from a close-up vantage point. Their findings made it clear that advanced life simply does not, and cannot, exist beyond Earth in our solar system, and likely never did. Given the centuries of human speculation otherwise, this was a significant disappointment. But it was quickly displaced by other intriguing discoveries and possibilities. For one, it became clear for the first time that the moons of other planets were numerous, diverse, and in many ways more interesting than their planets. Jupiter's Io, for example, is a tumultuous hot and hellish world of volcanoes, while Saturn's Titan has a thick atmosphere and liquid hydrocarbon seas. Intriguingly, Jupiter's Europa and Ganymede and Saturn's Enceladus have evidence of liquid water oceans underneath icy crusts (NASA 2025a). Now, wherever there is liquid water on Earth, we find microbial life. So, could microbial life exist in the oceans of these icy moons? We do not yet know, and we will not until we find ways of exploring deeply embedded water on faraway bodies.

Mars offers further mysteries. Probes and robotic rovers on Mars have been numerous since the 1970s, but they have not made any definitive discoveries of even single-celled life. What they find is a frozen desert of red dirt and rock. And riverbeds. That's right: Mars shows clear signs that it once had flowing rivers and robust lakes. And when these robots dig just a little under the dirt, they find a whole layer of frozen water. Mars was apparently once a water-rich, habitable

place. A massive change in climate accompanied the loss of atmosphere and both the evaporation and freezing of its water.

So far, scientific exploration of our solar system beyond Earth has turned up neither advanced life nor signs of even simple life. But it has drastically changed the questions we as humans are asking. Why does life thrive on Earth but nowhere else in the solar system? Why did Mars once have lakes, rivers, and a comfortable climate but now has only vestiges of mostly hidden frost? Was there ever microbial life on Mars? Is there microbial life in the oceans of Europa or other icy moons? And while it is clear life evolved in complexity on planet Earth, how did life get started in the first place? Was monocellular life a product of processes on Earth or was it transported to Earth via comets, dust, or asteroids (the panspermia concept)? And however life got started on Earth, could it have started similarly on other planets within our solar system if their conditions had been right? What about beyond the solar system?

Planets Beyond the Solar System: A New Era of Discovery

With the backdrop of centuries of contemplation and speculation, and the more recent solar system exploration, a monumental leap in human understanding of and encounters with worlds beyond Earth occurred in 1992. Astronomers Aleksander Wolszczan and Dale Frail discovered two planets orbiting the remains of a dead star known as a pulsar, not by imaging the planets but by detecting motion in the star caused by the gravitational tug of the orbiting bodies. Their phenomenal discovery and innovative technique led to the first detection of a planet orbiting an ordinary star, by astronomers Michel Mayor and Didier Queloz in 1995, leading to a Nobel Prize they shared with James Peebles in 2019.

With these discoveries, a frenzy of search and discovery for more "exoplanets"—planets orbiting stars outside our solar system—began worldwide (ESA 2024). In just three decades, humanity has gone from knowing of no planets orbiting any normal star other than our sun to knowing of more than 5,000 such planets in over 4,000 star systems in our region of the galaxy (some stars have more than one planet). Nothing as revolutionary has been known in astronomy since the discovery of galaxies a century ago.

Exoplanets are generally discovered and studied by indirect means. They are small compared to their parent stars and do not emit their own visible light. They only reflect starlight, so they can be a billion times dimmer than their parent star and get lost in the glare of the starlight for any astronomer trying to see one. The common analogy is of trying to see a firefly next to a lighthouse, though the actual contrast is even greater. The technique Wolszczan and Frail used, measuring the periodic "wobbling" of a star to infer the gravitational pull of an orbiting planet, has been used to find hundreds of exoplanetary systems, especially in the initial years of the quest.

Other techniques have subsequently been developed for exoplanet detection and study. Transiting exoplanets have offered the most powerful tool for both detection and characterization. A "transit" occurs if a planet just happens to orbit its parent star in an orientation where the orbital plane is along the line of sight of an observer (or telescope). As the planet passes in front of its parent star from the viewpoint of the observer, a small fraction of that star is occulted. This means that even though the observer likely cannot "see" the tiny exoplanet, the total amount of light seen from the star will temporarily and periodically be reduced because of the foreground orbiting exoplanet. The amount the observed starlight is reduced is directly related to the size of the occulting planet. As such, the transit method reveals the existence and size of exoplanets, while the amount a parent star wobbles due to the gravitational tug of a planet can yield that planet's mass. If you know a planet's size and mass, you can then deduce its average density. Furthermore, if a transiting planet has an atmosphere, light from the parent star will pass through the outer limbs of that atmosphere on its way to our telescopes. Certain wavelengths of light may be absorbed by atoms and molecules in the planet's atmosphere, and thus the final "rainbow" of light received at the telescope may be missing certain wavelengths of light. The technique of spectroscopy matches the pattern of "missing" light wavelengths to the types of atoms and molecules that must have absorbed it. Thus, "transit spectroscopy" and related "transmission spectra" are used by astronomers to determine the atmospheric composition of an exoplanet. Its orbital velocity is also easily determined, and this implies the distance between the star and the planet, which influences the planet's temperature (and therefore its habitability).

Astronomers are like detectives, using these indirect techniques to discover and crudely characterize exoplanets, and they now have done so for thousands of systems. They also study the parent stars, which vary widely in their nature. The nature of the star (its temperature, flares, radiation colors, etc.) will affect the nature of the exoplanet, including whether it has conditions that could be suitable for life to exist or thrive.

What Are Exoplanets Like? Could They Harbor Life?

Even the first few discoveries of exoplanets made it clear that other star systems may be very different from our own solar system. Many systems harbor what are called "hot Jupiters," that is, large, presumably gaseous planets analogous to Jupiter in our own solar system. The difference is that these giants orbit much closer to their parent star than Jupiter does to the sun—so close, in fact, that by the law of orbits, they must move very fast to keep from falling into their parent star, which can be closer than one-tenth the distance between Earth and the sun. These planets sometimes make their entire orbit in the matter of a few days (Jupiter takes nearly twelve years to orbit the sun).

Hot Jupiters were the easiest planets to first detect in exo-solar systems. After decades of searching, the full range of exoplanet masses and orbits now have been detected. We know they range from terrestrial planets smaller than Earth to super-giants bigger than Jupiter. But we have found that the most common size of planet in other star systems is not found in our own, and that is what we call a "super-Earth" or "sub-Neptune," that is, a planet a bit larger than Earth but a bit smaller than Neptune (Figure 2).

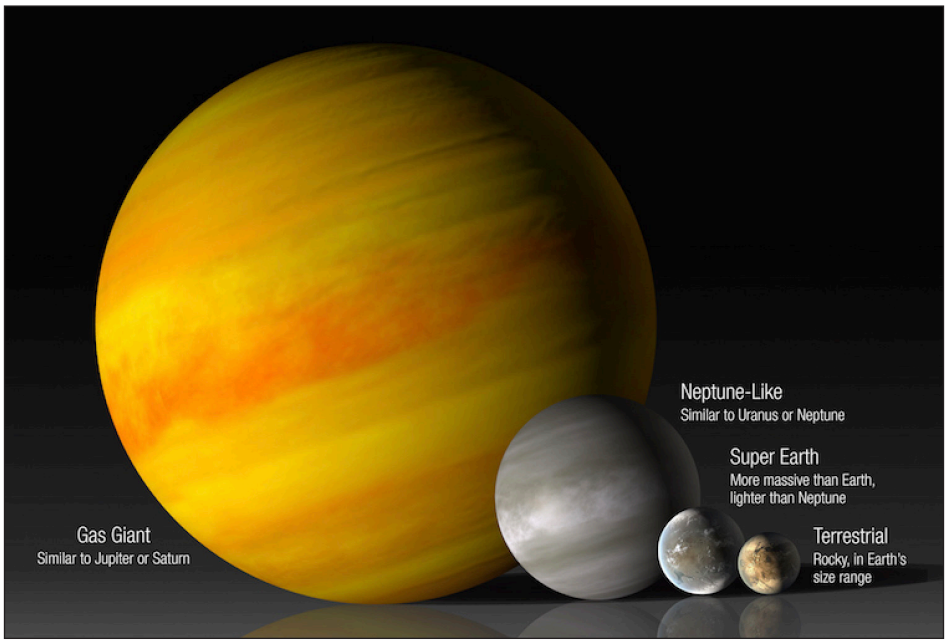

Figure 2: The several thousand planets so far confirmed to be in orbit around other stars—exoplanets—fall into four broad categories: large gas giants, Neptune-like worlds, "super-Earths" bigger than Earth but smaller than Neptune, and terrestrial planets in Earth's size range. Within these categories, however, scientists find even more variety. Among the gas giants, for instance, are "hot Jupiters," infernal worlds with tight, star-hugging orbits. These images are artist conceptions of the many indirectly detected exoplanets, most of which we cannot yet image (NASA 2025b).

Planets can range in density from diamond-like solids to foamlike balls. Some show signs of water vapor or carbon dioxide in their atmospheres, like exoplanet WASP 39b. Others disappointingly show no signs of an atmosphere at all, like several of the terrestrial planets in the habitable zone of the red dwarf star TRAPPIST-1. The "habitable zone" is the range of distance from a star where it is possible for water to exist in liquid form (not all frozen or boiled away) on an orbiting planet. Since liquid water seems to be a requirement for life on Earth, it is reasonable to deduce that the exoplanets with the highest probability of sustaining life would be in the habitable zone of their parent stars. Habitable zones are closer in for cooler stars, like the plentiful dwarf stars,

than for larger, warmer stars like the sun. However, being in the habitable zone does not necessarily mean a planet can support life; other factors also come into play. Take, for example, Venus and Mars in our own solar system. They are in our sun's habitable zone, along with Earth, but Venus and Mars are unsuitable for life because of their atmospheres and resulting extreme environments. On the other hand, even planets outside the habitable zone might sustain life, especially on their moons, if those bodies have thermal properties that enable liquid water (possibly under an icy crust, like on Europa). Furthermore, the most common stars in our galaxy, red dwarfs, generally produce frequent large flares and ejections of charged material that likely would make stable life on planets in their nearby habitable zone impossible.

So, on the one hand, thanks to the bountiful discoveries from recent telescopic surveys and statistical extrapolation, we now know that planets are very common; on average, every star has at least one planet, which means there are hundreds of billions of planets in our galaxy alone. But on the other hand, it appears that most of these planetary systems could be inhospitable to sustaining life, especially advanced life requiring long-term environmental stability. Studying the nature of exoplanets and their interactions with their parent stars is now one of the highest priorities of astronomical research worldwide.

The Nature of Life beyond Earth

If we want to look for life beyond Earth, we need to know what we are looking for and how we would recognize it. That may seem obvious, but the task of understanding possible life in alien environments and its detectable signs is a rich interdisciplinary challenge. The relatively new scientific field of astrobiology addresses issues related to the origins of life, the definition of life, the environments where life can thrive and evolve, and the observable signs of biological activity, including the "biosignatures" we might detect on a distant exoplanet with observations from our own telescopes nearby Earth. If we were to observe Earth from a distant star system, for example, a good telescope might tell us that Earth's atmosphere contains oxygen, methane, and water vapor. None of these on their own are proof of life on Earth, but together they provide strong evidence of habitability and biological activity. While our best professional telescopes are not quite yet capable of detecting conclusive biosignatures from Earthlike exoplanets, it will not be too many years before the advancing technology will enable such detections, and astrobiologists will be telling us what we should be looking for in the light spectra from these alien worlds.

This might be good enough for finding simple life (e.g., microbes) on other worlds, and that discovery would be profound. But what about finding intelligent, advanced, or even communicative life and civilizations? That is harder. Much harder. Not only because of the difficulty most star systems would have in

providing long-term stability for advanced life (see earlier) but also because even if these life forms exist, the likely distances involved between such planets harboring advanced life would be daunting for any likely detection, and even more prohibitive for meaningful communication.

The most famous attempt to quantify the likely number of advanced civilizations in our own Milky Way galaxy was developed by Frank Drake in the 1960s and expressed in his famous "Drake Equation." In this formulation, the number of technologically advanced civilizations detectable today is a product of several terms, each of which can be determined with lessening uncertainty as scientific methods improve. These terms include factors like the rate of formation of stars, the fraction of stars with planetary systems, the fraction of life-bearing planets on which intelligent life emerges, and, most difficult to estimate, the length of time such civilizations release detectable signals into space (or, rather, how long they survive). A modified version of the Drake equation seeks to deduce only the number of technological species ever formed over the history of the universe (Frank and Sullivan 2016). The conclusion from these approaches seems to be that although technologically advanced species must be incredibly rare, we are likely not the only one. Yet, detecting (or visiting) and communicating with other advanced civilizations is practically impossible given the vastness of time and space, our current technologies, and the limits of the speed of light and electromagnetic communication. (A big disappointment for Star Trek science fiction fans.) Nevertheless, the uncertainties in all the measured quantities of the Drake Equation (Figure 3) compel us to keep studying alien worlds and the history of the cosmos because the possibility of finding life, especially simple life, beyond Earth is real, and its consequences profound.

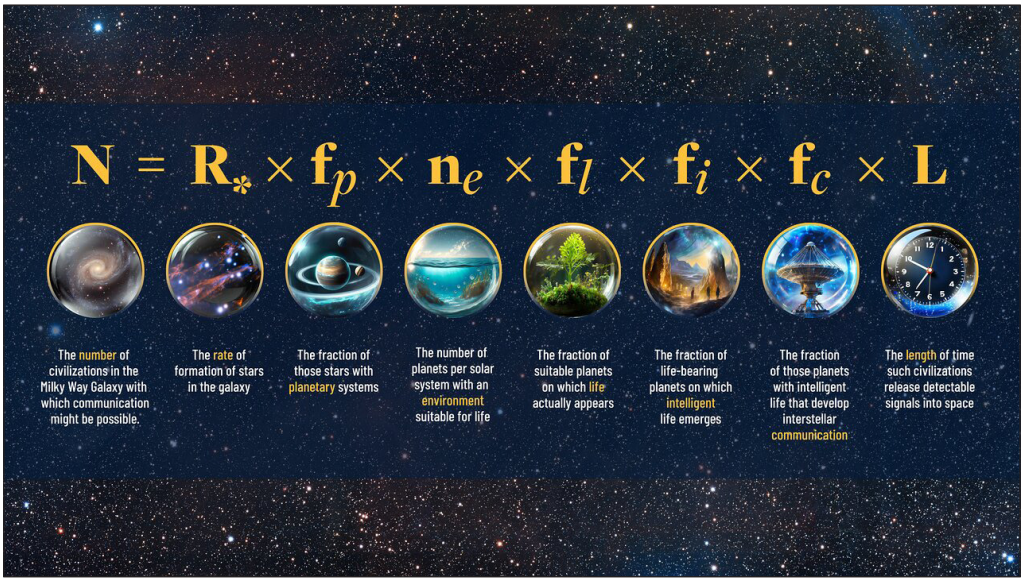

Figure 3: One form of the Drake Equation, a mathematical formula for estimating the number of technologically advanced civilizations (NOIRLab 2025).

The Significance of Life in the Universe

What is perhaps most profound regarding the universe is simply that there is any life at all. To state what is obvious yet in some sense astonishing: we know there is life in the universe, on at least one planet! Including self-reflective life (that's us). And this life is intricately connected with the content and history of the entire cosmos.

Astronomers are now busy detecting and studying exoplanetary systems, but that is in some sense like plucking apples off an apple tree; studying the tree itself and its roots is the core of astrophysics and cosmology, and this tells us how the "apples" came to be. Perhaps the most profound discovery since Galileo confirmed a sun-centered solar system is the finding in the early twentieth century by astronomer Edwin Hubble that other galaxies outside our Milky Way exist, and the universe is expanding. This led to the study of distant galaxies, which is a venture back in time, because it takes time for light to travel from stars and galaxies to our telescopes. We are seeing objects in space as they were, and for galaxies, that generally means millions and sometimes billions of years ago. By comparing galaxies distant in space and time to those like our own, we can see that galaxies have changed over cosmic time. They have formed grand spiral structures (Figure 4), and often those structures have been disrupted and enlarged by mergers with other galaxies.

The stars inside galaxies are also not stagnant. Advances in stellar astrophysics have made it clear that stars are balls of condensed gas with atoms at the core undergoing fusion and releasing photons of light. These fusion reactions create elements heavier than the original hydrogen atoms that make up the bulk of stars. The heavier elements can include carbon, iron, oxygen, and more. When stars run out of a stable supply of hydrogen at their cores (after millions or sometimes billions of years, depending on the star's mass), they release some of this heavier material they produced into the interstellar environment. Thus, heavier elements seed interstellar gas clouds, and future stars that form within these clouds have a larger fraction of heavier elements. Eventually, stars can and do form with orbiting disks of dusty material made of heavier elements orbiting around them. It is in these disks that planets form along with the star. With telescopes like the Hubble and the newer Webb space telescope as well as ground-based radio observatories like ALMA, astronomers are studying young stars with circumstellar disks and embedded planets.

The point here is that planetary systems like our own solar system required previous generations of stars to produce the heavier elements needed for solids and water to form. These in turn enabled disks and planetary systems to form around stars like our sun. Stars were not just created once. We know there were generations of massive stars (they have the shortest lifespans) coming and going before our solar system formed 4.5 billion years ago and that many other star and planetary systems have formed since.

Figure 4: Galaxy NGC 5248, as viewed with the Hubble Space Telescope (ESA/Hubble and NASA, F. Belfiore, J. Lee and the PHANGS-HST Team). Spiral galaxies like this one, and our own Milky Way, contain hundreds of billions of stars. Stars are still actively forming from galactic gas, lighting up colorful nebulae along the spiral arms of the galaxy. Those stars, and the planetary systems that form around them, contain heavier elements like carbon and oxygen produced in previous generations of stars.

Some would point out that none of this stellar manufacturing would be taking place were it not for the finely tuned fundamental physical constants and laws that govern the universe. It appears from many current physical models that if, for example, the gravitational constant or the electromagnetic constants that govern atomic structure were even slightly different, stars (and thus planets and life) could not form. That is indeed an eye-opening realization. But even if the universe were not "fine-tuned" and stars and life were inevitable, the fact the universe exists at all and produces life is remarkable.

The recent detections of thousands of exoplanets and the realization that planets are common feed into an ancient question humans have had about ourselves: Are we significant? As we realize our planet is just one of hundreds of billions in our galaxy alone, does this make us insignificant? What if we do or do not find life beyond Earth—does that make life on Earth more or less significant? These questions do not have a consensus answer, because they are philosophical. If significance is based on position in the universe or lifespan relative to the cosmos, then we are indeed insignificant. But perhaps the significance of life in the universe comes not from position, lifespan, or rarity but rather from the fact that we are literally and physically connected with the universe and its processes from the very beginning of time as we know it. Our bodies contain atoms that were literally made in stars before the birth of our own solar system. And we are here to contemplate this. Whether or not there is life beyond Earth, the very existence of our life here speaks of profound significance.

Some Implications of Exoplanet Discoveries and the Search for Life

The aim of this article has been to summarize the incredible scientific advances of the last century in the search for worlds beyond Earth, and the related search for extraterrestrial life. This quest has profound implications for humanity. Initial theological implications of this contemporary scientific search have been addressed by, for example, theologians David Wilkinson (2017; Wilkinson and Wiseman 2024), Ted Peters (2018), Andrew Davison (2024), and their collaborators. Potential impacts for society more broadly have been explored by, for example, historian Steven Dick (2000; 2020).

Given the more recent explosion of exoplanet detections, which open up genuine possibilities of finding at least simple life beyond Earth in the coming decades, theology and philosophy must now engage with renewed vigor the implications of possible myriad life-bearing worlds. Are we, as humans, ready?

And what about the spiritual state of potential life on other planets? Centuries of thorough but inconclusive thought on this topic cannot be adequately summarized here; we simply do not know (but check out C. S. Lewis's space trilogy for a fictional approach).

Contemplations of life on and beyond Earth lead to reflections, both corporate and personal, on the spiritual significance of life in the cosmos. Informed people of faith can no longer envision the heavens as static and sterile. As a scientist and a person of faith, my personal reaction to a lively universe is one of enriched appreciation of God—God as Creator, God Incarnate, and the God we worship. Here, I elaborate on each.

First, can the universe teach us something about the nature of God? Science is a good tool for addressing how the universe works but not for analyzing a possible "who" behind it. That said, for observers looking through a lens of faith, it is possible to infer some character qualities of God through what

is seen in the universe, as per Psalm 19: "The heavens declare the glory of God; the skies proclaim the work of his hands." Thinking about the cosmos, myriad exoplanets, and a universe that produces life, I conclude that God is powerful, creative, and a lover of life, including life that can contemplate beauty and meaning.

Next, in arguably the most profound passage in the New Testament, John 1 states that "[i]n the beginning was the Word" and that "[t]hrough him all things were made." And then, the great declaration: "The Word became flesh and made his dwelling among us. And we have seen his glory, the glory of the one and only Son, who came from the Father, full of grace and truth." The word of God is manifest in Jesus, and Jesus's birth on planet Earth marks the incarnation of God among us. I reflect on this in light of the modern cosmology described earlier. According to this passage, an aspect of God, through whom the dynamic universe was created, was born in human flesh on our planet, with a body containing atoms forged in stars. If we are made of "star stuff," as Carl Sagan mused, then so was Jesus. What does this mean for us? I conclude it means that God's incarnation in Jesus must have relevance for the entire universe. It also means God cares about life on this particular planet.

Finally, as science and technology are quickly opening up a universe to us richer in content and history than ever imagined, I believe faith communities and their leaders would be wise to embrace with joy our new knowledge of a universe full of planets and the potential for a universe full of life. Worship of the Creator—including hymns, prayers, liturgy, and sermons—should honor the God of a fruitful, evolving universe, abundant in planets and the elements needed for life.

Perhaps a twentieth century hymn is a good starting point for envisioning science-revitalized twenty-first century worship. The 1955 version of "How Great Thou Art" (Carl Boberg, Stuart Hine) contains a prescient mention of worlds we can now envision as exoplanets and directs human response toward awestruck and exuberant worship:

Oh Lord my God
When I in awesome wonder
Consider all the worlds thy hands have made

I see the stars;
I hear the rolling thunder;
Thy power throughout the universe displayed

Then sings my soul; my Savior, God to thee:
How Great Thou Art! How Great Thou Art!

Note

[1] The *Extraterrestrial Life Debate* sourcebooks edited by Michael Crowe (1986, 2008) provide a helpful collection of writings from antiquity through the eighteenth century on the philosophical and theological implications of life existing beyond Earth.

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The Dawn of a Mindful Universe: A Pathway towards a Biocentric Global Ethics

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This article presents arguments for a biocentric worldview based on the rarity and uniqueness of planet Earth as confronted with trillions of other worlds in our galaxy alone. This cosmic outlook comes from recent astronomical knowledge concerning the distribution of exoplanets and the growing understanding of the interconnectedness and codependence of all life on Earth, past and present. Confronting the uniqueness of Earth's biosphere and its current fragile state due to centuries of aggressive human presence, the biocentric worldview proposes an ethics of belonging that takes life center stage as humanity struggles to chart its path toward a sustainable future.

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Introduction

The story of who we are as cohabitants of a diverse and fragile biosphere needs to be retold. We need a new narrative of what it means to be human on planet Earth. Civilization is at a crossroads and time is running out. It is hard not to sound alarmist when one considers the current political and social fragmentation under the mounting threats of climate change and technological existential threats. Although our collective history is no stranger to crisis, the challenges we now face are unprecedented. What is different is the scale of the crisis, truly global in its reach. The remarkable industrial and economic growth of the past two centuries has come with an enormous environmental cost. Unless we redefine our relation to nature and realign our economy within a moral framework anchored on sustainable and regenerative practices, we may indeed come to experience some of the many dystopian scenarios seen in the news and in popular culture: droughts, floods, massive climate migration, and political and social unrest (Berry 1988). How we arrived at our current predicament and what could possibly be done to rescue our project of civilization is the focus of this article. The new narrative for humanity proposed here combines elements not often brought together: Indigenous wisdom, astrobiology and the search for life on exoplanets, and a post-Copernican approach to modern cosmology.

With the aid of technology and the success of agrarian practices, humans have moved away from the very essence of our evolutionary history: hunter-gathering groups well adapted to coexist with the planet and its resources gradually transitioned to concentrated populations in ever-growing cities. Anthropologists trace the origins of our species to some 300,000 years ago. For about 290,000 of those years, our ancestors developed strategies to function within nature, seeing themselves as an integral part of the life collective (Graeber and Wengrow 2022). The shift to agrarian civilization happened roughly within the past 10,000 years or so as people gathered in fertile regions, spurring the growth of cities with increased populations and accumulation of goods. Cities are, in a sense, unnatural conglomerates of humans, artificial constructions built out of processed materials designed to house as many people as possible within the smallest space possible. Built to leave nature mostly outside their boundaries, cities aggregate large numbers of humans to the exclusion of other living creatures, except for scattered trees and flowerbeds, or those species that thrive on our refuse, like cockroaches, rats, and a small number of birds. Of course, cities also offer great benefits (to those who can afford them), from cultural activities and diverse entertainment to sheltered housing, policed security, and easy access to food. They are an integral part of modern civilization and no realistic proposal considering our collective future would be taken seriously without them. (A recent study compared large cities and their suburban spread linked by rail lines to cancerous growths on the surface of the planet (Capel-Timms et al. 2024).) How to house, feed, educate, and care for

a population of eight billion humans, with over 55% currently living in urban areas, is an enormous challenge.[1]

Dystopian scenarios claim it is impossible for a living planet to support a dominant species so out of balance with the rest of the biosphere (Kolbert 2014), gloomily suggesting that sufficiently advanced civilizations—if they exist—sooner or later inevitably self-destruct (Frank 2018). At this pivoting point in our collective history, we must ask: Is this our inexorable destiny or are there other possible pathways forward? Although there are clearly no simple or unique answers to such a vastly complex question, we can try to isolate the root causes of our current predicament to then suggest a possible course correction.

Fermi's Paradox and Our Cosmic Loneliness

In 1950, physicist Enrico Fermi was having lunch with a few colleagues at the Los Alamos Laboratory cafeteria, apparently lost in thought. As the story goes, after scribbling some calculations on his napkin, he stopped suddenly and asked his colleagues: "Where is everybody?" (Webb [2002] 2015). "Everybody" referred to aliens. In particular, aliens capable of creating a technological, space-faring civilization. He reasoned that since the Milky Way galaxy is about 100,000 light years across and 10 billion years old, a civilization that had developed technologies for space exploration would have had plenty of time to colonize, or at least explore, the galaxy. Their forays should, Fermi believed, have included a visit to our home planet. The numbers do make sense. If aliens with a flair for technology and exploration flourished a few million years before we came about, they could have developed technologies for travelling at speeds close to the speed of light. If they reached, say, one-tenth of the speed of light, which is not unreasonable even by our current standards, it would have taken them "only" a million years or so to cross the galaxy. After a few million years of exploration, they could have planted outposts across countless stellar systems, including ours. And since it takes life to recognize life, they would have spotted our planet with some curiosity. How come, then, we have no indication of any such civilization in our galactic neighborhood? Hence was born the Fermi Paradox, a frequent topic in countless sci-fi movies and novels as well as popular and academic books and scientific papers.

Given Fermi's role in the development of controlled nuclear fission and the atomic bomb, and the subsequent threats of global annihilation during the Cold War, the paradox is often associated with what is sometimes called a civilizational bottleneck: any civilization that develops advanced technologies would, sooner or later, self-destruct (Leslie 1996; Rees 2021). According to this premise, aliens have not visited here simply because they did not survive long enough.

The Cold War is long gone, but the threat of nuclear annihilation remains very present. In a 2023 survey, the number of nuclear warheads was estimated to be around 12,500, with 90% belonging to the United States and Russia. A staggering 9,600 remain in military service, while the rest await dismantlement

(Arms Control Association 2025). For now, the polity of Mutual Assured Destruction has held. We cannot know, of course, what the future holds.

Nuclear obliteration is only one possible existential risk that haunts technological civilizations like ours. Dystopian scenarios abound where nanobots, AI, or bioengineered diseases get out of "control" and become an unstoppable threat to our collective future. Bombs, robots, crazed self-conscious computers, and bioengineered germs have a common source: scientific research serving the interests of the state and stockholders gets out of human control or is controlled by groups or leaders with destructive intent. Science's noble goal of alleviating human suffering is turned on itself to become the most efficient perpetrator of human suffering. Together, technological existential threats represent the tragedy of the modern human, the neglect of life in favor of power. Considering the current political climate and predictions for excessive global warming due to the rampant use of fossil fuels, we must add runaway climate change and its devastating consequences as the frontrunner existential risk for humanity (Mann 2022). We may indeed become another technological civilization unable to pass through the civilizational bottleneck.

The obvious difficulty with discussing alien life is the complete lack of data. We have no data pointing to life in any of the worlds of our solar system, despite a few false alarms with Mars, as with the famous ALH84001 meteorite.[2] Planned future missions to explore Europa, Enceladus, and Titan may change this general picture, but given the extreme conditions in these worlds, the chance they harbor life is quite small. Even if, say, subsurface water-based life exists on Europa or Enceladus, it will be very simple, most probably unicellular.[3]

It goes without saying that the discovery of any kind of alien life would be deeply transformative. Given that the laws of physics and chemistry are the same across the observable universe, if life is confirmed to exist in one world beyond ours, it will probably exist in many more, though inductive thinking is inadequate for biological speculation about the ubiquity of life in the cosmos (Gleiser 2023). Still, the discovery of simple alien life, certainly a spectacular find, would not directly impact our current need to solve the planetary crisis and safeguard Earth's biosphere, us included. Indeed, it would probably foster a conceptually mistaken inductive generalization of the Copernican principle into biology, that not only is Earth a common kind of world in the universe but so are worlds with biospheres. Inductive thinking works well for stellar systems because the process of stellar formation and gravitational dynamics follows well-understood physics laws. This is surely not the case with the origin and evolution of life here or (if applicable) elsewhere in the cosmos (Kauffman 2019).

The James Webb Space Telescope is now helping us uncover the atmospheric chemical composition of exoplanets (Ahrer et al. 2023a, 649; 2023b, 653). We search for biosignatures, that is, molecules or groups of molecules directly or indirectly associated with biological activity. As James Lovelock and Lynn Margulis argued in 1974, life changed Earth as a whole, in particular by keeping

the atmosphere out of thermal equilibrium, expressed here through the coexistence of both oxidizing (CO_2) and reducing (CH_4) carbon compounds (Lovelock and Margulis 1974). It is reasonable to suppose that similar principles apply for alien worlds with biospheres, although, of course, specific biospheres and their resulting biosignatures will depend on the details of alien biology. Climbing further in complexity, technosignatures would point to life capable of large-scale engineering works that could be observed from afar (Frank 2024; Lingam et al. 2023; Wilkinson 2013). It is interesting to consider that the first popular alien life craze in history was prompted by the presumed discovery of a technosignature, Percival Lowell's misinterpretation of Giovanni Schiaparreli's Mars *canali* as being channels dug by a dying civilization (Lane 2011).

Although we currently cannot be certain of the existence of life elsewhere, we can state with confidence that the difficulties of interstellar travel severely constrain the possibility that aliens visited here in the past or that we will be travelling to other stellar systems in the near or not-so-near future. For example, to travel to the star system closest to the sun, the Centauri triple-star system at 4.2 light years away, would take our fastest spaceship roughly 80,000 years. We are, for all practical purposes, alone to decide our collective future. Human civilization thus finds itself at the edge of Fermi's civilizational bottleneck, a pre-galaxy-faring technological civilization teetering on the brink of massive social and economic collapse prompted by its disregard for the existential risks of climate change.

Beyond Copernicus: Earth Is a Special World

In the past two decades or so, exoplanet finding techniques, in particular through the Doppler and Transit methods, have produced spectacular results, allowing us to have an approximate grasp of their astronomical properties, such as radius, mass, and distance from their parent star or stars (Scharf 2009). The results, which tend to favor large-mass planets in closer proximity to their stars, indicate that about 3.5% of the planets in the Milky Way galaxy are "terrestrial," that is, with a mass and radius similar to Earth's. Extrapolating this statistic, if there are about one trillion planets in our galaxy, about thirty billion (or 3%) have a mass and radius similar to Earth's. Of those, a smaller but substantial number orbit G-type stars like the sun: since about 7% of stars in the galaxy are sunlike, in simple numbers, that would mean there are about two billion terrestrial worlds orbiting sunlike stars. This may sound like a large number of potentially life-bearing, Earthlike planets. But as remarked earlier, we cannot use inductive thinking to conclude that all (or even any) of these worlds harbor life. When the focus is on finding life, having a mass and radius *like* Earth's, or orbiting a star *like* the sun, is a long way from *being a living planet like* Earth.

Our planet is much more than a rocky world with a certain mass and radius orbiting a G-type star once a year. To assess Earth's uniqueness, we must begin by disentangling astronomy from biology. In his *Commentariolus* of 1514, and later in his great 1543 book *On the Revolutions of the Heavenly Spheres*, Copernicus

famously suggested that Earth is just another planet orbiting the sun. Discounting Aristarchus of Samos's earlier speculations from about 250 BCE, Copernicus's thesis was the first in a series of astronomical steps that shifted Earth from its cosmic centrality to an ordinary world orbiting an ordinary star among billions of other stars, belonging to an ordinary galaxy among billions of other galaxies receding from each other in an expanding universe where stars, planets, clouds, and people are made of matter that makes up only 5% of the total stuff that fills space. (The other 95% are conjectured to be dark matter and dark energy, both still unidentified.) During the past four centuries, this ongoing shift in astronomical perspective, coupled with the fast pace of industrial growth fed by our voracious appetite for natural resources, led to a devastating objectification of nature. What was once a sacred realm became an increasingly desacralized material commodity, just another world wandering the vastness of cosmic space. In growing numbers, humans separated themselves from the natural world, congregating in cities and in artificially built working environments, believing to be above the natural order. The general sentiment is one of disregard: we own nature and its living inhabitants. This narrative has become unsustainable and needs to change. Perhaps a rereading of what the new astronomy of exoplanets is telling us could help.

What separates Earth from other known worlds is that it is a living world, unique in its biodiversity. "Living world" here means a world where life has spread over diverse environments and persisted long enough to become an ever-evolving biosphere. Some worlds may have been living worlds for part of their history (as many conjecture is the case with Mars (Sauterey et al. 2022)), while others may yet become living worlds. The essential point is that even if there are other living worlds in the galaxy and beyond, each will have its own particular biosphere—none will have the same type of life found here. This includes life as we know it, that is, carbon/water based, with RNA/DNA for genetic coding. Even within this terrestrial framework, evolution will always take a different turn due to variations in geophysical and geochemical conditions in alien worlds. As Lovelock and Margulis suggest, once life takes hold of a planet, planet and life become an inseparable, mutually interactive, and codependent whole. Life affects the planet's geochemical cycles, and the planet affects life's evolution, adaptability, and diversity. For example, cosmic cataclysms of global impact reset evolution in unpredictable ways. Consequently, with or without life, every single world in the observable universe— planets, moons, and asteroids—is by necessity unique. Each will have its own formation history and initial chemical composition, and each will evolve according to local variabilities, which are highly unlikely (I would argue impossible) to be duplicated elsewhere in the universe. Worlds may share similar astronomical and geochemical properties and characteristics, but no two worlds will be the same. When life is added to this picture, even two living worlds that are very similar will have very different biospheres.

From a physics perspective, Earth is remarkable for many reasons, including having a strong enough magnetic field and a dense enough atmosphere to shield the surface from different kinds of cosmic and solar radiation; having a single moon large enough to affect the precession of the equinoxes and sustain the seasons; having a large amount of surface area that allowed for life to eventually migrate to the surface and mutate into a hugely differentiated biodiversity; having a hot and active interior that spewed and keeps spewing materials onto the surface and into the atmosphere; being covered with tectonic plates that syphon CO_2 from the atmosphere into Earth's mantle, releasing it back upwards through volcanic activity and thus regulating long-term CO_2 levels; being in a peculiar solar system with very large planets in its outer regions that shield the interior (including Earth) from life-endangering collisions with comets; and so on. The conclusion is straightforward: there is no Earth 2.0 in the universe. Even if all the physical conditions listed are duplicated elsewhere, the unpredictability of cosmic cataclysms will have created unique conditions in each world. When life is added, the variability among worlds sharply increases, as does the unpredictability of how specific biospheres would have evolved. Starting with a prokaryotic cell three billion years ago, no one could have predicted the existence of a lobster. Or a human. Every living world will by necessity be different.

Living Worlds as Sacred Realms

As argued, a living world is not only rare but unique. We can thus conclude that we are the only humans in the universe. Any living creature has a certain level of cognition and agency, an ability to interact with the environment to maximize its viability, that is, the urge we share with bacteria to remain alive (Sowinski et al. 2023). On this planet, for better and for worse, humans are the dominant intelligent life-form, as our capacity for symbolic thinking enables us to expand our reach into imaginary and inaccessible realms, from writing poetry and composing symphonies to building radio telescopes, fMRI machines, and nuclear bombs. If there are intelligent life-forms in other stellar systems, "they" will not be like us, even if they share some of our physical traits, such as an approximate left-right symmetry. Furthermore, as remarked earlier, any existing alien life-form is so far away that, for all practical purposes, we are alone to decide our collective fate. Modern science has allowed us to describe how our planet transformed from a barren ball of molten rock to a thriving abode for life. Over the past seven decades, we have pushed the boundaries of this narrative to the very first moments after the origin of the universe itself, some 13.8 billion years ago (Swimme and Tucker 2014). Before our species came into existence about 300,000 years ago, the universe evolved in silence, as collisions between particles created ever more complex material structures, from atoms to stars to chemicals to planets and moons. If other species elsewhere also tell stories of creation, they will be particular to their physical and cognitive realities. Humans tell human stories of creation, each echoing in unique ways the realities of their originating cultures (Gleiser 1997).

The current scientific narrative of creation, the Big Bang model of cosmology, leaves life out. The evolutionary narrative of life on Earth leaves the universe out. Although physics and biology seem to be telling two separate stories, and that is how we study them in school, the stories are profoundly interwoven. The universe only has a story because we are here to tell it. This discipline-based separation—nonliving and living matter—took hold over the past two centuries as a consequence of a compartmentalization of knowledge that grew from the hyper-specialization of scientific research. Science's success created its own blind spots. Of central relevance to us here, one of the key blind spots is the objectification of nature as something separate from us, as an object of study detached from value (Frank, Gleiser, and Thompson 2024). It was this objectification, allied with the remarkable technological growth generated from the Newtonian mechanistic worldview, that propelled our immense material success, as witnessed through the industrial and now digital revolutions. Although there is no going back on this growth, there are options for how to go forward. The first obvious point is that an ideology of infinite material progress is inconsistent with a planet of finite resources. We have reached a point in our collective history where we need to make hard choices about how to coexist with a fragile biosphere.

The biocentric view discussed here and elsewhere (Gleiser 2023) proposes the sacrality of every living world. "Sacred" here should primarily be seen as secular, divested of specific creeds, although of course many religious traditions propose that the planet that allows us to exist is holy and should be venerated as such. Among countless examples, the Guarani Indigenous tradition of Brazil calls Earth *Nhandecy*, "Mother Earth."[4] When we call Earth our mother, we do so with humility and gratitude. We understand at the rational level that we could not survive on a sick planet, that what we receive from the skies and land are essential to our existence. We understand that we are not alone on this planet but profoundly codependent with the biosphere and its rich diversity, which we can call the life collective, of which we are an integral part. But more than understand, we also feel it in our hearts as we gaze in wonder at the beauty of our world and its mysteries. In the words of Thomas Berry (1999, xi), "Intimacy with the planet in its wonder and beauty and the full depth of its meaning is what enables us an integral human relationship with the planet to function . . . The fulfillment of the Earth community is to be caught up in the grandeur of existence itself and in admiration of those mysterious powers whence all this has emerged." We have forgotten that our very existence comes from a secret buried in Earth's distant past, the emergence of life itself. It is time we rekindle this memory of our distant origins based on the lens of a new scientific narrative that connects us to all forms of life and the cosmos itself.

Concluding Remarks

Earth may not be the only living world in the cosmos, but it is our living world, the one to which we belong. We may fly into outer space in search of other worlds, but as we do so, we must carry bits of our world with us—the water

we drink, the air we breathe, the food we eat—or else we will not survive. Technology allows us to extend our reach to the stars and beyond. It helps us extend our lives and redefine our lifestyle and the way we communicate. But it cannot solve all our problems. It may alleviate some of them—for example, we may capture energy from the sun and wind and sequester carbon dioxide from the atmosphere—but, in doing so, it will inevitably create new ones. No machine is 100% efficient, and every machine is built from and must use natural resources extracted from the environment at a cost. Nothing in the universe, not even the universe itself, escapes the inexorability of thermodynamics.

The reapproximating of humans with nature, which Thomas Berry so eloquently urged, inspired by a reevaluation of our role as partners rather than owners of the natural world, cannot be based only on rational decision-making. We have tried this for decades and failed, as the many violations and implementation failures of already-limited climate agreements continue to show. To be sure, governments and large corporations have an essential role to play in facilitating this reawakening, but it is at the level of the individual that this mindset change probably will unfold. Possible steps to achieve this mindset change have been suggested elsewhere (Gleiser 2023). In short, we need to reenchant the planet. This reenchanting can be inspired by an intense exposure to the wonders, beauty, and power of our home planet. This exposure to nature takes many shapes. In schools, at all levels, we must teach the post-Copernican modern scientific narrative of belonging briefly described here, tracing our roots to the deep past of cosmic history and to all forms of life on this planet. Consumers with sufficient purchasing power can choose to buy goods from corporations aligned with sustainable and bioethical practices, for example, in accordance with the rules of the B Corporation certification movement.[5] Schools, families, and communities can choose to organize trips to awe-inspiring landscapes as a study in re-belonging, with the goal of reconnecting with our evolutionary history. Biocentrism is the cornerstone of a bioethics profoundly engaged in preserving and celebrating life on this and any other living planet based on a confluence of Indigenous values and scientific discoveries that place life center stage in the cosmos.

Religions traditionally revere what is more powerful than humans, the unknowable forces that are responsible for our origins and allow us to exist. The ineffability of existence inspires the experience of the sacred. The creation myths of countless cultures past and present tell us of our origins and the origins of the sky and the Earth, the sun and the moon, the planets and animals. Our modern scientific narrative based on the Big Bang theory of cosmology and the evolutionary theory of biology tells us of our profound connection to both the cosmic history and all life on Earth, past and present. This remarkable convergence of narratives—if not in method, at least in meaning—should bond us in our shared humanity as we move forward toward an uncertain future.

Notes

[1] This number is expected to reach 68% by 2050, as reported by the United Nations in https://www.un.org/uk/desa/68-world-population-projected-live-urban-areas-2050-says-un.

[2] For research on the ALH84001 meteorite, see, e.g., https://curator.jsc.nasa.gov/antmet/mmc/alh84001.pdf.

[3] A contrasting argument is defended by British biologist Simon Conway Morris: that evolution towards complexity is a natural and probable outcome of life's adaptation and refinement over billions of years. See, e.g., Conway Morris (2004). That being the case, if we ever find life in another world, and this life has existed long enough, it would have evolved beyond unicellularity.

[4] See Sandra Benites (2025), where Nhandecy is explained as the Guarani term for "our mother."

[5] https://www.bcorporation.net/en-us/.

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The Big Bang and Theology

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This article extends and clarifies a case previously made that the cosmic singularity provides negligible support for creation and hence theism. A key task is to provide a modally robust notion of beginning to yield a valid argument. A physical theory might have no metric or multiple metrics, so a beginning, to avoid conventionality, equivocation, and modal provincialism, should imply a lack of past maximal extension, whereas Big Bang models are past maximally extended. The mathematical analogy between the Big Bang and stellar gravitational collapse indicates that the former requires a Creator only if the latter requires a Destroyer. Gravitational thermodynamics, though making rapid progress, is still immature, making it questionable whether thermodynamic arguments against eternal cosmological models will survive. Recent philosophical discussion of the opaque justification of maximal extension toward the past is noted and related to other themes in philosophy and science–religion literature such as rationalism versus empiricism.

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Introduction: Why Revisit the Big Bang and Theism?

One might view this article as an instance of analytic theology or perhaps analytic philosophy of religion. Much of it addresses a deductive argument made by William Lane Craig and how to evaluate it. Seeking more precision in various areas is therefore important.

The article revisits a case made about seventeen years ago that there is no good theistic argument from the Big Bang singularity (Pitts 2008). Like that earlier paper, this one has very little to say about cosmic fine-tuning, a fascinating topic that has inspired interesting work.[1] While I remain largely content with the original paper, it did have a flaw (as Joshua Rasmussen first convinced me), a readily fixable one, I believe, but I have had no simple way to say how.[2] Response to the paper has been largely positive, but critics have latched onto the flaw while mostly ignoring the important points motivating it (Monton 2009; Craig and Sinclair 2012b; Craig and Sinclair 2018). This article aims to fix the flaw and address other issues discussed by William Lane Craig and James Sinclair in their response. Further issues are also addressed involving the question of past maximal extension, a criterion now proposed for lacking a beginning.[3]

Craig (1979, 63) formulates the *kalām* cosmological argument along these lines:

1. Everything that begins to exist has a cause of its existence.
2. The universe began to exist.
3. Therefore, the universe has a cause of its existence.

This argument is valid—that is, the premises, if true, would ensure the truth of the conclusion—assuming it is unproblematic to treat the universe as a thing and assuming no equivocation on "beginning," on which more later. If "beginning" and its relatives are allowed to mean different things in different premises, then the argument will be subtly fallacious.

My 2008 paper's remarks on the relevance of quantum gravity—the sought but possibly not yet achieved merger of gravity (perhaps as described by general relativity) and quantum mechanics (more strictly, quantum field theory)—still apply: one should have little confidence, I think, that the Big Bang singularity will persist once quantum gravity is achieved, so something like an eternal universe model is likely to result. Those who embrace scientific realism without qualification will thus likely feel pressure to accept that the universe is eternal. A good expression of these expectations and careful evaluation of what precisely they should mean and how plausible the various precise candidates are has been given recently by Karim Thébault (2023).

On the other hand, one should be wary of too-quick claims, such as Stephen Hawking's no-boundary appeal to imaginary time as having already removed

the singularity. If such a claim were taken very seriously among physicists (as opposed to being an instrumentally useful mathematical trick or one possible avenue within one possible program), there would be much less ongoing work in quantum gravity than there is.

Beginning as (Not) Requiring a First Moment

Craig and Sinclair devoted much of a chapter to refuting the 2008 paper (Craig and Sinclair 2012b; Craig and Sinclair 2018). Most of their critique focuses on the first moment criterion for a beginning.

The fixable flaw in the paper is the claim that a beginning in the sense relevant to making the *kalām* cosmological argument work, avoiding conventionality and modal provincialism,[4] requires a first moment. Instead, there might be some more general feature that is also nonconventional and more modally robust that applies in more of, or one hopes all of, the cases that intuitively imply a beginning. In 2008, such a thing did not come to mind, while others seem not to have been looking for it.

The fix envisaged relaxes having a first moment in favor of lacking maximal extension toward the past—one might say, being past-extendible. In other words, a universe with a beginning could have had more of a past than it actually has, having all the same past as well as some earlier events. One could say a "longer past," but that suggests a metric exists (and is probably unique) and is used as the standard of length, which is just what is to be avoided. This informal condition (with some unspecified conditions of differentiability assumed) is inspired loosely by notions used in global general relativity literature, but it does not assume either the existence of a metric or its uniqueness. If the universe actually came into existence five minutes ago, c. 7,000 years ago, three minutes "after the Big Bang,"[5] or at any other time later than $t = 0$ (the "time" of the extrapolated singularity), then it could have had more of a past than it actually has. Such possibilities permit versions with a first moment and versions without. The point of requiring a first moment was to avoid conventionality (a familiar issue in this debate) while also pursuing modal robustness (on which more later). Note that "more of a past" makes sense given multiple metrics or given conformal invariance, in which one has only 90% of a metric, a notion of space-time shape without size (4-volume) and hence without length, including temporal length.

If one entertains the failure of maximal extension toward the past, one might want to expand one's idea of the possibilities using notions of simultaneity that have become popular in numerical relativity, such as hyperboloidal simultaneity slices (Frauendiener 2000). Informally, the present started earlier in distant locations than it did here, making it possible to see further than one would have expected. Nothing requires the universe's front edge of existence to make spatial homogeneity manifest; the front edge could be curved or wiggly.

Modality and Beginnings

Perhaps the least satisfactory aspect of Craig and collaborators' argumentation involves the modal status and univocity of "beginning." For assessing the validity of an argument, the use of a term must be univocal, having the same meaning in all instances. As the argument is presented, there is no "necessarily" in premise 1 that whatever begins to exist has a cause. But why not? The considerations Craig et al. employ are intended to be true outside the actual world or even worlds much like it. "Does anyone in his right mind really believe that, say, a raging tiger could suddenly come into existence uncaused, out of nothing, in this room right now?" (Craig 2008, 113). If not, could a tiger pop into existence in similar possible world, one in which I wear a blue shirt instead of a gray one while typing this sentence? Surely not: premise 1 is intended to apply beyond the actual world. This issue occupied much of an exchange between Craig and Wes Morriston some time ago (Morriston 2000; Craig 2002; Morriston 2002). The premise, according to Craig and Sinclair (2012a, 182), is based on a metaphysical intuition that *ex nihilo nihil fit* (out of nothing, nothing comes). Thus, this causal principle is a necessary truth, holding in all possible worlds. So Craig holds, a view that strikes me as plausible enough, though I do not know that doubters are insincere or out of their right minds, as he claims.

Reasoning about duration and causation should not essentially rely on physical assumptions that could easily be false. Suppose a scalar-tensor theory of gravity (or any other bimetric or multi-metric theory) is true (or the best classical theory, ignoring quantum gravity). The Brans-Dicke (1961) scalar-tensor theory of gravity—which has an additional scalar field (an extra number at each place and time, here relating to the effective gravitational constant G), along with the usual space-time metric of general relativity—was the most visible rival theory for some time, and so was a somewhat plausible idea when Craig started writing. A scalar-tensor theory can be viewed as having two different (but conformally related, giving the same shapes and angles but different lengths and volumes) metrics, known as the Jordan frame (in which the dynamics of gravity itself feature this scalar field) and the Einstein frame (in which the dynamics of gravity itself look like Einstein's general relativity but matter also couples explicitly to a new scalar field). These different metrics define different ages. Which age is relevant for a beginning? Perhaps it does not matter if they are both finite or both infinite. But what assurance is there of that agreement? Either there is no assurance or it depends on detailed study of a great variety of bimetric/multi-metric theories, considerations Craig et al. have generally neglected in assuming that the actual world has a unique metric. Supposing some bimetric or multi-metric theory is empirically satisfactory and permits one age to be finite and one to be infinite, can tigers plausibly pop into existence in that theory? Of course not. Plausibly, our expectation that tigers cannot pop into existence is a modally robust a priori intuition on which we

would insist even if we learned that the space-time metric is not unique and the age of the world is ambiguous between infinity and some finite value. Given the protracted failure to solve David Hume's problem of induction (Howson 2000; Pitts 2023), a solution that would assure of the exceptionless uniformity of nature, our high confidence that tigers cannot just pop into existence is not merely inferred from experience.

If massive, slow-moving particles/fields fit with conformally invariant theories such as the Bach-Weyl theory—at first glance they do not, but perhaps some clever symmetry-breaking idea is possible—then our world could lack volumes and lengths and hence ages, at least fundamentally, yet we would remain confident that tigers could not pop into existence. In short, our confidence that whatever begins to exist has a cause is modally robust, unaffected by the possibilities that age is either radically ambiguous or meaningless. These considerations motivated seeking a non-metrical notion of a beginning (Pitts 2008).

Furthermore, premise 1 does not seem to be equivocal in content— meaning one thing (finite age) in some worlds (perhaps the actual world) and something else in others—or inhomogeneous in warrant, credible for one reason in one possible world and another reason in another world. If we make a serious effort to sort this question out, we will seek a modally robust notion of "beginning" that fits at least all these classical field theory cases. Having a first moment was modally robust enough and nonconventional but too strict: a tiger that suddenly exists for all moments after some given moment is as surprising as a tiger that suddenly exists starting at that given moment. But a metrical notion of beginning that fails to apply to many possible worlds describable in classical field theory, especially some that seem epistemically possible (might be real for all we know), simply does not suffice. Craig (2002) is apparently less committed to the a priori nature of the causal principle than to its metaphysical necessity: "It could well be that only logically posterior to our experience of reality do we intuitively grasp the necessary truth of the causal principle." But necessity is the key feature that motivated my search for a modally robust notion of beginning. Since the causal principle is a necessary truth (Craig holds), it must be meaningful in all possible worlds. My own effort has merely been to require it to make sense in all classical field theory worlds, a lower bar than all possible worlds (or even all worlds conceivable with current mathematical physics) but an obvious place to start and a higher bar than Paul Copan and Craig (2004, 199) reached in defining "beginning" in terms of metrical time. If one is making key use of a claimed necessary truth, one would want to know what it means and have that meaning and the warrant be the same in all possible worlds.

Craig and Sinclair (2012b, 102), however, apparently disagree:

> Pitts' presumption seems to be that Copan and Craig take, not only the premises of the *kalām* argument, but more particularly their proffered criterion for there

> being a beginning of the series of past events to be metaphysically necessary truths....Pitts recognizes, as mentioned, that the actual world is characterized by an objective metric; but he insists that "a doctrine of creation needs to be modally rich enough to accommodate the possibility of God's creating worlds with physical laws without a unique or preferred metrical structure to license an answer of 'finite' or 'infinite' age" (Pitts 2008, 681).
>
> Pitts' presumption is wrong. The proffered criterion was intended to apply only to the actual world. There is no intention or need to seek its application to other metaphysically possible words [*sic*] governed by different laws of nature.

Why Craig and Sinclair (2012b, 99) think that despite my "flirtation with metric conventionalism, [I] recognize that our universe is characterized by an objective temporal metric" is not entirely clear, though it would be useful to them in a debate. An aside on my other work is called for given Craig and Sinclair's attempted *ad hominem* argument. Perhaps they misinterpreted this line: "It turns out that the actual universe probably does not behave in accord with a scalar-tensor theory, given the empirical confirmation of the various principles of equivalence in gravity (Will 1993), which make it difficult for theories empirically distinguishable from GTR in weak or moderate gravitational fields to be empirically viable" (Pitts 2008, 681). This sentence, while recognizing that scalar-tensor theories (at least the ones studied by Clifford Will) tend to differ from general relativity in weak and moderate fields, by no means excludes all bimetric or multi-metric theories. Some theories inspired by particle physics (Ogievetsky and Polubarinov 1965; Freund, Maheshwari, and Schonberg 1969; Pitts and Schieve 2007; Pitts 2011b, 2016c), namely massive spin-2 gravity, differ from general relativity only in strong fields (Visser 1998)—or at least do so if certain devils in the details can be handled (Boulware and Deser 1972; van Dam and Veltman 1972), a topic on which optimism grew considerably in the 2000s (though it has not remained as high). It would be odd for someone who sympathizes with conventionalism, particle physics, and massive gravity (as even the 2008 paper showed); emphasizes the need to pay attention to physical theories outside the "canon" of single-geometry theories (Pitts 2016b, 2019); and derives bimetric massive gravity theories from universal coupling (Pitts and Schieve 2007; Pitts 2011a, 2012, 2016c) to "recognize that our universe is characterized by an objective temporal metric," because that would be practically a profession of faith in general relativity as the true theory in the classical limit. My confidence in general relativity, though fairly high, is not that great, as a glance at the works I cite and produce suggests. A massless spin-2 field is a natural animal in the particle physics zoo of masses and spins (Pauli and Fierz 1939) (due to representations of the Poincaré group of special relativistic symmetries) and yields Einstein's equations using some rather compelling arguments, starting from flat space-time (Deser 1970; Pitts and Schieve 2001; Pitts 2016a). But why assume that the graviton mass is exactly zero instead of

merely small? This is a natural question to ask for those influenced by particle physics. I am of course happy to try to interpret Einstein's equations properly; I claim the theory makes better sense of energy conservation (Pitts 2010) and change in the Hamiltonian formalism (Pitts 2014, 2017) than is commonly held, if one listens to the mathematics without introducing interpretive postulates. But in my view, it is not implausible that the metrical criterion for a beginning fails even in the actual world.

Regardless of whatever I supposedly conceded, the need for a modally robust notion of beginning comes from attempting to make sense of Craig's view that the causal principle is a necessary truth. I find his notion of a necessary truth that means radically different things in different possible worlds, such that one need not bother with its meaning in most possible worlds, unintelligible. The cause of careful argumentation cannot be served by this opportunism. If my presumption of Copan and Craig's intention was incorrect, at least I saw a need for something modally robust. Once one takes seriously the project of understanding the notion of beginning in a modally robust way, as Craig's necessarily true premise 1 requires, one rejects the metrical notion, seeking something that does not assume the existence or uniqueness of a metric. If the criterion of a first moment was too strict, the criterion of lacking maximal extension toward the past appears to do the job (at least in the realm of classical field theories). Conventionality and gross modal provincialism are avoided, as one would expect in a serious metaphysical argument.

However, once one defines beginning in terms of lacking past maximal extension, the Big Bang no longer counts as a beginning. Hence, removing the equivocation on a "beginning" achieves validity at the cost of making premise 2 unsupported by Big Bang cosmology. Craig has presented his case as a deductive argument but tends to avoid the usual standards for assessing deductive validity, standards I am to reinstate.

Cosmic Destroyer Argument Vindicated

Craig and Sinclair's (2012b, 100, 133) response to my Cosmic Destroyer argument (Pitts 2008) pits it against the notion of beginning as requiring a first moment, so correcting the first moment criterion tends to vindicate the argument. The Cosmic Destroyer argument is intended as a *reductio ad absurdum* of the *kalām* argument's use in the context of Big Bang cosmology. Noting that the mathematics of the Big Bang are the same as the mathematics of a simple homogeneous model of a collapsing star (Misner, Thorne, and Wheeler 1973, 846–59)—apart from the fact that the star is surrounded by empty space (which one can choose as a variant of the Big Bang if one wishes; references besides Charles Misner, Kip Thorne, and John A. Wheeler are in the earlier article) and apart from the direction of time—I inferred by parity of reasoning that stars collapsing into black holes call for a Destroyer God. Granting that Abrahamic

theists generally take matter to persist due to continuous divine upholding as opposed to some kind of deistic existential inertia, one can infer (absurdly?) the need for special divine action. Much as the sudden disappearance of my desk would involve special divine action, even if it only required God to stop upholding my desk, the disappearance of a star due to singularity formation would involve special divine action. The time reversal of God's creating (all or part of) a Robertson-Walker solution in gravitational collapse requires special divine action if God's creating (all or part of) a Robertson-Walker solution requires special divine action in cosmology. But that time reversal, applied on a suitable distance scale (recalling the surrounding empty space option), is mathematically identical to the destruction of a star in the formation of a singularity. So, if the Big Bang requires God as Creator, continued stellar collapse requires God as Destroyer—perhaps welcome in Hinduism but an unwelcome innovation in Abrahamic religions.

Once the nonconventional, modally robust notion of a beginning has been generalized from having a first moment to lacking past maximal extension, the Cosmic Destroyer argument implies that a star that ceases to exist without a last moment of existence still needs God as Destroyer. While one could bite the bullet and simply accept that God destroys stars that collapse into black holes, the comparatively mundane nature of stellar collapse—it is just one of those things that happens from time to time, like bread getting moldy and unlike the creation of the universe—makes it peculiar to infer special divine action in a context calling for ordinary divine providence (and probably quantum gravity).

Is Gravitational Thermodynamics Mature?

Craig's appeals to thermodynamics as heavily constraining eternal universe models are longstanding, reducing dependence on the singularity. On the other hand, until recently, gravitational thermodynamics was quite immature, and it was difficult to be confident in results that did not take the thermodynamics of both matter and gravity into account. One can compare that assessment to Craig's (2008, 150) remark, plausible about non-gravitational thermodynamics: "Indeed, thermodynamics is so well established that this field is virtually a closed science."

Plenty of challenges remain in gravitational thermodynamics. Two distinctive features of gravity are that it spontaneously leads to clumpiness rather than uniform distribution and that it makes certain quantities proportional to area rather than volume, blurring the textbook binary distinction between extensive (proportional to volume) and intensive (independent of volume) quantities (Oppenheim 2003). Energy also plays a crucial role in thermodynamics, but gravitational energy has been controversial for more than a century. Recent decades have seen substantial progress in gravitational thermodynamics on various fronts, so perhaps thermodynamic arguments made today are more credible than older ones.

Two recent sources of doubt might add to the older doubts, however. First, physical theories with funny minus signs in various places have come to be entertained since 2000: "ghosts" (fields with negative energy or negative probability) (Hawking and Hertog 2002; Mukohyama and Volkov 2018), "phantoms," etc. Some are not as automatically disastrous as previously believed. Hence, there is a greater prospect that even bounded quantities (such as energy) are not so constraining if they might contain both positive and negative contributions. Perhaps monotonic behaviors found in the thermodynamics of matter can be counteracted when gravity is included? The fact that in general relativity the total energy equals zero apart from boundary terms (in some cases themselves equal to zero) is a precedent for gravitational compensation of the positive energy contribution of matter. (Naturalists sometimes invoke zero total energy as implying that universes can pop into being spontaneously, though I am not convinced the local conservation laws can be ignored.) Maybe entropy does something similar? Second, it is not clear yet even how many energies there ought to be in general relativity; perhaps the most principled answer based on the Noether symmetry-conservation law link—uncountably infinitely many (one for each vector field) (Bergmann 1958; Pitts 2010)— has rarely been entertained and has not been systematically explored. Clearly gravitational thermodynamics is a lively area to watch carefully. Making arguments based on a predicted outcome, however, still seems rather speculative.

On the Justification of Maximal Extension toward the Past: Empiricism or Rationalism?

The question of maximal extension is potentially interesting both in terms of scientific considerations (such as whether the universe existed "before" the "Big Bang") and in terms of philosophical–theological considerations, to which this section now more fully turns. Maximal extension turns out to be more difficult to justify than one might have thought.

This section comments on a recent thread in the philosophy of science involving roughly the condition I propose as an analysis of "beginning." It reflects both how philosophers of science are inclined to deny premise 2 (that the universe began to exist) and their limited success in justifying that denial. If these grounds are weaker than expected, that could make premise 2 easier to accept.

Given that philosophers of science are generally very pro-science as well as naturalistic in views, it is noteworthy that the justification of maximal extension toward the past has recently been a topic of puzzlement. The passages are sufficiently remarkable as to justify quoting at some length. Some time ago, John Earman (1977) pondered the question of what it would be for time to have a beginning or end. The discussion soon was restricted to "relativistic space-times," by which he meant that there is a unique metric and, at least

in physically interesting cases, Einstein's equations hold (Earman 1977). (Clearly Earman was not concerned about modal robustness.) Here are some relevant excerpts:

> [A]re there good reasons for believing that actual spacetime cannot be truncated?
>
> If one holds that there are no good reasons, then one would be wise to receive extreme unction as soon as possible, since time may run out any second now. Moreover, such a position implies a profound skepticism with respect to our knowledge of the past and future; it implies that we do not in fact know the great bulk of the things we ordinarily claim to know about the past and future. (Earman 1977, 118, 119)

> One's initial reaction to such skepticism is apt to be that it is too absurd to be taken seriously. Whether or not this reaction can be sustained remains to be seen.
>
> On the other hand, if one holds that there are good reasons to reject [truncated space-times] as a model for actual spacetime, then these reasons must be supplied. We shall see that this order is less simple to fill than one might think at first glance. (Earman 1977, 119)

> At this point, common sense cries out: "If my world line cannot be extended backwards in time from now more than five seconds, then most of my memory impressions are mistaken. But this is absurd." But exactly where does the absurdity lie? There is no logical contradiction, nor—apparently—any inconsistency with the basic laws of physics. Of course, it does seem that the likelihood that the universe switched itself on, so to speak, a few seconds ago in such a way that people are endowed with the memory impressions they in fact have, is very low. But this estimate of likelihood is surely not an estimate of probability based on either observed relative frequencies or on the implications of the laws of physics . . . The estimate of low likelihood in this case seems simply an expression of our unwillingness to accept a certain kind of explanation. But whether or not this unwillingness can be backed by philosophically respectable reasons is the question at issue. (Earman 1977, 121)

Earman later took up the question in a book-length treatment, becoming more explicit about metaphysical, or even theological, considerations.

> Metaphysical considerations suggest that to be a serious candidate for describing actuality, a spacetime should be maximal. For example, for the Creative Force to actualize a proper subpart of a larger spacetime would seem to be a violation of Leibniz's principles of sufficient reason and plenitude. If one adopts the image of spacetime as being generated or built up as time passes then the dynamical version of the principle of sufficient reason would ask why the Creative Force

> would stop building if it is possible to continue. However, this image does not sit well with the four-dimensional way of thinking, and in any case it runs into trouble in its own terms: since extensions of spacetime are generally non-unique there may be many ways to continue building and the Creative Force may be stymied by a Buridan's ass choice (see Clarke 1993, 8–9). Some readers may be shocked by the introduction of metaphysical considerations in the hardest of the "hard sciences." But in fact leading workers in relativistic gravitation, though they don't invoke the name of Leibniz, are motivated by such principles (see, for example, Geroch 1970, 262; Penrose 1969, 253). The intrusion of metaphysics will also be evidenced in all of the chapters to follow. (Earman 1995, 32, 33)

So, does rationalist metaphysics (theology?) justify scientific claims in this area? Given how induction is related to the uniformity of nature, one might hope that philosophers of induction have finally delivered the goods; surveying three significant works will be illuminating. Colin Howson (2000) argues otherwise: Bayesianism gives us a good framework for updating our opinions using evidence, period; nothing requires that you and I have similar initial opinions, so we can still have differing current opinions. Recently, Gerhard Schurz (2019) has argued persuasively for the optimality of meta-induction, roughly, the idea that whatever predictive method has been most successful so far is the best choice for making future predictions. However, it is unclear that induction uniquely follows from meta-induction and the evidence (as he had claimed (Schurz 2008)) once one recognizes that it is question-begging to filter the evidence using induction when induction is in question (Pitts 2023).

John Norton's work, addressing both induction and space-time philosophy, requires more discussion. Norton (2021), finding all induction to be local and fact-based in his material theory of induction, diagnoses various shortages of the requisite facts. In particular, facts are scarce in justifying the past maximal extension of space-time, oddly enough (Norton 2011).

> What is troublesome from the material perspective is the absence of warranting facts for the inductions in the spacetime case. Take the case of extendability. It seems natural to infer inductively to the fully extended Minkowski spacetime rather than the extendable half Minkowski spacetime; or, more generally, to avoid admitting holed spacetimes that are created from other spacetimes by excising even quite small parts. However it is very hard to specify just what facts ground the inference. That we have never seen holes in spacetime does not settle the matter. By their construction, there cannot be an observable trace of holes, if that is what our spacetime has. That remains true even if our world tubes pass directly through the hole. We would cease to be for the portion of our world tubes coinciding with the excision. However the portion

> of our world tubes in the future of the hole would be reconstituted precisely with all the memories and other traces of the excised spacetime. If observed facts do not ground the inductive inference, what of physical laws? We could cite the common postulate in relativity texts that spacetimes are inextendable. However that postulate is merely the supposition of precisely what is at issue and is distinctive as being dispensable from a physical perspective. It is present as much for mathematical convenience
>
> One cannot help but be struck by how tenuous the grounding has become. We are now to secure our inductions in abstract metaphysics. (Norton 2011, 173)

> We routinely dismiss as desperate zealots those who tell us our universe was created last Wednesday complete with all records of an ancient past.
>
> Yet, when we try to display the proper warrant of those inductive inferences we favor, whether the warrant is in general principles or material facts, the ground crumbles around our feet. (Norton 2011, 174)

To summarize, inductive logic has not solved the problem; it lets us repackage our opinions in more impressive language and revise them systematically using evidence but never free ourselves wholly of their influence. Bayesian convergence-of-opinion theorems (claiming that evidence eventually causes disagreeing initial subjective prior probabilities to wash out, leaving agreement on which theory is best) assume there are no theories with identical empirical consequences (Hawthorne 1993). Thus, we remain free to adhere to widely shared intuitions but struggle to turn them into a compelling argument.

The most sustained attention to the question of justifying past maximal extension evidently has been paid by John Manchak in a quest to understand what counts as a reasonable space-time (for example, see Manchak 2009, 2011, 2016b, 2016a). Manchak quotes or cites global general relativity authorities such as Roger Penrose, Robert Geroch, and C. J. S. Clarke, making Leibniz-like metaphysical proposals to justify maximal extension, much as Earman indicated. (Geroch seems the most explicit.)

Apparently, when one removes naive or intuitive (largely tacit) plausibility judgments about large scale space-time features in favor of a rigorous deductive evaluation of many possibilities, one gets a taxonomy of often startling possibilities and no way to close Pandora's box. This situation resembles philosophers' efforts to address skeptical arguments, often unsuccessfully. Perhaps the lesson is, as some ancient skeptics as well as Blaise Pascal (Merlan 1967), Bishop Huet ([1723] 1725, 184), Hume (Hume 1978, 269), and Thomas Reid (as a basic thrust of Scottish Common Sense) taught, that nature rather than reasoning leads away from skepticism.

A more explicit argument might take these hints at rationalistic theology more seriously. According to rationalistic theism, rationalistic theism is truth-conductive: it is a coherent and self-recommending belief system positing that

a reasonable God has designed our minds to believe various things, including in a reasonable God and a lawful natural order. Rationalism's being self-recommending means that according to rationalism, rationalism is a good way to gain knowledge. Such a feature will not impress non-rationalists but does provide a measure of reassurance to rationalists. In comparison to medieval nominalists, most modern Westerners are rationalists to some degree. Most readers of *Zygon: Journal of Religion and Science* are probably less scandalized than most philosophers of science by the idea that rationalistic theology would provide the justification for certain scientific claims; after all, rationalistic theology played a role in the shift from Leibniz's view, which still accepted creation in the finite past (Alexander 1956, 76), to Friedrich Schleiermacher's lack of attachment to the initial creation event (Russell 1996; Copan and Craig 2004, 150, 151) as well as motivated Darwin (Dilley 2012). The idea that empiricism might not lead readily to naturalism is hardly novel, having been suggested by rationalistic anti-supernaturalists such as F. H. Bradley, who advised filtering the evidence to match prior understanding (Bradley [1874] 2011; Vincent 1995, 13, 14), and advocated for by empiricist non-naturalists (Broad 1916–1917; Merlan 1967; Swain 1967; Stoller and Olkes 1987; Redmond 1987; Graubner 1989; Popkin 2003; Turner 2006). However, philosopher of biology Elliott Sober (2008, 127, 128) has cautioned against using rationalistic theology in scientific argument in biology; his reasoning might generalize to other sciences. Admittedly, being self-recommending is not unique to rationalistic theism; traditional orthodox theology, insofar as it posits divine grace in epistemology (as in Alvin Plantinga's (2000, chapt. 8 and 9) internal testimony of the Holy Spirit), is also self-recommending. If the religious believer is correct that religious faith is caused by the Holy Spirit, then this faith is also true and warranted. While these two beliefs (rationalistic and orthodox theisms) vied for acceptance a few centuries ago, they have much in common, differing partly in a wholesale versus retail appeal to divine assistance. Given that rationalism is usually considered the antithesis of enthusiasm (the old name for disreputable belief that one is personally divinely inspired), it is illuminating that René Descartes's rationalist epistemology was accused of enthusiasm (Heyd 1995, chapt. 4). By contrast to these theisms (existing perhaps on a spectrum rather than as two discrete rivals), naturalism is not self-recommending; indeed, sometimes roughly the opposite is argued (such as by Plantinga): that naturalism is self-defeating, so that it is an unwarranted belief if true and therefore cannot be knowledge, whether true or not (Beilby 2002).

Though one may believe in the maximal extension of cosmic history, some might not. Craig's argument apparently uncovers people who doubt the causal premise 1, namely, Quentin Smith and J. L. Mackie (Craig 2008, 112). It seems to me that if one doubts premise 1, one could think the world popped into existence at some stage "after" the Big Bang rather than "at" the Big Bang. If universes can pop into existence, who knows, why not? If the universe popped into existence too recently, it could be awkward if our memories are false,

for example. But if it is merely rock layers or cosmic nuclear abundances that lack their expected origin, those things, lacking truth values, cannot be false—though they might have some comparable defect, especially if too recent. The issue bears some resemblance to Boltzmann brains, which supposedly arise due to statistical fluctuations and have illusory experiences (assuming something like physicalism in the philosophy of mind). There also exist people who accept Craig's premise 2 on scriptural grounds and think God created the world such that space-time did not maximally extend to the past;[6] such people might consider the *kalām* argument sound but dialectically ineffective because they use the conclusion, accepted on other grounds, to motivate premise 2. While this view does not cohere well with the spirit of Enlightenment, it can be empirically adequate, which is better than what one sometimes sees. Derek Turner (2007) has discussed how to be relaxed about realism in the historical sciences, such as by holding the natural historical attitude, according to which one does not know or care—not his favorite view but a contender. For critique and leads into the discussion of (anti)realism about the past, one might see Sophie Botros (2017) and Efraim Wallach (2022). This seems not to be primarily a scientific question.

A striking example of how rationalistic theology can justify past maximal extension has appeared recently in the science–theology literature (Klose 2021). Joshua Klose (2021) apparently aimed to drive yet another nail into the coffin of young-Earth creation science, thinking hard about creation with apparent age (such as whether a circumscribed set of examples justified by functionality can be identified) but ultimately finding it unbelievable and entailing the "absurd position that much of the universe's apparent history never occurred." I confess finding the argument obscure. The implication of non-actual history is right there on the surface, not requiring the amount of reflection invested; on the other hand, finding something resembling a problem of evil or a philosophical skeptical puzzle is not automatically decisive. A problem of evil might be answered by some greater good, perhaps even one not yet articulated or articulated long ago. Descartes inaugurated early modern naturalistic historical science, anti-realistically construed, in terms of epistemic convenience (Descartes and Reynolds 1988, 37, 38). Michael Murray (2008, chapt. 3, 5, 6), in considering the question of animal suffering, finds that because criteria with apparent age have the advantage of avoiding pre-Adamic animal pain and suffering, he has to work fairly hard to find an alternative theodicy (or something weaker) consistent with scientific realism back to the Big Bang. A skeptical worry might be everyone's problem (or, in this case, everyone who does not accept the eternity of the world, which was condemned by the fourth and fifth Lateran Western church councils) (McMullin 1981; Tanner 1990, 606). Hence, it seems Klose has more work to do before declaring another victory.

Given the unclear logic, I have relied on statements that seem clear; Klose offers what he considers an internal critique, concluding that efforts to avoid drawing

unsavory conclusions from creation with apparent age all fail. One might wonder, however, whether Klose's case proves too much, effectively a priori forbidding God from creating in the finite past (no matter how far back) and ensnaring most of the Christian tradition (and Jewish and Islamic traditions as well, Aristotle's eternity of the world versus scriptures being a long-lasting trans-confessional controversy involving mutual influence). No matter when God created the world in the finite past (ignoring general relativity for the moment, given that Klose's argument is not related to cosmology, and recalling that quantum gravity might permit eternal worlds again), doing so presumably would have involved creating it such that "much of the universe's apparent history never occurred." There is perhaps a difference in degree only, a degree that cannot even be expressed in terms of fractions, because any finite age is negligible compared to infinity. What it would be appropriate for God to do presumably aligns closely with what it would be appropriate for humans to claim God did. If an effort to address creation science appears to tar St. Augustine, John Philoponus, al-Ghazali, Moses Maimonides, St. Bonaventure, Thomas Aquinas, Martin Luther, John Calvin, etc., and two Western church councils with the same brush, one might want to reflect on that implication. Perhaps some other measure could make a difference, distinguishing intended from unintended targets, given that evidence about the more remote past is harder to find?

Creation science in any case can be criticized for misunderstandings of general relativity involving the question of energy conservation (Pitts 2004a, 2004b, 2009). This issue highlights the importance of making as much sense of energy conservation as general relativity will admit, emphasizing its similarity to other field theories and the symmetries of its laws (Pitts 2010).

If one is an empiricist and hence struggles to justify past maximal extension, one is of course still free to believe it. I personally believe we see stars because light left them, propagated across space, and reached our eyes. Perhaps the issue of past maximal extension pertains more to typical questions of epistemology, such as how to address skepticism (many versions of which are acknowledged by most philosophers as irrefutable though also incredible), than to science.

Conclusion

While Big Bang cosmology remains an excellent physical model far enough from the singularity and general relativity remains an excellent theory of space-time and gravity (albeit calling for quantum gravity), the Big Bang still seems not to support a good *kalām* theistic argument. Understanding "beginning" in a nonconventional and modally robust way in terms of past extendibility seems necessary to produce a valid argument with sufficiently broad modal scope. The justification of past maximal extension proves surprisingly difficult to find empirically, though one might justify it to oneself as a rationalist or simply believe it if it seems very plausible.

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Notes

[1] Readers interested in a survey of broader issues in cosmology and theology might see the article in the *Stanford Encyclopedia of Philosophy* (Halvorson and Kragh 2021).

[2] The editor of the *British Journal for the Philosophy of Science* wanted a whole new paper as opposed to an erratum, but I did not have that much to say. The reprinting of the paper in the volume edited by Paul Copan and William Lane Craig, though welcome, was done without my involvement. That the flaw was readily fixable (in my view) reduced the urgency.

[3] While some worthy literature inevitably has been missed, I especially regret not being acquainted with the following two recent papers by Daniel Linford while writing this article: "A Modal Condition for the Beginning of the Universe," *Erkenntnis* 89 (2024) 2343–75; "On the Boundary of the Cosmos," *Foundations of Physics* 53 (76) (2023). I hope to interact with these works in the future.

[4] By modal provincialism I have in mind the idea that all possible worlds, or all that are worth thinking about, are very much like ours in relevant respects, so one does not need to think hard about how the actual world might differ from standard views about it, such as by having multiple geometries (Pitts 2019). A typical example invokes some supposed feature of general relativity and infers that the feature is true of the actual world. Lack of imagination and refraining from searching the literature for alternatives tend to be involved.

[5] These somewhat arbitrarily chosen times are, respectively, a skeptical hypothesis type devised by Bertrand Russell (1921, 159, 160); the approximate age of the world according to St. Augustine (1984, 484) (more in line with the Septuagint than with the Hebrew manuscript tradition generally followed by Protestants); and an illustrative repurposing of the title of Steven Weinberg's *The First Three Minutes*. Obviously, these and the uncountable infinity of other candidates do not all have precisely the same intuitive plausibility or potential to generate skeptical worries about our maybe not knowing what we think we know.

[6] Hans Halvorson and Helge Kragh (2021) survey the range of opinions among Christians in some detail.

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Does a Fine-Tuned Universe Tell Us Anything about God?

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The apparent fine-tuning of several fundamental parameters that determine the properties of our universe and make it hospitable to life is sometimes used as an argument for God from design. I review the concept of cosmic fine-tuning and critically examine the claim that God is its most probable cause. While not definitively repudiating this claim, I argue that it is potentially in tension with the more apophatic approach to God found in the Abrahamic traditions. I then offer a metaphysical analysis of the contingency of fine-tuning that situates it within the classical analogy of being that points to the Divinity.

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Introduction

Fine-tuning refers to the fact that several very fundamental properties of the cosmos appear to be delicately balanced such that it is possible for life to exist. In a hypothetical universe where these properties are changed, in some cases only slightly, it is very difficult—indeed, probably impossible—to envisage how living organisms of any type could exist. These striking coincidences that enabled the emergence of life are often used in arguments for why the universe must have a divine Creator: in brief, the fine-tuning is construed as the result of a purposeful choice of an intelligence that is identified with God. Unsurprisingly, this sort of argument is not without its difficulties, and there are naturalistic counter proposals to explain the fine-tuning. My goal in this article is not, however, to dwell on the technical merits of probabilistic arguments for God based on fine-tuning but rather to look more deeply at the metaphysics of fine-tuning per se as a clue for how it might be related to the Abrahamic doctrine of creation. I propose that fine-tuning provides a compelling entry point to the classical analogy of being by which the created order gestures towards God.

To reach this point, I begin with a brief review of the fine-tuning phenomenon and how it has been leveraged to argue for a Creator. I then proceed to describe some of the difficulties with establishing the exact degree of fine-tuning together with its possible naturalistic explanations that have ramifications for a probability-based argument for God. I also explain how this sort of theistic argument, which leans on empirical observations, may be in tension with traditional philosophical approaches to God, as represented by Thomas Aquinas. The probabilistic approach runs the risk of being, in the language of Kathryn Tanner (1988, 46), "not radical enough." To explore how fine-tuning might better be related to theology, I first analyze how fine-tuned cosmic properties fit into empirical science itself using the distinction between "classical" and "statistical" investigations proposed by Bernard Lonergan. This allows me to, finally, relate fine-tuning to Erich Przywara's notions of creaturely actuality and arrive at the analogy of being.

The Phenomenon of Cosmic Fine-Tuning

Today, we have a remarkably good understanding of how the universe has expanded and evolved over its fourteen-billion-year history. One of the most important empirical tools we have for this is the cosmic microwave background (CMB), the glow of the primordial material of the universe that was emitted about 400,000 years after the Big Bang. This was very early on in cosmic history, when the universe was only 0.003% of its present age. There were no stars or galaxies, just a hot gas of roughly 3,000°C, that was glowing as any hot material does. We literally see that glow, but in microwaves rather than visible light because its wavelength has been stretched by a factor of around 1,000 due to the expansion of the universe. The glowing gas was the material that

collapsed into stars hundreds of millions of years later, but in this primordial epoch, it was almost perfectly smooth everywhere, with variations in its density typically being only one part in 100,000. (To get a sense of scale, that is roughly how much a loud machine causes the density of air to oscillate. You need a very sensitive instrument, like your eardrum, to detect these tiny changes in pressure.) Still, these variations in density were extremely important, because where the universe was slightly more dense, there was slightly more gravity, allowing that region to attract the surrounding material so that eventually stars and galaxies would form hundreds of millions of years later. We often call these the *seeds of structure* because they were the initial conditions for the rich distribution of stars and galaxies today.

Now, there are a few aspects of this situation that appear fine-tuned. First, the average density of the universe—the average density around which you have these part-in-100,000 variations—is quite special. If it had been larger, the force of gravity would have caused the whole universe to stop expanding very early on, and it would have collapsed in on itself. For instance, if the universe had been just 1% denser one second after the Big Bang, it would have collapsed, effectively coming to an end, less than seven minutes later. On the other hand, if it had been a bit smaller, the reduced gravitational attraction would have allowed the universe to expand much more quickly, making it far too diffuse for stars, or any sort of complex structure, to ever form. To have a universe that lasts as long as ours, the initial density had to be extremely fine-tuned.

Second, it is surprising that the density of the universe was the same everywhere to a part in 100,000. That may not seem strange, because intuitively one expects that any gas in a volume would be spread out evenly. However, it takes time for a gas to even out. When we observe the CMB, we are looking at a volume of the universe that was roughly 100 million light years across, but the universe was only 400,000 years old, and the maximum distance light could have traveled in this time was only about one million light years, or a hundred times smaller than the span of the total volume. (The reason light would have traveled a million rather than 400,000 light years is that space was stretching the whole time.) Now, nothing can move through space faster than the speed of light. That means there was not enough time for the density at one end of the volume to smooth out across to the other end of the volume—it was more than 100 times too far away for it to have had causal contact with that region. On this reckoning, the CMB we observe contains roughly 10,000 independent regions that were never in causal contact with each other. That implies that at the beginning of the universe, somehow these 10,000 different locations started out with almost exactly the same density. There is no a priori reason this coincidence should obtain.

Third, the amplitude of the tiny, part-in-100,000 variations in this average density also appears fine-tuned. If the variations had been too small, they

would not have had sufficient gravity to pull enough matter together to make stars or similar structures: the expansion of the universe would have won out against their gravity, and we just would have had a universe filled with uninteresting, diffuse gas. If they had been larger, the universe would have produced too many stars. The stars would have been so crowded that any planet would have gotten knocked out of orbit around its star by other nearby stars, making its surface conditions too unstable for life to evolve (Adams 2019, §6.2). And if the density variations had been even larger, the gas would have collapsed into black holes near the beginning of the universe, and we would not have had any stars or planets at all. Thus, the size of density variations in our universe was in a sweet spot: not too big or too small.

In addition to these global properties of the universe, there are many other examples of fine-tuning in how the universe operates. For instance, stars require a balance between the force of gravity, which pushes everything towards the core of the star, and the outward pressure produced by the energy generated by nuclear fusion in the core. If nuclear reactions were too weak, there would not be enough energy for the star to even turn on and produce the outward pressure, but if they were too strong, the pressure would be so great that the star would just explode. It turns out that in our universe, the strength of gravity, the strength of the electric force, and the masses of electrons and protons all happen to have values that make this balance inside stars possible. Furthermore, it is not only the existence of stars that hinges on these particular parameters. Figure 1, reproduced from Barnes (2012), shows some other key properties of our universe that depend sensitively on these parameters, with the strength of the electric force on the x-axis and the ratio of the electron and proton masses on the y-axis. The diagram invites us to imagine how nature would behave if the electric force and the electron and proton masses had different values than they actually do. The actual values are shown with a cross near the bottom left of the graph, and the different colored regions show how radically different nature would be if the values were different. Region 7 (yellow) has to do with the stability of stars just mentioned: in this region, stars cannot exist because the balance between the nuclear reactions and gravity does not obtain. Region 4 (pink) is where complex molecules cannot form because atoms do not stick together strongly enough. In this case, the sorts of substances required for biology could never form. In region 1 (purple), not even the simplest element, hydrogen, could exist, so there would be no water (among other things). Each of the other colored regions shows a different catastrophic outcome. Only the small white region in the lower left of the diagram produces a universe with stars, water, and the elements of the periodic table required to make complex structures for life. The strength of the electric force needs to be quite small, and the electron needs to be more than 100 times lighter than the proton.

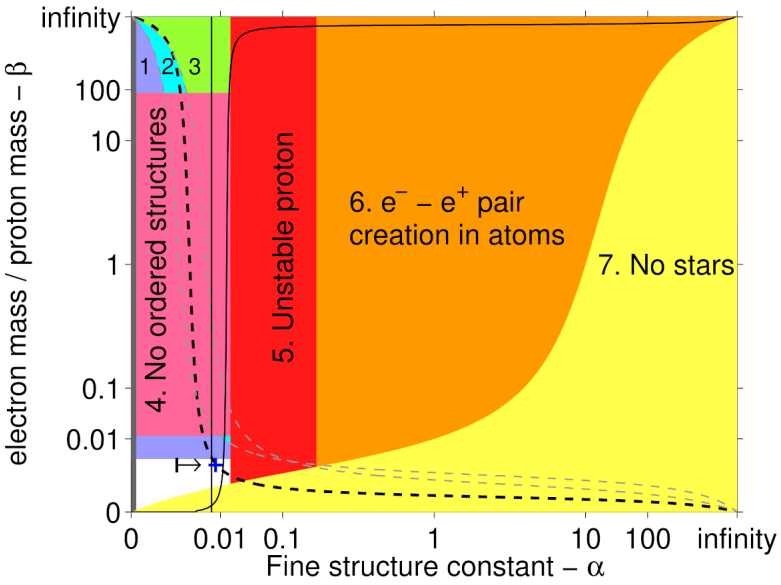

Figure 1: An example of fine-tuning for two physical parameters: the ratio of the electron to proton mass (y-axis) and the strength of the electric force, α (x-axis). The true values of these parameters, as measured in our universe, are indicated by the cross (with an arrow pointing to it) near the bottom left of the graph. The white region in which the cross lies shows which combination of parameters would allow the universe to behave in such a way that life could still exist. The colored regions are where the parameters cause at least one difference in how the cosmos behaves that would be catastrophic for life. Graphic taken from Figure 6 (left panel) of Luke A. Barnes's (2012) "The Fine-Tuning of the Universe for Intelligent Life." © Cambridge University Press reproduced with permission.

Figure 1 shows only two parameters that one can imagine changing, one on each axis. Altogether, there are about a dozen such parameters (e.g., Adams 2019, Table 2); moreover, there are lots of different physical properties and processes that depend sensitively on their values. If it were possible to make a graph that had not only two axes in two dimensions, like Figure 1, but a dozen axes in a dozen dimensions to represent each parameter that is possible to vary, then you would still find only an extremely tiny white region where the parameters allow for a universe capable of having stars, complex molecules, and stable conditions. Furthermore, there are a number of other properties of our universe that appear "selected" for life. To give just one example, we live in three spatial dimensions. There is no clear a priori reason why there could not be a different number of dimensions, but three dimensions appears to be the only configuration conducive to life. For instance, if there were more spatial dimensions, the orbits of planets around stars would not be stable.

A comprehensive exposition of all the known instances of fine-tuning in our cosmos is far beyond the scope of this article, and I have only scratched the

surface. Detailed scientific reviews of the subject can be found in Barnes (2012) and Fred C. Adams (2019), and an excellent popular overview is provided by Geraint F. Lewis and Barnes (2016). However, the examples I have sketched should be sufficient to convey the basic point, so I shall continue on to discuss the metaphysical implications.

The Probabilistic Fine-Tuning Argument for God and Its Technical Difficulties

Fine-tuning makes the universe appear very special. The universe had just the right conditions after the Big Bang to grow into a cosmos suitable for complex structures to form, and it has constants of nature and other fundamental physical properties that seem to fall right in the sweet spot that make life possible. It should be stressed that many of the parameters involved in fine-tuning, such as the masses of particles or the strengths of forces, are not fixed by any known theory. There is nothing in our knowledge of physics that says the proton must be 1836.15 times more massive than the electron. This ratio is a value we know only empirically, and the fine-tuning question arises because it is unclear why it and other fine-tuned parameters obtain in nature. But the fact that these particular values exist has been proposed as evidence for God, since it seems far more probable that fine-tuning is the result of a rational, purposeful choice of the Divinity rather than a fluke (see Simon 2021 for a review).

Probably the most familiar articulation of this sort of argument came from William Paley in the early nineteenth century. His analogy to someone coming across a watch lying in a field is well known:

> [W]hen we come to inspect the watch, we perceive . . . that its several parts are framed and put together for a purpose, e.g., that they are so formed and adjusted as to produce motion . . . that, if the different parts had been differently shaped from what they are, of a different size from what they are, or placed after any other manner, or in any other order, than that in which they are placed, either no motion at all would have been carried on in the machine, or none which would have answered the use that is now served by it. (Paley 2006, 7)

He considers this "invincible" evidence that the watch was deliberately created by a watchmaker (Paley 2006, 15), and, by analogy, the many instances of apparent design in the natural world are proof of an intelligent Creator. It is not difficult to understand why the fine-tuning discovered by modern physics and astronomy is seen by some as compelling evidence for the watchmaker argument. However, there is historical precedent for worrying about this line of reasoning. Paley's work leaned heavily on biological examples of the intricacy of living creatures, but then Darwin appeared on the scene and provided another explanation. We should ask whether something similar could happen with

cosmic fine-tuning, and in fact, there is reason to take a closer look at just how improbable it really is. Let me raise three issues the Paley-style design argument must confront when it is applied to fine-tuning.

The Difficulty in Quantifying Fine-Tuning

Exactly how improbable it is that fine-tuning is the result of mere chance is challenging to determine for a couple of reasons. First, the size of the life-friendly region of parameter space is hard to pin down. In the previous section, I emphasized the tininess of the region, as represented by white in Figure 1, but this size is based on current understandings of how nature works, and perhaps nature is more flexible than a diagram like this presumes. For instance, even if stars in our universe seem to depend on a certain combination of parameters, investigations into the details of their nuclear reactions show that there may be alternative ways for stars to remain stable that expand the allowed parameter space (Adams 2019, §7), and it has been argued more generally that the parameters required for a life-friendly universe are not as stringently constrained as is sometimes presented (Stenger 2011; see also Adams 2019, §10.6). Of course, this is contested (Barnes 2012). From my perspective, the actual degree of fine-tuning is still up for debate and further exploration, but denying there is any fine-tuning at all (*à la* Stenger) is premature.

The second issue has to do with the range of allowed values. The axes in Figure 1, which run from zero to infinity, present the most pessimistic and technically problematic scenario, for no matter how large your region of life-friendly values is, it will always be overwhelmingly small if you are drawing from an infinite number of possibilities. In fact, you cannot properly define probabilities at all, at least in a mathematical sense, if your parameter space is infinitely large. Now, it is possible that certain values are a priori disallowed, because, for instance, they would make physics internally inconsistent. For instance, the masses of particles are typically assumed to be smaller than the Planck scale at which gravity and quantum mechanics inevitably converge (e.g., Barr and Khan 2007; see also Barnes 2019, 1234–35). While this restriction of parameter space still allows for a huge range of values, it is at least finite. However, it is unclear whether the Planck scale is the correct cut-off point, exactly what span of values is actually possible for other parameters, and whether all allowed values have the same a priori probability (Adams 2019, 97–100; Hossenfelder 2021). Moreover, the foregoing presumes that the parameters are operating within the laws of physics we have discovered in our universe; if we allow for all possible laws of physics, then determining the allowed range becomes yet thornier (c.f. Barr 2003, 146–48, 153–54).

Thus, given our current knowledge of physics, we cannot definitively calculate how improbable fine-tuning actually is, and the lack of precision can be used to challenge the design argument (e.g., Hossenfelder 2021). This is not necessarily

fatal to the theistic argument, as I shall briefly describe further on, but at the end of the day, specifying the stringency of fine-tuning remains problematic at some level. We cannot calculate it in the same way we can calculate how likely it is to draw a full house in poker.

Fine-Tuning or Natural Process?

The analogy of drawing random cards from a deck might not be a good one. Consider the universe's initial density. As described, it was just the right size, and it was incredibly uniform, while also having minuscule variations of the right amplitude. It turns out there is an elegant way these seemingly special properties can be explained. If the universe did not begin in such a smooth state but rather with random, nonuniform densities everywhere before expanding extremely rapidly very early on, this would have smoothed everything out to the conditions we observe in the CMB. This scenario is called *inflation*. It posits that the whole observable universe came from a patch of space that was small enough that the density was already evened out inside of it right after the Big Bang. That tiny patch then expanded enormously—or "inflated"—during a fraction of the first second of the universe, after which it continued expanding at a regular rate. The required amount of growth would be roughly equivalent to a proton becoming the size of our solar system, all within about the first 10^{-34} seconds after the Big Bang. It may sound fantastical, but the physics that would have occurred during inflation is well understood. Crucially, the theory of inflation predicts an observable universe with a uniform density of the right size. It also explains the origin of the small density variations that are the seeds of structure. They are produced by quantum fluctuations during inflation, which again are quite well understood theoretically and whose properties match what we observe. Thus, inflation is widely considered the best theory of the early universe we have since it seems to explain our initial conditions so elegantly.

While the inflation paradigm is not without its issues, one of which I shall describe in the next section, it illustrates the possibility that parameters that appear to be fine-tuned might be the result of simple, physical mechanisms. If inflation may explain some of the initial conditions of the cosmological parameters, perhaps there are similar physical theories that will explain why other fine-tuned parameters take on the values they do. The probabilistic design argument would then become impotent.

The Multiverse

Although inflation elegantly explains the initial conditions of our universe, it does so at a cost, known as eternal inflation. For inflation to do the job of delivering our initial conditions, the period of rapid expansion would have only been required to last for a minuscule fraction of the first second after the Big Bang, but it turns out that theories of inflation typically have the curious property that

the universe goes on inflating indefinitely. They result in most of the universe stretching as fast as I described earlier, where spaces as small as protons become as big as solar systems in a sliver of the blink of an eye. It is only in small bubbles or pockets that inflation stops and the subsequent expansion occurs at the "slower" pace we observe in our universe.[1] Exactly when and where these pockets appear is a random process, and it is precisely in these tiny pockets that a universe like ours can be born—tiny, that is, compared to the immense sea of inflating space, but still so large that our whole observable universe can be contained inside one of these pockets. In other words, the pocket is large enough that we cannot see beyond it—light has not had time to reach us from beyond the pocket—but if we could, we would notice that our little region of the cosmos was unbelievably minuscule compared to the rest of space, which is expanding at breakneck pace. Moreover, we would see scattered here and there other little islands like ours that might also have life-friendly conditions.

The foregoing scenario is a version of the multiverse hypothesis: namely, that physical reality is enormously bigger than our observable universe. However, since any observer in the multiverse can only see a limited part of this reality, practically speaking, it is as though there were multiple universes separated from each other by vast stretches of space and time.

The multiverse hypothesis may seem far-fetched, and indeed some cosmologists eschew it because it seems impossible to ever empirically confirm: it seems too speculative to be real science (Ijjas, Steinhardt, and Loeb 2014, 2017). On the other hand, if inflation is the correct explanation for the initial conditions of our observable universe, then the multiverse does seem to be a natural consequence (Guth, Kaiser, and Nomura 2014; Guth et al. 2017). Another attraction of the multiverse hypothesis is that it might explain not only the smoothness at the beginning of our universe but also the fine-tuning of the constants of nature. In some theoretical frameworks, when a pocket of the multiverse stops inflating, the numerical values of physical constants inside it would be randomly generated. In most pockets, you would get values that are completely unsuitable for the formation of stars and planets and life: you would end up in one of the problematic regions in Figure 1. But if the multiverse extended far enough, then inevitably some of the pockets would happen to have just the right combination of values. So, even if the odds of a life-friendly universe are minute, you would have enough different island universes that you would get lucky in at least some of them. We would live in one of the lucky pockets where the strength of the electric force, the masses of protons and electrons, and so on were all suitable for life to evolve. As some physicists have emphasized, this is reminiscent of the theory of evolution (e.g., Weinberg 2007, 39–40; Hawking and Mlodinow 2010, 165). Before Darwin, people could not fathom how complex organisms could come to exist through any natural process, but then the combination of random mutations with the principle

of natural selection turned out to explain it elegantly. The complexity of our universe would analogously be the result of random selection.

To return to the poker analogy, the odds of getting a royal flush are one in 650,000. If you were only dealt a single hand, this would be very unlikely. But in the multiverse framework, the hands are being dealt continuously, everywhere, and so before long, someone, somewhere would get a royal flush. Unfortunately, the poker analogy breaks down again when it comes to the question of hard numbers. We would like to be able to calculate precisely how likely our universe is within the multiverse, just as we can calculate the odds of a poker hand. We would like to know how special we really are compared to all the other pockets. However, it turns out there is not a straightforward way to answer this question. Technically, this is called the measure problem: we do not know the "measure" for determining the odds. Thus, while the multiverse is an attractive explanation of fine-tuning for many people, it suffers from the problem that we cannot say precisely how likely or unlikely our pocket actually is. As we saw earlier when discussing the difficulty in determining how "small" the region of life-friendly parameter space is, it seems that our pocket of the multiverse must be special in some real way, but nailing this down with precision is elusive.

Assessment of the Technical Challenges of a Probabilistic Argument

The technical challenges presented regarding a fine-tuning argument for God may not be insuperable. Even if nobody really knows how to calculate the exact probabilities involved in fine-tuning, proponents of the theistic argument say that one only needs to establish that the odds of the parameters being random are so small that, on the balance of probability, it is much more likely that the fine-tuning comes from God rather than brute randomness (Barnes 2019; c.f. Swinburne 2010, 54ff). It has been argued that this approach, which one can do within the framework of Bayesian probability theory, is at home with the way scientists actually go about science. Namely, most scientists have a priori expectations about nature that are not precisely quantified yet are widely considered reasonable and work in practice (Lewis and Barnes 2016, 282–88).

Furthermore, it seems far-fetched to expect that the precise values of all the fine-tuned parameters will eventually be apodictically derivable from pure theory rather than only empirically measurable and therefore undetermined a priori. That is, it seems like wishful thinking to posit that fine-tuning is an illusion that will evanesce once a "theory of everything" proves that the values of these parameters must be what they are. While it may be true that inflation can explain away some of the fine-tuned parameters—though perhaps at the "cost" of a multiverse—there is no evidence that all parameters can be explained similarly. Indeed, the very hallmark of modern science is its empiricism: unlike in the old, Aristotelian approach, you cannot explain how nature works exclusively through deductive reasoning; you need to observe and measure how it actually

behaves. It seems reasonable to assume that some elements of physics and cosmology, such as constants of nature, will always remain brute facts, as far as science is concerned, that must simply be measured (*pace* Stenger 2011, 234). This assumption lies at the heart of the modern scientific project (see Hincks 2018, 333). Thus, I do not think opponents of fine-tuning arguments are on firm ground when they appeal to future theories that will somehow show that our universe's parameters are the only ones possible.

Finally, even though the multiverse is sometimes played as a trump card against the theistic argument, it yields some troubling possibilities. For instance, it has been argued that the multiverse would be far more likely to produce an isolated human brain complete with memories and the illusion it lived in a full universe than a full-fledged, finely tuned universe almost 100 billion light years across. The existence of multiverses containing more of these so-called Boltzmann brains—named for the nineteenth century physicist whose assistant inspired the idea (see Carroll 2021, 8–10 and references therein)—than proper universes is so bizarre that some think it deals a serious blow to the multiverse hypothesis (e.g., Lewis and Barnes 2016, 322).

In sum, it seems to me that the probabilistic argument for God from fine-tuning is a mixed bag. On the one hand, naturalistic responses can be leveled against it: the ambiguities in pinning down the probabilities, the hope of physical explanations for fine-tuning, and the possibility a multiverse will provide simpler explanations. On the other hand, theistic responses to the naturalistic proposals are available that are extremely compelling to some people. After all, almost everyone agrees that fine-tuning is striking in some sense, and it seems like a short step to make the obvious link to the traditional Abrahamic notion of God as the source of the purposefulness of the created order. Is it thus still possible to mount a convincing probabilistic argument for God from design based on fine-tuning despite the technical challenges I outlined in this section? While I think there may be merit in pursuing this sort of argument, there is an important issue with this overall approach I now wish to address.

Probabilistic Fine-Tuning Arguments and the Theological Tradition

The potential problem with probabilistic theistic arguments is their dependence on the results of empirical science. This places them in tension with the theological tradition that avoids treating God as the object of empirical investigation. The absolute transcendence of God is one of the cornerstones of Abrahamic theologies, which tend to insist that the apophatic approach to God never be far from view. In Western Christianity, this was most famously articulated by the Fourth Lateran Council (1215): "For between Creator and creature no similitude can be expressed without implying a greater dissimilitude" (Denzinger 2010, 806). In other words, any framework used to talk about God must immediately

be qualified as inadequate. Even though there may be true analogies for talking about God, the "similitude" the analogy expresses will always be outweighed by its "dissimilitude." God's act of creation is no exception.

We can take Thomas Aquinas, who lived soon after Lateran IV, as our representative of this tradition. Aquinas is careful not to confuse God's act of creation with the sort of creation that occurs in the regular course of nature (as when, for instance, a tree is created from an acorn, or a star is created from a cloud of dust). He goes so far as to consider them equivocal: "[T]he universal production of being by God is neither motion nor mutation, but a certain simple emanation. And so 'to become' and 'to make' are used equivocally in reference to this universal production of things and in reference to other productions" (Aquinas 1963, Book VIII, Lect. 2, 974). By "motion" and "mutation" here, one should understand the sorts of physical processes that are studied by the empirical sciences. Aquinas is emphatically denying that God's act of creation is of this sort.

The potential danger, therefore, with arguing that God is the most probable explanation of fine-tuning is that it treats of God as at the same level as the empirical world. Even if someone making this argument frames God as being apart from the universe in some way, God remains one option to be weighed against other options, and there is the risk that his transcendence is lost. Indeed, as Kathryn Tanner (1988, 46) has persuasively argued, if God is the Creator of everything as proposed by the Abrahamic traditions—if he is "the immediate source of being of every sort"—then his transcendence must be thoroughgoing and absolute. This sits in possible tension with the notion that he is more likely than another cause, for even if he is overwhelmingly more likely, he is still being conceived of in contrast to other possible causes. As Tanner (1988, 45) puts it: "Divinity characterized in terms of a direct contrast with certain sorts of being or with the world of non-divine being as a whole is brought down to the level of the world and the beings within it in virtue of that very opposition: God becomes one being among others within a single order." Thus, probabilistic design arguments may not go deep enough to fully arrive at the Abrahamic notion of God—nor the conceptions of the Divine found in other major religious traditions (see Hart 2013, 27ff).

A consideration of the phenomenon of miracles can elucidate this point. It is beyond the scope of this article to rigorously define or analyze miracles, but a good working definition is that miracles are phenomena that exceed or subvert nature's regular course so as to demand a supernatural explanation (e.g., Aquinas 1912–36, I.110.4). Probabilistic fine-tuning arguments operate in a similar spirit, since their claim is that nature per se is not an adequate explanation for the conjunction of parameters necessary for a life-friendly universe. However, it is noteworthy that traditional demonstrations for God's existence and about his attributes tend to be based on metaphysical arguments rather than appeals

to miraculous phenomena. In the first part of Aquinas's *Summa Theologiae*, which deals with God and the created order in general, including his famous five proofs for God's existence in Question 2 and his treatise on creation in questions 44–47, miracles are only considered in any detail in a few articles towards the end, comprising a minuscule fraction of the total text.[2] For Aquinas, miracles play an epistemic role that is posterior to the question of God. God is knowable in a general way through "natural reason," whereas miracles are a "gratuitous grace" that aid the "supernatural knowledge"—i.e., faith—relevant for salvation (1912–36, II–II.178.1). Aquinas tends, therefore, to speak of miracles as "for confirming faith [*ad fidei confirmationem*]" (e.g., Aquinas 1888, II–II.178.1, *ad* 5; 1965, VI.2, *arg* 9) and "for showing [*ad ostendendum*]" or "for manifesting [*ad manifestandum/manifestationem*]" God's power and presence (e.g., Aquinas 1888, III.43.1,3,4; 1961, III.9.10; 1965, VI.1, *ad* 4) rather than providing demonstrations of his existence in the strict sense.[3] This may help explain why probabilistic fine-tuning arguments do not have universal appeal. Those who accept that there is a God may find fine-tuning a powerful confirmation and an aid to faith, but it is not always sufficient to convince others. As Aquinas (1912–36, I.110.4) himself points out, it is possible for us to mistakenly call something a miracle if we do not fully understand how nature works, and this is precisely the sort of counterargument that can be made against probabilistic fine-tuning arguments, as seen earlier.

Furthermore, as explained earlier, God's act of creation is not a physical process and thus not empirically accessible. It therefore falls outside the category of the miraculous, since by definition miracles are always understood with reference to nature, and the act of creation is the ground of nature rather than an operation within nature (Aquinas 1912–36, I.105.7, *ad* 1). To put it another way, the God–world relation, which is what the Abrahamic doctrine of creation articulates, is metaphysically prior to anything natural sciences can investigate. Of course, this does not mean there might not be miracle-like clues, such as fine-tuning, within nature that point to a reality that transcends nature. I am not claiming that probabilistic analyses of fine-tuning are a theological dead end—after all, miracles can be compelling signs in aid of religious faith, as Aquinas certainly thinks and the broader Catholic tradition affirms[4]—but rather that they would not provide direct access to the work of creation per se.

Moreover, probabilistic design arguments are not the only option. Aquinas is sometimes credited with including an argument from design among his "five ways" for demonstrating God's existence (e.g., Ratzsch and Koperski 2022, §2), but it is quite different from Paley's:

> The fifth way is obtained from the governance of things. For we see that certain things that lack cognizance—namely, physical bodies—act for an end. This is evident from the fact that they always or very frequently act in the

> same way, such that they attain that which is best. It clearly follows that they arrive at this end not by chance but by an intention. For things that do not have cognizance do not tend to an end unless directed by something that is cognizant and intelligent, like an arrow from an archer. Thus there is something intelligent by which all physical things are ordered to an end, and we call this God. (Aquinas 1888, I.2.3)

Aquinas's approach is almost the opposite of Paley's: rather than appealing to the improbability of the world's constitution, it relies on the regularity of the laws of nature and the fact that physical processes operate in intelligible ways with determinate ends. Now, although fine-tuning appears necessary for our universe to be the way it is, in isolation, fine-tuning does not establish that laws of nature are regular or intelligible. It may be the result of regular laws of nature, and it may be part of a larger process that produces a life-friendly universe, but in and of itself, fine-tuning is just a set of facts. It is not clear whether fine-tuning is even relevant to an argument like Aquinas's, which is about the general intelligibility of natural processes, not a particular set of facts.[5]

Still, the laws of nature are discovered by empirically studying particular sets of facts, so we should ask whether there is a relationship between the fine-tuning of physical parameters (used for Paleyesque arguments) and the regularity of nature (used for the Thomistic approach). Here, we can benefit from the analysis of the twentieth-century Jesuit philosopher Bernard Lonergan.

Fine-Tuning and Emergent Probability

Lonergan (1992, 102ff and 126ff) noted there are two complementary ways to find intelligibility in nature. The first is via laws that use mathematical formulas to describe how the world regularly behaves, like thermodynamics or Einstein's theory of gravity. Lonergan calls this a "classical investigation" of nature. The second is via the patterns of actual events and facts that repeatedly occur in nature. For instance, an astronomer can measure where a planet is every night and make a table of positions. From that table, she can figure out what the planet's average motion is. Or a geneticist can look at the offspring of a particular species of animal and figure out how often certain traits appear. Lonergan calls this second type of empirical activity "statistical investigation." He then points out a profound "complementarity" between classical and statistical investigation. On the one hand, the laws of nature discovered by classical investigation are based upon the average occurrence of events or facts uncovered by statistical investigation. For instance, the laws of planetary orbits were derived by abstracting equations from the planets' average motions observed over many nights. The laws of genetic inheritance are derived by abstracting from the rates at which physical traits occur to an explain how traits are transmitted. On the other hand, statistical investigation tests the validity

of classical laws by verifying whether the measured events are configured and ordered in the manner predicted by the theory. Thus, the two go together: laws are abstracted from the behaviors of events, and the behaviors of events occur in patterns governed by the abstract laws. Close attention to the pattern of the behaviors also allows classical laws to be refined. For instance, in the early twentieth century, astronomers were puzzled when measurements of the orbit of Mercury deviated very slightly, but very reliably, from the predictions of Newton's theory of gravity.[6] When Einstein formulated his new theory of gravity, one of its first triumphs was that it cohered with the average behavior uncovered by the statistical investigation. The previous theory remained intact in the sense that Newton's equations provide a pretty good approximation to Einstein's equations in most regimes, but the classical theory had been refined.

Crucially, though, statistical investigation does more than confirm or refine classical laws: it carries scientific understanding beyond the merely classical to the more complex intelligibility of the world. In isolation, classical theories describe "systematic processes" in which a whole collection of data can be fully understood by the single application of an abstract law (Lonergan, 1992, 71). But as any working scientist will tell you, data never perfectly match the predictions of abstract laws. Lonergan (1992, 109ff, but esp. 117ff) calls these deviations from classical predictions "statistical residues." The residues may arise from random measurement uncertainties—and we know from quantum theory that at a certain level of precision this randomness is truly irreducible. They can also occur when no single classical law provides a complete explanation of a phenomenon. For instance, the deviation of today's weather from yesterday's weather forecast may be explainable by some appropriate combination of thermodynamics, fluid dynamics, and geophysics, but there is no systematic way to relate these classical frameworks that does not sensitively depend on initial conditions. Each day, the relevant conditions are such that the combination and application of classical laws is different, and as a result, weather prediction is never perfect. In "non-systematic processes" like weather, the ensemble of data cannot be explained by a single classical law but requires an unpredictable conjoining of multiple classical explanations (Lonergan, 1992, 72) and inevitably includes some irreducible randomness. Thus, non-systematic processes are intelligible, but their intelligibility is complex.

Moreover, "non-systematic process can be the womb of novelty" (Lonergan, 1992, 75). It is possible for a pattern to emerge in statistical residues that is merely coincidental with regard to one theory or set of theories but that can be explained by a completely new type of theory. The various branches of science exist because what is just a "coincidental manifold" of statistical residues to one science can be explained in a non-coincidental manner by a higher science (Lonergan, 1992, 230). So, to use Lonergan's (1992, 230, 281ff) example, all of the molecules in a biological cell behave according to chemical

laws. However, there are certain very regular patterns of behavior within a cell that are not explained by chemistry. You could not use chemistry to predict a priori that a cell should have particular parts like a nucleus, a membrane, or a Golgi apparatus. Nonetheless, all of these cellular parts are intelligible and require further explanations that chemical theory cannot provide: they require biological theory. When molecules are arranged in particularly precise and complex ways, they become not merely molecules but constituents of a living organism. Biology builds upon chemistry.

The latter example shows that in the interplay between the abstract regularity of the world and the deviations of actual events from that regularity, it is possible for new processes with new intelligibility to emerge. Lonergan (1992, 144ff, but esp. 280ff) calls this "emergent probability." Note that this concept is a metaphysical principle rather than a scientific theory. It is an explanation for why emergence is possible based on the complementarity between abstract intelligibility and concrete intelligibility, but it does not predict whether a higher system will actually emerge in any particular situation. Whether a higher system emerges or not is an empirical matter that must be determined in the usual scientific way. To return to the example of biology emerging from chemistry, as far as I am aware, we are still ignorant about how that emergence happened. If there is a young planet with a chemical soup floating around, we are not sure whether life will inevitably form, whether it is extremely unlikely, or whether it requires additional scientific ingredients we are currently unaware of. Perhaps one day we shall know the answer. Lonergan's notion of emergent probability, though, simply explains the mutual open-endedness of classical and statistical intelligibility, of which the appearance of life is a particular instantiation.

Now, we can consider fine-tuning in the context of emergent probability. Fine-tuning is striking because a number of seemingly disparate aspects of the early universe and physics have conspired together to enable a universe like ours to develop. It has the quality of a statistical residue, since the physical conditions of the early universe together with the values of the parameters of physics constitute a concrete pattern not predicted by either the Big Bang theory per se nor the structure of our (current) laws of physics per se. However, this pattern turns out to be just the right one such that particular, complex structures can emerge, like galaxies and stars and planets and a periodic table of elements that can form complex molecules and eventually life. Therefore, the science of physical cosmology, which provides a unified theory explaining the behavior of the universe on its largest scales of space and time, may be the fruit of emergent probability. What appears to elementary physics as merely a "coincidental manifold" (Lonergan, 1992, 230) of parameters may in fact be the basis for the intelligibility of our physical universe as a whole. Now, as stressed, although it appears that the emergence of the pattern called fine-tuning is unlikely in some real sense, this is difficult to quantify. Perhaps it will

be discovered that the pattern was inevitable after all and is not actually an example of emergent probability. Perhaps it was a hugely improbably fluke. Perhaps there is a vast multiverse and we inhabit a lucky spot where the right pattern happened to occur. Like the question about how life first appeared on Earth, this array of possibilities appears to me to be empirical in nature—and narrowing down the field is something scientists are working hard at.

However, we might ask whether there is more going on behind the empirical question about fine-tuning. Is there any significance to the fact that fine-tuning is a pattern open to the emergence of further complexly ordered patterns that indeed appear necessary for our very existence?

God and the Contingency of the Actual

To explore this question let me call upon another twentieth-century Jesuit philosopher, Erich Przywara, whose masterpiece *Analogia Entis* was only translated into English relatively recently (2014). Przywara analyses what it means to be a being in the world, how "creatureliness," as he puts it, is constituted. He characterizes it as an "immanent dynamic middle." Thus, not only is creaturely being "immanent," since it is actual and concrete, but its immanence is a "dynamic middle" that is "suspended" between two kinds of possibility (Przywara 2014, 216). On the one hand, what is actual or immanent is contingent on other states of affair. For instance, this article you are reading is immanent: it is actually before your eyes. But its being here is contingent on a whole host of factors. It is contingent on my having written it; it is contingent on me having thought about the topic of fine-tuning beforehand; it is contingent on my education; it is contingent on your computer screen or printer reproducing the text for you; and so on. On the other hand, what is actual or immanent is also the starting point for what will come next. The concrete is open to something new. This article you are actually reading is moving things forward: by its nature, it opens your understanding out towards a better understanding of fine-tuning—or, perhaps equally, it fails to do so. The point is that it is not a static actuality but one that lays out further possibilities. These possibilities are certainly conditioned. The ideas the article stirs up are dependent on its actual content, how well it is organized and communicated, and how cogent it is. So, it will not move you towards just any old ideas. But exactly what ideas it will stir up in you are still to be seen. The ending point is not completely determined.[7]

Przwyara thus concludes that the actuality of creaturely being is "suspended" (as he puts it) between the possibility out of which it emerges and the end towards which it is opening up. Relating this to traditional philosophical terms, he explains that "actuality (ἐνέργεια) [is] between dynamic possibility (δύναμις) and an inner end-directedness (ἐντελέχεια)" (Przwyara 2014, 216). This means there is a paradox in the being of this world. Beings are actual, but their actuality emerges from possibility and moves towards possibility. They are suspended

between possibilities, between non-actualities. In other words, their being—their "isness"[8]—is negatively qualified. Whenever there is a state of affairs, Przywara (2014, 207–8) reasons, it "is not not." It actually "is," but it only *is* contingently. It could *not* have been if the right conditions had not existed, and it is *not* what it still can be. It *is* by virtue of being *not not*. It is *not* not actual, because what was only possible has in fact been made actual. And it is not *not* actual, because what is still possible is not yet, and its actuality obtains here and now (see Hincks 2020, 30). To link this back to Lonergan (1992, 75), "non-systematic process can be the womb of novelty" because statistical residues reveal that classical laws are embedded in a world of "nots" that make room for newness to emerge.

The actual is therefore existentially striking. Aristotle famously observed that the world elicits wonder in us. We encounter a phenomenon, and we want to explain it: we want to know how it came to be and what it can become (Aristotle 2014, I.2, 982b12). In the framework of Przywara, we want to know why it *is not not*. In the framework of Lonergan, scientists are struck by phenomena and wonder if there is a pattern. They do a statistical investigation to discover the pattern. If they find one, they discern abstract principles in it. Now, the configuration of the early universe and the concrete values of the constants of nature constitute a particularly striking pattern that stimulates wonder. We wonder where it came from and to what extent it was necessary for what came next.

When it comes to the God question, I propose that we miss something significant by jumping immediately from this wonder to the question of what came before or after fine-tuning. To do so is to head away from the *is* to study the *nots* between which the *is* is suspended. Aristotle may have said that wonder drives philosophical inquiry, but he goes on to claim that the goal of philosophy is to remove wonder. Once you understand the causes of something, you no longer wonder about it (Aristotle 2014, I.2, 983a15). But the Divinity, at least in the great religious traditions, is not something that removes wonder, as if you could arrive at a definitive understanding of its nature.

In this vein, Przywara's chief insight is that the suspension of the actual between possibilities does not resolve itself. The way we humans know is through eliminating possibilities. We only know that something *is* insofar as it *is not not*. We know by comparison, by contrast, by elimination. The actual *isness* of creatures in the universe is never naked; creaturely being is always clothed with *nots*. But you cannot ultimately get the core notion of *is* from a *not*. The notion of isness, of being, must ultimately originate elsewhere (Przywara 2014, 216–37).[9] In more traditional philosophical language, the being we are familiar with—the being of this universe—is contingent. That is what Przywara means by "not not." Aquinas's (1888, I.2.3) famous demonstrations for God's existence look at this contingency from various angles—from five angles, to be precise—and conclude that the world's contingency is only resolved in something that is actual per se, and "we call this God." The *is* in the *is not not* of creatures is only finally

explained by the unqualified *is* of God. And since there is no *not* in the *is* of God, there is no termination of wonder, unlike in every other sort of investigation.

Thus, I propose that fine-tuning gestures towards God not primarily because he is an explanation for why it was possible for fine-tuning to arise and for the sorts of universe fine-tuning produces, even if that is certainly true in the ultimate analysis of God's creative power. Rather, the more important clue is the actuality of the fine-tuning: the unqualified wonder that it *is*. I use the term "unqualified" quite deliberately, because practically everyone who learns about fine-tuning finds it striking and wonderful, but to look for explanations that head away from the actuality—that attempt to qualify it—is paradoxically to head away from God. It is to leave the *is* in search of the *not*. Now, that is in fact the correct endeavor for the natural scientist and perhaps for the philosopher as well. When your question is about God, though, it is the wonder, the strikingness, the isness, the being per se that is arguably most relevant, because that is the closest analogy we have to what God is like: the analogy of being (see again Przywara 2014, 216–37).

Conclusion

My assessment of what fine-tuning says about God may appear quite modest. I have framed fine-tuning as a created actuality that has an intelligible pattern. It is actual, but where it comes from and where it heads is provisional, is suspended. The suspension is not resolved in itself and points to a transcendent resolution. There are plenty of other things in the world that point to God through this analogy of being—indeed, everything points to him. You do not need to go to the fine-tuning of the universe to find it, for it is all around you. If you dwell on what is actual in any type of creature or pattern or situation, even in the most ordinary circumstances, you have there a portal to the Divine, even if it is "in a glass, darkly." To coin a phrase from Ignatian spirituality, you can find God in all things (see Ignatius of Loyola 1952, 235–37). Now, I do not want to dismiss probabilistic arguments outright. But I reckon that they will be most successful insofar as they are framed in the deeper context of the thoroughgoing contingency of the world; otherwise they will be, to return to Tanner (1988, 46; emphasis added), "not radical enough to allow a direct creative involvement of God with the world *in its entirety*." For the Abrahamic claim is that God does not just orchestrate coincidences like fine-tuning but that the world depends on him in every respect; hence, Lonergan (2017, 101) can state that "the question of God is implicit in all our questioning," since every instance of contingency (or "suspension") prompts questions in us about its origin that remain ultimately unresolved within the world of contingency.

Yet, if fine-tuning is just one example of suspended actuality among many, it is certainly a remarkably striking example. Even if the analogy of being is in the world around us, and indeed within us, it can be hard to see just how remarkable created actuality is when we are busy living in that same world. You have to

step outside of your ordinary routine and have a contemplative experience of the natural world, or notice how remarkable it was a concrete decision in the past impacted your subsequent life, or reflect upon the peculiarities of your own culture you are normally unaware of to be struck by the contingency, indeed the strangeness, of the actual. When you have such moments as these in which you pause and see how created actuality is nested before and ahead in possibilities, you get a glimpse of that suspendedness. But immersed as we are in this matrix of "suspended," "dynamic middles" (Przywara 2014, 216), and therefore usually blind to it, there is an advantage to being able to look out at the cosmos, far from our own familiar world of existence, to see how created being is writ large. As far out in space and back in time as we can see, the actual, the *is* of creation, is starkly present.

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Notes

[1] In my experience, the term "bubble" is more widespread, but I prefer "pockets." It also has the virtue that it is used by Alan Guth (2007), one of the pioneers of inflationary theory.

[2] Miracles are not treated per se until Question 105, articles 7 and 8. Before this, they are only mentioned in objections and responses to objections, with only one passing exception (I.104.4). Subsequent to Question 105, they are discussed chiefly with reference to angelic powers (I.110.4, I.114.4). The foregoing is based on a search for "miracl*" in the *Index Thomisticus* (Busa and associates, n.d.).

[3] Here, and whenever Latin editions of Aquinas are cited, translations are mine.

[4] In response to certain fideistic ideas, the First Vatican Council (1870), insisted that miracles play an integral role in the dynamic of faith. The council document *Dei Filius* explains that faith, as a divine gift, has an "interior" aspect, but it is integrated with "exterior proofs" since "miracles and prophecies . . . are most certain signs of the divine revelation, adapted to the intelligence of all men" (Denzinger 2010, 3009, c.f. 3010, 3033–34). The context here is revelation rather than natural theology—the latter of which is still considered, though, a sure path to knowledge of God (Denzinger 2010, 3004, 3026). It is natural theology that is pertinent to this essay.

[5] The implicit premise in the argument of the Fifth Way is that purposeful behavior must ultimately be explained by an intelligent agent. Providing an argument for this premise would be beyond the scope of this article. However, it is worth pointing out that people today frequently interpret Aristotelian final causality in an overly anthropomorphic manner, as though there were a quasi-conscious agent hidden inside anything operating for an end. Final causality, however, just means what Aquinas says: that processes "are ordered to an end." There is no requirement for an immediate intentionality. A good modern example would be the principle of least action in physics. Aquinas's claim in the Fifth Way, though, is that this sort of principle requires an intelligent ground.

[6] Lonergan uses the example of the precession of Mercury's perihelion in a couple of places, though to illustrate different points. See Lonergan (1992, 728, 733).

[7] Lonergan (1992, 470ff) calls this "finality": through emergent probability, new, concrete states of affair can arise that are not necessarily mechanistically predicted. Here, Lonergan adds something to Przywara, or at least brings something forth that is only implicit in his writing. Przywara seems

to have in mind simply the classical notion of form with a proper τέλος (telos). Lonergan's notion of emergent probability, though, shows that not only can the actualized form develop according to its immanent τέλος but that new τέλοι can emerge from a matrix of actual forms.

[8] My term, not Przywara's, as far as I am aware.

[9] The foregoing is an extremely compact summary of what Przywara means by the analogy of being but hopefully gets at its core. In the cited pages, see especially 219 and 235–37.

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Fine Tuning and the Scope of Physical Laws

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Fine-tuning arguments claim that the precise parameter values and initial conditions required for complexity and life are extraordinarily improbable and demand explanation. This article examines whether such probability claims can be grounded in physics. A brief study of a historical case, Isaac Newton's design argument regarding the solar system, illustrates that assessments of "improbable coincidences" can result from overly narrow theoretical perspectives. The article then distinguishes between probabilities legitimately employed within physical theories and those invoked in fine-tuning arguments. While physics provides mathematical structures and dynamical justifications for probability assignments, fine-tuning arguments typically rely on unjustified applications of the principle of indifference over possibility spaces lacking unique measures. An appealing reformulation of the fine-tuning argument, due to John Roberts, avoids this and other challenges, but the argument clearly depends on what the Designer regards as aim worthy rather than physics. Closer examination of the aspects of physics routinely used in fine-tuning arguments exposes problems. "Naturalness" in particle physics conflates distinct concepts—autonomy of scales versus statistical typicality within theory space—where only the former is well motivated. Cosmological measures lack the dynamical grounding that justifies using them to make probabilistic claims similar to equilibrium statistical mechanics. The article concludes that fine-tuning arguments fail to establish their probabilistic claims, and as a result, fail to provide a version of the argument from design that should compel those not already committed to rationalist explanatory demands.

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Introduction

Physical theories trace some aspects of the world back to laws of nature while treating others as accidental or contingent. The fact that the planets move along approximately elliptical trajectories follows from the law of gravity, for example, whereas the number and masses of planets reflect contingent facts about how our solar system formed. This distinction is essential to how physics represents the world, with the full description of any specific system arising from a complex interplay between laws and contingent facts. The rich phenomenology our theories can describe depends on how the distinction is drawn, and allowing for contingencies gives theories the flexibility to apply in a wide range of circumstances.

Recent discussions of "fine tuning" in physics and cosmology reflect a conflict between two different perspectives on this demarcation between necessity and contingency. On the one hand, various aspects of contemporary physical theories—such as values of coupling constants in particle physics and density parameters for different kinds of matter in cosmology—are determined by observations. These are contingent or accidental in the sense that they cannot be derived from first principles and apparently could have taken different values. Yet, from the second perspective, the exact values of these parameters hardly seem to be accidental: they seem instead to be essential to the universe being like it is. The existence of complex structures at a variety of scales, ranging from molecules to stars to galaxies, apparently depends sensitively on the specific values we observe. If the coupling constants in the Standard Model, or the cosmological parameters, differed from their current values, even by the slightest amount, complex structures would not emerge. Since these are plausible preconditions for the existence of life, such a universe would be utterly barren.

Features that are entirely contingent, according to current physics, are apparently necessary to account for the complexity of the observed universe and the very possibility of life. Should our theories not explain something as fundamental as the complexity of the universe, and the existence of life, in terms of the underlying laws? This question reflects assumptions, often left implicit, regarding the explanatory scope and appropriate aims of physics. The question is often posed more forcefully: the required parameter values are not just unexplained but strikingly "improbable" in some sense to be made precise. How could the values of all these parameters be just so, finely tuned to match the required values, by sheer coincidence? Even those willing to grant that some explanations bottom out with an appeal to contingent facts may balk at explanations that exhibit such sensitive dependence. This line of thought is sometimes meant to spur the development of new theories free of fine tuning; other times, it is instead to encourage the use of quite different explanatory principles from metaphysics and theology.

Those who accept (some version of) the principle of sufficient reason already demand explanations for why the universe has the properties it

does. One appeal of fine-tuning arguments is that they might be effective in persuading even those who do not share such strong rationalist commitments. To make good on this appeal, advocates of fine tuning must counter a natural empiricist response, which is to dismiss fine tuning as a pseudo-problem. Fine tuning does not identify empirical anomalies or logical inconsistencies within existing theories. A finely tuned theory can successfully account for what we observe. What is the nature of the alleged deficiency in how it does so? The fine-tuning advocate insists that current theories cannot adequately account for something as essential to the universe as the presence of living things, or, less anthropocentrically, complex structures at a variety of scales. A case based on fine tuning is stronger if the nature of this deficiency can be clarified and shown to follow from criteria we routinely use in evaluating theories—criteria that even a skeptical empiricist ought to accept. One way of making the case is to argue that contemporary theories render the universe we observe to be remarkably, unbelievably, astronomically improbable. My main aim is to assess to what extent fine tuning can play this role by grounding probabilistic assessments like this in fundamental physics and cosmology.

Fine-tuning arguments (hereafter, FTAs) have played an increasingly important role in contemporary physics and cosmology, first in cosmology starting in the 1960s following the recognition that the hot Big Bang model requires a seemingly "improbable" initial state, and subsequently with discussions of "naturalness" in particle physics—giving rise to the estimates of the improbability of the universe we observe. Physicists have pursued theories that eliminate (or at least decrease) fine tuning in the past several decades, although there have been active debates regarding how this preference relates to other demands routinely placed on theories. Alongside these developments in physics, there has been a revival of interest in fine tuning in philosophy. Just as the physicists have debated what (if anything) is wrong with a finely tuned theory and how it should be remedied in a successor theory, philosophers have sought to elucidate the general structure of FTAs and assess responses to it.

Here, I explore two challenges to appealing to fine tuning in physics and cosmology in modern versions of the design argument. The first regards the nature and justification of probabilities. The basic issue regards when we can apply the mathematics of probability theory to represent uncertainty. In my view, physics theories often supply the mathematical structures needed to introduce probabilities and justify their use. Probabilities are an absolutely essential part of how physical theories are used to describe the world. We can assess the scope and reliability of the probabilistic assessments based on the success of the theory and the degree to which the probabilities follow directly from aspects of the theory we understand well. Assertions about probability in philosophical FTAs, however, often appeal to the principle of indifference applied over possible parameter values, or possible worlds, without the resources

to single out a unique measure or probability distribution. Recent defenders of the design argument have attempted to bridge the gap between these cases. I argue here that these efforts fail because they elide significant conceptual contrasts between the uses of probability in the two cases.

The second challenge starts with a very different response to the role apparently contingent features, such as parameter values and initial conditions, play in explaining the universe's complexity. From this view, given that physics provides an integrated representation of a broad array of phenomena starting from a few fundamental principles, we should expect to uncover dependencies like those emphasized and catalogued in the literature on fine tuning. By considering fragments of physical theory in isolation, we are tempted to treat various features as separable and probabilistically independent, despite the dependencies that arise when they are combined in an integrated account. The various cases of fine tuning illustrate that the explanations provided by physical theories rely on much more than just the laws—they also need to invoke facts about initial or boundary conditions, parameter values, and so on. Recognizing that these theoretical representations employ a wide variety of claims with different modal statuses does not provide a reason to reject the theories.

The article begins by returning to an influential historical case, Isaac Newton's design argument based on the structure of the solar system, that serves a dual purpose: to both introduce the basic structure of one influential FTA and illustrate how the assessment of certain features as "improbable coincidences" can go wrong. The next two sections turn to philosophical attempts to formalize FTAs, first in terms of explanation and then in terms of assessments of the likelihood of the design hypothesis versus competitors. I review three well-known challenges to the likelihood formulation before endorsing an alternative formulation advanced by John Roberts. While the Roberts formulation avoids some of these challenges, it also undermines claims connecting the probabilities invoked in FTAs to physically respectable probabilities—as opposed to hypotheses about the nature of a Designer and their intentions. The article then turns to examining two cases in physics often thought to ground the probabilities introduced in FTAs, ultimately concluding that they fail to do so. First, I distinguish between two different ideas that (unfortunately) both fall under the label "naturalness": autonomy of scales and statistical typicality, assessed based on a measure over theory space. In the penultimate section, I turn to the fine tuning of initial conditions in cosmology, where similar measure problems arise, before concluding the article with further reflections on the implications of this line of argument.

Design and Fine Tuning

The design argument has long played a central role in natural theology, reflecting the appeal of establishing substantive conclusions regarding the nature of the Designer on *a posteriori* grounds. Versions of the argument start from observations

of a wide variety of striking features, ranging from the adaptations exhibited by living creatures great and small to the arrangement of the solar system. FTAs regarding physics and cosmology have dominated recent discussions, ever since evolution provided a compelling account of how design can accumulate through natural selection without a guiding intelligence. But they are not a recent innovation. Some of the earliest design arguments appealed to basic structural features of the cosmos, and it will be useful to discuss them briefly and see how they have fared in light of the evolution of physics.

Newton published an influential design argument in the General Scholium, a concluding comment added to *Principia Mathematica*'s second edition. René Descartes had claimed that the solar system could have emerged out of pure "chaos" merely through the action of mechanical laws. By contrast, Newton ([1687] 1999, 940) argued that "[t]his most beautiful System of the Sun, Planets, and Comets, could only proceed from the counsel and dominion of an intelligent and powerful being" due to the regularity of the motion of the planets and their satellites. The planets revolve around the sun with the same orientation and (roughly) within a plane. Newton attributed the persistence of these regular motions, despite mutual interactions among the planets, to providential design, partially implemented through the carefully orchestrated motion of comets. This only seemed plausible due to Newton's dramatic overestimate of cometary masses as roughly on par with that of Earth. Such massive comets would have appreciable effects as they passed through the planetary orbits, and appropriate cometary motions—guided by an intelligent and powerful being—could enhance the dynamical stability of the solar system. Subsequent discussions turned to other features of the solar system thought to support a similar conclusion. William Paley ([1829] 2006, 199) devotes a chapter to astronomy, stating at the outset that, while not as compelling as arguments based on biological design, the solar system nonetheless displays "the magnificence of [the Creator's] operations," reflected in the central placement of the sun, which does not appear to follow from any "antecedent necessity" or from the sun's nature (assumed to be similar to that of the planets); the choice of the laws governing the solar system, given that an inverse-square force admits stable orbits, whereas other force laws do not; and so on.

These arguments focus on features that are not only strikingly well suited for our existence but also seem unlikely to arise by chance. Several scholars took the further step of estimating the relevant probability. In response to the Academié des Sciences prize contest in 1734, Daniel Bernoulli ([1734] 1987) calculated the probability of the finely tuned initial state needed to account for the nearly co-planar orbits of the six planets known at the time. These orbits fall within 6°54′ of one another, approximately $\frac{1}{3}$ of 90° (taking orientation into account); treating them as entirely independent leads to a probability of the required initial conditions equal to $\frac{1}{13^5 - 1} = \frac{1}{371{,}292}$. While admitting that this gave only a rough estimate, Bernoulli regarded it as sufficient to rule out mere

chance as an explanation—and he proposed a speculative physical mechanism instead, such that this feature would be an expected, stable outcome. Paley ([1829] 2006) also argued that several apparently designed features of the solar system exhibit fine tuning in a similar sense. The specific choice of the exponent in the gravitational force law ($f \propto r^n$), from among all possible values n, for example, falls "within narrow limits, compared with the possible laws. I much underrate the restriction, when I say, that in a scale of a mile they are confined to an inch" (Paley [1829] 2006, 207). In Paley's case, ruling out "mere chance" left providential design (rather than a speculative physical mechanism) as the most compelling explanation of these features.

The common structure of these design arguments runs roughly as follows. We first identify several striking features of the solar system that seem to be well suited to our existence, or even necessary for it, based on a specific theory. Yet, these features are fragile, in that fact that they hold depends sensitively on features of the initial state of the system or contingent features of the laws (such as the choice of apparently unconstrained parameters). The current theory treats these features as brute facts subject to no further explanation. When we assess how likely it is that the appropriate contingent facts obtain "by mere chance," we further discover, via arguments like Bernoulli's, that they are incredibly improbable. This prompts the demand to seek an explanation more satisfying than an appeal to mere contingency, with two distinct responses: augmenting current theory with new physics that has the effect of replacing fragility with stability, or an appeal to the existence of a Designer.

With the recent discovery of extra-solar planets, we can now make this line of argument more concrete by comparing our solar system to the catalog of other systems (which now has several hundred entries). With respect to this catalog, the solar system does have some unusual features with regard to both the number and masses of the planets and their orbital parameters, but nothing as improbable (in the sense of frequency within this ensemble) as Bernoulli's calculation suggests.[1] Many astronomers have advocated an anthropic response to these unusual features. Namely, they explain apparent fine tuning as the consequence of a selection effect applied to an ensemble of systems. Several features of our solar system, such as the low eccentricity of the planetary orbits and the absence of massive planets close to the sun, are plausibly essential to maintaining a planet in the so-called "Goldilocks zone" (with temperature and other conditions that are "just right" for creatures like us) for long periods of time. According to this approach, our presence explains (in some sense) the fact that the solar system has these unusual features. (Note that in this approach, what is explained is not the striking features of the solar system per se but rather the fact that creatures like us observe these unusual features.) We could not, after all, find ourselves in one of the planetary systems lacking the conditions needed to support

our existence. Anthropic selection from an ensemble of systems exhibiting variation in relevant respects is the third main response to fine tuning that takes the explanatory demand as legitimate.

Philosophers have offered several refinements and formalizations of fine tuning, leading to different assessments of its validity and force and the viability of these three responses.[2] Before turning to these, we are already in a position to reflect on the fate of the claims of Newton and Bernoulli. The apparent contingency of several features of the solar system has proven to be a consequence of framing the research questions narrowly, and later work dissolves this illusion by providing a richer account of the formation and evolution of planetary systems. The solar system would be a puzzling configuration of bodies interacting gravitationally if the sun and planets were (somehow) assembled by chance. But this evaluation changes drastically when we regard it instead as an outcome of stellar formation in a specific environment. The evolution of a protoplanetary disk into a planetary system is expected to yield planets moving roughly in a plane with the same orientation. In contrast with Bernoulli's speculative proposal, the modern account of stellar evolution and planet formation does far more than account for one puzzling feature of the solar system—it is the product of various lines of investigation, incorporates diverse aspects of physics and astrophysics, and generates a number of further predictions and insights. The impact on the argument from design for the solar system resembles that of evolutionary theory on biological design arguments: within this broader picture, there is a compelling and detailed account of how certain features arise. The initial evaluation that these features are strikingly improbable coincidences in need of further explanation resulted from treating the problem using a theory with narrow scope.

Surprise and Probability

In the opening scene of the film *Rosencrantz & Guildenstern are Dead*, Guildenstern contemplates an increasingly long run of coin tosses that come up heads. Granting that these tosses are fair and independent, his sequence of ninety-two heads has extremely low probability: $\left(\frac{1}{2}\right)^{92}$. Does this outcome demand an explanation? Striking real-world lottery results have often prompted similar questions. In October 2022, a lottery in the Philippines drew the following winning ticket (five numbers chosen randomly from one to fifty-five): nine, eighteen, twenty-seven, thirty-six, forty-five, fifty-four. This surprising result prompted calls for a fraud investigation and inquiries to the prominent mathematician Terence Tao.

Guildenstern considers various explanations of his run of ninety-two heads, including divine intervention. The final option is a simple denial that any explanation is needed (Stoppard 1967, 6): "[A] spectacular vindication of the principle that each individual coin spun individually is as likely to come down heads as tails and therefore should cause no surprise each individual time it does."

Martin Smith (2017) defends this response based on what he calls the "conjunction principle": the conjunction of two independent events, each

of which is itself unsurprising, is also unsurprising. There is just as little need to explain *n* consecutive heads (for any *n*, assuming independence) as there is to explain an individual toss coming up heads. The same argument applies, of course, to any specific sequence. This seems to be the correct response to the outcome in the Philippines, although there was no investigation to determine whether criminals with a fondness for the number nine had somehow rigged the lottery.

One way of evading this conclusion is to make the case that there is something striking or distinctive about the outcome. A sequence of ninety-two heads, or the first five multiples of nine, is easier to characterize concisely than a "typical" sequence. Mathematicians maintain a catalog (The On-line Encyclopedia of Integer Sequences) of integer sequences that have previously appeared in calculations (such as the Fibonacci sequence, alongside 370,000 less famous examples). We could, for example, characterize any sequence of integers appearing in this catalog as "unusual" or "surprising." Does a contrast along these lines justify treating an outcome as particularly salient and in need of explanation?

Any proposal for a further distinction along these lines goes beyond probability theory. The question of salience can only be answered in light of a proposed alternative hypothesis, or collection of hypotheses, regarding how the outcome has been generated—proposals that involve, in the case of Guildenstern, denying the independence of the coin tosses, the probabilities assigned to individual tosses, or both, or, in the case of a lottery, a specific way of generating an unusual sequence of integers. These examples illustrate a point that should not be controversial, even for those who doubt the conjunction principle: the probability calculus itself does not deliver verdicts regarding what requires explanation. Such judgments must draw on background knowledge, other principles, or an assessment of alternative hypotheses.

Our assessment of what calls out for explanation typically takes place against a backdrop of experience with similar cases and expectations based on them. For the reasons David Hume (1779 [1998], pt. II) emphasizes forcefully in the *Dialogues Concerning Natural Religion*, we should not expect these judgments to be reliable in assessing fundamental physics and cosmology, given the "limited sphere of action" of human thought: "[W]hat new and unknown principles would actuate her [Nature] in so new and unknown a situation as that of the formation of a universe, we cannot, without the utmost temerity, pretend to determine."

I do not have the space to evaluate the extent to which Hume's observations regarding the uniqueness of the universe, and inaccessibility of events such as its putative origin, undermine the design argument (as formulated by Cleanthes earlier in the *Dialogue*), but they certainly encourage skepticism about our ability to isolate explanatory targets in these domains.

There is a further reason to be skeptical of this ability, namely, recognition of the mistakes that arise from treating theoretical accounts of specific phenomena in isolation. Cory Juhl (2006) develops this line of argument and rejects the claim

that fine tuning for the existence of life cries out for explanation on the grounds that we should expect dependence on constants and boundary conditions as a direct consequence of the fact that physics has succeeded in describing nature using a small number of basic components, or types of systems, and a small number of fundamental equations. Many phenomena depend on a rich web of connections among the basic ingredients employed by physics. The description of the formation and evolution of a brown dwarf star, to take one example, draws on a variety of aspects of physics. Brown dwarfs are distinct from Jovian planets in that their core reaches temperatures high enough to sustain fusion reactions—more precisely, deuterium burning. This mass threshold depends sensitively on details of nuclear physics, such as the binding energy of deuterium and the cross sections for various nuclear reactions. The success in developing an account of the structure and evolution of brown dwarfs, compatible with various observational facts, entails a number of overlapping constraints among the relevant aspects of nuclear physics and astrophysics. Rather than being surprised that the value of deuterium binding energy plays such a significant role in this account, one should expect an integrated description of the formation and evolution of these complex systems to depend sensitively on the values of various constants as well as on aspects of the environment in which the systems form (as reflected in boundary conditions).

Such sensitive dependencies do not provoke a demand for further explanation, on Juhl's view. Rather, the existence of such dependencies should prompt recognition of the contribution constants and choices of boundary conditions make to the empirical success of physics, and the extent to which success in tying together seemingly disparate facts implies tight constraints on them (cf. Landsman 2016; Butterfield 2025). A brown dwarf is just one instance of what Juhl calls "causally ramified" phenomena, defined as phenomena that depend causally on a large number of logically independent facts. The success of physics leads us to expect causally ramified phenomena to be ubiquitous, and the existence of life is just one among many. Furthermore, any causally ramified phenomenon should be expected to exhibit sensitive dependencies on fundamental constants and boundary conditions. Note that this is not to claim that the intricate links among the relevant aspects of physics, astrophysics, chemistry, etc. and the sensitive dependencies they imply will be easy to unravel or quantify. Indeed, the literature devoted to fine tuning abounds with detailed case studies illuminating many fascinating links while also revealing the difficulties facing this kind of analysis. But given the success of natural science in accounting for causally ramified phenomena, including the existence of life, we should expect such dependencies rather than treating them as surprising and posing further explanatory demands.

These broadly Humean lines of argument raise a challenge: to vindicate intuitive judgments of surprise and the demands following from it. One response aims to avoid this challenge by reformulating FTAs in terms of probabilities.

Rather than evaluating whether Guildenstern's run of coin tosses cries out for explanation, this approach considers how such outcomes bear evidentially on competing hypotheses. The aim of the FTA is then to show that certain types of evidence, such as the structural features of the solar system noted by Paley and Newton, favor the hypothesis of a designer over other alternatives. Furthermore, the hope is that the probabilities invoked in this assessment—such as the probability that the values of coupling constants, treated as empirically determined parameters, fall within a particular interval or that the initial state has appropriate properties—can be respectably grounded in physics. But the use of probability along these lines has proven to be a double-edged sword. I first consider more formal formulations of FTAs in the following two sections before turning to two attempts to give a physical justification for probabilities.

Likelihoods

Translating the FTA into the language of formal epistemology promises to provide a clearer assessment by avoiding debates regarding explanation and instead appealing to general methodological precepts regarding how to evaluate the impact of evidence. Most philosophers of science treat questions about evidential relationships using the tools of probability theory. The probability conferred on the evidence E by a hypothesis H, called the likelihood, is taken to be given by the conditional probability $P(E|H)$.[3] One influential formulation of the FTA appeals to the likelihood principle (Sober 2003), according to which evidence E favors hypothesis H over an alternative H' if and only if $P(E|H \wedge K) > P(E|H' \wedge K)$, where K indicates background knowledge.[4]

We can then reconstruct the arguments of Newton and Bernoulli as follows. Suppose the solar system could be arranged with n planets moving along nearly aribtrary trajectories. Call FT_S the claim that only an extremely small subset of allowed trajectories—those in which planets move in roughly the same plane with the same orientation—is compatible with the existence of life. (The subscript S refers to the solar system, but we can also formulate a more general claim, FT, which holds that certain parameters appearing in physical theories and boundary conditions must fall within a narrow range of the space of possibilities for life to exist.) We will take this claim, for the sake of argument, to be accepted as part of the background knowledge. Now, consider the impact of the observational claim E^*, that the planets within our own solar system fall within this narrow range of life-friendly configurations, on three alternative hypothesis: H_C =: the planetary orbits arise "by chance"; H_D =: the planetary orbits arise by providential design; and H_P =: the planetary orbits are produced by a specific physical mechanism that drives a "large" subset of initial states towards life-friendly configurations. On this reconstruction, we can see Newton as asserting that $P(E^*|H_D) > P(E^*|H_C)$ (dropping reference to the background knowledge K, which we take to be fixed); Bernoulli, by contrast,

argues that $P(E^*|H_P) > P(E^*|H_C)$, and furthermore estimates the value of $P(E^*|H_C)$. (Note that there are variations that consider the evidential impact of different statements of the relevant evidence, such as the fact that life exists rather than E^*. Arguably, similar challenges arise for many alternatives to E^*. The next section considers an alternative treatment of FTAs that takes FT_S to be the relevant new evidence rather than E^*.)

This pattern extends to other types of fine tuning. Physicists have uncovered a number of observed features of the universe that appear to depend sensitively on values of the parameters appearing in the Standard Model or on cosmological boundary conditions. (See John D. Barrow and Frank J. Tipler (1986) for a classic, comprehensive review, and for example, see Geraint F. Lewis and Luke A. Barnes (2016) and David Sloan et al. (2020) for recent assessments; Simon Friederich (2023) provides an overview of the philosophical literature.) Many of these reflect "complexity," roughly characterized as the existence of stable structures of different kinds across a variety of physical scales. For example, our universe exhibits complexity in chemistry (with a wide variety of stable molecular structures, particularly those including carbon) as well as astrophysics (with stable structures ranging from stars to galaxies). Schematically, for a dimensionless parameter α, these arguments aim to show that even small variations, greater than some $\measuredangle\alpha$, are not compatible with (some specific aspects of) this observed complexity. The value of the parameter appears to be fine tuned because the interval of allowed values $\alpha \pm \measuredangle\alpha$ is a "small" subset of the full range of values α can take. Here, we usually assume α can take a "large" range of possible values; α may be only constrained to be a real number or a positive real number, for example. It seems improbable that an "arbitrarily chosen" value of α from the full range of possible values, granting a version of H_C, would fall within this small interval. To repeat an overused intuition pump: the specific values we observe seem as improbable as hitting an exceptionally tiny bull's-eye on a large dartboard representing the space of possible values. (Many FTAs take this form, but not all. As we will see later, naturalness problems in the Standard Model of particle physics may lead to a similar verdict—that the observed parameter values are problematic—via a different line of argument.)

The likelihood formulation of the FTA yields quite modest conclusions. The stated inequalities reflect a differential, incremental boost in the probability of specific hypotheses—but this does not imply that the favored hypothesis has high probability, or indeed probability above any stated threshold. To establish the absolute level of credence in the hypothesis requires further commitments. (Within a Bayesian approach to confirmation theory, this would take the form of an assignment of prior probabilities to the competing hypotheses, with the likelihoods then specifying how these priors change in light of the new evidence E^*.) The conclusion is also modest in a second sense. Newton's arguments would show that H_D has higher probability than

specific alternative hypotheses that account for E^* (such as H_C, and possibly H_B), but making the stronger claim that H_D has the highest probability overall would require surveying and evaluating the likelihoods of other hypotheses. This would require a global awareness of alternative hypotheses that account for the relevant evidence, such as the modern account of stellar formation. The historical case discussed earlier illustrates how difficult it is to obtain this kind of knowledge. (Note that one can take the chance hypothesis to be the denial that the action of a designer, or any other hypothetical physical mechanism, yields the relevant evidence. While this understanding of the chance hypothesis would eliminate the need to survey alternatives, it amplifies the difficulties in evaluating $P(E \mid H_C)$.)

Despite its modesty, this line of argument faces (at least) three challenges regarding evaluation of the likelihoods $P(E^* \mid H_C)$ and $P(E^* \mid H_D)$. First, the Humean concerns regarding our ability to identify targets for further explanation prompt skepticism regarding whether the hypotheses in question yield well-defined likelihoods at all. Second, granting a successful response to the first challenge, we need a defense of the propriety of assigning probabilities in the cases of interest. It is straightforward to calculate the likelihood of Guildenstern's outcome on the hypothesis that it is the result of ninety-two independent tosses of a fair coin, but to what extent are likelihood calculations like Bernoulli's well grounded? Third, the fact that we exist in our solar system makes E^* more likely (independent of the truth or falsity of the relevant hypotheses), and we need to take this observational selection effect into account in assessing the evidential impact of E^*.

We confront first the challenge in trying to calculate likelihoods based on H_C, H_D. What do these hypotheses imply for specific evidential claims? Calculating $P(E^* \mid H_D)$ seems to require some understanding of the goals and abilities of the postulated designer. Consider the contrasting likelihoods assigned to the expected features of a watch discovered on the heath, as in Paley's famous example, if we knew the designer to be Jony Ive (designer of the Apple Watch), or instead Peter Henlein (credited with design of the first pendant watch in 1505). Uncertainty regarding the goals and resources of human designers pales in comparison to the uncertainty associated with a Designer. Elliott Sober (2008, sec. 2.12), echoing Hume, argues convincingly for a sharp contrast between the case of human design of artifacts and Design: in the former case, but not the latter, we have independent evidence for assumptions regarding the designer that make it possible to compute the relevant likelihoods. He also identifies the circularity in a common response to this objection: claiming the Designer preferred a solar system with the appropriate features begs the question, as it presumes H_D is true in order to specify the Designer's aims and resources. It is also not clear how to calculate $P(E^* \mid H_C)$, for the reasons discussed in the second section. At any given stage of theorizing, our best theories apparently leave various features contingent and subject to blind chance—but the line

demarcating such contingencies often blurs and shifts with further work. Features of the solar system Newton regarded as left to chance are now seen as natural consequences of the process of its formation. (Other facts cited in design arguments have had a similar fate—see, e.g., Sober (2003).)

Regarding the second challenge, the phrases in scare quotes above ("small," "large," and "arbitrarily chosen") prompt questions about the cogency of assigning probabilities. Making sense of the intuitive idea that an interval around the observed value is "small" compared to the range of values allowed by the theory is harder than it seems. Suppose we take it to be equally likely that α falls in any interval of the same width. This assumption cannot be maintained if α takes values on the positive real line or the full real line. There is no probability measure that assigns equal, nonzero measures to all intervals on the real numbers (or the positive real numbers). This is because the real numbers (or the positive real numbers) have infinite Lebesgue measure. If we introduce a normalized probability, any finite interval—whether intuitively "small" or "large"—is assigned zero probability (McGrew, McGrew, and Vestrup 2001; Colyvan, Garfield, and Priest 2005). Probability theory applied in this way does not capture the intuitive contrast between sensitive dependence on the value of α and relative independence from it.

The second issue regards what the "arbitrary choice" of the observed value of α means. What justifies the step from an ensemble of possible values, with the appropriate mathematical structure to introduce a measure, to the assignment of probabilities? If this is taken to be an objective probability, the "choice" of value is the outcome of some process—presumably not a literal throw at a dartboard. Assumptions about this process are needed to warrant assigning an expected value of α (see, e.g., Norton 2010). An analogous problem faces appeals to the principle of indifference. The principle enjoins us to use a uniform probability distribution. But this uniformity is defined with respect to some choice of measure, and we have to then ask how to justify the judgments implicit in the definition of a measure regarding which cases count as equal. Finally, even if the language of "choice" is merely metaphorical and the probabilities in question subjective—representing degrees of belief—there is still a further question regarding why these should be assigned in accord with a particular measure.

These complaints may seem like technical quibbles. Yet, these are exactly the questions that need to be answered to justify applying probabilities (and other tools from formal epistemology) in these cases, rather than taking claims about "unlikely" values as merely loose talk. Insofar as we treat fine tuning as involving the choice of a parameter, or initial state, from among a space of logically possible values, the source or justification of probabilities remains obscure. Physics (and much else!) comes into play in revealing the fascinating, multifaceted ways in which the complexity of the universe around us depends on parameter values. Yet, the justification of probabilities assigned to the parameter

values or boundary conditions themselves is a separate question. It is not clear how to justify a unique, well-defined probability distribution based on treating parameter values as freely chosen from among the real numbers. (This is a well-known objection; see Sabine Hossenfelder (2021) for a trenchant formulation.) A proposed resolution of the normalizability problem—restricting the allowed range of α to some compact subset of the real line (Collins 2009; Barnes 2018)—makes it even less clear how to interpret and justify the relevant probabilities. We are left with deep puzzles regarding how to justify probabilities, and what low probability implies, without appropriate resources to resolve them.[5] Later, we turn to a more detailed discussion of how probabilities can be introduced in relevant areas of physics and cosmology, which will help to clarify the contrast between these well-grounded probabilities and those appealed to in FTAs.

The third challenge concerns how to account for observational selection effects in evaluating the evidential impact of E^*. Suppose, generally speaking, that some claim E provides a useful contrast between competing hypotheses H, H', in the sense that they have very different likelihoods. An observation selection threatens to undermine the value of E, in the sense that the process of gathering evidence washes out this contrast. To reuse Arthur Eddington (1939)'s simple illustration: we cannot use a fisherman's daily catch as evidence regarding the population of fish in a lake, for types of fish smaller than the holes in the net. Treating the fish caught in the net as if they are a random sample of the entire population neglects the selection effect due to the size of the holes. In the case at hand, our existence is intricately connected to E^*—we could not observe a solar system with radically different features than our own. (More explicitly, when we include relevant facts about our existence in K, this objection holds that we will have $P(E^* \mid H_C \wedge K) = P(E^* \mid H_D \wedge K) = 1$, eliminating the differential boost.) Statisticians have methods to handle selection effects, such as analyzing in detail the biases introduced by the process of observation or sampling. But within the context of FTAs, the most relevant questions regard the extent to which an appeal to selection effects serves as an adequate explanation of the initially surprising features by in effect shifting from analyzing the probability assigned to some feature to the probability assigned to our observation of that feature within a larger ensemble of possibilities. These questions have prompted an ongoing debate in philosophy, which I do not have the space to pursue further here (but see, e.g., Friederich 2023, sec. 3).

An Alternative Formulation

Roberts (2012) defends an alternative reconstruction of the FTA,[6] relevant for my purposes because it makes particularly clear the contrast between the nature of probabilities in the FTA and those introduced in physical theories.

The leading idea is that the fine-tuning argument primarily concerns the discovery that physics requires specific parameter values and boundary conditions

to be compatible with observations that are in some sense "unusual" within the space of possibilities allowed by the laws. We should consider the impact of the evidence that fine tuning is required (*FT* in the earlier notation) rather than the specific values required (E^*) or the existence of life, as in the previous section. Newton's design argument in the General Scholium stems, after all, not from a sudden realization that life exists, or from measuring the specific orbital parameters characterizing different planets, but from his discovery of the apparent fragility of the solar system. The same is true for more recent discussions in physics and cosmology.

The alternative reconstruction still concerns evaluation of the likelihood of this evidence based on different hypotheses and aims to show that $P(FT|H_D) > P(FT|H_C)$. Roberts (2012) shows that this inequality follows from two plausible assumptions that can be formulated in general terms for a case of selecting an outcome X from among a space of possibilities. Suppose there is some feature of X that obtains that "makes it intelligibly choice worthy or aim worthy" in a way that demarcates it from among other possibilities (call this proposition A, for the "aim worthiness" of X). The assumptions hold that, first, $P(X \wedge H_D|A) >> P(X \wedge H_D)$—a Designer is much more likely to aim for the distinguished outcome; and, second, $P(X \wedge H_C|A) \approx P(X \wedge H_C)$—a "chancy" selection process ignores the features that distinguish outcome X. From these two assumptions, and Bayes's theorem, it follows that $P(A|X \wedge H_D) > P(A|X \wedge H_C)$—that is, obtaining an outcome, distinguished in some way from other elements of the space of possibilities, boosts the likelihood that the value was chosen by a designer sensitive to the relevant feature.

Roberts accompanies this formal analysis with a memorable thought experiment. Suppose we first observe a dart thrown at an unmarked wall, but how and why the dart was thrown is obscure. The dart's exact position does not help in determining whether it was thrown aimlessly (and perhaps recklessly) or by a skilled thrower aiming at a target. Next, we are given a pair of infrared goggles, leading to the discovery that the wall features a painted target, invisible to the naked eye. Suppose the dart has hit this preexisting target's bull's-eye. This fact then provides strong evidence that it was aimed rather than thrown at random. The crucial evidence that prompts this reevaluation is not the location of the dart itself but the fact that it is positioned in such an "aim-worthy" spot.

Roberts argues, to my mind convincingly, that this reconstruction more accurately captures current versions of cosmic fine tuning: it appropriately emphasizes, rather than the discovery that parameters have specific values, the significance of the fact that these values fall within a narrow range distinguished by being "life permitting." He further argues that this formulation avoids some of the challenges with the likelihood formulation discussed in the previous section. Assessing the two assumptions discussed earlier does not depend on introducing a probability distribution over the space of non-aim-worthy possibilities. The technical obstacles to introducing the probabilities reviewed earlier are then,

arguably, irrelevant to this formulation. The only plausible way of understanding the relevant probabilities are as credences, and the credences are plausible almost by definition (if we grant that it makes sense to treat the parameter values as determined by some kind of "choice" process): the key contrast is between a hypothesized choice by a Designer responsive to some "aim-worthy" feature and a "chance hypothesis" that ignores that same feature. Since the process by which physicists discovered that *FT* holds is not sufficient to guarantee its truth, concerns about selection effects do not undermine its evidential value.

Despite these advantages, this formulation renders Humean skepticism regarding our knowledge of a Desginer even more salient. What would be aim worthy for a Designer? Roberts makes the case that these assumptions hold even on a deflationary account, essentially only requiring an agent capable of drawing distinctions we recognize as intelligible. But on this formulation, the characterization of the Designer, and the Designer's choice, comes front and center. Roberts's goal was to provide a more accurate reconstruction of informal versions of FTAs, and in doing so he has made it clear that the relevant probabilistic claims have little to do with physics. The assessment of probabilities entirely concerns the Designer and their "choice" of parameter values or an initial state. The exchange between Roger White and Jonathan Weisberg (see fn. 6), for example, concerns whether it is more plausible for a Designer to choose "lax" laws that require supplementation by specific finely tuned parameter values or "stringent" laws that do not. I will not pursue these questions further here, but this formulation of the FTA makes it clear how little the answers to such challenges have to do with the assessments of probabilities assigned to parameter values or initial conditions within physics, to which I now turn.

Naturalness

For the last several decades, the need to fix apparent violations of "naturalness" has driven the search for extensions to the Standard Model of particle physics. In a "natural" theory, physics at low energy scales does not depend sensitively on physics at much higher energy scales—the low-energy physics decouples, in a sense that can be made precise. Naturalness is extremely appealing: insofar as it holds, ignorance of high-energy physics does not undermine efforts to describe physics at currently accessible scales, and it has played an important heuristic role in the development of the Standard Model. Major lines of research have been motivated by the need to resolve or eliminate apparent violations of naturalness, in particular the Higgs mass and the cosmological constant. Yet, the proposed remedies, such as the introduction of supersymmetry, have further consequences that have not been found experimentally. This failure has prompted active debate and reevaluation of naturalness over the past decade.

Clarifying the content and status of naturalness is a central problem in contemporary foundations of physics,[7] but my limited purpose here is to understand how naturalness relates to fine tuning. This requires a brief

overview of the relevant physics. Many fine-tuning advocates take the failures of naturalness to show that observed parameter values are incredibly improbable, leading to an extremely low likelihood $P(E^* \mid H_C)$. Luke Barnes's (2020) estimate of this likelihood as10^{-136}), for example, depends almost entirely on failures of naturalness.[8] Here, I argue that this assertion elides a significant difference between distinct notions of "naturalness" (a confusion abetted by the physics literature, unfortunately).

The primary idea of naturalness can be introduced in terms of renormalization group flows on theory space. One way of formulating quantum field theory starts with the Lagrangian L, which characterizes fields, their associated mass terms, and the interactions among the fields. The fundamental equations governing the evolution of the fields, and predictions for various observable quantities, can then be derived from a specific Lagrangian. We can also consider how the dynamics and predictions depend on the values of the parameters appearing in the Lagrangian, such as the mass terms and coupling constants in the interaction terms. This leads naturally to the idea of a theory space including all possible values of these parameters. Varying, for example, the mass term for one of the fields appearing in the Lagrangian would define a trajectory through theory space: a collection of Lagrangians with the same overall form but different mass values.

The renormalization group flow identifies a particularly significant set of trajectories. Renormalization refers to mathematical techniques that play an essential role in calculating observable quantities from a Lagrangian in order to control divergences. The initial Lagrangian includes "bare" parameters that have an unclear physical interpretation because they neglect the impact of interactions: for example, the mass term in the Lagrangian describes a particle as if it were propagating through empty space (the ground state of the quantum fields), even though the presence of the particle changes the ground state due to interactions. Initial attempts to calculate the effect of including interactions led to divergent quantities, such as infinite second-order corrections to the hydrogen spectrum in quantum electrodynamics. Eliminating these divergences required including counter-terms in the Lagrangian, such as shifting from the bare mass m_0 to a renormalized mass m_r: $m_0 \rightarrow m_r = m_0 + \delta m$, where δm is the counter-term. (Similar corrections have to be made to both the fields and the coupling constants.) This procedure tames the infinities that plagued calculations of observable quantities. In the best case, a finite set of transformations from bare to renormalized values eliminates all of divergences that arise at higher orders in pertubative calculations.

Crucially, counter-terms such as δm depend on a cut-off scale l introduced as part of this procedure.[9] The cutoff scale is usually taken to be at some energy scale much higher than all of the masses and interactions relevant to the observables of interest. Renormalization group equations follow from the further assumption that the values obtained for observable quantities are

independent of the choice of l. To obtain the same predictions after shifting cut-off scales, $l \rightarrow l'$, the values of the various parameters appearing in the Lagrangian have to make compensating changes. The required changes are characterized by a set of differential equations governing iterative changes in the parameters as a function of l; solutions to these equations specify trajectories through theory space. Lagrangians lying along any given trajectory describe the same low-energy physics.

The behavior of the renormalization trajectories through theory space reveals the relationship between physics at different scales. Consider, for example, a collection of theories within a large region of theory space, given a cutoff scale l, representing diverse, conflicting descriptions of high-energy physics. If they all flow towards the same point, L_0, as the cutoff l is lowered, the structure of L_0, as well as any observed quantities that can be calculated based on it, are remarkably robust to changes in high-energy physics. The theory L_0 captures the universal low-energy physics for the entire region of theory space we started with. The convergence of trajectories on a single low-energy theory makes manifest the decoupling between high- and low-energy physics.

We can also use this framework to understand failures of naturalness such as the Higgs mass. For a scalar field like the Standard Model Higgs, renormalization contributes a correction term to the mass that scales quadratically with the cutoff scale—that is, $\delta m_H^2 \approx l^2$. (The case of the cosmological constant is even more dramatic—it scales as l^4!—but there are further questions regarding how to treat the coupling to gravity (see Koberinski and Smeenk 2023).) As a consequence, the low-energy theory is remarkably sensitive to detailed features of the high-energy theory. The behavior is just the opposite of the case described earlier: trajectories through points that differ by an incredibly small amount in theory space, for a specified high-energy cut-off, diverge rapidly and lead to very different low-energy theories. If we set the cutoff at the Planck scale, the counter-term δm_H^2 would need to cancel out the bare mass to roughly thirty-four orders of magnitude to yield the mass of the Higgs measured by physicists at CERN (the European Organization for Nuclear Research). Note that this is not a case of an incorrect prediction or logical inconsistency. It is possible to choose a value of the bare mass that delicately cancels the correction term to yield the observed mass. But the need to do so violates the assumption of naturalness, which holds that details of the low-energy physics should decouple from higher energies rather than exhibit such sensitive dependence on the precise parameter values and structural features at the cutoff scale.

This conception of naturalness is thus directly linked to the autonomy of physics at different energy scales. The plausibility and heuristic value of naturalness stem from this connection, which also explains why the failure to find evidence for the most plausible mechanisms to save naturalness have generated such consternation. Yet, the fragility or sensitivity of low-energy

physics does not have such a direct link to fine tuning in the senses discussed earlier. The appeal to failures of naturalness by fine-tuning advocates relies on a distinct conception that has developed in the physics literature.[10] This alternative treats naturalness along the same lines as other discussions of fine tuning, namely, that a model is natural if the parameters appearing in it are probable given some measure over the space of possible parameter values. This account starts with a possibility space consisting of "all viable theories of low-energy physics," defined by varying not only the parameter values but also the symmetries and particle content of the theory. The aim is then to define a measure over this possibility space so that we can assess the probability of specific parameter values and support assertions regarding the likelihood of the observed parameter values if we imagine they are "chosen randomly."

These two notions of naturalness are conceptually quite distinct. This is clear from the different verdicts they render on one popular extension of the Standard Model, namely, low-energy supersymmetry (Williams 2019). If it were to succeed, this proposal would exemplify restoring naturalness in the first sense. Yet, there have been active debates regarding whether it is natural in the second sense of being statistically favored in the space of low-energy theories. The reason for the contrasting verdict stems from the fact that, despite the confusing use of a single term, evaluating naturalness in the two different senses concerns distinct aspects of a theory and how it is situated in theory space. The second notion of naturalness requires "global" knowledge of the entire space of possible low-energy theories in order to first delimit the relevant possibility space and then introduce a meaningful and well-justified measure over the space. By contrast, the first notion focuses on the sensitivity of a specific theory to variation in parameters, and this sensitivity can be evaluated based on "local" knowledge restricted to the theory under consideration. Obtaining global knowledge of theory space is far more challenging, as illustrated by ongoing debates regarding swampland conjectures, which hold that apparently viable low-energy theories are not in fact compatible with theories of quantum gravity. Whether these conjectures are true or not, they reflect the difficulty of delimiting the probability space, to say nothing of justifying a measure over that space. The sensitivity of a given theory to small variations does not, by contrast, require anything like this kind of structural knowledge of the entire theory space.

Fine Tuning of the Initial State

Standard Big Bang cosmology describes the universe as having expanded and evolved over 13.8 billion years from an initial state. Although there is no "first moment" of time, we can take the physical state at the expected boundary of the domain of applicability of general relativity as the "initial state." The initial state in the Big Bang model must have several features. It must be isotropic to

remarkably high precision, to be compatible with the uniform temperature of the observed cosmic background radiation; have total energy density extremely close to the "critical" density, such that measurements of the energy density now are still close to this value; have the density fluctuations needed to provide the seeds to form galaxies and other structures through gravitational enhancement; and so on. From the standpoint of general relativity, these features all trace back to the contingent distribution of mass-energy, and gravitational degrees of freedom, at early times. The dynamical equations govern subsequent evolution but place weak constraints on allowed initial states.

The Big Bang model uses the Friedmann-Lemaître-Robertson-Walker (FLRW) expanding universe models, even in describing the very early universe. These models have maximal symmetry: they represent the universe as a sequence of spacelike surfaces of constant curvature, with one of three possible geometries, labeled by cosmic time. This dramatically simplifies the complex nonlinear dynamics of general relativity. Yet, because of this striking simplicity, they differ from what one might expect to be a "generic" or "typical" cosmological model. Roger Penrose has estimated that the probability of choosing an approximately FLRW initial state "at random" from the space of possible states allowed by general relativity is 1 part in $10^{10^{123}}$, an extraordinarily small number (Penrose 1989, and in several subsequent discussions). He often accompanies this estimate with a figure illustrating a Designer who has to carefully pinpoint a region corresponding to the observed initial state, an incredibly small volume in the phase space of allowed models. A random choice (with the chance of being realized weighted according to phase space volume) would be expected to yield an equilibrium state. The difference between the maximal entropy—based on heuristic arguments from black hole thermodynamics—and the entropy of the observed state, far from equilibrium, is used to estimate the ratio of respective volumes, leading to the dramatic probability estimate.[11]

Does this special initial state cry out for an explanation? Physicists have considered different responses similar to those above. C. B. Collins and Stephen Hawking (1973) offered an anthropic explanation: to the question "Why is the Universe Isotropic?" (the title of the paper), they responded, "[B]ecause we are here," following theorems regarding the growth of anisotropies in cosmological models. (In slightly more detail: if galaxies and other structures necessary for the existence of life exist only in the subset of models that tend to become increasingly isotropic, we should not be surprised to observe isotropy.) Another possibility is to introduce principles that single out a unique initial state for the universe. There is also a modern analog of Bernoulli's approach. Alan Guth (1981) proposes that a modification of early universe dynamics, inflation, would make it possible for a "typical" early state to evolve into a state compatible with observations. This approach to explaining the observed early state of the universe has been enormously influential.

Formulating the problem this way depends on a particular understanding of the measure defined over the phase space of a dynamical theory. For a system described using classical mechanics, its possible states are represented as points in a phase space Γ. Each point in this space completely represents the system's properties. The system's dynamical evolution describes how its state moves through phase space over time and is given by a map $D(t)$: $\Gamma \rightarrow \Gamma$ (for elapsed time t). The phase space has a structure that supports an intuitive notion of "similarity" among these states. The topological structure of Γ allows one to define neighborhoods of a point, which can be thought of as the collection of nearby states reached by "arbitrarily small changes" to the system's properties. There are many distinct exact states compatible with the same value of large-scale properties. These properties can be thought of, roughly, as dividing the phase space Γ into regions.[12] Given the phase space Γ and the dynamics D, there is a preferred measure μ, known as the Liouville measure, that assigns an analog of "size" to different regions. According to this measure, subsets of the phase space stay the same size under the dynamical flow.

The measure μ enters into techniques for calculating properties of equilibrium systems in statistical mechanics. It is natural that a probability measure would play some role in such calculations to reflect our ignorance of the system's exact state. Consider a property Q that holds if and only if the exact state of the system falls within a region of phase space Γ_Q. Roughly put, the probability this property holds, in equilibrium, is given by the fraction of the available phase space (compatible with external constraints, such as constant energy) occupied by Γ_Q.

Some textbook discussions suggest that the "principle of indifference" justifies taking phase space volume to represent the probability that a typical system will have a particular property. But there are good reasons to reject this proposal. First, as briefly noted earlier, is the well-known problem that the "indifferent" assignment of probabilities depends on how the problem is described. Second, this proposal would offer a much more sweeping justification of probabilities than actually provided by statistical mechanics. Equilibrium probabilities can be reliably used to estimate, for example, the properties of systems that have been evolving over time scales that are long compared to the time required to relax to their equilibrium state, with dynamics that effectively "erase" the imprint of earlier states. Determining when equilibrium probabilities can be used relies on models of the approach to equilibrium. The details of how this justification works are subtle and still a subject of some dispute. But my claim—that dynamics plays an essential role in this justification—does not depend on these finer points.

Turning back to the case of cosmology, can we construct an appropriate phase space measure to evaluate fine tuning of the initial state? General relativity can be formulated as a dynamical theory, similar to that described earlier. In this Hamiltonian formulation, the evolution of the gravitational

field is described in terms of two variables: a spatial metric, which specifies the geometry on a three-dimensional surface, and the extrinsic curvature, which characterizes how the surface is embedded in the four-dimensional space-time. These quantities can be used to define analogs of position and momentum in the case of particle mechanics, leading to a phase space Γ.[13] Gary W. Gibbons, Stephen Hawking, and John M. Stewart (1987) carried out this construction for a specific type of cosmological model (FLRW models with a scalar field), leading to a phase space equipped with a measure μ_{GHS}.

Would this measure be of any use in determining what is a "typical" initial state? Does it give the probability that the actual universe has a particular property? I argued earlier that in the case of statistical mechanics, whether the measure can be successfully applied depends on the dynamics governing the approach to equilibrium. To the extent this problem is understood for this case, the results are not encouraging. For example, the dynamical relaxation time for large-scale gravitational degrees of freedom, such as density perturbations at cosmologically relevant length scales, is estimated to be on the order of the current age of the universe. Unlike the systems that statistical mechanics is typically applied to, there is thus no reason to expect the gravitational degrees of freedom on cosmological scales will have sufficient time to equilibriate, so that μ_{GHS} can be applied. (A more challenging obstacle arises because the phase space has infinite measure; as a result, probabilities depend upon the choice of a regularization scheme.)

Penrose has emphasized a distinct problem with taking any such measure to provide guidance regarding the initial state (see Penrose 1989, as well as Albrecht 2004, Wald 2006, and Wallace 2023). There are a wide variety of physical processes that exhibit an arrow of time. Although evolution in either temporal direction is possible according to the underlying laws, we only observe processes unfolding in one direction. The existence of such an arrow constrains possible initial states. A "randomly chosen" initial state, such as that supposed to obtain by many early universe theorists, is expected be in equilibrium (or close to it). But, as Penrose emphasizes, it is then not obvious whether thermodynamic asymmetry could arise. He argues instead that the initial state must have extremely low entropy, and hence small phase space volume. (This is often called the "Past Hypothesis.") He further proposes that quantum gravity may enforce this restriction on the initial state through an explicitly time-asymmetric fundamental law.

Although there is much more to be said here, this line of argument raises the following worry related to the FTA. The standard way of thinking about fine tuning the initial state may suffer from an illusion of contingency. How should we conceive of the space of "possible cosmological models" in order to pose questions about whether the observed universe is "improbable" or remarkable? If we take general relativity alone as the basis for defining the space of possible models, we will certainly overestimate how many models are possible, and hence incorrectly draw the line between contingent and necessary. We know

much more about physics and cosmology than what is captured in this space of models, and the requirement that a cosmological model can incorporate other aspects of physics will presumably restrict the space of possible models further. Rather than looking for new theories free of fine tuning, we should investigate whether what we already know imposes unexpected constraints on the space of possibilities. The need to impose the Past Hypothesis as a constraint on boundary conditions is simply the most striking form of this kind of restriction. Some form of the Past Hypothesis is needed to ensure the fundamental dynamics are compatible with macroscopic thermodynamic asymmetry, but there may be other restrictions imposed on the space of possibilities for similar reasons. What strikes us at first as an arbitrary, implausible, and finely tuned "choice" about features of the initial state ends up looking instead like a condition for the applicability of various aspects of physics.

The advocate of fine tuning may continue to press her case: Does the success of physics itself not cry out for an explanation? Perhaps, but this argument would not play the role I suggested for the FTA—namely, persuading an empiricist wary of this rationalist demand.

Conclusion

We have revisited a common theme in discussions of fine tuning: What does it mean to say the value of a particular coupling constant, or the initial state of the universe, is "improbable"? While we can treat the value of the parameter, or the initial state, as part of a larger possibility space, and construct a measure over that space, I have argued here that these ways of introducing probability do not have the same status as other probabilistic claims in physics. Recognizing the contrast between the distinct uses of probability undermines the attempts to use ideas from the foundations of physics to support the design argument.

In making this case, I have developed two related lines of argument. Contemporary advocates of the design argument have claimed to make common purpose with physicists concerned about naturalness and the remarkable fine tuning of the initial state. But I have argued that, first, despite several similarities, there are significant conceptual gaps between these discussions in physics and the probabilities invoked in FTAs. The attempt to ground such probabilities in physics fails. Naturalness in the sense of scale autonomy is conceptually distinct from statistical typicality; cosmological measures do not provide a way to assess the probability of the initial state, and there exists no unique, physically motivated measure over the possibility spaces appealed to in FTAs. Roberts's reformulation makes this disconnect explicit: the relevant probabilities concern not physics but rather claims about what a Designer can plausibly regard as aim worthy.

Second, what appears as fine tuning may be better understood as an illusion of contingency arising from incomplete theoretical understanding. The historical case of Newton and Bernoulli proves instructive: features of the solar system

that seemed to require delicate fine tuning lost their status as contingencies once they were embedded in a more complete account of stellar and planetary formation. Similarly, Juhl's insight about causally ramified phenomena suggests that sensitive parameter dependencies should be expected, not surprising, given the success of physics in providing integrated explanations across multiple domains. The dense web of constraints arising from requiring consistency across different areas of physics, from nuclear physics to chemistry to astrophysics, necessarily restricts what might initially appear as free parameters.

These arguments have further methodological implications. For physics, they suggest that unnaturalness and parameter sensitivity, while important for theory development, should not be interpreted as requiring other forms of explanation, such as design, or even necessarily pointing toward new physics that eliminates these features. The history of physics shows repeatedly that apparent fine tuning can result from taking too narrow a theoretical perspective. In addition, the failure of FTAs to justify probability assignments over parameter values does not undermine physics itself, which never required such assignments for its empirical success. More positively, the remarkable success of physics in explaining the complexity we observe should reshape our understanding of how physical theories work. In particular, we should not presume the laws bear the entire explanatory burden and regard the need to make substantive assumptions about parameters or initial conditions as revealing a failure or limitation. The intricate dependencies between fundamental parameters reflect the stringent requirements for a consistent, empirically adequate description of nature that provides an integrated account of a wide range of phenomena. The features needed to ensure this success may in fact reflect deeper structural connections that appear contingent only when viewed from the narrow perspective we have to adopt in developing our theories.

With regards to philosophy, this article began by asking whether FTAs can play a role in convincing empiricists, who do not share rationalist demands, of the need for design or some other form of explanation. FTAs fail to do so, insofar as they require prior metaphysical commitments about the nature of probability, possibility, and explanation that an empiricist need not accept. Nothing I have said settles the more fundamental question of whether the universe's properties ultimately require explanation beyond what physics provides. The more modest conclusion is that FTAs fail to make the case that we need other explanatory resources in a way that should compel those not already committed to such a conclusion.

Notes

[1] Rebecca G. Martin and Mario Livio (2015) find that the eccentricities of the planetary orbits and the distribution of masses is not particularly unusual, although the lack of planets close to the sun, as well as the lack of "super-Earths" (planets with two to 10 times the mass of the Earth), does distinguish our solar system from other observed systems. This assessment is challenging due to observational selection effects.

[2] For reasons of space, I almost entirely set aside the third response in the ensuing discussion, although the lines of argument I develop also challenge the motivations for a multiverse; see Simon Friederich (2021) and Jeremy Butterfield (2025) for more.

[3] How to interpret this probability is an important further question. The probabilities are often treated as credences, subjective degrees of belief in the truth of the propositions, or as objective chances, with H specifying a stochastic process that generates E, but there are other options.

[4] Within Bayesian confirmation theory, the relative import of the evidence E for two competing hypotheses is fully captured by the likelihood ratio $\frac{P(E|H)}{P(E|H')}$. This motivates the likelihood principle, but the principle itself is weaker than Bayesianism. See, e.g., Elliott Sober (2003, 2008) for a further discussion and defense of the likelihood principle and the likelihood formulation of the FTA.

[5] See Hans Halvorson (2018) for further discussion of the difficulties associated with justifying probabilities. He also argues that the commitments the defenders of the FTA make regarding the nature of the relevant probabilities imply that $P(FT|H_D)$ is extremely low, apparently contradicting their views regarding God's intentions and resources as a designer.

[6] Roger White proposed a similar view independently of Roberts in the course of an exchange with Jacob Weisberg (Weisberg 2010, 2012; White 2011).

[7] For philosophical discussions, see, for example, Hossenfelder (2021), Adam Koberinski and Doreen Fraser (2023), Koberinski (2025), David Wallace (2019), and James D. Wells (2019). Here, I mainly follow the analysis in Porter Williams (2015, 2019).

[8] Barnes formulates the likelihood as the probability of the observed values of the parameters conditional on "naturalism," defined as the denial of a multiverse and (implicitly) the denial that there is any agential choice involved in setting the parameter values, which I take to be roughly equivalent to H_C. In his evaluation of this likelihood, the cosmological constant and Higgs mass contribute a probability of 10^{-123}, with the remainder due to a number of other sources of fine tuning.

[9] The techniques described here include a regularization procedure used to control divergent quantities by changing the mathematical structure of the theory in some way. As a simple illustration, terms in perturbative calculations in quantum field theory often include loop integrals that diverge when integrated over momentum values from 0 to ∞. Introducing a finite cutoff at some scale l renders the value of the integral finite, and also a function of the scale l. Here, I am setting aside regularization procedures, such as dimensional regularization, that do not employ a cutoff; the conceptual and technical contrasts with different regularization procedures do not effect the overall argument here regarding the nature of probabilities.

[10] Here, I follow Williams (2019), who provides a more detailed analysis of the historical evolution of this second conception of naturalness. Although this second notion was initially proposed as a way of quantitatively measuring naturalness in the first sense, as Williams argues convincingly, this connection was attenuated and then broken in subsequent work.

[11] There is as of yet no definition of gravitational entropy to bolster this estimate, and significant obstacles to constructing one (see Earman 2006; Wald 2006; Wallace 2010).

[12] More precisely, we are assuming that the values of all large-scale properties are fully fixed by the exact state. A property P is then represented as a function on the phase space $f_P : \Gamma \to \mathbb{R}$. For an integer-valued function, the phase space is partitioned into regions that map to distinct values of P.

[13] There are various complexities here, described very clearly in Joshua S. Schiffrin and Robert M. Wald (2012). The phase space Γ for is infinite-dimensional, and that blocks the construction of a volume measure. This motivates considering a subset of solutions with fewer degrees of freedom; in particular, much work has focused on the FLRW cosmological models, which are highly symmetric (homogeneous and isotropic). The more subtle technical problem facing these constructions regards

dealing with constraints, to go from the phase space Γ to a reduced phase space $\tilde{\Gamma}$, representing the true physical degrees of freedom. The final step is to clarify the sense in which there is "time evolution" on $\tilde{\Gamma}$ and define a Liouville measure that is preserved under this evolution.

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Black Holes and Cosmology: Linking Physics, Philosophy, and Theology

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The boundary between physics and philosophy is often blurred at the frontiers of knowledge because the ideas involved are not initially testable. Interesting examples of this arise in the context of cosmology and black holes, with the nature of time and singularities—also topics on the physics/philosophy interface—providing an important link between these areas of research. The history of cosmology and black holes also connects physics and theology, pioneering papers on both topics having been written by priests. Some questions addressed by cosmologists clearly have religious implications and—although the theological aspects of black holes are less clear—the physics of black holes and cosmology are closely related.

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Introduction

The history of physics involves the growth of knowledge outwards to ever larger scales and inwards to ever smaller ones, with ideas at the smallest and largest scales often viewed as bordering on philosophy because they lack empirical confirmation. Physicists with an antipathy to philosophy therefore regard such ideas disparagingly. However, this may be unwarranted since physics had its origin in natural philosophy, and the physics/philosophy boundary steadily shifts as fresh data expand the domain of physics. The criteria for what is regarded as legitimate physics have also changed.

An interesting example of this arises in the context of cosmology, which involves both the macro and micro extremes. While cosmography studies the structure of the universe on the largest scales, where gravity dominates, cosmogeny studies the origin of the universe and involves arbitrarily small scales, where the other forces are important. So, cosmology is doubly prone to accusations of being too philosophical and has often struggled to maintain its scientific respectability. Indeed, it only attained the status of a proper science in 1915, when the advent of general relativity gave the subject a secure mathematical basis. The discovery of the cosmological expansion in the 1920s then gave it a firm empirical foundation, and the detection of the cosmic microwave background radiation in 1965 established the hot Big Bang theory as a branch of mainstream physics. Nevertheless, more conservative physicists still regard some cosmological speculations as going beyond proper science. One example concerns the current debate over the multiverse.

Another topic that straddles the boundary between physics and philosophy is black holes. These objects were predicted by general relativity in 1916, but Albert Einstein thought they were mathematical artefacts, and it was 50 years before there was observational evidence for their existence. Black holes from stellar collapse were the first to be confirmed, but there is now evidence for increasingly massive ones, with "intermediate mass" black holes being associated with gamma-ray bursts and "supermassive" ones powering quasars. There may also be "primordial" black holes that formed shortly after the Big Bang, and these could be much smaller than a solar mass. However, the smallest ones would have evaporated by now, so their physical reality is hard to confirm. There are also objects termed "wormholes" with even more exotic properties than black holes, and therefore beloved by science fiction, that some physicists would relegate to philosophy.

Speculations about both cosmology and black holes have involved an extrapolation of theory to ever larger and smaller scales, with the physics involved being very speculative at the extremes. While they both derive from general relativity, they may also play a role in some final theory that unifies relativity and quantum mechanics. For example, they both involve singularities and anomalies in the nature of time, raising issues that go beyond currently understood physics but are conceivably part of future physics.

There is also a boundary between physics and theology. Indeed, one might regard physics, philosophy and theology as forming three overlapping magisteria, as indicated in Figure 1a. However, most physicists are even more uncomfortable with theology than philosophy, with the physics/theology boundary sometimes being regarded as a battlefield. They might therefore prefer to regard these magisteria as forming a sequence, with theology being further removed from physics than philosophy, as illustrated in Figure 1b.

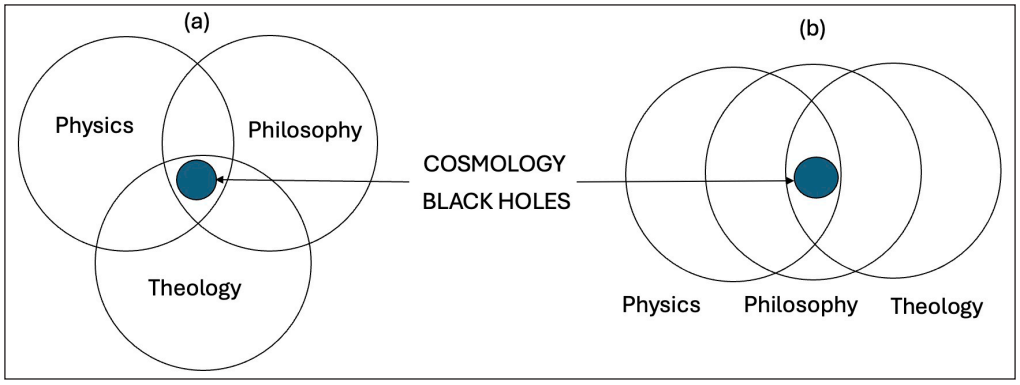

Figure 1: Illustrating how cosmological and black hole research provides an interesting interface between physics, philosophy, and theology (a), although one might also regard these three disciplines as forming a sequence (b).

This physics/theology boundary is also illustrated by black holes and cosmo logy. As regards cosmology, it was a Belgian priest (Georges Lemaitre) who introduced the idea of the Big Bang in 1931, and many questions addressed by cosmologists are traditionally regarded as being in the domain of religion. For example, all human cultures have their creation myths—a skeptic might claim the Big Bang theory is just the most recent one—and the earliest (prescientific) cosmological models explicitly reflected religious views. Of course, modern cosmologists would prefer to emphasize their links with science rather than religion. The theological aspects of black holes are not so explicit. However, it was an English priest (John Michell) who first introduced the idea in 1783, and we will see that black holes and cosmology raise similar conceptual issues. While the remit of religion goes well beyond the materialistic issues that are the focus of physics, in so much as religious and scientific truths overlap, they must be compatible.

This article first expands on the notion of the outward and inward journey of physics. Second, it discusses the link between cosmology, philosophy, and theology, introducing the concept of "metacosmology" to describe ideas on the border of cosmology and philosophy. Third, it focuses on the philosophical and theological aspects of black holes and shows that similar considerations apply. Fourth, it discusses time and singularities, these providing a link between cosmology and black holes and also residing on the physics/philosophy interface. Finally, it draws some general conclusions about the nature of science and the possible relevance of mind.

The Macro–Micro Connection and the Triumph of Physics

The outward journey into the macroscopic domain and the inward journey into the microscopic domain have revealed ever larger and smaller levels of structure in the universe, and these are summarized in the image of the cosmic uroboros in Figure 2. Planets, stars, galaxies, clusters of galaxies, and the entire observable universe are in the macroscopic domain; cells, DNA, atoms, nuclei, subatomic particles, and the Planck scale are in the microscopic domain.

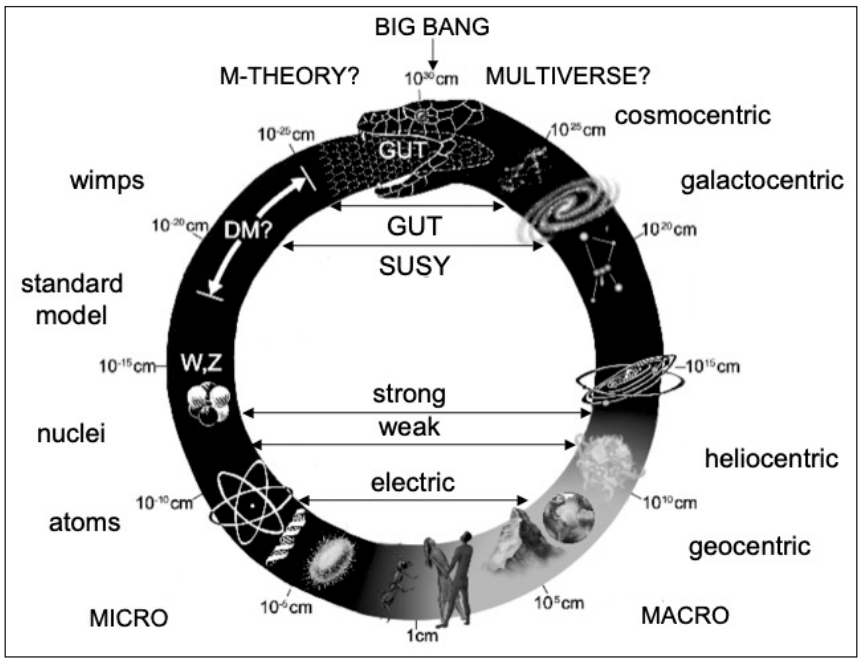

Figure 2: The cosmic uroboros summarizes the different types of structure in the universe. Also shown are the cross-links associated with various forces. The macro and micro scales merge at the Big Bang, where new physics may arise. From Bernard Carr (2014).

The numbers at the edge indicate the sizes of these structures in centimeters. As one moves anticlockwise from the tail to the head, the scale increases from the Planck scale (10^{-33}cm) —the smallest meaningful distance allowed by quantum gravity—to the scale of the observable universe (10^{27}cm). So, the cosmic uroboros is like a clock, with each minute corresponding to one of sixty decades in scale. Although humans are not at the center of the universe geometrically, Figure 2 shows we are at the center of the scales of structure. This is because physics shows that the size of a human—or any living being—is roughly the geometric mean of the Planck length and the size of the observable universe.

The inward and outward journeys have also revealed the forces that determine the nature of these structures. These forces link the macroscopic and microscopic domains and are shown by the horizontal lines in Figure 2.

For example, the "electric" line connects an atom to a planet because the force that binds the electron to a nucleus in an atom and the intermolecular force that binds solid objects are both electrical. The "strong" and "weak" lines connect a nucleus to a star because the strong force that holds nuclei together also provides the energy released in the nuclear reactions that power a star and the weak force that causes nuclei to decay also prevents stars from burning out too soon. The "SUSY" (supersymmetry) line connects certain types of particles to galaxies because these may provide the dark matter halos revealed by galactic rotation curves. The "GUT" (grand unified theory) line connects even smaller scales with galaxies and clusters because the density fluctuations generating these objects originated when the universe was hot enough for GUT interactions to be important.

So, progress of physics has connected the macroscopic and microscopic domains, revealing a surprising unity to the universe. The Big Bang is the ultimate macro–micro connection since it implies that the entire universe was once compressed to a tiny region of huge density. Since light travels at a finite speed, we can never see further than the distance light has travelled since the Big Bang; this is about 40 billion light-years, three times the age of the universe times the speed of light because the cosmic expansion helps light travel further. Near this cosmic horizon, more powerful telescopes probe to earlier times rather than larger distances, which is why the head of the snake meets the tail. This has led to an exciting collaboration between particle physicists and cosmologists. Although we now have a fairly complete picture of the history of universe after the first microsecond, our understanding becomes increasingly speculative at times earlier than that. In particular, we do not understand what happens as one approaches the top of the uroboros, where one encounters the multiverse on the macroscopic side and M-theory on the microscopic side.

The possibility of incorporating gravity into the unification of forces has led some physicists to proclaim that we are on the verge of obtaining a Theory of Everything. An intriguing feature of such a theory is the possibility of extra compactified dimensions. For example, Theodor Kaluza (1921) and Oskar Klein (1926) proposed that a fifth dimension could explain electromagnetism. Much later, "superstring" theory suggested there could be six extra dimensions, and the way they are compactified is described by the Calabi-Yau group. There were originally five superstring theories, but it was then realized that these are all embraced by "M-theory," which has seven extra dimensions (Witten 1995). In a variant of this proposed by Lisa Randall and Raman Sundrum (1999), the eleventh dimension is extended so that the physical world is a four-dimensional "brane" in a higher-dimensional "bulk." The development of these ideas is summarized in Figure 3. We have not yet detected these extra dimensions, as their effects only become noticeable at the top of the uroboros, where the energies are experimentally inaccessible.

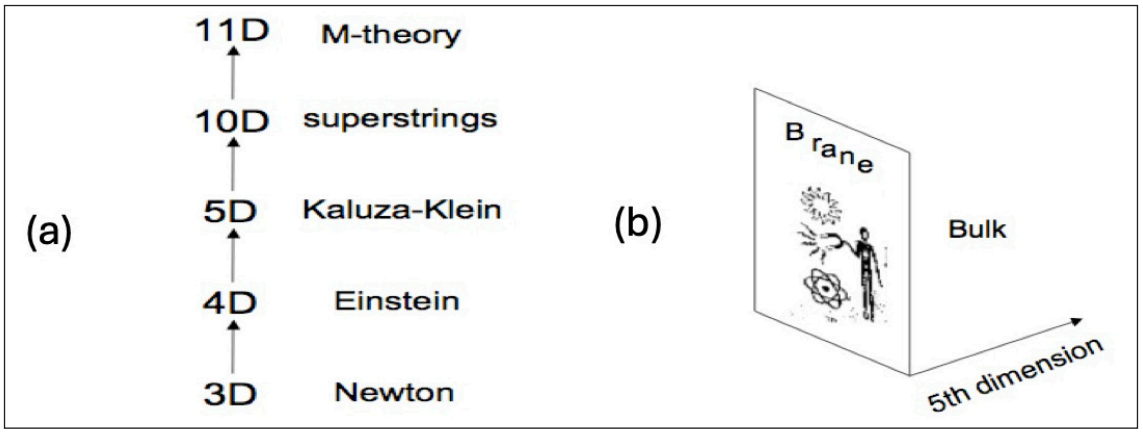

Figure 3: The sequence of extra dimensions invoked in modern physics (a), one of which is extended in brane cosmology (b).

The inward and outward journeys have also led to dramatic changes in our worldview. The outward one has led to shifts from geocentric to heliocentric to galactocentric to cosmocentric worldviews and the radical change of view of space and time required by relativity theory. The inward journey has led to atomic theory, in which the atom is mainly empty space; quantum theory, in which particles are not solid but smeared out everywhere; and a unified view of the forces of nature through higher dimensions. These developments have shattered our common-sense view of reality, which has led more conservative physicists to reject them as philosophy rather than science. However, as demonstrated in the following section, the growth of knowledge has also entailed a change in our view of the nature of science.

Cosmology and the Philosophy/Theology Interface

Cosmology is now regarded as mainstream physics, but it is different from other branches of science: one cannot experiment with the universe or observe other ones, and speculations about processes at early times depend upon theories that have not been directly tested. In particular, we are clearly stretching physics to its limits when we speculate about the multiverse, as we cannot see further than the distance light has travelled since the Big Bang (10^{25} m). Therefore, our belief in other universes might seem to be based on faith (like religion) rather than data, and some physicists are deeply uncomfortable with this proposal (Ellis and Silk 2014).

On the other hand, one might counterargue that the idea of other universes is consistent with the anthropic fine-tunings (Carter 1974; Carr and Rees 1979; Barrow and Tipler 1986). Although the multiverse proposal was not originally motivated by an attempt to explain these tunings, the two concepts are connected, for if there are many universes, the question arises as to why we inhabit this particular one, and our existence is clearly a relevant selection effect (Carr 2007).

A huge number of universes will allow all combinations of constants to occur, so at least some of them must be life-supporting. Many physicists therefore regard the multiverse as providing the most natural explanation of the tunings (Tegmark 2003). If one wins the lottery, it is natural to infer that one is not the only person to have bought a ticket.

Of course, some physicists do not recognise anthropic speculations as proper physics, and a similar dilemma arises in other cosmological contexts. Therefore, I use the term "metacosmology" to describe aspects of cosmology that might be regarded as bordering on philosophy, reflecting the overlap represented in Figure 1. There is also an overlap with theology. However, since most cosmologists are more averse to theology than philosophy, it may be appropriate to regard cosmology, metacosmology, and theology as forming a sequence, with metacosmology occupying a middle ground. This is illustrated in Figure 4, which might be compared to Figure 1b.

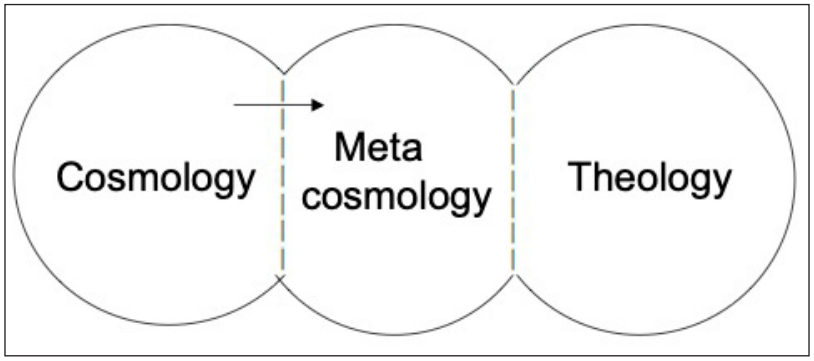

Figure 4: This illustrates the sequence from cosmology to metacosmology to theology. The arrow indicates that the cosmology/metacosmology boundary evolves, with today's metacosmology becomes tomorrow's cosmology. From Carr (2014).

The perspective shown in Figure 4 can be applied to three possible explanations of the anthropic tunings, as indicated in Figure 5. The first is the multiverse proposal discussed earlier. At least some physicists would regard this as scientific and therefore put it in the cosmology circle of Figure 4a. The second possibility is based on the notion that consciousness is required to collapse the quantum wave function, so that the universe does not exist until consciousness has arisen. Once it has done so, it may reflect on the Big Bang, thereby forming a closed circuit and bringing the universe into existence (Wheeler 1977). This explanation is in the metacosmology circle because consciousness is not usually regarded as being in the domain of physics. The third possibility, clearly in the theology circle, is that God or some beneficent Creator made the universe specially for us by carefully placing a "pin" in the space of coupling constants (Holder 2004).

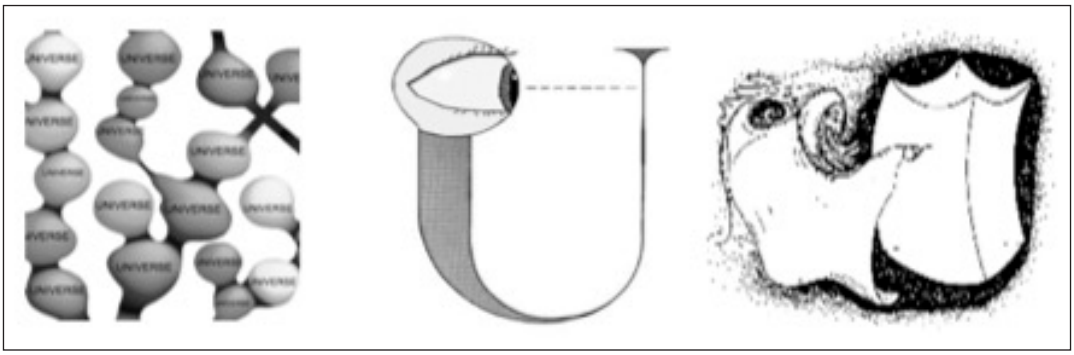

Figure 5: This indicates three explanations of the anthropic fine-tunings: the multiverse, consciousness collapsing the quantum wave function, and a fine-tuner. These relate to the three circles in Figure 4 and might be regarded as increasingly "wild" from a physics perspective. From Carr (2014).

These possibilities reflect increasing degrees of unpalatability for many physicists, with the A word (anthropic), the C word (consciousness), and the G word (God) being increasingly taboo. Even physicists uncomfortable with the notion of a multiverse would prefer it to invoking consciousness, but that is itself preferable to invoking God. On the other hand, all three explanations are logically possible, and the dichotomy between God and the multiverse is simplistic. While the fine-tunings certainly do not prove the existence God, nor would the multiverse preclude Him. I will not discuss such theological issues further here.

It should be stressed that the location of the cosmology/metacosmology boundary in Figure 4a is fuzzy. Some people would regard only a single self-created universe as proper physics—cf. the "universe in a nutshell" of Stephen Hawking (2001)—and dismiss the multiverse as philosophy. This issue was the focus of my dialogue with George Ellis, in which I defended and he opposed its scientific status (Carr and Ellis 2008). While conceding that the multiverse should *currently* be regarded as metacosmology, I argue that the cosmology/metacosmology boundary might eventually shift sufficiently for it to be reclassified. Perhaps one day we will create baby universes in a laboratory or visit other universes through wormholes!

The possibility that today's metacosmology may become tomorrow's cosmology is indicated by the right-pointing arrow in Figure 4. Indeed, the constant shift of the cosmology/metacosmology interface is illustrated by some historical examples:

- Even after Galileo had realized that the Milky Way is an assemblage of stars, the general opinion was that the region outside the solar system was beyond the domain of science. This is illustrated by comments of Auguste Comte (1835) on the study of stars: "We will never be able by any means to study their chemical compositions. The field of positive philosophy lies entirely within the Solar System, the study of the Universe

being inaccessible in any possible science." Comte had not foreseen the use of spectroscopy, which identifies chemical elements with absorption features in stellar spectra. New observational developments are hard to anticipate, so prescribing the limits of science is dangerous.

- Although general relativity gave cosmology a secure mathematical basis in 1915, resistance to extending physics beyond the galaxy continued for a further decade. Indeed, many astronomers did not believe there was anything beyond the galaxy. While Immanuel Kant had speculated as early as 1755 that some nebulae are "island universes" like the Milky Way, most astronomers adopted a galactocentric view until the 1920s. Indeed, Ernest Rutherford was so averse to the notion of the universe that he remarked, "Don't let me hear anyone use the word 'universe' in my department!" The controversy led to a famous debate between Heber Curtis and Harlow Shapley in 1920. The issue was only resolved when Edwin Hubble measured the distance to M31 using Cepheid variable stars in 1924.
- A few years later, Hubble found that all galaxies are moving away from us with a speed proportional to their distance. This had been predicted by Alexander Friedmann in 1922 using the equations of general relativity, but Einstein himself still believed the Milky Way *was* the universe and invoked the cosmological constant to make it static. He only changed his mind several years after Hubble's discovery. Georges Lemaître also derived Friedmann's equations and was the first person to infer that the universe started in a highly compressed state. This is now almost universally accepted, and Lemaître is known as the father of the Big Bang theory, but the reaction of some eminent contemporaries is revealing. In 1927, Einstein told Lemaître: "Your maths is correct, but your physics is abominable." Arthur Eddington (1931) rejected the Big Bang because it implied a fusion of physics and theology he found uncomfortable as a religious man: "Philosophically, the notion of a beginning of the present order of nature is repugnant to me." This is an example of tensions on the physics/theology boundary.
- Even after Hubble's discovery, cosmology was only accepted as a branch of mainstream physics when the cosmic microwave background was detected in 1964. Subsequent studies of this radiation have established cosmology as a precision science. Recent decades have brought two more important developments. First, observations of distant supernovae suggest that the expansion of the universe is accelerating (Riess et al. 1998; Perlmutter et al. 1999), although one expects it to slow down because of gravity. Some exotic form of "dark energy" is likely to be causing this, possibly related to the cosmological constant introduced by Einstein to allow a static model, leading to the concordance "LCDM" model. However, this is not certain, and many would prefer to relegate dark energy to the domain of metacosmology until we have determined its nature.

- Theory predicts that the early universe also underwent an accelerating phase—termed "inflation"—as a result of the vacuum energy (Guth 1981). This proposal initially seemed remote from observations, but then cosmic microwave background anisotropies were discovered by the cosmic background explorer satellite (Smoot et al. 1992) and subsequently measured with great precision with the Wilkinson Microwave Anisotropy Probe (Spergel et al. 2003) and Planck (2014). The fluctuations have exactly the form predicted by inflation, and the data determine various cosmological parameters very precisely. This illustrates how metacosmology can become cosmology because of new data.

Turning now to the theology boundary, cosmology addresses fundamental questions about the origin of matter and life, which are clearly relevant to religion, so theologians need to be aware of the answers it provides. In a sense, cosmology should provide the raw material from which religious belief is fashioned. Ellis (1993) uses the term "Cosmology" (with a capital C) to accommodate "the magnificent gestures of humanity," whereas cosmology (with a lowercase c) just focuses on the universe's physical features. On the other hand, astronomical revelations have sometimes clearly opposed theology. In particular, cosmology might appear to have removed the need for a Creator. The heavens have been progressively stripped of their divinity, and the extent of space is now so all-encompassing that there seems to be nowhere left for the God. Indeed, the more we understand the universe, from the vast expanses of the cosmos to the tiny world of particle physics, the more soul-less it seems to become.

Nor can we comfort ourselves with the delusion that humans are the focus of creation. The view that we have a direct link to the God (or Gods) who sustained the world was strongly challenged once science started to expand its domain of interest beyond the human scale. Indeed, the bigger the universe has grown, the more insignificant humans seem to have become, and modern cosmology might be regarded as the culmination of this process. The progress of physics has entailed our humbling and a loss of purpose. As Steven Weinberg (1977) says: "The more the Universe seems comprehensible, the more it seems pointless."

However, recent decades have seen a reversal of this trend. As discussed in detail elsewhere (Carr 2006), this comes from the unity, beauty, and comprehensibility of the universe, the anthropic fine-tunings and the realization that mind may be a fundamental rather than incidental feature of the universe. Although humans are insignificant from a material perspective (i.e., compared to the huge length and time scales of the cosmos), we are hugely significant from a mental perspective because, as emphasized by the cosmic uroboros, our minds encompass the entire universe.

Black Holes and the Philosophy/Theology Interface

According to general relativity, when the matter in a region of mass M is sufficiently compressed, gravity causes it to collapse to a black hole. If there

are no hidden dimensions, the size of the black hole (the Schwarzschild radius) is proportional to the mass ($R_s = 2GM/c^2$), so the resulting density is inversely proportional to M^2. This result also arises in Newtonian theory, as first pointed out by John Michell. The sun would need to collapse to a radius of three kilometers and a density of 10^{19} kg m^{-3} (i.e., 100 times nuclear density). Although the sun is not massive enough to do this, there are many situations in which black holes could form:

- The collapse of sufficiently massive stars that have finished their nuclear burning is the most likely mechanism for black hole formation. Stars smaller than $4M_\odot$ contract to white dwarfs, with collapse halted by electron degeneracy pressure. Those between $4M_\odot$ and about $10^2M_\odot$ continue to burn in a stable manner until an iron/nickel core is formed, when nuclear reactions can release no more energy and the core collapses. If the core is small enough, it becomes a neutron star, with the collapse halted by neutron degeneracy pressure; at the same time, a hydrodynamic shock is reflected from the core and ejects the star's envelope as a Type II supernova. However, if the core is large enough, collapse to a black hole ensues (MacFadyen et al. 2001).
- It is likely that the first stars to form were larger than 100 $M_\odot$. During their hydrogen and helium burning phases, they would have been dominated by radiation, leading to large-amplitude pulsations. However, the pulsations are dissipated by the formation of shock waves, and the resulting loss of mass allows the stars to survive for the few million years of their main-sequence phase. They go unstable when oxygen begins to burn in the core, since the temperature becomes high enough for electron-positron pairs to be generated (Fowler & Hoyle 1964). Smaller cores explode, while larger ones collapse and form intermediate-mass black holes. This occurs for stars with mass larger than about 200 $M_\odot$ (Woosley et al. 1982; Bond et al. 1984). The existence of such intermediate-mass black holes used to be regarded skeptically, but they are now believed to power ultra-luminous x-ray sources or gamma-ray bursts or be present in the middle of some globular clusters.
- The existence of much bigger stars has taken much longer to be accepted. Those larger than 10^5 $M_\odot$ are unstable to general relativistic instabilities, allowing them to collapse directly to "supermassive black holes" without undergoing nuclear burning (Fowler 1966). Such stars may possibly form in the centers of dense star clusters by dynamical relaxation. The stars would then be disrupted by collisions to form a single supermassive star from the newly released gas. Other routes to supermassive black hole formation may be coalescence of smaller black holes or accretion onto a single intermediate-mass black hole. Galactic nuclei have been shown to harbor supermassive black holes (Kormendy and Richstone 1995), with our own

galaxy possessing one of 4×10^6 $M_\odot$. Quasars, which occur during the early evolution of galaxies, are powered by even larger black holes of mass between 10^8 $M_\odot$ and 4×10^{10} $M_\odot$. supermassive black hole formation does not involve extreme physical conditions. For example, when a 10^9 $M_\odot$ object falls within its event horizon, it just has the density of water.

- Primordial black holes much smaller than a solar mass could have been produced in the early universe since the cosmological density rises indefinitely at early times, exceeding nuclear density within the first microsecond of the Big Bang. Comparing this with the Schwarzschild density implies that a primordial black hole produced at time t must have around the cosmological horizon mass $c^3t/G \sim 10^5(t/s)M_\odot$. Therefore, primordial black holes could span a huge mass range: from 10^{-5} g for those forming at the Planck time to 10^6 M_O for those forming at 10 s (the epoch of electron-positron annihilation). They may have formed from initial inhomogeneities or at some sort of cosmological phase transition (Zel'dovich and Novikov 1967; Hawking 1971; Carr and Hawking 1974). Those larger than 10^{21} kg (the mass of the moon) could have significant astrophysical consequences. For example, they could generate detectable lensing and dynamical effects or gravitational waves, and they might provide the dark matter (Carr et al. 2024).

In 1974, Hawking discovered that a black hole is not black after all but radiates thermally with a temperature inversely proportional to its mass (Hawking 1974). The temperature is around 10^{-6} K and hence unobservable for a solar mass. But it is 10^{12} K for 10^{12} kg, corresponding to the mass of a mountain and the size of a proton. Such a black hole, which could only be primordial, radiates 100 MeV gamma-rays. However, as it loses mass as a result of this emission, it gets hotter and emits increasingly energetic particles. A black hole evaporates completely in a time proportional to the cube of its mass. This is unobservably long for a solar mass hole (10^{66} y) but comparable to the age of the universe for 10^{12} kg. So, such primordial black holes would be completing their evaporation today, and smaller ones would have done so much earlier. Black holes below 10^{21} kg can be regarded as quantum since they are hotter than the cosmic microwave background, so accretion does not swamp their evaporation. When the black hole mass gets down to about 10^6 kg, the remaining energy is released in just a second, so the evaporation becomes explosive. These explosions are undetectable in the simplest picture, but according to James M. Cline and collaborators, primordial black hole explosions might explain some short timescale gamma-ray bursts (Cline et al. 1999).

Even if primordial black hole explosions are not detected, Hawking's work was a tremendous conceptual advance because it unified three previously disparate areas of physics: general relativity, quantum theory, and thermodynamics. So, it has been useful to study primordial black holes even if they never

formed. However, Hawking's theory is only a first step toward a full quantum theory of gravity, since his analysis breaks down when the density reaches the Planck value of 10^{97} kg m^{-3} because of quantum gravitational fluctuations in the metric (Wheeler 1955). An evaporating black hole reaches this density when it gets down to the Planck mass of 10^{-8} kg. A theory of quantum gravity would be required to understand the formation and evaporation of such an object. This might even allow black holes to leave stable Planck-mass relics rather than evaporate completely, in which case these relics could be dark matter candidates.

As indicated in Figure 3a, the existence of extra dimensions may come into play as a black hole shrinks towards the Planck scale. These are usually assumed to be compactified on the Planck scale, in which case their effects are unimportant for black holes heavier than the Planck mass. However, they are much larger than the Planck length in some models, with the consequence that gravity should grow much stronger at short distances than implied by the Newtonian inverse square law (Arkani-Ahmed et al. 2000). In other models, the extra dimensions are "warped" so that matter is confined to a 4D hypersurface (Randall and Sundrum 1999), as indicated in Figure 3b. In either case, the Planck energy (and hence the minimum black hole mass) is reduced. This has the important implication that black holes might be made in accelerators. For example, particles at the Large Hadron Collider reach an energy of roughly 10 TeV, which is equivalent to a mass of 10^{-25} kg. When two such particles collide, the likelihood of forming a black hole is very small in the standard model because this is much less than the Planck mass of 10^{-8} kg. However, if there are large extra dimensions, the Planck scale is lowered and the energy required to create black holes could lie within the LHC range. However, there is still no evidence for this.

Lee Smolin (1997) has pointed out an interesting link between black holes and cosmology. He argues that black hole formation can give birth to another expanding universe in which the fundamental constants are mutated. Our own universe may have been generated in this way (i.e., via gravitational collapse in some parent universe). Cosmological models with constants permitting the formation of black holes will therefore produce progeny (which may in turn produce further black holes, since the constants are nearly the same), whereas those with the wrong constants will be infertile. Through successive generations of universes, the physical constants will then naturally evolve to have the values for which black hole (and hence baby universe) production is maximized. Smolin's proposal involves very speculative physics but there is no need for the anthropic principle because observers are just an incidental consequence of the universe being complex enough to give rise to black holes.

Figure 6 locates the various types of black holes around the cosmic uroboros according to their radius, this being proportional to their mass for three spatial dimensions. The well-established astrophysical black holes are on the right. The more speculative primordial black holes are on the left and possibly extend

somewhat to the right. We have seen that black holes might be produced in accelerators if there are large extra dimensions.

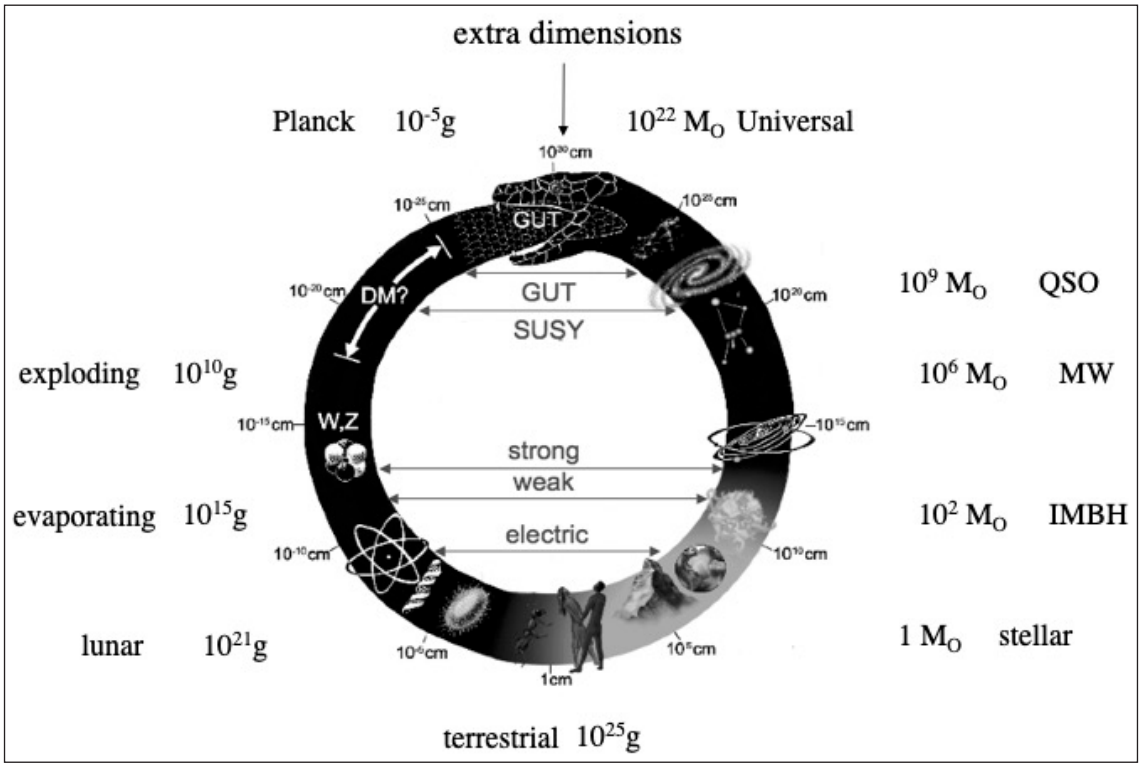

Figure 6: The cosmic uroboros, with black holes as a link between macro and micro physics. QSO stands for "quasi-stellar object," MW for "Milky Way," and IMBH for "intermediate-mass black hole."

This discussion shows that the history of black holes—like cosmology—has entailed an evolving boundary between physics and philosophy. Their exotic properties resulted in their initial dismissal by many physicists; even today, they border on philosophy at the smallest and largest scales because the relevant physics is untestable (cf. metacosmology). In the first case, we have the possibility of black hole production in accelerators, but the energies required may not be attainable; in the second case, we have the possibility that our universe emerged from a black hole in some parent universe (Smolin 1997) or some previous cosmic cycle (Carr and Coley 2011), but neither of these can be observed. The theological implications of black holes are less clear than those of cosmology. However, as discussed in the following section, there are many links between black holes and cosmology, so such implications may still arise indirectly.

Time and Singularities: Linking Black Holes and Cosmology

Black holes and cosmology share two interesting features, both of which might themselves be regarded as being on the philosophy/theology interface: the existence of singularities and anomalous time behavior. Classical physics

breaks down at a singularity, with the density perhaps becoming infinite there and the notion of space-time as a smooth continuum failing due to quantum gravity effects (Wheeler 1955). For a black hole, the singularity is at the center of the collapsing region and in the future (Penrose 1965); for cosmology, the singularity is associated with the Big Bang and in the past (Hawking 1966). There is a time anomaly in each case associated with both the singularity and the existence of horizons.

Let us first consider the time anomaly. The arena of Newtonian physics is three-dimensional space and time, both of which are absolute (i.e., the same for all observers). Newton's paradigm is also mechanistic in the sense that the future and past are implicit in present. This was emphasized by Pierre Laplace, who pointed out that an omniscient intellect, knowing the position and velocity of every object in the universe, could predict its future and retrodict its past. This was the start of a trend in physics for the passage of time (i.e., the present moment) to become incidental rather than fundamental. I return to this issue later.

The arena of Einstein's special relativity is four-dimensional spacetime, with objects being described by worldlines. Time is still different from space, because the distance in the time direction is mathematically imaginary, but there is no absolute present and moving clocks run slow. This time-dilation effect gives rise to the twin paradox, in which the twin who travels on a journey from Earth at high speed ages much less than one who remains on Earth. Time is more complicated in general relativity because space-time is curved by gravity, which means the duration experienced depends on the space-time path. Clocks run slow in a gravitational field, with the longest duration being experienced by a freely falling observer (e.g., an astronaut in orbit). The combination of special and general relativistic effects on time has been tested by flying atomic clocks on planes (Hafele and Keating 1972).

The effect of a gravitational field on clocks is most pronounced for a black hole. Time stops at the event horizon in the sense that an infalling astronaut appears to freeze there for external observers. However, it continues to pass in the astronaut's own experience, and they may see the whole future of our universe while falling towards the central singularity. By orbiting close to the black hole without falling inside it, the astronaut can travel arbitrarily far into the future relative to someone on Earth, but time travel into the past is more challenging. In special relativity, this would require tachyons (i.e., objects moving faster than light), which are probably precluded. However, it may be possible in general relativity due the existence of closed time-like curves. For example, these arise in a rotating universe (Gödel 1949) and can be generated by a rotating cylinder (Tipler 1974). One can also travel into the past through a wormhole—different from a black hole because there is no singularity—but only to a time after it was created (Thorne 1994). It is not clear whether this is physically realistic, since one needs negative energy to hold the wormhole mouth open

and the chronology protection conjecture (Hawking 1992) may preclude this. So, this notion is also on the physics/philosophy interface.

Another anomaly relates to the various arrows of time, each corresponding to some form of past/future asymmetry: cause and effect, birth and death, the cosmic expansion, retarded rather than advanced radiation, quantum collapse. There is also the psychological arrow, associated with consciousness, to which I return later. The puzzle is that the laws of fundamental physics are time reversible, apart from a tiny charge-parity violation. It is often argued that all these arrows arise from the second law of thermodynamics: entropy is always increasing because the environment is far from equilibrium. The most natural explanation for this increase is that the universe began in a low-entropy state (the Past Hypothesis), corresponding to the Big Bang, although the reason for this is not well understood.

This raises the issue of the origin of time. Aristotle argues there could be no beginning of time, whereas St. Augustine argues that God created time with the universe. Of course, neither knew about the Big Bang, which might seem to support the Augustinian view. However, some cosmologists envisage the universe undergoing a "big bounce" at some point in the past (e.g., due to a cosmological constant), so that the current expanding phase would have been preceded by a collapsing phase. One could even have a cyclic model with successive expansion and contraction phases (Tolman 1934), as arises in the ekpyrotic model (Steinhardt and Turok 2006). In this case, the universe would be eternal, supporting the Aristotelian view.

Let us now consider the singularity anomaly. Until a few decades ago, it was assumed that physics would break down at a singularity, but recent developments have changed this perspective. Indeed, quantum cosmology purports to describe the physics of the Big Bang itself. In this approach, one associates probabilities with three-dimensional spatial hypersurfaces and then determines the evolution of the universe by using a "sum-over-histories" calculation, which allows for all possible paths from some initial 3-space to some final one. The crucial development in this approach was the "no boundary" proposal of James B. Hartle and Hawking (1983). This removes the initial surface by making time imaginary (i.e., spacelike) at the Planck epoch (10^{-43} s after Big Bang). This adroitly sidesteps the usual philosophical problems associated with a moment of creation and means the universe can be created as a quantum fluctuation out of nothing (Isham 1988).

This brings in the link with theology. Pope Pius XII once proclaimed that the Big Bang theory supports the account of Genesis, since the physicist's description of creation must break down at a sufficiently early time. One might argue that God is required to "light the fuse." On the other hand, cosmology seems to provide an ever more complete description. For example, one could envisage the following dialogue:

> How did the universe originate? The universe started as a state of compressed matter. But where did the matter come from? The matter arose from radiation as a result of GUT processes occurring when the universe had the size of a grapefruit. But where did the radiation come from? The radiation was generated from empty space as a result of a vacuum phase transition. But where did space come from? Space appeared from nowhere as a result of quantum gravity effects. But where did the laws of quantum gravity come from? The laws of quantum gravity are probably no more than logical necessities.

Each step in this dialogue represents many years of theoretical work, but the implication is clear: no first cause is needed, because the universe contains its own explanation. There is an obvious connection here with the theological concept of *creatio ex nihilo*, and Willem B. Drees (1987; 1990) has explored the theological implications of quantum cosmology in some detail. Even if quantum gravity is necessary, it may not change the nature of the Big Bang predicted by classical theory, and the existence of Hilbert spaces etc. is perhaps more mysterious than the universe itself (Russell 1996). Also, there is a distinction between the question of *how* the universe came into existence and *why* it did so (Carr 2012). Even if the laws of quantum gravity are logically necessary, this need not imply there has to be a physical universe they describe.

We have seen that theological considerations may also arise in discussions of the anthropic tunings. The key issue here is whether some of the physical constants are contingent on accidental features of symmetry breaking and the initial conditions of our universe or whether some fundamental theory will determine them all uniquely (Rees 2001). The two cases correspond to the multiverse and single universe options, respectively. This relates to Einstein's famous question: "Did God have any choice when he created the Universe?" If the answer is no, there would be no room for the anthropic principle. If the answer is yes, then trying to predict the values of the constants would be as forlorn as Johannes Kepler's attempts to predict the spacing of the planets based on the properties of Platonic solids.

Another important problem on the interface of physics and philosophy is the passage of time. In the "block universe" of special relativity, nothing identifies the present moment (Savitt 2006). Past, present, and future coexist, so if consciousness is viewed as travelling along the world-line of the brain, as illustrated in Figure 7a, that motion itself cannot be described by relativity theory. Thus, the physical time of the outer world is distinct from the mental time of the inner world. This also relates to the problem of free will. At any experiential time, one feels that there are a number of possible future world-lines, as illustrated in Figure 7b, with one's conscious will selecting one of these. This implies that the past is fixed but the future undetermined. But this contradicts the mechanistic block universe. These failures of relativity theory

may also relate to quantum theory, because the collapse of the wave function to one of a number of possible states implies a basic irreversibility. Indeed, Figure 7b is reminiscent of the Everett "many worlds" picture (Everett 1957).

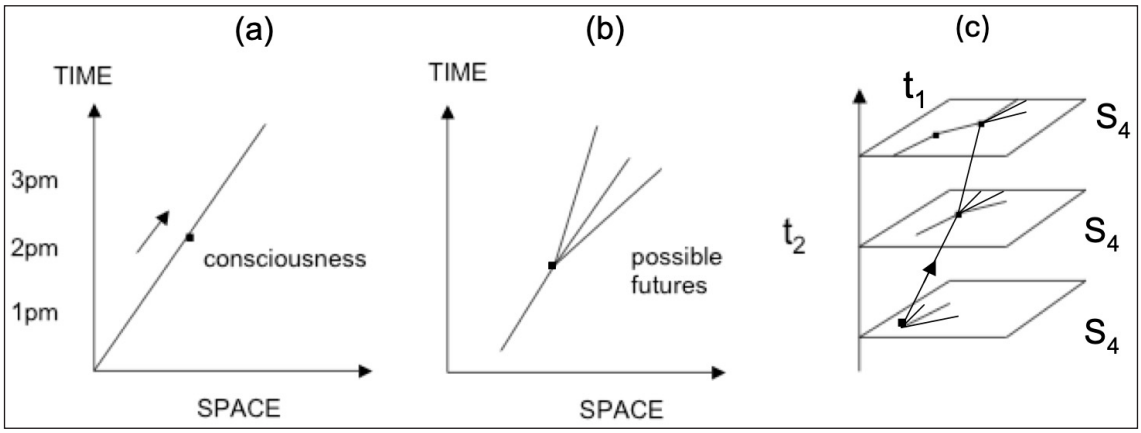

Figure 7: Illustrating two problems of consciousness from a relativistic perspective and their possible resolution: (a) the passage of time; (b) the selection of possible futures; (c) describing flow of conscious time with a second time.

The flow of time and collapse of the wave function seem to require what is termed a "growing block universe" (Ellis 2006). However, this does not describe the flow itself, so we need some extra ingredient. The philosopher C. D. Broad (1953) proposed that a second type of time (t_2), different from physical time (t_1), is required, and this is illustrated in Figure 7c. The progression of consciousness is then represented as a path in a five-dimensional space. At any value of t_2, a physical object has a unique future world-line in a mechanistic model or a number of possible world-lines in a quantum model. However, the intervention of consciousness or quantum collapse allows the future world-line to change or be selected from, respectively. So, the past in t_1 is uniquely prescribed, but the future is fuzzy. This interpretation may also be suggested by Figure 3b, in which space-time is viewed as a four-dimensional brane in a five-dimensional bulk. In the simplest case, the brane corresponds to flat space-time and is static. However, there is a cosmological case—called "brane cosmology"—in which the brane is curved and moves through the bulk (Maartens 2004), thereby generating the cosmic expansion. By identifying the extra dimension with t_2, one can link cosmology with an old philosophical problem (Carr 2021).

Concluding Remarks

In drawing conclusions about the physics/philosophy interface, I have stressed that the domain of legitimate physics changes with time, despite the resistance from more conservative physicists. The domain of legitimate physics is also sociologically determined. For example, one reason the anthropic principle has become more respectable in recent years is that it has been supported by

physicists with the stature of Steven Weinberg (1987), Martin Rees (2001), Leonard Susskind (2005), Alexander Vilenkin (2006), and Frank Wilzcek (2007). The growth of knowledge has also entailed a change in the nature of science itself. In this context, Weinberg (2007) has remarked: "We usually mark advances in the history of science by what we learn about nature, but at certain critical moments the most important thing is what we discover about science itself. These discoveries lead to changes in how we score our work, in what we consider to be an acceptable theory." Weinberg is referring specifically to M-theory and the multiverse, and the question of whether these proposals should be regarded as physics or philosophy is still contentious (Woit 2006; Smolin 2007). However, this insightful remark expresses a more general truth about the nature of science.

The current situation is very special in one sense: the macro and micro physics/philosophy boundaries in Figure 2 have now merged, with the very large and very small meeting at the top of the cosmic uroboros. Does this merging represent a transformation of physics—of the kind that tends to happen with every paradigm shift (Kuhn 1970)— or the completion of physics? I favor the former view and suggest that one feature of the new paradigm may be some reference to consciousness. This contrasts with the mainstream view that physics is concerned with a "third-person" account of the world (experiment) rather than a "first-person" account (experience), thereby excluding any reference to consciousness. On the other hand, some physicists are skeptical of claims of being close to a Theory of Everything when such a conspicuous aspect of the world is neglected. Thus, Roger Penrose (1994) predicts that "[w]e need a revolution in physics on the scale of quantum theory and relativity before we can understand mind," and Andrei Linde (2004) suggests that "consciousness is as fundamental to the cosmos as space-time and mass-energy."

Certainly, there are several hints from physics itself that mind may be a fundamental rather than incidental features of the universe, and I discuss this elsewhere (Carr 2006). A related point comes from contemplating the vast array of complex structures in Figure 2. These have evolved in the 14 billion years since the Big Bang, and the culmination of this complexity is the human brain. It is therefore curious that the most remarkable attribute of the brain—consciousness—is neglected by physics. It is also interesting that historically the uroboros represents the way in which we have systematically expanded our outermost and innermost limits of awareness through the progress of physics.

But how could the marriage of relativity theory and quantum theory at the top of the uroboros involve mind? I argue that most mental experiences involve some form of space different from ordinary physical space but maybe amalgamated with it. In particular, my proposal identifies this amalgamated space with the higher-dimensional space of M-theory (Carr 2021). After all, if the physical world is just a four-dimensional brane in a five-dimensional bulk,

as indicated in Figure 3b, one is bound to ask what else resides in the bulk, and the only other entities of which I am aware are mental ones. This also relates to linking the passage of time with brane cosmology.

Let us conclude with some remarks about the physics/theology interface. The requirement that physics and religion should be compatible has two important implications. First, it makes a "God of the Gaps" view very unattractive from a theological perspective, since it implies that religion is always on the retreat as physics advances. Second, since physics progresses by a series of paradigm shifts, each providing a better approximation to reality than the previous but none representing ultimate truth, one should be wary of religious claims of possessing absolute (God-given) truths. Indeed, one might expect religion (like physics) to undergo paradigm shifts, so that some questions addressed in the past (e.g., the location of heaven and hell) become meaningless. Clearly, none of the pro- or anti-divine arguments from physics are decisive, and the evidence provided by the study of the physical world will probably always be equivocal. Even those physicists who are mystically inclined have not usually based their faith on scientific revelations (Wilbur 2001). Some merely take the view that the existence of God is more consistent with their experience than the nonexistence of God (Priest 2016). This article has stressed the involvement of Christian priests in black holes in cosmological research, but this need not imply any specific theological agenda. The faith connection may simply be that they are exploring the richness of God's creation.

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A Universe Designed for Life?

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Why are the laws of nature so special ("fine-tuned") that the universe gives rise to intelligent creatures like ourselves, who can observe it and discover those laws? Is there really anything to explain, given that, if this were otherwise, we would not be here to pose the question? Can some better theory (a theory of everything?) do what is required by calculating the constants, so removing all free parameters from the equations? Alternatively, can the existence of a multiverse, a vast or infinite collection of universes, explain the specialness of this universe? Or, in the light of discoveries in modern cosmology, can we still speak of a divine mind behind the creation? These are the questions explored in this article.

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Our Life-Friendly Universe: Cosmic Fine-Tuning

The Big Bang theory of the origin and subsequent evolution of the universe is very well supported by the evidence, most especially the cosmic microwave background radiation, which is being studied in ever greater detail by successive satellite observations. One might also mention, besides the obvious evidence of expansion, the neat synthesis of light element production in the early universe and heavy element manufacture in stars. Nevertheless, the Big Bang presents us with some puzzles, not least the nature of the so-called dark matter and dark energy that compose 95% of the stuff of which the universe is made. The problem I wish to address in this article concerns the very special way in which the universe seems to be set up so that we can exist to observe it. Denoted by the term "fine-tuning," this specialness is manifested in two areas:

1. The initial conditions, very near to the Big Bang itself, must be very tightly constrained if the universe is to be conducive to life arising within it at some stage.
2. The constants embedded in the laws of physics, which are not derived from theory but determined empirically, must lie in very narrow ranges for the universe to be life producing. These constants tell us (a) how strong the fundamental forces of nature are, i.e., the forces of gravity, electromagnetism, and the weak and strong nuclear interactions; and (b) how massive the fundamental particles are, such as the electron, proton, and neutron.

In the literature, the term "anthropic principle," coined by pioneer in the subject Brandon Carter (1974), is widely used to denote these constraints on the laws of nature and the initial conditions at the Big Bang needed for our existence. The term has several variants and can be taken either as a tautology or a strong metaphysical claim, as helpfully discussed by Geraint Lewis and Luke Barnes (2016, 15–21). As a result, I shall generally use the term "fine-tuning" and use the term "anthropic" much more sparingly.

Examples of Fine-Tuning

Numerous examples of fine-tuning can be given, and I have chosen five to give the flavor of what we are talking about:

1. The parameter Ω is defined as the density of the universe divided by a so-called critical density that demarcates eternally expanding from re-collapsing universes. If Ω is even slightly less than one, the universe will expand forever; if it is even slightly greater than one, the universe will re-collapse under gravity. Martin Rees (1999, 88) informs us that, at one second from the Big Bang, Ω needs to be equal to unity to 1

part in 10^{15}. If Ω lies outside this range, the universe will either expand or re-collapse much too quickly for galaxies and stars to form. In either case, the evolution of life will be impossible. John D. Barrow and Frank F. Tipler (1986, 410) take the calculation back to the Planck time, 10^{-43} seconds from the Big Bang, when a quantum theory of gravity is needed to describe the universe. At that point, Ω needs to be equal to unity to the utterly remarkable accuracy of 1 part in 10^{57}. This is termed the "flatness problem" by cosmologists, since it implies that space-time is geometrically flat rather than positively or negatively curved.

Today, Ω is still very close to unity, so close that we cannot easily distinguish what the ultimate fate of the universe will be. It is also interesting that ordinary matter that we understand only comprises 5% of what the universe is made of. Another 27% is so-called dark matter. We do not know what dark matter is, but it needs to be there, otherwise galaxies will fly apart and not be held together by gravity. The remaining 68% is sometimes called dark energy and is also very mysterious. I shall come back to that shortly.

2. The philosopher Robin Collins (2012, 176–77; a slight update on 2003, 189–90) argues that the probability that intelligent life (what he calls "embodied conscious agents," ECAs) could arise in the universe would be reduced to zero if the strength of gravity were more than about 10^{9} times the actual value it takes in our universe. That sounds a large factor, but by comparison, the range that permits a universe at all is something like 0 to 10^{38} times the actual value (the latter would make gravity equal in strength to the strong nuclear force, the strongest of nature's four forces). An increase in the strength of gravity by a factor of a billion would imply that any land animal the size of humans would be crushed; even insects would require thick legs to support them, and no animals could grow much bigger. To reduce the planet's size so that its gravity were only a thousand times that of Earth—still marginal for the possibility of organisms with brain size comparable to ours—would imply a planetary diameter of about forty feet, utterly insufficient to sustain the appropriate ecological environment. If gravity were multiplied by a factor of 3,000, then planets could not last for more than a billion years, dramatically reducing the time for ECAs to evolve. Even a factor of 100 would have serious consequences for what ECAs could do technologically. Dividing 10^{9}, the absolute maximum value for ECAs to be viable at all, by the possible maximum value of 10^{38} yields a tiny probability of 10^{-29} for gravity to be fine-tuned (utilizing the "principle of indifference," admittedly philosophically controversial but adopted for reasons of simplicity in the absence of further information—see a justification for this in Richard Swinburne (2001, 115–19)). Within the narrow, fine-tuned range of values for observers to exist at all, we as

humans find a surprising bonus: extra fine-tuning that enables scientific discovery and technology—one of a number of such bonuses identified by Collins (2018, 89–107).

3. The chemical elements from which the planets and we ourselves are made are manufactured in the intensely hot interiors of stars by nuclear reactions. Foremost in this seminal work on stellar nucleosynthesis was the atheist Cambridge astrophysicist Sir Fred Hoyle. It was Hoyle who coined the term "Big Bang," not necessarily as a pejorative description, although he was strongly opposed to it. Indeed, he was one of a group of three Cambridge astrophysicists who produced the steady-state theory, describing an eternal unchanging universe, as an alternative to the Big Bang. Yet, Hoyle noted what he saw as very surprising connections between the origin of life, the building up of chemical elements in stars, and the laws of nuclear physics. According to Hoyle (1959, 64), these connections are either "random quirks" or signs of a super-intellect behind the universe.

   Hoyle discovered the particular "coincidences" required for carbon, vital for life, to be made in stars through the so-called triple-alpha reaction: the crashing together of three helium nuclei (alpha particles) to form a carbon nucleus. Because the intermediate element beryllium is extremely short-lived, Hoyle realized there had to be a particular energy level (a resonance) in the carbon atom for the reaction to work. His prediction of this energy level was verified by colleagues William Fowler and others in the United States. Hoyle also realized that energy levels in the oxygen atom need to be nonresonant so that oxygen can be formed by the addition of a further helium nucleus without destroying all the carbon in the process. These seeming coincidences can be related to the fine-tuning of the strong nuclear force, which is responsible for binding the particles in atomic nuclei, to within about 0.5% (see Oberhummer et al. 2000).

   Hoyle's (1981, 12) discoveries led him to remark that "a superintellect had monkeyed with physics, as well as with chemistry and biology, and that there are no blind forces worth speaking about in nature. The numbers one calculates from the facts seem to me so overwhelming as to put this conclusion almost beyond question." He said further:

> If this were a purely scientific question and not one that touched on the religious problem, I do not believe that any scientist who examined the evidence would fail to draw the inference that the laws of nuclear physics have been deliberately designed with regard to the consequences they produce inside the stars. If this is so, then my apparently random quirks become part of a deep laid scheme. If not, then we are back again to a monstrous sequence of accidents. (Hoyle 1959, 64)

Note that Hoyle (1950, 115) had formerly regarded religion as blind escapism.

There are numerous examples of fine-tuning that I shall not discuss in detail. Lewis and Barnes discuss many of them, e.g., delving deeper into atomic structure and asking what would happen if the up and down quark masses were different from their actual values. They cite Craig Hogan on this theme, in particular a plot of the down quark mass minus the up quark mass against the electron mass given a constant value of the sum of the quark masses. Only a tiny region of the parameter space allows for chemistry; outside this region, one has either a proton or neutron universe (Lewis and Barnes 2016, 46–53; Hogan 2007, 224–26). I shall mention some further highly significant examples later.

Cosmologist Paul Davies (2006, 3) expresses it thus: "Like the porridge in the tale of Goldilocks and the three bears, the universe seems to be 'just right' for life, in so many intriguing ways."

Is There Really Anything to Explain?

Some philosophers and physicists have argued along the following lines. We inhabit this particular universe with the apparently fine-tuned features described. If these features were not as they are, we would not be here to observe them. This is the "observer selection effect." We can only observe a universe that gives rise to our own existence. It follows that we should not be surprised to observe fine-tuned parameters that necessarily have to be as they are in order for us to exist in the first place.

Richard Swinburne (2004, 156–57) gives a helpful example against this argument. A madman operates a machine that shuffles ten packs of cards simultaneously. He tells his kidnapped victim that, unless the machine produces, and continues to produce for every draw, ten aces of hearts, the machine will explode so that the victim will be killed and no longer able to observe any draws. But when the victim does observe successive draws, his conclusion is surely that the machine is rigged rather than that there is nothing to explain, because he would not be around if anything else but ten aces of hearts were drawn.

John Leslie (1989, 13–14) has a similar example that also brings out the fallacy of thinking that because we can only observe "our" set of parameters, the need for explanation is thereby removed. A firing squad of fifty sharpshooters is lined up against me. If they all miss, it is not adequate to shrug my shoulders and reply, "If they hadn't all missed, then I shouldn't be considering the affair." My still being alive requires explanation—either the sharpshooters all deliberately missed or perhaps "immensely many firing squads are at work and I'm among the very rare survivors." I consider the latter possibility, which corresponds to the many-universes hypothesis, here.

Given that I am here to tell the tale, the (posterior) probability that the sharpshooters all missed is of course 1 (they certainly had to), but the prior

probability that they would all miss, on the basis of random chance, is very low indeed. The fact that they did so has a better explanation than chance, namely, they all deliberately missed. I actually doubt whether invoking a huge ensemble of firing squads around the universe makes any difference to my survival, and this may indicate a problem for the multiverse explanation—a point I shall return to later.

Nobel Prize-winning physicist Richard Feynman (1995, xix) once gave a public lecture in which a different issue was raised. He described how, on his way into the lecture, he observed a car in the parking lot with Tennessee number plate ARW 357: "Can you imagine? Of all the millions of license plates in the state, what was the chance I would see that particular one tonight? Amazing!" Of course, the *a priori* probability is very small, but this causes Feynman no problem, because any other car would be just as unlikely and just as insignificant. It just so happens that the car with number plate ARW 357 was the one that showed up. Similarly, according to some physicists, we do indeed live in a universe in which the laws of physics are ordered in a particular way, but if they were different in any number of equally improbable ways, we would not be here. Some cosmologists and philosophers believe that life is insignificant, a bit of froth on the surface of a meaningless universe, in which case alternative universes are just like alternative cars showing up in the car park. An example of an author who takes a view akin to this is M. C. Bradley (2002), who does not see life as significant in the sense of having objective value and therefore supports the car park analogy.

This argument is vulnerable at two points (Holder 2004, 43–47; 2013, 100–4). First, surely most of us would regard life, and in particular our own existence, not as mere froth but, contra Bradley and others, of real significance and value. For this reason, the universe that actually exists is in a different category than the vast majority of universes that do not possess this value. Second, we can provide an explanation, namely the theistic hypothesis, for why, of the vastly many universes that could exist, one of meaning and value actually does.

I had a schoolmaster, Mr. A. R. Williams, who collected classic cars. He was born on May 3, 1907. One day, a 1920 Wolseley Fifteen Tourer with the number plate ARW 357 turned up in the school car park. The car and number plate are highly significant, and there is a perfectly rational and superior alternative explanation to pure chance for this particular car to turn up.

As another example, suppose I shuffle a pack of cards and deal them out on the table. Suppose they come out in the order: ace, king, queen, all the way down to the two of clubs, then the same for diamonds, hearts, clubs, and spades. This hand is in fact just as improbable as any other. Indeed, it has about a 1 in 10^{68} chance of of occurring. It seems to me, however, that there is a better

explanation in this case than just sheer luck. If I were a card sharp, it would not be in the least surprising that I could produce such a hand, and it would be more rational to suppose that I am a card sharp than to believe the outcome to be entirely due to chance.

The difference between the hand dealt and the vast majority of other hands is that this one is meaningful—indeed, it displays a perfect pattern. Hence, it makes sense to look for an explanation beyond mere randomness. Added to which, there is a straightforward explanation available.

It is similar with the universe. I would argue, despite philosophical controversy surrounding the objectivity of value, that this universe possesses precisely that, namely, objective value. It is not just "any old universe." The vast majority of universe configurations obtained by changing the parameters by the smallest amount are completely dead and boring. They are almost entirely devoid of meaning and value. This universe is shot through with meaning and value because, at least in one small part of it, it has produced creatures with rational powers to understand it and appreciate its beauty and the capacity to exercise moral responsibility. The universe has in a sense "become aware of itself." Moreover, many scientists see objective value exhibited in the universe (why else study it?). Paul Davies (1992, 214) says this: "My own inclination is to suppose that qualities such as ingenuity, economy, beauty, and so on have a genuine transcendent reality—they are not merely the product of human experience—and that these qualities are reflected in the structure of the natural world."

Explaining the Fine-Tuning

If the parameters of physics and cosmology were not fine-tuned, the universe would be lifeless. This fact demands an explanation. The theist has a ready-made one: God designed the universe this way, intending that life would arise. More than this, God intended the existence of rational creatures possessing free will who would be able to explore his handiwork and relate to him.

Of course, this explanation is not universally popular. The idea of divine design is anathema to scientists and philosophers of an atheist persuasion. Thus, it is important to consider possible alternatives.

Two main options for avoiding the design inference have been suggested:

1. Perhaps there is a better, more fundamental theory from which the constants can be derived. This may be what has been dubbed a "theory of everything," an ultimate theory that unites general relativity and quantum theory. Einstein (1949, 63) himself, having argued that one could express the basic equations of physics using only "dimension-less constants," went on to remark:

> Concerning such I would like to state a theorem which at present can not be based upon anything more than upon a faith in the simplicity, i.e., intelligibility, of nature: there are no *arbitrary* constants of this kind; that is to say, nature is so constituted that it is possible logically to lay down such strongly determined laws that within these laws only rationally completely determined constants occur (not constants, therefore, whose numerical value could be changed without destroying the theory).

A similar argument pertains to the initial conditions: perhaps they too can be predicted from a more fundamental theory (see later discussion of inflation).

2. In total contrast is the suggestion that not only *can* the constants and initial conditions take different values from those we observe, but they actually *do* take different values in other existing universes. This is the multiverse hypothesis. The implication is that in a sufficiently comprehensive multiverse, while the vast majority of universes will be life-averse, a set of parameters within the bio-friendly region of parameter space is nevertheless bound to be instantiated. This is supposed to remove the surprise we find when we consider fine-tuning.

Option 1 can be interpreted in two ways. The first is to say that, given our laws of nature, the constants that go into them can be calculated from a more fundamental theory and hence must take the values they do. From the point of view of fine-tuning, this simply transfers our astonishment at the constants taking just the right values for life to the new fundamental theory itself. Why is that particular theory instantiated in the universe?

The second, more radical interpretation of option 1 goes further to say that there is only one set of self-consistent laws, and the physical constants are also determined to be what they are. There is then no alternative configuration for the universe and, provided it exists, it must necessarily exist as it does.

If this is the case, we are presented with a huge puzzle, namely, why is the only possible universe bio-friendly? In our imaginations, we can think of vastly simpler universes, perhaps comprising just a few isolated particles. How is it that the only self-consistent possibility is the universe we inhabit?

The puzzle may be helpfully elucidated by an analogy. Philosopher Peter van Inwagen (1993, 137–38) postulates dividing a square into a million smaller squares by dividing each side into a thousand equal lengths. He then supposes that we assign the first million digits of the decimal part of π to the million small squares, going left to right and line by line from top to bottom. Finally, we assign a color to each of the numbers zero through nine and paint each of the small squares with the color corresponding to the number assigned to it.

Suppose the result of this procedure were a stunningly beautiful painting. Surely this would be totally amazing and unexpected. Yet, it would be such by necessity, given that the digits of π are necessarily what they are. Somewhere in the infinite, unrepeating decimal part of π there will be a picture-generating million-digit sequence, but it would be truly astonishing if that were the case for the first million. I would not want to place a bet on it turning out so. It is similar for a universe, which is necessarily the only possibility, to be life-generating. To quote van Inwagen (1993, 137): "To me, in my ignorance, it seems as unlikely that a 'cosmos design' that was the only possible cosmos design should turn out to be life-permitting as that π should turn out to be picture-generating."

Option 2, the multiverse hypothesis, proposes that the constants and laws of physics can indeed be different from those pertaining to our universe. Not only that, they are different in different existing universes, and this fact is supposed to render it more probable that one or more bio-friendly universes exists. One possible interpretation of this, analogous to the second interpretation of option 1 mentioned earlier, would be to say that there is a unique self-consistent set of laws that governs the multiverse and that the laws and constants for the individual universes, including our own, are what they are out of necessity. I would argue that the astonishment I expressed earlier for the unique single universe described would transfer in this case to the multiverse itself.

In practice, it would appear there are different ways of getting a multiverse, and this creates a puzzle. What determines which of the possible multiverses exists? Stephen Hawking (1988, 174) famously asked, "What is it that breathes fire into the equations and makes a universe for them to describe?" We now need to know which sets of equations have fire breathed into them, how many universes are generated, and how these choices are determined.

Cosmologist Max Tegmark (2003, 40–51) answers this conundrum with the bold proposal that all mathematical structures exist physically (his Level IV multiverse). Our universe with its particular mathematical structure is of course then bound to exist. This is, however, pure metaphysical speculation. It is not an answer that can be derived from science, which is how I understand a multiverse to be intended by atheists who invoke one to explain fine-tuning. Of course, theism is also a metaphysical explanation, though I argue that it is a better one. Moreover, the Level IV multiverse presents its own difficulties. Simply to formulate "all mathematical structures" is problematic. Furthermore, we can see that not everything that is possible can be physically instantiated, e.g., I am currently writing about cosmic fine-tuning, though it would be perfectly possible for me to be watching TV instead. There could be copies of me in other universes who have made different choices, but I have made this particular choice.

A Brief History of Modern Cosmology

The Big Bang theory is well established but presents a number of problems in its simplest form, not least the fine-tuning. In 1979, cosmologist Alun Guth (1997) proposed a theory called "inflation" as a solution. According to inflation, the universe expanded exponentially rapidly for a tiny fraction of a second after the origin—more specifically, by a factor of something like 10^{26} between roughly 10^{-35} and 10^{-32} seconds from the beginning. One effect of this is that the density is driven ultra-close to the critical value, thus solving the flatness problem. Inflation also implies that all parts of our visible universe have been in causal contact, thus explaining the temperature uniformity of the microwave background across the universe—this is to solve the so-called "smoothness problem."

This would seem to be positive. However, it turns out that the fine-tuning is not eliminated, just put up a level into inflation itself. If inflation has to be fine-tuned, it can hardly be regarded as a solution to the fine-tuning issue.

The consequence of this is a profusion of inflation models—Paul Shellard (2003, 764) counted 111 back in 2003, wryly noting that "[t]he most difficult model to rule out may well be supernatural inflation." Of particular interest is the shift from option 1 to option 2 represented by Andrei Linde's chaotic and eternal inflationary scenarios proposed in the 1980s. In chaotic inflation, different regions of the universe experience different amounts of inflation, with some regions growing large enough to produce galaxies, stars, and observers. This goes a step further in eternal inflation, with subregions of inflating domains themselves inflating so that we get regions giving rise to subregions giving rise to sub-subregions *ad infinitum*. These regions and subregions, etc., in which density and temperature and even the forces and constants of nature will vary, can be regarded as the different universes comprising a multiverse (Barrow 2005, 193–98).

Inflation is not yet the much sought-after theory of everything. That is what is required to describe the first 10^{-43} seconds of cosmic history. To do so, the theory must unite the fundamental forces of nature, i.e., it must combine Einstein's theory of gravity, the general theory of relativity, with quantum mechanics, which via the standard model describes the other three forces.

That theory is as yet unknown. A leading candidate has been string theory, which posits that the fundamental constituents of matter are no longer point-like particles but ultra-small objects that behave like vibrating strings. The particles we observe in nature are the product of different vibrational states of the strings. Unfortunately, the theory is only mathematically consistent in more than the usual four space-time dimensions. Since we do not observe these extra dimensions, they rather mysteriously have to be "compactified" or curled up so small as to be beyond detection in our most powerful particle accelerators.

Originally, string theory could be regarded as a form of option 1, since the aim was to calculate the properties, such as mass and charge, of all the fundamental particles. A serious problem has been the complete lack of observational or experimental evidence for the theory, whence the motivation has shifted to its mathematical elegance. Some physicists still pursue the theory with its original aim, though an interesting development has been the discovery of a small positive value of the cosmological constant, which I discuss later, and which seems to require option 2. Since nothing has been calculated in practice, some string theorists, notably Leonard Susskind (2006), have in any case switched to option 2. Interestingly, Susskind (2006, 12–13, 126–30, 288–89, 377, 379) denies string theory's elegance and likens it to a "Rube Goldberg machine," i.e., a "Heath Robinson contraption" in English English.

Susskind and his colleagues talk about the "landscape of string theory." They find that there is not just one but many solutions of the theory, anywhere between 10^{100} and 10^{1000}, with 10^{500} as the best estimate (Woit, 2006, 242; Susskind 2006, 21). These solutions represent possible universes, so questions arise as to how they are instantiated, how the "landscape" is populated, and how the possibilities become realized. The neat answer is that they are generated as the bubble universes of eternal inflation (Davies 2006, 192–94). It should be acknowledged that if there is a theory that in some sense naturally gives rise to many universes, then the plausibility of a multiverse is enhanced. However, this whole idea remains at the level of speculation and is controversial among physicists and philosophers. While the theistic hypothesis is no doubt regarded as speculative and controversial by many, I shall go on to explain why I see it as explanatorily superior to an atheistic multiverse.

There are a number of other ways of conceiving a multiverse than by inflation and string theory. Given the speculative nature of these proposals and inability to adjudicate them by means of observational evidence, a remark attributed to Russian physicist Lev Landau would seem apposite: "[C]osmologists are often in error, but never in doubt." The next section expands on some of the difficulties that arise from the multiverse proposal.

Problems with the Multiverse Hypothesis

Of course God could create as many universes as he likes, and there are Christian philosophers and scientists who are happy to affirm that he did create a multiverse. However, it seems to me that there are many problems with the idea, and I now enumerate what I regard as the most significant of them (Holder 2004, 113–29; 2013, 130–54). Philosopher of science Simon Friederich (2021) has given a detailed, balanced account of some these, not least the issue of empirical testability, in a recent book.

1. I have stated that the multiverse proposal is speculative. It is notable that there is division even among string theorists over the existence of the landscape. Nobel Prizewinner David Gross (2005), a string theorist himself, is a skeptic regarding the multiverse, as are Gordon Kane et al. (2000), who go back to option 1, which they believe evades anthropic arguments. Tom Banks (2004; 2012) too is skeptical about the landscape, arguing that it is illusory to regard the different universe solutions as arising from the same theory.

   It is important to recognize that we cannot, even in principle, observe the other universes proposed by multiverse models since they are not in causal contact. The lack of empirical testing leads some to doubt that the multiverse idea is science at all. Thus, George Ellis and Joe Silk (2014) believe that the very integrity of physics is at stake where string theory and the multiverse are concerned.

   Cosmologist Martin Rees (2000, 138) numbers himself among "cautious empiricists" who feel "more at home" contemplating an era of the universe's history beginning at about 10^{-3} seconds from the beginning when we have known physics and empirical support (it is when the light elements are manufactured). Elsewhere, however, Rees ([2001] 2002, 164) opts for a multiverse in preference to providential design while admitting that his choice is "a highly speculative one" and "can be no more than a hunch." The physics of multiverses takes us back, not to 10^{-3} seconds from the beginning, but to 10^{-35} seconds (inflation) or even 10^{-43} seconds (string theory). Rees's normal scientific preference for empirical evidence appears to be trumped by his ideological preference as an atheist. Although Rees ([2001] 2002, xi) recognizes that the ultimate question of why there is anything at all lies beyond science and leaves that to philosophers and theologians, he nevertheless favors a multiverse so as to avoid divine design. String theory pioneer Leonard Susskind is similar. The question of why there is something rather than nothing is untouched by the theory, but the landscape does explain the fine-tuning without the need to invoke a creator (Susskind 2006, 380).
2. There is a question mark over whether actual infinities can exist in nature. Cantorian set theory was developed to handle different degrees of infinity consistently in the abstract realm of mathematics. However, when we consider the possibility of infinite numbers of physical entities existing in the real world, we come up against some well-known paradoxes. For example, Hilbert's Hotel has an infinite number of rooms and all of them are full. Nevertheless, infinitely many new guests can easily be accommodated! Simply move the guest in room 1 to room 2, the guest in room 2 to room 4, etc., and in general the guest in room n to room $2n$ for every value of n. There is now room for another infinity of guests

since, while all the even-numbered rooms are full, all the odd-numbered rooms are vacant. It was the existence of paradoxes, famously Bertrand Russell's paradox concerning the set of all sets that are not members of themselves, that led mathematician David Hilbert ([1926] 2012, 191) himself to state that "the infinite is nowhere to be found in reality, no matter what experiences, observations and knowledge are appealed to."

Suppose now that the parameters of physics vary across an infinite number of regions. Identical and near-identical copies of me will then arise, and arise an infinite number of times. Some of them will be writing about multiverses, others will be watching TV instead. It is quite bizarre even to begin to think about this. Among the issues raised is that of free will. Some cosmologists and philosophers rule out a multiverse with infinitely many member universes in light of the paradoxes (e.g., Ellis, Kirchner, and Stoeger 2004; Stoeger, Ellis, and Kirchner 2018; Copan and Craig 2004, 200–11; though the main interest of the latter is the impossibility of an infinite temporal regress).

3. When comparing competing hypotheses that are all compatible with the data, scientists would normally adopt that which is simplest. As William of Ockham put it in the fourteenth century, "[e]ntities should not be multiplied beyond necessity." This is the principle known as Ockham's razor, and it would seem to be violated by the multiverse idea. As noted, we also need to ask, "Why this and not another possible multiverse?"—unless of course we adopt the empirically unverifiable Tegmark Level IV multiverse, or, even more radically, David Lewis's modal realism, whereby all possible universes (not just those realizing mathematical structures) exist. I note the problem concerning a possible alternative universe containing me making the free choices I did not make in this universe. Phenomenologically, it would seem simplest to suppose that I am where I am doing what I am doing rather than question notions such as personal identity and free will that would arise with the alternative. Philosopher and theologian Keith Ward (2008, 67–82) notes further consequences of the "maximal multiverse" proposal, in which "anything that can happen does happen." Thus, on the one hand, there will be universes in which a virgin birth occurs, and on the other hand, universes where there is vastly more and greater evil than in our own.
4. The turn from option 1 to option 2 implies a departure from scientific method in another way. Scientists use their theories to make predictions. Suppose some unexplained phenomenon occurs in the laboratory or elsewhere in the cosmos. Rather than attempting to explain it rationally using science, we may now be tempted to say, "We just happen to live in a universe that produces that phenomenon." Theories of this kind cannot be falsified (though see point 6).

Related to this is the problem of induction, a point drawn out by Tim Mawson (2011). We rely on the future resembling the past, but it is not a necessary truth that it do so. We think all emeralds are green, but perhaps they are "grue," green up until now but turning blue at midnight tonight, as in Nelson Goodman's (1946) "new riddle of induction." For every universe similar to ours up to time *t*, there will be an infinity of possible universes in which normal inductive procedures as we know them break down at that point in their history.

5. I referred earlier to the cosmological constant, which represents a repulsive force in opposition to gravity. Denoted by the Greek letter Λ (lambda), Einstein added this to his equations in 1917 so they would yield a static universe. He later called this his "biggest blunder," since, without Λ, the equations would have predicted either an expanding or contracting cosmos. Einstein accepted that Λ was zero once we had the evidence of the expansion, and this was the position until a few years ago. Then, in 1998, a small positive value of Λ was observed, indicating an accelerating expansion (Riess et al. 1998; Schmidt et al. 1998; Perlmutter et al. 1999).

   Physicists think they know where Λ comes from. In quantum theory, the vacuum is not empty but a hive of constantly fluctuating activity, and possesses energy. Λ is believed to be the energy of the vacuum. Unfortunately, when Λ is calculated, it gives a value 10^{120} times that which is compatible with observations. If Λ really took the calculated value, any material object would be pulled apart in an instant, with parts flying away to the ends of the universe.

   If one accepts the landscape proposal of string theory (but see earlier for reservations), there may be a multiverse solution to this problem. This is because the different universes within the landscape correspond to varying values of Λ. Moreover, as noted, the landscape is populated via eternal inflation, the bubble universes that are the different universes of the landscape. Universes with small values of Λ like ours will inevitably be instantiated.

   Given the proviso that the landscape exists, this would appear to explain the fine-tuning. However, there are further questions to ask. In order for this to work, there need to be enough solutions to make it probable that at least one fine-tuned universe exists. A mere 10^{100} solutions would not be enough to make it probable that Λ alone would be in the anthropic range. 10^{500} or 10^{1000} solutions would do that, but careful analysis would be needed for this to make it probable that the whole set of free parameters is fine-tuned. If this succeeded, one would still have to ask, "Why are there enough solutions to do the trick?" Our surprise would transfer to the landscape itself.

A further question arises because, as Dennis Sciama (1989, 111) pointed out some years ago, and others have done since, we ought to regard our universe as typical of those conducive to producing observers. Is that the case, or is the universe more special than required?

It turns out that the average bio-friendly Λ value exceeds the value compatible with observation by a significant margin. Steven Weinberg's (1987) initial calculations demonstrated that vacuum energy density could be a factor of 100 greater than mass density and be compatible with life. This ratio has come down with subsequent calculations by Weinberg (2007, 32), but the observed vacuum energy level still looks a bit low, as Weinberg himself acknowledges. Paul Davies (2007, 492) notes that Λ could be an order of magnitude greater and not threaten the existence of galaxies or stars, and hence life. For Davies (2007, 491), this means our universe is not "minimally biophilic" but may be "optimally biophilic," i.e., characterized by parameters close to the center of biologically compatible parameter space rather than taking typical life-conducive values.

Of course, there could be many other parameters of our universe besides Λ that are more finely tuned than is strictly required for our own existence. It would appear there are. The charge on the electron is fixed to eleven significant figures, but it could fluctuate by 1 part in 10^6 without affecting biochemistry (Davies 2007, 492–93). The lifetime of the proton is at least 2×10^{32} years, i.e., at least 10^{22} times the age of the universe, vastly longer than needed for life (Wilczek 2007, 52). These numbers make our universe look distinctly atypical of those comprising the tiny subset of life-bearing universes in a multiverse. I return to a highly significant further example in point 7.

6. A multiverse is usually taken to mean an overarching infinite space-time in which there are many distinct regions, which are denoted "universes" since there is no causal connection between them. If the total mean density of the universe is greater than the critical value, however, the universe will not be infinite but finite. Given the huge range of possible values of density that may well be probable, and a finite, not infinite universe most likely.

   This raises the possibility that observations of our universe could falsify multiverse models such as the string landscape. Indeed, there is tentative evidence that we already have such observations. It has been understood by cosmologists that data on the cosmic background radiation from the Planck satellite confirms inflation. The mean density is very close to the critical value, which has been taken to imply that the universe is spatially flat or very close to being spatially flat (Planck Collaboration 2020, reporting on Planck 2018 results). However, in a significant paper, Eleonora Di Valentino, Alessandro Melchiorri, and

Joseph Silk (2019) calculate that the best fit to the data for the density parameter corresponds to a closed universe. The parameter Ω, which measures the ratio of actual density to the critical value, lies between 1.007 and 1.095 to 99% confidence level. That is to say, space-time has positive curvature, and the universe is closed and finite. The authors acknowledge that this result is in tension with data on other cosmological parameters, which to them indicates a possible crisis in cosmology.

If a finite universe were sufficiently small, that is to say, of dimension less than fifty billion light years or so, it might be possible to "see all round the universe," in the sense that we might see the same object in the sky at two different locations. Models of this kind have been suggested in the past (see Luminet et al. 2003a, 2003b; Luminet 2005). Such models would have the advantage of being empirically testable and avoid the paradoxes of infinity. If the finite universe were too large, we would not be able to confirm it in this way, and it might just be that we are in an over-dense region of an infinite universe. On the other hand, if density measurements indicated Ω to be slightly below unity, it would not necessarily follow that our universe was open and infinite. As pointed out by Barrow (2005, 144), it might just be that we inhabit an under-dense region of a finite universe.

7. Perhaps the most serious challenge to a multiverse explanation of fine-tuning comes from Roger Penrose. Penrose has calculated the entropy of the universe, which measures the amount of disorder in it and which increases over time. He calculates that, at the beginning, "the Creator" had to choose one from a set of $10^{10^{123}}$ possible universe configurations to give our universe, with all the order and structure it possesses (Penrose 1989, 342–44). That is fine-tuning in the extreme, although a multiverse with $10^{10^{123}}$ members or more would give a good chance of its existence.

Penrose, however, goes further. A bio-friendly universe needs to be very highly ordered, but much less so than to 1 part in $10^{10^{123}}$ (Penrose 1989, 354). A universe with 10^{22} stars with their planets is not required; rather, a single solar system would suffice. Penrose notes that the entire solar system with all its inhabitants could be created by random collisions of particles with an "improbability" of one part in much less than $10^{10^{60}}$.

$10^{10^{123}}$ utterly swamps $10^{10^{60}}$. Hence, we may infer that, given a multiverse, the probability of our being in a universe as ordered and structured as ours is one in $10^{10^{123}}$. The multiverse is no advance on the single universe! We are very far from being in a typical universe within the subset of bio-friendly universes, which, as we have seen, is how we ought to regard ourselves. Typical life-conducive universes would be much more like the single solar system surrounded by chaos than like our universe. Even more common than these would be universes in which the "life" produced comprises

something like Boltzmann brains (isolated, disembodied, but self-aware entities) rather than embodied conscious agents (Collins 2012, 174–80). Our atypicality to the highest degree as observers places a large question mark over the multiverse solution to fine-tuning. In particular, the ultra-fine-tuning of entropy does that much more strongly than the earlier instances of extra-special fine-tuning noted earlier.

Comparing the Explanatory Hypotheses

I will now compare the two main hypotheses advanced to explain fine-tuning, namely, a multiverse and divine design. In common with Richard Swinburne and others, I argue that invoking God as designer gives a simple explanation. At least part of why this is so is that the God of theism exists necessarily and is necessarily omnipotent and omniscient. In contrast, I note (point 3) that the multiverse explanation is not simple. Not only is it complex because it multiplies entities (universes) beyond necessity but also because each of those entities in turn is a complex physical universe. On the design hypothesis, God deliberately created our universe, intending that it produce intelligent creatures able to exercise reason and free will and relate to him. Moreover, God is likely to have created the highly ordered universe we observe rather than the single solar system or Boltzmann-brain universe discussed in point 7.

This assessment takes us back to my earlier point about objective value. I argue that embodied conscious agents are of far greater value than mere Boltzmann brains. I noted earlier Robin Collins's point about extra fine-tuning enabling scientific discovery and technology. This includes discovering the rich cosmos well beyond our solar system. We gaze in wonder at the night sky and at images of distant spiral and elliptical galaxies millions of light years distant. This universe seems to possess a more complete objective value than a single solar system embedded in chaos. If God wanted to create rational creatures like ourselves, he could of course have simply created the latter. But it seems to me that the God of classical theism would indeed be much more likely to create greater order, not just for our own but for his contemplation, perhaps as on a smaller scale he brings rain "on a land where no one lives" (Job 38:26). God may even intend that other rational creatures evolve elsewhere in the universe, though that is not a topic that can be delved into here. The point is that surely any reasonable probability for the existence of the ultra-fine-tuned universe we observe, given that there is a God, will totally outweigh the almost infinitesimal probability of one in $10^{10^{123}}$.

We can express the fine-tuning argument formally utilizing Bayesian confirmation theory, widely employed in the philosophy of religion (Holder 2021, 60–62). I ignore for the moment the hypothesis that there is just one universe, since that leaves the fine-tuning unexplained, and focus simply on the multiverse hypothesis (with no God) as an alternative to God.

Let FT = the fine-tuning evidence, G = the hypothesis that there is a God, and M = the multiverse and no-God hypothesis. Bayes's theorem for the two hypotheses states:

$$P[G|FT] = \frac{P[FT|G].P[G]}{P[FT]} \tag{1}$$

and

$$P[M|FT] = \frac{P[FT|M].P[M]}{P[FT]} \tag{2}$$

A simple and useful consequence of Bayes's theorem is obtained by dividing the left-hand sides and right-hand sides of these equations:

$$\frac{P[G|FT]}{P[M|FT]} = \frac{P[FT|G]}{P[FT|M]}.\frac{P[G]}{P[M]} \tag{3}$$

Of course, I recognize that it is not possible to assign precise values to the terms in this equation. However, as noted, the lesson from our utter atypicality as observers within a multiverse is that $P[FT|M]$ is extremely low. Indeed, Penrose's calculations would indicate that the probability of finding ourselves in a universe, necessarily a member of the bio-friendly subset of universes but with the ultra-high degree of order and structure that ours has, is of order $1/10^{10^{123}}$.

Any reasonable values for the other probabilities in equation (3) will be completely swamped by this ultra-low value of $P[FT|M]$. The probability that God would create a totally ordered universe, $P[FT|G]$, is hugely greater since God would have good reason to do so, as discussed. Suppose, for the sake of argument, that $P[FT|G] = 1/10$. The first factor on the right-hand side of equation (3) would then be $10^{10^{123}}$.

Assigning probabilities to the numerator and denominator of the second factor in the third equation, i.e., the prior probabilities that God and the multiverse exist, is more controversial. Swinburne (2004, 96–109, 165, 185–88) argues that $P[G] >> P[M]$ on the grounds of divine simplicity versus universe, and, *a fortiori*, multiverse complexity. Davies (2006, 249) in contrast regards G and M as of equal probability. Yet, even if we thought $P[G] < P[M]$, there would be no reason to assign an absurdly low value to $P[G]$ when compared with $P[M]$. Given the dominance of the first factor, any reasonable estimate of the second will yield

$$\frac{P[G|FT]}{P[M|FT]} = 10^{10^{123}} \tag{4}$$

The implication is that God as designer provides a far more highly probable explanation for fine-tuning than a multiverse. The enormous number $10^{10^{123}}$ washes out any moderate probabilities that may be inserted in the third equation.

Expanding the denominator of the first equation, we obtain

$$P[G|FT] = \frac{P[FT|G].P[G]}{P[FT|G].P[G] + P[FT|\sim G].P[\sim G]} \quad (5)$$

To obtain an absolute value for $P[G|FT]$ from the fifth equation would entail estimating not $P[FT|M]$ but the more comprehensive $P[FT|\sim G]$, where $\sim G$ embraces all non-theistic explanations for the fine-tuning, not just M. The main alternative to M is the single universe U without God. However, I have focused on M precisely because $P[FT|U]$ is small, indeed ultra-small and of order $1/10^{10^{123}}$. What is seen, perhaps surprisingly, is that M is no advance on U in light of the typicality requirement.

There are also alternative theistic hypotheses to that which have been considered. Chief of these would be a plurality of gods rather than the one God of the monotheistic Abrahamic faiths. Swinburne argues, again on grounds of simplicity, that the existence of many gods is far less probable than the existence of one (Swinburne 2004, 145–47). It certainly violates Ockham's razor. Moreover, the universal validity of the laws of physics across space and time is much better explained by a single divine designer than by many. It is hard to see why, with any reasonable values assigned to the probabilities $P[FT|G]$ and $P[G]$, $P[FT|G].P[G]$ should not be much greater than $P[FT|\sim G]$ and hence than $P[FT|\sim G].P[\sim G]$, from which it would follow from the fifth equation that $P[G|FT]$ would lie very little short of unity.

In response to this argument, it seems to me that the atheist is almost forced to assert that the prior probability of God's existence before consideration of the evidence is ultra-small, i.e., that $P[G] < 1/10^{10^{123}}$. The only plausible way to justify that is to argue that the very idea of God is incoherent, so that in fact $P[G] = 0$. That is a challenge to which, in my view, the most implacable atheist would be hard pressed to rise.

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Islamic Views on Contemporary Cosmology

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Here, I present classical and contemporary Islamic views on cosmology in both its ancient or medieval and modern definitions. I briefly review the main ideas of Muslim thinkers (philosophers, exegetes, Sufis, etc.) from over a thousand years ago to today. Then, I examine how cosmology has changed with the advent of modern science and astronomy and what new, essential results and ideas we need to digest and firmly adopt when attempting to construct any "cultural cosmology," one that brings in philosophy, religion, and culture at large. In the last section, I put forward the main ideas that Islam (Muslim thinkers) needs to "work on": toning down and reinterpreting both the old anthropocentrism and the classical argument from design, and adopting a "big history" approach to the cosmos, Earth, life, and humanity. I also present a few important notions Islam brings to human culture that could benefit both theists from other traditions and non-theists.

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Introduction

Today, most people understand the term *cosmology* to mean "the science of the cosmos, i.e., of the universe as a whole," a branch of astronomy, a science. But in medieval times, cosmology was a subject of philosophy and theology, calling upon (intuitive) reason, scriptures, or myths. In fact, even today, many theistic thinkers in particular insist that cosmology be viewed much more broadly than science does (with its observational data, physical principles and equations, etc.) to include metaphysical considerations. Alongside such approaches, serious works on the philosophy of cosmology have proliferated in the past decade or two (Smeenk and Ellis 2017).

Dictionaries and encyclopedias acknowledge this double nature of cosmology. The *Merriam-Webster Dictionary* (n.d.) gives two definitions for cosmology: a) a branch of metaphysics that deals with the nature of the universe; and b) a branch of astronomy that deals with the origin, structure, and space–time relationships of the universe. The *Oxford English Dictionary* (n.d.) gives the following definition: "The science or theory of the universe as an ordered whole, and of the general laws which govern it. Also, a particular account or system of the universe and its laws." The *Concise Oxford Dictionary of Archaeology* gives a somewhat different definition: "The world view and belief system of a community based upon their understanding of order in the universe" (Darvill [2000] 2003, 238). And in a section on "Cosmology and Worldview," the Encyclopedia of Religion (n.d.) says: "Cosmology refers to more consciously entertained images, doctrines, and scientific views concerning the universe."

Three other terms associated with cosmology, though much less frequently used, complicate matters: cosmogony, cosmogenesis, and cosmography. Cosmogony, which deals with the origin of the universe, is rarely used because first, as per the aforementioned definitions of *cosmology*, it is supposed to be encompassed by the latter, more general term, and second, because there is very little that can be said about the origin of the universe scientifically and rigorously, as will be discussed later. *Cosmogenesis* is sometimes used to refer to the origin and very early evolution of the universe, i.e., a bridge between cosmogony and cosmology, if one does distinguish between the two. Cosmography, which describes the contents (objects) and features (geometry and changes) of the cosmos, is thus supposed to be part of cosmology, as per the aforementioned. In old works, however, since the cosmos was simply the Earth, the moon, the sun, the planets, and the stars, cosmography was nothing more than Earth-based astronomical descriptions of the sky, its contents, and its phenomena.

Islamic works on cosmology tend to be a mixture of these three concepts/topics/branches infused to varying extents with scriptural and theological inputs. Seyyed H. Nasr (1998), a neo-traditionalist Muslim theo-Sufi-philosopher, stresses: "The meaning of the term cosmology in the Islamic, or other traditional,

contexts differs profoundly from the meaning given to it in the context of modern science . . . Traditional cosmologies [including the Islamic conceptions] deal with cosmic reality in its totality including the intelligible or angelic, [and] the metaphysical principles [pertaining] to the cosmic realm." He adds: "Islamic thought has always considered the question of cosmogenesis to be religious and metaphysical, not merely extrapolation of the natural sciences." He goes further: "The genesis and history of the cosmos is based on a qualitative conception of time totally different from the quantitative time of modern geology, astronomy, and astrophysics" (Nasr 2006). Muzaffar Iqbal (2006), also a neo-traditionalist Muslim thinker, says: "Before the emergence of the [Greek-influenced] Islamic philosophical cosmology, however, there existed another cosmological tradition, the 'Sacred Cosmology,' based on the Qurʾānic descriptions of creation and on the sayings of the Prophet." And Angelika Neuwirth (2001) explains the "Qurʾānic understanding of cosmology" as "[a] divinely governed order of the universe and the place of humans within it."

Reading scientific papers on cosmology and Islamic medieval and even contemporary Muslim thinkers' works on cosmology are two very different exercises that tend to have little overlap, as we shall see. In this article, I want to review and (gingerly) propose views on contemporary cosmology with an Islamic background or worldview: What can the Islamic culture bring to current and future cosmological discussions, such as what relates to "big history" (cosmic times, very large scales, etc.), multiverse, the anthropic principle, etc.?

I will start by summarizing Islamic cosmology as found in medieval works and as carried forward today by Muslim neo-traditionalist thinkers such as Nasr and Iqbal. I will then summarize the main ideas and results from modern (scientific) cosmology. And, last but not least, I will look at the philosophical and theological issues contemporary cosmology raises and present Islamic views on it, both from recent writings and potential future contributions.

Classical Islamic Cosmology

In addition to the "Sacred Cosmology" Iqbal claims was constructed very early on from the Qurʾān and the Prophetic tradition, Islamic classical cosmologies came to include full models by Greek-influenced Muslim philosophers (the *falāsifah*), Sufi cosmic visions, synthetic approaches by groups/schools such as the Ikhwan as-Safa (tenth century CE) and the Illuminationists (the Ishraqi school), and ideas proposed by individual, independent thinkers such as Al-Biruni (973–1051).

In presenting Sacred Cosmology, Iqbal (2006) starts with "Qurʾānic data," i.e. the "cosmological" elements and descriptions that can be found in the Qurʾān. For Iqbal, these include God's Throne and Footstool; the Guarded Tablet and the Pen; the angels; the sun, the moon, and the stars; water and winds; mountains and oceans, etc. Additional Sacred Cosmology elements

and descriptions include "cosmic distances" (500 years of travel between one heaven and another), time (night and day), light and darkness (thousands of "veils" between the heavens), and more ("mansions" of the moon, etc.).

One may be surprised by this strange mix of physical and metaphysical elements, but it must be recalled that Iqbal came to subscribe to Nasr's "scientia sacra" philosophy, which insists (see the previously quoted Nasr statements) that the cosmos must be viewed in an integrated way, with everything from water and mountains to angels and spirits, all the way to the divine throne. Iqbal is far from the only Muslim author to try to mine the Qur'ān for cosmological "data": Mohammad Ali Tabataba'i and Saida Mirsadri (2016) published a long paper on Qur'ānic cosmography, discussing the shape of the firmament and God's footstool with several diagrams, insisting that the Qur'ānic heavens are actually flat. However, one can simply object to this idea of "Qur'ānic data" by recalling that the Qur'ān itself tells us to adopt an empirical or at least observational approach, "Say, [O Muhammad], Travel through the land and observe how creation began (or was begun)" (Qur'ān 29:20), not to look in the text, much less in the hadiths, for "data."

In fact, there is in the Qur'ān and in the Islamic tradition (Guessoum 2010) an important distinction that tends to be blurred or even totally ignored in such mixed or integrated cosmological conceptions: the idea of "two worlds," the physical, observable world (*'alam al-shahādah*) and the "unseen," metaphysical world (*'alam al-ghayb*). The first, defined as containing all material beings and things, is therefore the universe, as scientists define it. The second, defined as all matters relating to God, paradise, hell, angels, and spirits, etc., can only be discussed on purely religious bases, usually inferred from the scriptures and prophetic statements.

The Qur'ān does have numerous verses pointing to various natural and cosmic objects and phenomena (in particular, the word *sama* (heaven) and its derivatives can be found 310 times). However, its aim is not to present a cosmology but rather to insist on the following important principles:

- The universe was created by God, who has absolute and exclusive power of creation.
- The universe was created with a purpose.
- The universe is continuously sustained by God.
- The cosmos is characterized by wholeness, order, and harmony between all its elements and events.

For a more detailed treatment of classical Islamic cosmologies, one should refer to Nasr's ([1963] 1993) seminal work, *Introduction to Islamic Cosmological Doctrines*. For a concise summary and discussion, the chapter on "Islam and Cosmology" in my (Guessoum 2010) *Islam's Quantum Question* may be useful. Here, I only

mention very briefly the foremost Muslim thinkers and schools and their main cosmological ideas, focusing on those that may help us later consider Islamic views on contemporary cosmology.

Al-Kindi (800–73) adhered to the doctrine of creation *ex nihilo*, but most later Muslim philosophers, Al-Farabi (870–950) in particular, stayed true to Aristotle and rejected the idea that God had "suddenly" decided to create the world, as that would have involved the eternal and static God in unseemly change.

Ibn Sina (Avicenna 981–1037), one of the greatest and most sophisticated of the Muslim philosophers, conceptualized the creation process as a self-awareness and a self-discovery by the Divine and divided the process of creation into four kinds:

- *Ihdāth*: Creation of objects or entities in nature, either temporary or eternal.
- *Ibdā`*: Creation—without intermediary—of eternal, non-decaying entities.
- *Khalq*: Creation through other agents.
- *Takween*: Creation through worldly, decaying, temporary agents.

The Ikhwān as-Safā (literally the Brethren of Purity), an esoteric society that appeared in Basra (Iraq) in the tenth century, represented a complex school of thought, a mixture/synthesis of rationalism, peripatetics, and Sufism. In their cosmology, they subscribed to the Platonic doctrine of emanation and a numerological system for the universe, starting from 1, which to them represents "existence" or "being", and ending with 0 (for them, the same as 10), which represented infinity or the divine essence. They also associated the divine throne with the ninth sphere/heaven that separates the realm of the Divine from the cosmos of matter, and the divine footstool with the firmament of stars.

Al-Biruni (973–1051), Muslim polymath extraordinaire, saw the world as the handiwork of God and considered the observation and study of nature a religious duty (Nasr [1963] 1993, 275–76). He subscribed to the doctrine of creation *ex nihilo*, but based on various considerations, including widely different and unrealistic dates given by ancient civilizations, concluded that the age of the universe could not be determined. His cosmology/cosmography to a large extent resembled that of the Greeks (Aristotle and Ptolemy): a spherical cosmos centered at Earth, made up of spheres or shells containing the elements of Aristotle (water, earth, air, fire) and the planets. He also stated that his observations and investigations of nature led him to conclude that the laws of nature must remain unchanged through time.

Ibn Rushd (Averroes 1126–98), another great Muslim philosopher and polymath, although strongly influenced by Aristotle, remained true to the spirit—but not the letter—of the Islamic/Qur'ānic teachings. He subscribed to the doctrine of the eternal cosmos, but he insisted that the universe is and has remained in constant change or evolution, as God continues His creation. He also remained true to the Aristotelian theory of final causes, in which the

reasons for any phenomenon or event must be found in the goal that any being is meant to reach.

The later centuries of the Islamic civilization were dominated by the Sufi doctrines, particularly Ibn Arabi (1165–240) and disciples, and the Gnostic Ishraqi (illumination) doctrines of Suhrawardi (c. 1155–91) and others.

The Sufi doctrine can be stated in the following central principle: there is no reality outside of the absolute reality; that is, there is nothing other than God. Furthermore, in the Sufi philosophy, important knowledge, including cosmological knowledge, can be acquired through spiritual experience. In fact, objective results obtained exclusively through reasoning can constitute a "veil" that actually prevents one from seeing the true nature of things. Sufis consider the universe a theophany, whereby God "sees" Himself in His creation (see, for instance, Chittick 1987).

Scientific Cosmology

Knowledge of the universe, with its general field and branches (astronomy, cosmology, etc.) has witnessed extraordinary developments over the past century. Seminal theoretical works and crucial observations have led to more and more sophisticated theories (relativity, Big Bang, inflation, imaginary time, etc.) and increasingly accurate data and constraints.

Scientific cosmology can be said to have been born in 1917 with Albert Einstein's ([1917] 1952) historic paper on "Cosmological Considerations," based on his general theory of relativity. The universe had suddenly become the subject of mathematical and physical investigation, and scientific conclusions (dynamic versus static) could now be drawn. In 1923, Edwin Hubble, using the newly constructed 100-inch telescope at Mount Wilson Observatory in California, established that the Andromeda "nebula" was too far away and hence too big to be a nebula (cloud), and thus had to be a galaxy of its own; the Milky Way was theretofore one of a multitude of galaxies. And in 1929, Hubble found that most galaxies are receding away from us and from each other, and that this could only be explained by the whole universe expanding forth. At about the same time, Georges Lemaitre ([1927] 1979, 844–48), a Belgian physicist and Jesuit priest, proposed a "primeval atom theory," which later evolved into the Big Bang theory, whereby the universe was initially in a highly compact and hot state that expanded all the way to the huge cosmos we see today.

In almost exactly 100 years, we have gone from a universe that is less than 100,000 light years across to one that is a million times bigger, with trillions of galaxies each containing billions of stars and planets, and 13.8 billion years old (an age now accurately determined to within 0.02 billion years). It is also accelerating and made mostly of dark matter and dark energy, as well as a small amount of "normal" matter (what we know in nature around us, from Hydrogen to the rest of the elements in the periodic table).

This huge leap in cosmological knowledge has been strikingly expressed by the UCLA cosmologist Edward L. Wright (2005) as: "Only one (cosmological) fact was known in 1917, namely that the sky is dark at night—and Einstein ignored it" (referring to the fact that a static and infinitely old and big universe could not be dark).

The main findings of contemporary cosmology may briefly be summarized as follows:

1. Our universe is not static and infinitely old; it started from a point (a "singularity" where temperature, density, and other parameters are infinite) at a specific time in the past (13.8 billion years ago) and evolved to its present state. This is the now strongly evidence-supported Big Bang theory, which allows cosmologists to calculate various characteristics of the universe, past, present, and future.
2. The expansion of the universe has, for the last few billion years, been accelerating due to some "dark energy," which stretches space–time as if some internal repulsion was pulling the fabric apart. While an accelerating expansion intuitively seems to imply an "open," infinitely expanding universe leading to a dark, cold "Big Chill" or even a "Big Rip" (parts of the universe splitting from others), a "Standstill" (equilibrium between gravitational pull back and expansion) or even a "Big Crunch" (gravity succeeding in pulling the whole universe back to contraction to a point/singularity) are theoretically possible. Which of these scenarios represents the future of the universe depends on the as-yet-undetermined natures of dark matter and dark energy and the total mass–energy content of the universe.
3. The age and the size of the observable universe (since its creation/emergence) can now be determined very accurately. However, first we can only observe part of our universe, as "other parts" are unreachable to us, being on farther and faster-expanding regions of the universe. Second, our cosmos may be part of an infinite structure where bubbles such as ours appear and collapse all the time. Furthermore, our universe could be one of zillions of (finite-sized but very different) universes in a multiverse.
4. Only 5% of our universe's matter–energy content is the "ordinary" forms we know; an additional 27% is "dark matter" (which manifests itself only gravitationally), and 68% is "dark energy," which accelerates the universe in its expansion (ESA and the Planck Collaboration 2013).

This modern view of the cosmos raises some important philosophical and theological questions. First, in terms of size: What does it mean that the universe is one hundred billion times bigger than the solar system (even when we include its cometary Oort cloud, which makes it bigger than the last orbit of planets by a factor of a thousand) and one million billion billion

times bigger than humans? Even more striking is the fact that humans have only existed in the last tiny fraction of the universe's history. Indeed, if we represent the universe's timeline by one calendar year, then the sun would have formed on September 1, Earth on September 2, the moon on September 3, and humans (in their sapiens stage of evolution) on December 31 at 11:40pm. How can any theistic anthropocentrism survive the knowledge that the universe has existed without us for 99.998% of its history? Or how could Earth and humanity still be seen as central in any way when the Milky Way alone contains an estimated ten billion Earth-size planets and the observable universe consists of trillions of galaxies, at least half of them more or less similar to the Milky Way?

But in the last few decades, a new development, the discovery of the "fine-tuning of the universe" and the formulation of an "anthropic principle" has given a new, important twist to the humbling—and to some, depressing—conception of humanity's place in the universe. What has been discovered is that our universe seems to be particularly suited to the emergence of complexity and life: if the parameters that make up the physical cosmos had been drawn at random, the probability that they would have values allowing for life and intelligence to appear (at some point in time and space) would be ridiculously small, one in billions of billions of billions . . . This observation and realization is referred to as the "fine-tuned universe," while the conclusion that, as Freeman Dyson (1979, 250) puts it, "the universe in some sense must have known we were coming," is often called the "anthropic principle" (*anthropos* meaning "human" in Greek). This idea has given birth to countless articles and books. One of the earliest and most extensive (with 738 pages) is *The Anthropic Cosmological Principle* by John D. Barrow and Frank J. Tipler (1988), and one of the most thorough in recent years is *A Fortunate Universe: Life in a Finely Tuned Cosmos* by Geraint F. Lewis and Luke A. Barnes (2016).

However, I should note that not everyone is impressed, much less enthralled, with the anthropic principle. Michel Paty (2006), emeritus director of research at the French National Centre for Scientific Research, declares: "The strong anthropic principle is a useless metaphysical concept." (The strong version of the anthropic principle stipulates that the universe, from the start, had to have properties allowing life to develop within it at some stage in its history. The aforementioned references on the subject unpack this controversial idea.) A bit more tellingly, Malcolm S. Longair, Jacksonian Professor of Natural Philosophy at Cambridge University, said: "I hate the anthropic principle theory; I consider it as an absolutely last recourse, in case all physical arguments failed. The whole essence of the anthropic argumentation seems to go against the flow of what we aspire to achieve as scientists" (Demaret and Lambert 1994, ix).

Few people dispute the fine-tuning observations; for instance, had our universe had any other number of dimensions than three for space and one for time, there would be no complexity (planets and big molecules like DNA),

let alone any life or intelligence. Other "fine-tuning marvels" (Davies 2006, 164–66), the number of which varies between six and at least a few dozen, range from "the nuclear interaction could not have been more than 4 to 6% stronger" to "the cosmological mass-energy density Ω could not have deviated by 10^{-60}–10^{-56} from the critical value."

This much is agreed upon: for us (and the rest of life in the universe and even its wonderful stellar and planetary phenomena) to exist, our universe had to be very finely tuned. What is in dispute is whether this gives the universe any teleological arrow toward life and humans, whether any *anthropic* principle should be formulated. Indeed, the majority of scientists and philosophers respond to the fine-tuning observation that either science will, sooner or later, explain this fine-tuning or there must be zillions of universes out there (the multiverse), with a random distribution of parameters and laws such that one or more of them would have the "right" set of values to allow for life, intelligence, and consciousness to emerge at some point somewhere.

I should also note, however, that Robin Collins has made an additional argument from the fine-tuning of the universe, one for discoverability: "[T]he fundamental parameters of physics fall in a relatively small range that maximizes our ability to make scientific discoveries" (Collins 2016), and "[u]nlike the much discussed anthropic fine-tuning (or fine-tuning for life), this kind of fine-tuning cannot be explained by the multiverse hypothesis since it does not encounter an observer-selection effect" (Collins 2018). Similar, but less developed, ideas were put forward in 2004 by Guillermo Gonzalez and Jay Richards in *The Privileged Planet: How Our Place in the Cosmos is Designed for Discovery*.

Philo-Theological Reactions

The first major result established by modern cosmology is that the universe has a finite age; it started from a singular "point" in an "explosive" event and process (the big bang) and has expanded and evolved under the combined effect of that thrust and the gravitational forces, leading to the formation of stars and planets and other cosmic objects. Of course, this has brought back the discussions on creation *ex nihilo* versus an eternal universe, recalling the old debates and arguments about God and creation (among Christians, Muslims, and others) and adding new scientific ingredients. For example, Pope Pius XII in 1951 proclaimed the church's support for the Big Bang theory, which had first been introduced as Lemaitre's "primeval atom"; the pope noted the similarity with the *Fiat lux* of Genesis and declared: "Hence creation took place in time, therefore there is a creator, therefore God exists!" (Pope Pius XII 1951). Likewise, Muslims (e.g., Alkassimi [2008] 2023; Nasser 2019) saw in this development support for the Qurʾānic verse "Be! And it is," which appears eight times in the book and was a final victory of the (classical) Muslim theologians, who insisted on creation at a specific moment in time, over the philosophers, who preferred an old, eternal

universe. This support for creation *ex nihilo* also propelled among theists the "cosmological argument" for the existence of God (the "Kalam argument"), which originated with Muslim philosophers (Al-Kindi and others later).

Resistance to such "inferences," or even any theo-philosophical discussions from cosmological findings, was expressed by materialists such as David Bohm, who accused "scientists who effectively turn traitor to science" of "discard[ing] scientific facts [in order] to reach conclusions that are convenient to the Catholic Church" (Peat 1997, 145), and Stephen Hawking, who in his paper with James B. Hartle (Hartle and Hawking 1983) and in his famous book, *A Brief History of Time* (Hawking 1988), tried hard to show that the Big Bang's beginning was not necessarily a boundary or edge, and famously asked: "[W]hat place then for a creator?" Others, like Fred Hoyle (1948), railed against the "creation-in-the-past" that the Big Bang (which he rejected) suggests: "It is against the spirit of scientific enquiry to regard observable effects as arising from 'causes unknown to science' and this in principle is what creation-in-the-past implies."

The philosopher Ernan McMullin has noted that the word "creation" is an explanatory term; it points to a cause (a Creator) for the appearance of the universe. Obviously, this is not a scientific explanation, for science cannot establish "a sufficiently strong principle of causality" to that effect (McMullin 1981). He then asks: Can philosophy do so? He then explains that *ex nihilo* creation is not the only way to establish a divine origin of the universe; this is only the most intuitive view; one can indeed argue almost equally well for a divine origin of an eternal universe.

The "singularity"—with or without cause— and creation *ex nihilo* or *continua* have also led to numerous writings and pronouncements. As usual, Paul Davies (1988, 55–56) expressed the central issue—and the stakes—most eloquently: "[A] singularity is the nearest thing that science has found to a supernatural agent," i.e., a creator. Hawking and others have tried to eliminate the singularity from Big Bang cosmology using imaginary time, quantum effects, and other approaches. The problem still remains and awaits a unified theory of gravity with quantum mechanics and the rest of physics.

Contemporary philosophers and theologians have also debated whether a universe that starts from a point is a stronger argument for God. Ian Barbour's (1997, 214) view is that "the doctrine of creation is not really about temporal beginning but about the basic relationship between the world and God." John Polkinghorne (1998, 54) reinforces this idea: "[T]heology could have lived with either physical theory, for the assertion that God is Creator is not a statement that at a particular time he did something but rather that at all times he keeps the world in being." This is indeed an important argument, as it broadens the conception of creation from the "origination" of things (including the universe) in various ways (see previously how Ibn Sina defined four types of creation) to the *sustaining* of the world/cosmos through the laws that keep nature functioning

perfectly. Both ideas, whether there was a big-bang type of beginning or not and whether creation entails a sustaining of the world/cosmos, are most strongly expressed by Keith Ward:

> The Big Bang has not the slightest theological significance. It does not matter whether the world began with a bang or whether it began at all. It might always have been there. Theologians have always agreed that this does not make any difference. When you say that God "creates" the Universe, you just mean that everything—however long it has been there—always depends, at every moment of time, upon God. That is all you mean. It's a pity that some physicists use the world "creation" when they actually mean "origin" of the Universe. Creation isn't at the beginning, it is now and always. (Stannard 1996, 16)

Now, as I mentioned, the universe that contemporary cosmology has revealed is incredibly huge and old. We really seem like a speck of dust in its immensity, and at most a distant goal in its evolution, humans appearing in the last evening of the cosmic year, though it later appeared that "the universe must have known we were coming." But in fact, the universe could not have been small or young today.

Indeed, since humans, and all complex living creatures (from the simplest bacteria to the most biologically and neurologically advanced animals), are the product of evolution, we could only have emerged after a few billion years of the universe's existence (that is how long evolution took to go from single cell to intelligent animals). In other words, no creature (on Earth or elsewhere) could be asking any question or wondering about its existence in a universe that is younger than a few billion years. And since the universe expands in all directions, it had to reach a size of dozens of billions of light years during that time. And finally, only a universe with enough initial energy could expand so much in time and space that it ends up producing so much matter in the form of countless stars, planets, and complex creatures.

What about our small size (compared to any and all cosmic objects, particularly the universe as a whole) and makeup? The cosmologist Joel Primack and his artist and philosopher wife Nancy Ellen Abrams have tried to address such questions in their book, *The View from the Center of the Universe* (Primack and Abrams 2006), by building strong connections between cosmology and culture/myths. They insist that cosmology must address humans and their conception of, and place and role in, the universe. They write: "Traditional cultures' cosmologies were not factually correct, but they offered guidance about how to live with a sense of belonging in the world" (Primack and Abrams 2006, 16).

They argue that in a non-literal but very meaningful way, we are at the "center" of the universe (Primack and Abrams 2006, 270–72). They expound on seven such "center points," but the following three are the more convincing:

- We are made of the rarest elements the cosmos has made.
- We live at the midpoint of our planet's and sun's lifetimes.
- We have sizes that are, in powers of ten, in the middle of the entire scale of objects.

Primack and Abrams sometimes use cosmology to enlighten certain old traditional concepts, for instance the "pre-initial vacuum field," to explain the scriptural "primeval waters" that one finds in Islam, in Christianity, and in Babylonian creation stories, or the Kabbalistic beliefs to illustrate the ideas of "eternal cosmic inflation."

Similarly to what Primack and Abrams did, that is, relate contemporary cosmology in all its rigor and surprising results to human culture and myth, discussions of Islamic cosmologies that relate tradition and modern science in an intelligent way, may be useful and even needed today in light of the crisis of meaning that has disturbed humans everywhere and led to rejections of both religion and science by large segments of humanity.

Islamic Views on Contemporary Cosmological Issues

The Islamic discourse has always adopted the argument from design as a strong and obvious argument for the existence of God. Indeed, one can find numerous verses to this effect in the Qur'ān, and this argument constitutes the backbone of the Islamic "natural theology." Ibn Rushd makes the design argument a *bona fide* proof for the existence of God, the Maker, and insists that the recognition of design ("the existence in the artifact of an order in its parts") is a greater channel to humans' knowledge of God than the mere belief that objects have been "made" (Ibn Rushd, n.d., translated by Hourani 1976). So, for Muslims, the fine-tuning of the universe is nothing new. However, modern-day Islamic culture promotes traditionalist theology rather than natural theology, especially one (the anthropic principle) that is built on a grand evolutionary scheme, from the Big Bang to humans. Still, some Muslim authors have found in the Qur'ān verses that seem to support fine tuning, e.g., "Verily, all things have We created in proportion and measure" (54:49). Likewise, in 15:19, the Qur'ān describes the creation of "all kinds of things in due balance." Furthermore, the Qur'ān adopts an anthropocentrist view by stressing that "He has made subservient to you whatever is in the heavens and whatever is in the earth" (45:13 and other verses), which has led some Muslim commentators (Setia 2004; Altaie 2008) to rather hastily identify the concept of *taskheer* (subservience) with the anthropic principle.

However, in the classical Islamic corpus, one can find a few references to the idea of "balance" in creation, relating to both nature and humans. In his masterful Qur'ān exegesis/commentary *Mafātīh al-Ghayb*, Fakhr al-Din al-Razi (twelfth-century exegete, theologian, and philosopher) stresses the idea that each

object in nature has its proper mode of physical existence among many possible ones, a mode that is precisely predetermined (*muqaddar bi maqādīr makhsusah*) by the Creator; for example, the celestial objects have precise orbits and space–time coordinates that show a complete ordinance (*tadbir kamil*) and a profound wisdom (*hikmah bāligbah*) (Setia 2004). Al-Razi insists that all objects, in the heavens and in the Earth, living or inert (*jamādāt*) have been decreed by Allah in a manner that serves the interests (*masālih*) of humans. Finally, Al-Razi draws our attention toward the complex interconnections between the benefits that lie in the cosmic horizons (*al-ni`am al-āfāqyiyyah*) and those that can be found within ourselves (*al-ni`am al-anfusiyyah*), biologically or spiritually. He concludes that such benefits are for drawing humans to attain the deeper everlasting spiritual benefits of showing gratitude to the Creator.

According to Marc Geoffroy (2000, 131; my translation), for Ibn Rushd the idea of "measure" (*qadar*, *miqdār*) "must be understood both as 'measured quantity' and as 'decision', as when we say for example 'taking measures', the measure given to something implying a destination or purpose for that thing."

Finally, Badī`uzzaman Said al-Nursi, Turkish theologian and thinker (1877–1960), was very impressed with the "ubiquitous balance" and the "cooperation" one can see throughout the cosmos, and this for him constitutes "material evidence" of the divine unity. Adi Setia (2004) cites Nursi (1993) from *The Supreme Sign: The Observations of a Traveller Questioning the Universe Concerning His Maker*, with statements like: "[U]niversal co-operation visible throughout the cosmos" and "the comprehensive equilibrium and all-embracing preservation prevailing with the utmost regularity in all things."

Let us now turn to the concept of "multiverse," which has received extensive discussion from both scientific and philosophical perspectives. This topic has historical roots extending over centuries, if not millennia, if we consider the ancient and medieval "many worlds" debates, which bear some resemblance, though not equivalence, to multiverse discussions. The contemporary discourse has been refueled by new scientific ideas, particularly fine-tuning, eternal inflation, bubble universes, and the many worlds interpretation of quantum mechanics. In contrast, premodern debates were predominantly based on philosophical arguments and sometimes theological considerations. The new multiverse hypothesis is, in part, a response to the fine-tuning problem, but also an outcome of theoretical models that, while yet unconfirmed, predict the possible existence of countless universes characterized by different parameters and laws. If that is the case, then the presence of a universe hospitable to life is not just unsurprising but even expected.

Within the Islamic intellectual discourse, divergent perspectives on the concept of the multiverse have emerged. Some scholars have shown resistance to this idea, seeing it as a materialist response to the fine-tuning discovery, a rather desperate response to the theistic position, which sees fine-tuning as

indicative of divine design. Conversely, some Muslim thinkers have embraced the multiverse hypothesis, interpreting it as a manifestation of God's omnipotence and in consonance with the Qurʾān. (For instance, "It is Allah Who has created seven heavens and of the earth the like thereof (i.e., seven)" (Qurʾān 65:12), "seven" being commonly interpreted as "many.") Furthermore, they point to the endorsement of the many-world idea by eminent classical Muslim philosophers and theologians. Indeed, Al-Farabi (nineth century) and Ibn Sina (tenth and eleventh centuries) advocated for the concept, envisioning multiple worlds either as parts of "our world" or as entities existing outside of it. Similarly, major scholars such as Al-Biruni (eleventh century) and Al-Razi (twelfth century), who were steeped in diverse disciplines, formulated arguments expressing the infinitude of God's grace and creation across temporal and spatial dimensions. The prime opponent of the many-worlds idea was the hugely influential theologian Abu Hamid Al-Ghazali (1058–1111), who believed our world represents *the* singularly optimal creation—and thus has to be unique.

Contemporary Muslim scientists and intellectuals display a spectrum of perspectives on the multiverse. The eminent Shii philosopher Morteza Motahhari (b. 1919/1920, with varying name spellings and birth dates in the literature) has expressed support for the idea of worlds before ours: "[H]ow do we know that there were not other worlds before, with different laws?" (Motahhari 1950–51, 109).

Faheem Ashraf (n.d.) sees some similarity and consonance between the multiverse and the "seven heavens" of the Qurʾān (e.g., 65:12). Indeed, he identifies the term "heavens"(*samāwāt*) with "universes," then interprets the term "seven" as simply an indication of multiplicity. Finally, he points to the adoption of the present tense in the Qurʾānic verses of relevance as indicating the continued existence of the many universes, each (according to him) with "their own values of physical constants and nature of the physical laws."

At the other end of the spectrum of positions, astrophysicist Jamal Mimouni vehemently rejects the idea of the multiverse, saying: "From an ontological point of view, it's a catastrophe, because you're proposing things you can never observe, universes that are causally disconnected from our universe" (El-Showk 2016).

Models positing a universe existing prior to the Big Bang and giving birth to ours are rooted in the rejection of the *ex nihilo* idea (science does not allow for matter and energy to emerge from "nothingness") as well of as the singularity; as David Hilbert ([1926] 1984) put it, "The infinite is nowhere to be found in reality." In fact, if the total internal mass-energy of the universe is larger than the critical value (**Ω** larger than 1), then the universe will, over hundreds of billions of years, reverse its expansion under gravitational forces and undergo a collapse, leading to a "Big Crunch." Importantly, such a collapse does not entail a disappearance into "nothingness" (again unacceptable to science) but rather, it is postulated, would lead to the emergence of a new universe,

possibly characterized by different laws and parameters. M. Basil Altaie has argued for a bouncing universe, which he views as consistent with the Qurʾān (El-Showk 2016).

The possibility of pre-Big Bang phases may be consistent or consonant with "quantum gravity," a theoretical construct that remains elusive. Martin Bojowald (2007) underscores the formidable challenge in extrapolating to pre-Big Bang epochs, cautioning that such extrapolations "require exceedingly precise knowledge of the present state [of the universe] that cannot realistically be obtained." Consequently, "scientific" discussions relating to before the Big Bang are currently largely speculative and will likely remain so for some time, considering the information required to lend the topic more scientific solidity.

Discussion and Conclusions

In the Islamic culture, where the Qurʾān is the paramount, *über alles* reference, new scientific results are quickly compared to the sacred texts to check for "consistency" and, in a more recent trend (*I`jāz*, "miraculous scientific content of the Qurʾān"; for a review and critique of this trend, see Guessoum 2010 and Bigliardi 2014), to see if the Qurʾān had already stated or hinted at any of the new results. However, from that, a rather amateuristic cosmology that freely mixes scientific information and religious texts started to appear and spread in the Islamic cultural landscape.

More generally, recent years have witnessed a proliferation of articles on Islam, the cosmos, and "creation," rekindling the old debates on an eternal versus finite-age universe—a discourse that was highly contentious between classical Muslim theologians and philosophers (eliciting accusations of heresy).

But in the twenty-first century, now that science has come to dictate so many things in our lives and minds, can one still discuss subjects such as cosmology, which evidently owe so much to physical science, with a religious perspective and present Islamic or other faith-based views on contemporary cosmology?

Primack and Abrams (2006, 298) weigh in: "[S]cientists alone can never . . . create a visual and poetic language through which the universe as we scientifically understand it can speak accurately and meaningfully to a global, science-based culture." They add: "Great imagery is an essential ingredient of cosmology. Cosmology is always based on symbolism" (Primack and Abrams 2006, 51).

I agree that an important way in which philosophers, theologians, educators, artists, and others can contribute to making sense of the cosmos is by providing ideas that speak to humans from their cultural backgrounds, from myths and scriptures to science fiction and other elements the human mind readily interacts with. Furthermore, another important reason scientists and other cultural influencers should collaborate on such an ambitious, albeit controversial, project (constructing a coherent and meaningful cosmology) is the inherent inability of modern science to provide meaning for many/most of its discoveries. Can one

discuss the "big bang singularity" without discussing its philosophical meaning and its theological implications? Can one discuss the nature of the physical laws in the universe and not relate them to the existence of life, intelligence, and humanity? Can one discuss the existence of other causally disconnected universes and not explore the meaning of that? Clearly there are many issues on which science admits not to be in a position to say much (of cultural importance) and where paradoxically the interest and thirst of humans is heightened.

It is becoming increasing clear to many thinkers and scientists that a purely scientific approach to the cosmos is not satisfactory; in modern cosmology, the universe (which is totally material in science) is supposed to be self-consistent and thus not require a Creator. But then we may run into an infinite regression of causations, or at the very least get lost in a cosmos empty of meaning.

So, what could Islam today contribute to attempts at marrying rigorous scientific cosmology with culturally and philosophically rich and meaningful approaches to "the world"? Before I suggest a few ideas in that sense, I must ask what Islam can learn from modern, scientific cosmology; what it can or should integrate into its worldview.

The first important thing is for Islam to take on board the main findings of modern, scientific cosmology, findings outlined in the Scientific Cosmology section, most importantly, the fact that the universe is old, huge, made of matter that is mostly different from us and our environment, and ever evolving. I have explained that those findings are humbling (and to some, depressing; indeed, we are incredibly tiny in comparison to all cosmic objects and only came on the scene on the last evening of the "cosmic year"), but in some ways, they could not be otherwise; in fact, in some ways, we are special. But those findings need to be digested and integrated into Islam's—and all other cultures'—conceptions of "the world," God, humanity, and history.

Indeed, another important idea that has appeared in recent years is "big history," a holistic and multidisciplinary view of the evolution of cosmos, the solar system, Earth, life, and humanity from the Big Bang to the present, including the emergence of religion, philosophy, and science. Islam (i.e., Muslim thinkers) need(s) to adopt and integrate such a holistic approach that can only prevent conflicting and schizophrenic viewpoints on humans and the cosmos.

Some steps have started to be taken in that direction, such as reinterpreting Qurʾānic passages in accordance with now-established cosmological, or more generally, scientific, knowledge. Haslin Hasan and Ab Hafiz Mat Tuah (2014) have shown that exegetical interpretations of various verses have evolved greatly under the influence of contemporary cosmology. For example:

- Qurʾān 21:30 ("Have the unbelievers not considered that the heavens and the earth were one piece and that We clove them asunder; and We have made of water everything living; will they then not believe?") used

to be interpreted as: "The earth and skies were once joined and then split or broken into separate entities. The act of separation is by the way of the skies being raised up. The separation allows for raining from the sky and vegetation production from the earth" (Hasan and Tuah 2014). Modern exegesis, however, takes this verse to refer to the moment of creation, i.e., either the Big Bang or the formation of our solar system from nebular matter.

- Qur'ān 25:59 ("He Who created the heavens and the earth and all that is in between, in six days, and is firmly established on the Throne") used to be interpreted as: "The sky [being] everything above us. 'Day' is . . . either the earthbound period or God's period . . . which . . . duration differs from ours . . . 'heavens and earth and everything in between' refers to all of His creation existing in this physical world" (Hasan and Tuah 2014). Modern exegesis, however, interprets this verse as "'heavens and earth' represent[ing] the entire physical universe. Heavens (*al-samāwāt*) therefore refers to the entire universe minus the earth. But heavens might also refer to celestial objects such as galaxies, stars, suns and planets . . . 'Between heavens and earth' refers to everything above the earth such as the atmosphere and the rest of celestial objects including space. More recent interpretation (e.g., [al-Najjar] 2006) refers to this as the interstellar medium (such as gas, dust and radiation) or even the vacuum energy throughout space. 'Day' refers to the relativity of time, phases of creation, the 'cosmic day', or an extended period of time such as an era, eon or epoch" (Hasan and Tuah 2014).
- Qur'ān 51:47 ("We have built the heaven with might, and it is We who expand it"). Classical exegesis interpreted this verse as "God's most expansive power" and "the vastness of the heavens." Modern exegesis reads in this "the expanding universe as understood by modern physics" (Hasan and Tuah 2014).

One important issue Muslim theologians—and thinkers, more generally—need to work on is the ultra-anthropic aspect of the traditional Islamic viewpoint. Indeed, Muslims need to take full stock of the fact that humans have only existed for the tiniest fraction of cosmic history. Conceiving of the cosmos, Earth, life, and humans as a "big history" would help remedy the ultra-anthropic perspective.

In reviewing Ibn Rushd's position with regard to the teleological argument, Taneli Kukkonen (2002) notes that the argument from providence in Averroes's *Al-Kashf* treatise "appears almost embarrassingly anthropocentric in character." However, Kukkonen then argues that if one reviews all of Ibn Rushd's works, including and especially his commentaries on Aristotle, one realizes that this argument occupies only a mid-level position, the highest one being reserved to the truly demonstrative ones, i.e., the logically deductive

philosophical proofs. Indeed, Kukkonen reminds us that Averroes always stressed that mankind is inferior to the cosmos, and the superior cannot exist "in first intention" (Ibn Rushd's words) for the sake of the inferior. But Averroes insists that the very fact that one can find in the heavens final causes that are of benefit to us down here is an indication that there is a higher intelligence at work.

Ibn Rushd attenuates the traditional Islamic anthropocentrism even more by noting that not everything that exists in nature is obviously of benefit to man. Clearly there are many animals that do not benefit us directly or indirectly. For this reason specifically, Barrow and Tipler (1988, 46–47) also cite Averroes as a prime example of a non-anthropic stand. Kukkonen (2002) explains that Ibn Rushd considers creatures to fulfill a principle of "great good . . . tainted by little evil," and this secondarily turns out to benefit mankind; as Kukkonen puts it: "[M]an's wellbeing itself comes as a corollary to the primary good of universal design."

Finally, the argument from design needs to be both toned down a bit and updated with the fine-tuning discoveries (of the cosmic building blocks and of the discoverability idea). Muslims must properly digest the fine-tuning and anthropic principle developments and not read them as simplistic confirmation of the "subservience" of nature and the cosmos to humans. Likewise, the idea that we are in some way at the "center" of the universe needs to be reinterpreted, as Primack and Abrams have proposed. Indeed, one must always remember that the purpose of creation is a divine reason, which will remain largely outside of our understanding.

And what ideas could Islam then contribute to the above ambitious program of a multidisciplinary, multicultural understanding of the cosmos? In my view, what Islam brings first is this concept of unity and harmony in the cosmos/creation, with elegance and perfection in the phenomena and the (divine) laws that underlie them. Indeed, what underlies those simple yet powerful cosmic laws and principles is God, who is the perfect abstraction of all being and reality; He is the sustainer of everything that exists, entities, phenomena, and laws, leading to regularity and harmony. A similar but somewhat different view is the Sufi conception of the universe as an effusion from God and of creation as continuous, since God never ceases to disclose Himself (to Himself) without being directly apparent to us.

Even non-theists could benefit from the Islamic worldview of simplicity, unity, and elegance in the underlying principles and laws, and harmony in the phenomena that are then produced. Theists from different traditions may appreciate the Islamic conception of humans as having been created to worship God, and nature being here to facilitate this, physically, emotionally, and spiritually, by helping us at least reflect upon it and perhaps come to know God through it.

To conclude, I should stress the importance of humility in general, and on cosmological matters in particular. Mehdi Golshani ([2002] 2016, 245), prominent Iranian physicist-philosopher, advises: "I, personally, recommend the following strategy: we should explore our universe through science as much as we can, but we must avoid making claims about the absolute origination of the universe on physical grounds."

In this he echoes John Bahcall, the late illustrious American astrophysicist, who had stated: "I personally feel it is presumptuous to believe that man can determine the whole temporal structure of the universe, its evolution, development and ultimate fate from the first nanosecond of creation to the last 10^{10} years on the basis of three or four [quantities] which are not very accurately known and are disputed among the experts. That I find, I would say, almost immodest" (Regis 1988, 210–11).

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What the Future Holds for the Universe and Us? Christian Theology in Conversation with Stephen Hawking

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Stephen Hawking used his worldwide fame to warn of several future existential threats to humanity. The pessimism of some of these scenarios was interwoven with a belief in science as savior and an increasing skepticism of the value of religion and belief in God. Yet, alongside the challenge of how the power of science can be used responsibly, there are also challenges that are beyond the power of science. For example, the future futility of the universe due to its acceleration, which is driven by dark energy. The long-term future is a cold and lifeless state. Here, science as savior is unable to provide optimism. Likewise, it challenges religious views of a creation getting increasingly better. This article argues that Christian theology, which takes seriously the bodily resurrection of Jesus and includes the New Testament's understanding of new creation, is a fruitful conversation partner with this scientific picture. In addition, it recognizes science as a transformative gift of God to be used alongside and for God's purposes.

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Introduction

A few years ago, British television's Channel 4 devoted an evening of programming to an "End of the World Night." In contrast to the scientific optimism that has sometimes been used to dream of future utopia or the belief in science as savior that will deliver humanity from global challenges, scientists presented ever more pessimistic scenarios for the future. Naturally occurring or bioengineered viruses, out of control AI seeing humanity as a threat, and weapons of mass destruction being created and controlled by power hungry dictators were all placed alongside an environmental crisis where global warming leads to rising sea levels, food insecurity, and worldwide environmental refugees. And behind it all was the end of the universe itself, in futility.

Those who hold Christian faith will have noted that Channel 4 chose to air this End of the World Night on Holy Saturday, the day between Good Friday and Easter Sunday. It did not seem this was intentional, but for those of Christian faith, perhaps it was noteworthy. For Christians, hope for the world stands between the reality of evil and destruction in the crucifixion and then God's victory of love over death in the resurrection of Jesus. Yet, in the pessimism-fest of the End of the World Night, the discussion was all about science, and even in the midst of such a Christian festival, it was hermetically sealed from any theological considerations.

Part of the reason for this is that Christian theologians have been slow to engage with such specific science, especially to see it in dialogue with the death and resurrection of Jesus. The surprise of this is that in the latter part of the twentieth century, Christian theology saw a renaissance in thinking about the future, which is eschatology. In Hans Urs von Balthasar's (1960, 276) famous dictum, eschatology in the last few decades was working overtime, since its office was shut down in the nineteenth century.

Therefore, a conference about the legacy of Stephen Hawking held in Jerusalem where Christians looked back to a cross and empty tomb raised intriguing theological conversations. Of course, Hawking was most famous for challenging theological thinking through his work on the origin of the universe rather than the end of the universe. Yet, as Nick Spencer and Hannah Waite have recently argued, for too long, the science and religion debate has fixated on creation, evolution, cosmology, miracles, and quantum theory (Spencer and Waite 2024). They suggest that where science and religion come together, sometimes furiously, sometimes fruitfully, is over the status and nature of the human, and that is most exposed in how science and technology engage with the future. So, it was of interest that one of the scientists featured in the End of the World Night was Stephen Hawking. His brief comments on the future do lead us to some deeper scientific and theological issues.

Hawking Predicting the Future

Hawking's (1988, 1993, 2001; Hawking and Mlodinow 2010) scientific work and subsequent public popularity were founded on general relativity, black holes, and the origin of the universe. But increasingly as a celebrity scientist, he was often drawn outside his field of expertise to more general questions of science, philosophy, and social and humanitarian concerns. Indeed, in his final book, *Brief Answers to the Big Questions*, Hawking (et al. 2018) responds to many of the questions posed to him over the years, especially regarding the challenges of the future such as climate change, the threat of nuclear war, and the development of AI. In this book, he shows his skill in science communication, but there are some deeper themes. The pessimism of some of the scenarios for the future stand alongside the optimistic belief that science plays a critical role in finding solutions.

Hawking used his worldwide fame to highlight great challenges and existential threats for humanity. These comments often became media headlines, even if perhaps taken out of context (Rincon 2018). Lord Martin Rees (2018), the British Astronomer Royal, said of Hawking: "He had robust common sense and was ready to express forceful political opinions. However, a downside of his iconic status was that that his comments attracted exaggerated attention even on topics where he had no special expertise—for instance philosophy, or the dangers from aliens or from intelligent machines."

In an earlier book, *The Universe in a Nutshell,* Hawking (2001, 158) commented that "by 2600 the world's population will be standing shoulder to shoulder, and the electricity use will make the Earth glow red hot." Of course, this is well-known strategy for science communication: "If we don't do anything about this and if things go on as they are, then . . . " He also argues that human DNA will increase in its complexity rapidly and that this needs to happen to live in a complex world and keep ahead of electronic systems.

Of course, warnings about the climate emergency have rightly used this approach but with a lot more subtlety and detailed modeling. The work of the Intergovernmental Panel on Climate Change, begun in the late 1980s, has looked in detail at the effects of the continued emission of greenhouse gases, including the warming of the planet, long-lasting changes in all components of the climate system, and the increasing likelihood of severe, pervasive, and irreversible impacts for people and ecosystems (Jenkins et al. 1990). This is quite a long way from the picture of people standing shoulder to shoulder, but it does give strong motivation that limiting climate change will require substantial and sustained reductions in greenhouse gas emissions, which, together with adaptation, can limit risks (Pachauri and Meyer 2014). The difficulty demonstrated by the last three decades however is that while the scientific scenarios are clear, they do not convince and motivate individuals, institutions, and governments to make

sufficient changes. The key is not just scientific predictions of an apocalyptic future but convincing of the need for moral change. As Sam Berry (2003) pointed out a couple of decades ago, the environmental devastation is due to human selfishness, or what the Christian would call sin.

However, the voices of scientists in the area of climate change were prophetic to Western Christian theologians who had spiritualized the message of the Bible in a way that devalued the physical creation and God's concern for it. Books such as Rachel Carson's (1963) *Silent Spring*, the iconic Earthrise photograph from Apollo 8 (Poole 2008), and the wealth of work in biodiversity and atmospheric physics led to a rediscovery of the Christian doctrine of creation as it applied to ecology and environmental responsibility. Theologians rightly responded to these insights by finding new resources in the Bible and Christian thinking (Horrell 2010; Harakas 1999, 149–62; DeWitt 1991; Moltmann 1985).

The powerful threat of the climate crisis partly led Hawking, with several other scientific voices, to become a strong supporter of the need for humans to move into space and colonize other planets. The argument here was one of resilience towards the future. He was worried by the vulnerability of humanity if we were all on one planet. In addition to the climate crisis, a threat to the planet such as a large asteroid or comet impacting the Earth in a global extinction event, or the rise of artificial intelligence, viruses, or nuclear war would lead to the end of humanity if we were not distributed in space colonies in orbit or on other planets. In 2016, Hawking commented, "Although the chance of a disaster to planet Earth in a given year may be quite low, it adds up over time, and becomes a near certainty in the next thousand or ten thousand years" (Shukman 2016).

Lord Martin Rees (2003, 8) has also set out the many risks presented by the future, adding rogue nanotechnology and experiments eroding the atoms of the Earth or tearing the fabric of space-time. He concludes that the odds "are no better than fifty-fifty that our present civilization on Earth will survive to the end of the present century." In the face of such pessimism, Rees sees the future of human beings in a cosmic rather than Earthbound setting. The development of science coupled with human ingenuity means a spread of human intelligence across the universe would make us less vulnerable to being wiped out by one major event.

Such astro-futurism must also take seriously that when the sun eventually runs out of hydrogen fuel in 4.5 billion years and begins to swell in a red giant phase, the Earth will either be "crispified" in its outer swollen layers or at the very least be completely stripped of its atmosphere (Aungwerojwit et al. 2024). Some speculate that humans will then find other planets outside our solar system capable of sustaining life or terraform other planets to make them capable of sustaining life (Beech 2009). There is also some thinking about directed panspermia, that is, sending simple life from Earth to seed many other planets (Sleator and Smith 2017). Those who advocate such possibilities argue that the special nature of life on the Earth gives us responsibility for sustaining life in

the universe. Here, traditional religious thought is embodied in new ways in the sanctity of life, stewardship of the gift of biological life, and many ethical questions, such as whether we as humans have a right to colonize or even seed other planets that may have their own indigenous life-forms.

It is not only professional scientists who speculate about such scenarios. Hawking is also joined by the new generation of space entrepreneurs (Francis 2023). Elon Musk (2017) has set out a strategy for SpaceX to colonize Mars. Blue Origin's Jeff Bezos prefers industry and human colonies in orbit rather than on other planets (Clifford 2019). Here, Bezos follows the Princeton physicist Gerard K. O'Neill (1982), who described human colonies in space back in the 1970s. For Bezos, moving people and manufacturing to Earth's orbit would deal with the problems of overpopulation, limited energy, and resources, and indeed climate change. Heavy industry would be based on the mining of the moon and asteroids, the sun would provide limitless energy, and pollution would go out into space rather than messing up the Earth's atmosphere. The reduced gravitational forces of orbit would allow new industrial techniques and a different experience of being human. In 2007, Hawking himself famously experienced weightlessness in a specially modified jet that goes through several dives to give passengers an experience of zero gravity. He spoke of the freedom from being wheelchair-bound (*New Scientist* 2007).

Yet, regarding the expansion of humanity into the cosmos, Hawking showed a particular hesitancy. While he was open to the existence of other intelligent life forms in the universe, and supportive of listening for signals in the SETI (Search for Extraterrestrial Intelligence), he was worried about what kind of aliens we might encounter. He therefore joined a few scientists, such as the former Astronomer Royal Martin Ryle, in cautioning against trying to send messages out from Earth. In November 1974, the strongest human-made signal ever transmitted was beamed by the Arecibo radio telescope in the direction of the Great Cluster of the constellation Hercules by Frank Drake. It consisted of a binary message that included numbers, stick figures, chemical formulas, and a crude image of the telescope itself. Ryle objected to this in case it revealed our position to aliens who might then come and conquer us. He suggested that "any creatures out there [may be] malevolent or hungry." Hawking shared this view. He was worried about aliens raiding the Earth for resources. In 2010, he told the Discovery Channel, "We only have to look at ourselves to see how intelligent life might develop into something we wouldn't want to meet" (Riddick, Williams, and Williams 2010).

This not only describes one of the potential problems of aliens, but it is also a reflection upon ourselves as humans. The conflicted nature of human beings is that we demonstrate both goodness and selfishness. Perhaps this is at the heart of the juxtaposition of optimism and pessimism about science and the future. That is, science is done by scientists, with all the frailties of being human. Science as a community with its own checks and balances in terms of

funding, refereeing, and culture can often filter out the mad megalomaniac, but science is often funded by political bodies, which have their own economic and military motives. Individual people and the institutions they populate are seen as both good and fallen by Christian theology.

Even with the successes of science and technology in solving problems from pandemic vaccines to the safety of buildings in earthquake zones, science is embedded in a culture where vaccines are not universally available and the poor cannot afford safe housing and therefore are always more vulnerable. Optimism and pessimism go hand in hand, and the myth of human progress of the early twentieth century that science, technology, and education will lead to human utopia was never fulfilled (Bauckham and Hart 1999). Science discloses and works with a world that is both wonderful and fragile for human beings; indeed, in its exciting new possibilities, it also raises huge risks (Geraci 2012; Blake et. al. 2012; Church and Regis 2012).

In her Gifford Lectures, the philosopher Mary Midgley (1992) discusses the myth of science as salvation. She argues that concepts of salvation, immortality, and mastery of both our bodies and the universe are "adolescent fantasies" that have become embedded into the professional lives of some scientists. She saw danger in a culture where religion no longer is trusted and the myth of science as salvation is uncritically and eagerly accepted as the source of hope (Midgley 1992).

Up to this point, I have used Hawking's brief comments on the future to illustrate the potential and problems of human agency in science. However, there is one scenario of a longer-term future that has been highlighted in contemporary cosmology that is predominately pessimistic and seems to have little capacity for human agency. That is the far future of the universe itself.

The far future of the universe was not a major interest of Hawking's, although some of its physics is shared with his work on the origin of the universe. But such was his celebrity status as a cosmologist that when our picture radically changed in the early twenty-first century, the journal *Science* noted that he had "blessed" the conclusions of this scientific work (Glanz 1999, 34–35).

Hope in an Accelerating Universe?

In 2011, the Nobel Prize was awarded to Saul Perlmutter, Brian Schmidt, and Adam Reiss for new discoveries concerning the expansion of the universe. This work began in 1998 and the Nobel Prize recognized not only the brilliance of the research but also the significance of their discovery. The project used Type 1a supernovae explosions to study how the expansion of the universe was slowing down. Up to that point, physicists were divided on whether a slowing expansion would continue forever or if there was enough mass in the universe—then, the expansion could be reversed into a collapse of a Big Crunch, the opposite of the Big Bang. To the surprise of everyone, they showed that the universe is accelerating in its rate of expansion due to some unknown type of force, the

so-called "dark energy" (Riess et al. 1998; Perlmutter et al. 1999; Riess et al. 2001; Perlmutter 2003; Kirshner 2016). Roughly 70% of the universe seems to be in the form of dark energy. It is thought to fill space uniformly at a very low density of 10^{-27} kg/m^3.

This led to a frenzy of observations and theoretical work to test the original findings and explain them in new theoretical models. While some have questioned the supernovae data, the evidence has built strongly in favor of the universe accelerating (Nielsen et al. 2016; Betoule et al. 2014; Spergel et al. 2007). But what can explain the data, and what is the dark energy? Several suggestions have been made. First, a vacuum energy that is a constant background in the universe. When Einstein applied his general relativity to the universe as a whole, he added a cosmological constant to balance gravity and so give a static universe, neither expanding nor contracting (O'Raifeartaigh et al. 2017). This effectively took the role of gravitating negative masses. According to George Gamow (1970, 44), Einstein remarked that this was the "biggest blunder of his life." Yet, dark energy has raised again this possibility. The vacuum energy acts as a cosmological constant, and it has been suggested that it is produced by quantum theory's possibility of the constant appearance and disappearance of pairs of particles and antiparticles in line with the Heisenberg uncertainty principle (Rugh and Zinkernagel 2002). However, theoretical modeling of this continues to have problems.

Second, quintessence is the possibility of an energy that can vary in its amount and distribution through both space and time. Here, the observed acceleration is caused by the potential energy of a dynamical field, referred to as the quintessence field. There is currently no evidence for quintessence, but some have argued that it may be shown in variation of the fundamental constants in space and time. One of the advantages for quintessence is the observation that the acceleration starts a few billion years into the universe's expansion. If it had started earlier, then galaxies would not have been able to form. Some have suggested that the quintessence field does not switch on the acceleration until a certain point in the universe's history marked by matter–radiation equality.

Third, it may be that our understanding of how gravity works on the large-scale universe is limited. In this explanation, what we call dark energy is not a new force but a variation in general relativity's explanation of gravity. It may be that both dark matter and dark energy modify the laws of gravity at various scales. This may mean that dark energy and dark matter interact or can be unified (Oztas et al. 2018). Others have argued for a modification of general relativity, although some of the first results from the detection of gravitational waves are not consistent with this (Joyce et al. 2016; Lombriser and Lima 2017). It is also important to note that some have argued dark energy is a mirage and not needed to understand the universe, but this has not been generally accepted by cosmologists (Mattsson 2010). A number of experiments are currently

searching for answers to these candidates for dark energy, using both ground-based and orbiting telescopes (Castelvecchi 2023; Huterer and Shafer 2018).

The long-term future of an accelerating universe is heat death. But if the effect of dark energy keeps increasing, the universe will experience a "Big Rip," where gravitationally bound structures would be ripped apart and eventually other forces such as the electrical and nuclear forces will be overcome, leading to the ripping apart of atoms.

The lack of any agreement on the best theoretical model and the need for more observations to constrain these models gives quite a large solution space to some of this discussion. Within this solution space, not only scientific preferences but also more philosophical preferences can be expressed. In particular, the pessimism of a future where an accelerating universe leads to a future universe that is cold and dark, and where structures no longer can be sustained, is difficult for scientists to maintain.

For example, Jeremiah P. Ostriker and Paul J. Steinhardt comment on different options:

> As acceleration takes hold over the next tens of billions of years, the matter and energy in the universe will become more and more diluted and space will stretch too rapidly to enable new structures to form. Living things will find the cosmos increasingly hostile. If the acceleration is caused by vacuum energy, then the cosmic story is complete: the planets, stars and galaxies we see today are the pinnacle of cosmic evolution.

However, they go on to try and find hope in quintessence:

> But if the acceleration is caused by quintessence, the ending has yet to be written. The universe might accelerate forever, or the quintessence could decay into new form of matter and radiation, repopulating the universe . . . [T]he universe had once been alive and then died, only to be a given a second chance. (Ostriker and Steinhardt 2001)

It is interesting to see the passion for the universe to be given a second chance. Of course, scientists will be guided by the data, but they do science in the context of culture, a diversity of religious beliefs, and their own fundamental beliefs and hopes. In the 1980s, I worked with a young Indian cosmologist, Dr. N. C. Rana, on the dark matter problem (Rana and Wilkinson 1987). At that point, the scientific community was wondering whether there was enough dark matter in the universe to reverse the expansion. Rana was very keen on this, even if the observational evidence suggested the opposite. He was very honest that as a Hindu he was drawn to an oscillating universe resonating with beliefs in reincarnation.

Throughout discussions of the end of the universe, several scientists have resisted the pessimism of the accelerating universe. Some have pointed to the possibility that this universe may be one of many; therefore, even if this universe ends in futility, there are other universes that will continue to exist and may contain life. Many universes appear in many different theories (Carr 2007; Gribbin 2009; Friederich 2021; Halpern 2024). The accelerating universe seems to rule out a very popular model of the previous decades. This was the view mentioned previously that the universe would expand and then contract under gravity, leading to a bounce into another universe. This eternal oscillating existence of the universe finds a termination to its cycle in the acceleration and eternal expansion. Of course, earlier universes with different laws of physics can never be ruled out, but they do not give any hope for the present and future. Another model of multiverse arises out of inflationary theories that explain certain features of the early universe, but some of these have the consequence that our universe is one universe in a sea of bubble universes, rather like bubbles in a foam. In all these multiverse theories, there remains the fundamental problem of passing the information of one universe to another. Here is a metaphysical hope rather than any real evidence of other universes or indeed of life in these other universes. That is why John Polkinghorne (2002, 27) comments that such a scenario presents "a scene of occasional islands of meaningfulness erupting within an ocean of absurdity."

It can be noted in passing that in his final paper, Hawking makes a contribution to this area. Having employed multiverse in his book *The Grand Design* as a way of dealing with the very beginning of the universe, he and coauthor Thomas Hertog argue against eternal inflation and multiverse (Hawking and Hertog 2018). They employ string theory to suggest a beginning to the universe with no time at all. In *A Brief History of Time*, Hawking had tried to deal with the problem of how science could describe the very first moment of the universe's history by speculating on a theory of quantum gravity where time becomes a dimension of space. In contrast, in this new work, time ceases to have any meaning. This is an illustration of some of the uncertainty around the beginning of the universe but also a reminder that the beginning and the future are intricately linked.

Other physicists, rather than finding hope in other universes, have attempted to find hope by appealing to the myth of human progress, or science as savior. Freeman Dyson and Frank Tipler were struck by the ability of humans to manipulate the environment of the Earth and wonder if this could be extrapolated forward to engineering projects on a much larger cosmic scale. Dyson suggests genetic engineering of biological life could lead to life having a longer survival time in a cold, expanding universe. Then, consciousness could be transferred to non-biological structures that could exist at very low temperatures, for example, a complex dust cloud. In this way, "life and intelligence are potentially immortal" (Dyson 1988). Tipler (1994) saw consciousness transferred to computer neural

networks expanding across the universe. However, the Dyson and Tipler models were constructed on the basis of an expanding but not accelerating universe. The accelerating universe makes it impossible for such structures to be maintained, which means science cannot promise that life and intelligence are immortal.

In the end, the accelerating universe predicts a future of the universe that is one of futility. Paul Davies (2002, 48) writes that an "almost empty universe growing steadily more cold and dark for all eternity is profoundly depressing."

Engaging Science with Theology

If science cannot provide hope in the face of the long-term future of the universe, might Christian theology bring a contribution to this End of the World night? It may be worth pausing here for a moment to consider a few options for how science can engage with theology. This is to avoid the charge that the theologian is simply trying to insert God into the gaps of scientific uncertainty or tell a story that has no real interaction with the scientific story. Some years ago, Ian Barbour (2000, 113) produced a now widely used fourfold typology of conflict, independence, dialogue, and integration to characterize the relationships between science and religion. While others have critiqued Barbour and suggested more nuanced models (Stenmark 2013), it is instructive to locate our discussion of the end of the universe within this framework.

The conflict model, used by both scientific atheists and six-day creationists, pits science in warfare with religion, each striving for complete victory over the other. Yet in terms of the end of the universe, this approach is not convincing, whichever end of the theological spectrum it comes from. Oxford chemist and atheist Peter Atkins (1995, 129) wrote, "Science has never encountered a barrier it has not surmounted or that we can reasonably suppose it has power to surmount." Yet as we have seen, that will not quite work for the end of the universe. At the same time, the six-day creationist case (within the Christian church), which also uses the conflict model, is severely undermined by the futility of the physical universe. To argue that God created a perfect creation some 6,000 years ago does not do justice to a universe that is falling apart. This creation does not seem to be a perfect end product. Creationism neglects both the importance of eschatology for the physical creation and a wealth of scientific observations. Creationists either argue against the scientific data regarding the age and expansion of the universe or argue that the futility is simply the result of a cosmic Fall. While I acknowledge that the doctrine of the Fall should not be ignored, it is not strong enough to support such creationist claims (Berry and Noble 2009).

The second model, that of independence, sees science and religion in separate domains. This has been advocated by theologians in the Barthian tradition, philosophers exploring the nature of language, and some scientists such as Stephen Jay Gould (1999, 207–8). While of course science and religion

have different foci in their exploration and description of the world, scientific predictions of the future and the end of the universe in particular challenge such a complete separation. Questions of hope and salvation are at the heart of such discussions. In fact, it can be seen even in the language used by scientists such as Dyson and Tipler that they fall into the fallacy of believing that science and religion are non-interactive disciplines. For example, Tipler (1994, xiii) wants to "rescue eschatology from the hands of theologians who with a few exceptions . . . are quite ignorant of it." For the theologian, the belief that the universe is God's creation must then take seriously the reality of what we can see of the future in the present. Just as with creation care in the midst of the climate emergency, science can bring new insights and challenges to the theological task. So, when it comes to the futility of the future of the universe, as a Christian theologian, I want to take this seriously.

While independence would mean there is no engagement at all, Barbour's model of integration wants to build science and theology into a seamless philosophy. At the simplest form of integration, some have looked for God to fill the gaps of scientific ignorance. Yet, such a program of integration does not take seriously enough the complexity, rate of change, and ambiguity of the scientific picture. Both science and theology are provisional activities. A god of the gaps is often pushed out of the gap and becomes irrelevant as science explains more and more of its own territory.

Some might say that the difficulty of predicting the end of the universe is unique in this provisional texture, but the provisionality exists in all science. Barbour's own more nuanced commitment to integration pushed him towards process theology, which uses an analogy between God's action and our experience as agents and attempts to proceed by assimilating the nature of the universe to our nature. Developed from the metaphysics of A. N. Whitehead with theological development by Charles Hartshorne, process theology reacts against a mechanistic universe by suggesting each event in the universe has a psychic pole and a material pole, and God works as an agent at the subjective level, exercising power by persuasion. This allows space for human agency to be maintained but has been critiqued for severely limiting God's ability to exercise agency in any significant way (see, for example, Gunton 1978). Certainly, it has a problem with the futility of the future of the universe, with God as spectator as the whole thing falls apart.

For me, the alternative and fourth model is much more convincing. This is dialogue and sees science and theology in a series of open-ended conversations. While they come from different perspectives with their own methodologies, there is common ground for the conversation. This may be in the questions raised within the different disciplines that cannot be fully answered by them. It may be that the different methodologies have some common foundations and interaction. It may be that one discipline gives resources to the other in insights or analogies. For example, concepts from science can be used as analogies for

talking about God's relation to the world, and models of God's action may be furthered enriched or constrained by scientific insights into the nature of the world. It may be that in conversation one discipline is reminded of its own limits. The conversation may never reach integration, but its usefulness is in enriching the partner discipline's.

We have already seen that the exploration of the end of the physical universe within contemporary cosmology has involved questions of futility, progress, and the limits of science as savior. Such insights raise major issues for the Christian theologian. The end of the universe points to a future of futility for the physical and with it the end of the survival of intelligent life within the universe. It raises the question of how the end can be understood within a theology of creation. Some theologians will say that this is so far in the future that it is irrelevant, while others have concentrated their thinking about the future on the future of the Earth, the individual believer, or the church. Yet, the physicist will pursue the conversation. A Christian doctrine of creation does raise the question of what God thinks of the physicality of creation. In addition, the end of a story is key to understanding the story, however far in the future that may be.

Hawking was never reserved about bringing God into the conversation with the results and speculations of cosmology. As noted, this was often in connection with the origin of the universe, where he initially, in *A Brief History of Time*, attacked a deistic rather than fully Christian picture of God on the basis of his speculative thinking about quantum gravity (Wilkinson 2001; Wilkinson and Hutchings 2020). Deism believes in a God who started the universe and then retired a safe distance from it, not doing anything of note in the universe. This is a long way from traditional Christian theism, which sees God sustaining the universe at every moment through the faithfulness of the laws of physics and becoming a human being in the life, death, and resurrection of Jesus. Hawking was right in attacking such a deistic god of the gaps who simply started off the initial state of the universe and then had nothing more to do with it. Indeed, Hawking's work was welcomed by several of us who wanted to think more deeply about God's creative work.

During his career and especially as his media fame grew, Hawking's public comments on the existence of God became more negative. Sometimes he followed Einstein, who did not believe in any personal God but equated god with "nature." In a series for the Discovery Channel, Hawking (2011) gave a quote that has often been repeated:

> We are each free to believe what we want, and it is my view that the simplest explanation is there is no God. No one created the universe, and no one directs our fate. This leads me to a profound realization. There is probably no heaven, and no afterlife either. We have this one life to appreciate the grand design of the universe, and for that, I am extremely grateful.

The Christian theologian might want to pick up on at least two things here! The first is to ask to whom Professor Hawking is grateful. For some, the word "design" might also raise the question of agency. The second may be to point out the apparent huge leap from "no God" to "no heaven and no afterlife." Indeed, others from parts of other faith communities such as Buddhism may not follow such logic. Yet, within Christian theology, I follow Professor Hawking on this point. Hope for life to come is entirely based in belief in a creator God who acts within the universe. It is to this that I now turn in a mode of dialogue.

Gazing Forward in Conversation with the Bible

In Paul's letter to the Romans, after seven chapters discussing human rebellion and the gift of salvation through faith in the atoning work of Jesus, he turns to what this means for the future. One consequence is that there is no condemnation for those who are in relation with the risen Christ (Romans 8:1); another is that whatever happens in the future will not separate us from the love of God in Jesus (Romans 8:38–39). Sandwiched in between is a short passage that reflects on the present and our experiences in this creation (Romans 8:18–22):

> I consider that our present sufferings are not worth comparing with the glory that will be revealed in us. For the creation waits in eager expectation for the children of God to be revealed. For the creation was subjected to frustration, not by its own choice, but by the will of the one who subjected it, in hope that the creation itself will be liberated from its bondage to decay and brought into the freedom and glory of the children of God. We know that the whole creation has been groaning as in the pains of childbirth right up to the present time.

Of course, Paul has no knowledge of scientific predictions about the end of the universe, but he senses a creation in bondage to decay. Christian theology holds creation good because it is created by God, yet at the same time, this theology is characterized by frustration, decay, and groaning for something beyond this present creation.

In the eighteenth century, the founder of Methodism, John Wesley, was particularly moved by this passage. He was fascinated by the science of his day, especially Thomas Hartley's *Paradise Restored*, Thomas Burnet's *Theory of the Earth*, and James Knight's *A Discourse on the Conflagration and Renovation of the World*. As part of the evangelical revival, he had become a noted preacher of the necessity of new birth in the conversion of an individual (Whitefield et al. 1986). He saw the church as God's new community, but as Randy Maddox has argued, Wesley's perceived scope of God's work was not confined to human beings. At the heart of the New Testament of hope, he saw the promise of new creation—an action of God leading to physical change of key importance (Maddox 2004). His thinking led him to argue in his 1781 sermon "The General

Deliverance," which used Romans 8:19–22 as its text, that a range of animals would be present in this renewed creation.

Wesley was bringing biblical insights into conversation with the science of his day and in doing so speaking afresh of God's work in the world. Can we do a similar thing in terms of scientific predictions of the future? I have explored such material in greater depth elsewhere (Wilkinson 2010, 53–114; 2017, 97–110), but how might such insights be in dialogue with some of the scientific scenarios I have described in this article?

First, I note, with Wesley, the importance of the theme of new creation within a range of biblical genres. New creation is not about a wispy, greyish, and ghostly heaven to which souls are liberated at the point of death, having left this physical world behind completely. In the book of Revelation (21:1), the vision is of "a new heaven and a new earth." It is about God doing something with the totality of existence, a point Wesley notes in speculating about the future of animals as well as men and women. The question of the futility of the universe and the danger of science being used for power and injustice are here in conversation with a creator who still is concerned with the physical. The "new heaven and new earth" is a picture not of separation of God's concern but a unity of God's concern that is as much about the "spiritual" life of inner religious experience as the physical life of science and technology. Here is an affirmation of the role of science as an enduring gift of God and the vocations of the scientist to explore the world and the technologist or engineer to develop the potential of the world for good. At the same time, it is about something new, not about keeping this creation alive for as long as possible. Here is a critique of the hope given by the "eschatological scientists" such as Dyson and Tipler. Hope is not to be found in life continuing in interstellar gas clouds. This stands alongside the critique of Christian theology, especially that found in funeral liturgy and Christian hymns that paint an overly human-centered and non-physical hope (Wright 2007).

Second, new creation is a possibility not because of human scientific achievement but because of a creator God. Thinking about new creation in the Bible is continually linked to God's original creative work, and hope for the future is built on an understanding of God as creator (Isaiah 65:17–25). Whatever the circumstances, creation is not limited to its own inherent possibilities, because the God of creation is still at work. This is in stark contrast to the myth of human progress and the belief that science can be the ultimate savior. Thus, the sovereignty of God in creation is the basis of hope in new creation. This raises questions of whether God can act in the universe. These questions of providence are complex, but a God who is not free to work in the universe must watch the slow heat death of creation. Scientific predictions of the end of the universe are a reminder that models of providence must take seriously the universe over its entire history rather than just its present state. Further, those models, which picture the universe as God's body, work reasonably well with a universe of its present structure, variety, and life but are weak when we look forward to a universe

that decays in the futility of a lifeless and unstructured heat death. Models that stress immanence too much at the expense of transcendence face a bleak future in the end of the universe. At the extreme limit of this, models where God is a superior intelligence totally contained in the universe, as have been developed by some scientists in a revamped natural theology, become gods who eventually will die (see, for example, Hoyle 1983). Likewise, models that stress God's non-intervention in the universe are presented with an interesting question in terms of the end of the universe: Is God sustaining a process that will end in futility?

Richard Bauckham (1993, 51) rightly comments:

> A God who is not the transcendent origin of all things but a way of speaking of the immanent creative possibilities of the universe itself cannot be the ground of ultimate hope for the future of creation. Where faith in God the Creator wanes, so inevitably does hope for the resurrection, let alone the new creation of all things.

Third, new creation is a transformation of the present creation rather than a total annihilation and beginning again. Some religious thinkers have welcomed the death of the universe either because it resonates with a form of reincarnation where there is no continuity between the past, the present, and the future, or because they view this world as completely infected by evil and therefore God needs to start again. Some Christian commentators have pointed out a verse in 2 Peter that in many English translations reads, "But the day of the Lord will come like a thief. The heavens will disappear with a roar; the elements will be destroyed by fire, and the earth and everything done in it will be burned up" (2 Peter 3:10). As might be imagined, this has caused some commentators to draw too close a connection between the apocalyptic imagery of the Bible and scientific scenarios. For example, Bo Reicke (1980) comments:

> The solar system and the great galaxies, even space-time relationships will be abolished . . . All elements which make up the physical world will be dissolved by heat and utterly melt away. It is a picture which in an astonishing degree corresponds to what might actually happen according to modern theories of the physical universe.

That "[a]ll elements which make up the physical world will be dissolved . . . and utterly melt away" conveys the sense that this physical universe will be destroyed by God. In fact, the verse does not mean this at all. Bauckham is correct in seeing such passages as 2 Peter 3:10–13 in the context of the Jewish apocalyptic. In contrast to the dissolving and renewing fire of the Stoics, and the Zoroastrian view of purification, here the emphasis is on judgment. Rather than the end of verse 10 speaking about all things being burned up, it is better understood as "laid bare." Bauckham (1983, 326) concludes that such passages

"emphasise the radical discontinuity between the old and the new, but it is nevertheless clear that they intend to describe a renewal not an abolition of creation." As Polkinghorne has argued, the first creation was *ex nihilo*, while the new creation will be *ex vetere*. In other words, the old creation is God's bringing into being a universe that is free to exist "on its own" in the ontological space made available by the divine kenotic act of allowing the existence of something wholly other; the new creation is the divine redemption of the old (Polkinghorne 1994, 167). Once again, this theme is an affirmation of the physical creation and the transformative capacity of science and technology. Environmental concern and action are important because God's purposes are not to throw away this evil world but to use both divine and human agency to transform it. At this, the point might be raised: Could humans do anything, especially in terms of Earth's environment, that has implications for the whole universe? This is fair, but central to the parables of Jesus such as the mustard seed is that the nature of the Kingdom is counterintuitive on this point, that the small may profoundly affect the bigger picture. The new creation is already begun in the life, death, and resurrection of Jesus, giving hope and confidence that something on the Earth does have cosmic consequences.

Fourth, the nature of that divine agency is represented in the Bible both in continual process and in particular event. In their discussion of Christian hope, Bauckham and Trevor Hart are right to emphasize the importance of the biblical tradition of the second coming of Christ (Bauckham and Hart 1999). This may feel a strange topic to introduce into dialogue with science. It is often used in popular expressions of Christianity to paint an apocalyptic picture of end times suffering and the final triumph of Christians over the world. Yet for the mainstream Christian tradition, it is a reminder that biblical eschatology, that is, thinking about the future, has a focus on Jesus Christ. Further, the images used are suggestive of an eschatological event that is both in space and time and yet transcends space and time (1 Thessalonians 4:13–5:11). It is a reminder of the importance of the particular action of God within God's more general activity of sustaining and transforming creation. Thus, the redemption of this creation is pictured in terms of a long process, working through contemporary structures as well as a specific event of judgment. Former Astronomer Royal Sir Arnold Wolfendale, who returned to Christian faith later in his life, remarked to me that there is some parallel here to the moment of phase change within a process. For example, in the early universe, the period of early expansion called inflation switches on and off, changing the universe fundamentally. The acceleration of the universe due to dark energy certainly seems to also switch on a few billion years after the Big Bang. Now, I am not suggesting in any way an interventionist God who is responsible for such things. But the analogy might be instructive for an understanding of how a particular form of engagement by God alongside the normal sustaining of the universe might give a fulfilment of new creation.

Fifth, the resurrection of Jesus is central in all of this. It provides the evidence that God has agency within the space-time history of the world as well as a model for the nature of new creation. The scientist will want to ask about evidence. Christian proclamation about the resurrection has always put forward the historical evidence for the bodily resurrection of Jesus (Wright 2003). The scientist will recognize that this is different from many areas of scientific evidence. There is no repeatability of the experiment but rather a collecting of data and then questioning of the best model that explains the evidence for a one-off event. This is the historical method, and there are areas of science that at times share this. The Big Bang is a one-off event, and cosmology has collected evidence and then reconstructed the best model that explains that evidence. The resurrection as an unusual act of God outside God's normal ways of working may never be open to scientific explanation, but the scientist may be guided by the evidence even if the model defies everyday experience or common sense.

But the resurrection is also, in the words of Paul, "the first fruits" of that which is to come (1 Corinthians 15:20). What is striking about the gospel writers' description of the risen Jesus is both the continuity and discontinuity with the Jesus who is crucified. The risen Jesus seems to be physical in terms of eating and even pointing to the scars of the crucifixion on his body. Yet, he seems to be different. The disciples do not immediately recognize him, and he appears in rooms with locked doors. So, if the resurrection is the initial picture of God's transformative work, then there should be both continuity and discontinuity in the relationship of creation and new creation, as there was in the relationship between Jesus before the cross and Jesus risen. Once again, the empty tomb is a sign that God's purpose for the material world is that it should be transformed not discarded. But if resurrection affirms creation, then it also points forward to new creation.

Continuity and discontinuity in the transformation of the physical universe may be located in the nature of matter, space, and time. To take time as an example, the resurrected Jesus does not seem limited by space and time. In new creation, the continuity may be that time is real, but the discontinuity may be that time no longer limits us in the way it does in this creation. It could be argued that the resurrection body is characterized by decay's reversal, that is, a purposeful flourishing. In this creation, time is associated with decay and growth, but in new creation, time might be simply about growth (Thiselton 2012). I am therefore suggesting that our experience of time in the physical universe is a small and limited part of an ontologically real time we might call eternity.

Conclusion

Consideration of the end of the world, whether in pop culture or in serious scientific research, illustrates a series of deeper questions for the understanding of the role of science and for Christian theology. Trust in science as ultimate

savior is undermined by the impossibility of human agency in the accelerating universe and the recognition that in those scenarios where agency is possible, it is dependent on both the goodness and fallenness of scientists. Science can make a positive difference to the future, but it does not and cannot solve all problems.

Christian theology, which is centered on the bodily resurrection of Jesus, affirms the role of scientists in working for future good, but it also cautions that only God can transform this creation into new creation. The accelerating universe and the consequent heat death provide key questions for theology, which are opportunities more than problems. It highlights a greater engagement with scripture and the need to engage more with themes of new creation, eschatological transformation, and resurrection.

An "end of the world night" is therefore ideally located between Good Friday and Easter Sunday.

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Developing Knowledge for Social Change: A Response to *Critical Approaches to Science and Religion*

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This is a response to the 2023 volume entitled *Critical Approaches to Science and Religion*. It examines the role of ontic commitments in shaping ethical claims. It also considers the possibility of objectivity in knowledge projects.

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Critical Approaches to Science and Religion is a welcome contribution to the subfield of science and religion, which tends to be overly dominated by voices that are Christian, white, and male (as valuable as those voices are). As the editors of this volume rightly note, there has not yet been enough work done to examine how histories of "slavery, patriarchy, and colonialism" (Perez Sheldon, Ragab, and Keel 2023, 1) have shaped the field, thus putting the area at risk of perpetuating oppressive assumptions and conclusions. A volume like this has been sorely needed. It is important to emphasize, however, along with the editors of the project, that this volume by itself is not enough. I echo the hope of the editors that it will chart a course for new directions of research in science and religion and generatively "engage, enrage, and embolden future scholars" (Perez Sheldon, Ragab, and Keel 2023, 378) to imagine and work to produce a more just world. The importance of this work has only increased since the publication of the volume in 2023, as authoritarianism and xenophobia continue to fuel political violence and threats to academic freedom. Indeed, patriarchy, racism, and colonialism are far from being relics of the past—so fresh, rigorous diagnosis and analysis of these ills are constantly demanded. This volume serves an important role to this end.

There were many aspects of the volume I found simultaneously challenging and edifying, and I want to commend, in particular, Myrna Perez Sheldon's contribution entitled "A Feminist Theology of Abortion." I also reference this essay as a way of providing context for some questions and observations that emerged for me about the volume as a whole. I express these in the hopes of sparking further conversation and a creative extension of the themes and arguments of the book. Perez's essay is one of the most nuanced and creative pieces of writing to date on the topic of reproductive justice. It reflects on the destructive legacies of both the sciences and religions when it comes to the issue of reproductive justice by examining the "parallel violences done to women by racial biopolitics and patriarchal Christianity" (Perez Sheldon 2023, 62). She persuasively argues that reaction to Christian ethnonationalist abortion politics in the United States should not drive us to uncritically embrace so-called "scientific" approaches to reproductive rights without taking seriously the ways in which these approaches have colluded with racist and eugenicist aims. In fact, as she demonstrates, the global history of abortion policy is shot through with eugenicist ideology. At the same time, acknowledging the reality of the entanglement of abortion policy with eugenics, in her view, does not legitimize an embrace of right-wing pro-life policies that would seek to abolish access to abortion. Perez Sheldon argues that for people who can or will experience pregnancy, both religion and science have been false friends, claiming to bring protection or liberation but doing violence instead.

Perez Sheldon's integration of theoretical insight with wisdom from activists working on the ground provides an excellent example of some of the best

aspirations of the volume, including its intention to develop "knowledge for social change" (Perez Sheldon, Ragab, and Keel 2023, 4), in contrast to knowledge that remains ensconced in the academy, and "design a future that is more just and humane" (Perez Sheldon, Ragab, and Keel 2023, 1). Particularly effective is Perez Sheldon's (2023, 79) suggestion of "deep listening" as a practice that can help people to "break out of the bind between religion and biopolitics." Perez Sheldon's radical refusal to oversimplify material and lived realities that are inexorably complex is admirable. Her ethical exhortation to readers is to listen to pregnant people—to trust women to make their own medical choices, not because women are morally perfect, but because allowing that freedom is worth the risk that women might make mistakes. The orientation to praxis in this essay is important and compelling.

Perez Sheldon's essay is especially helpful because it developed in detail one concrete perspective on what type of "more just and humane" world the editors and authors of the volume imagine and want us to strive for. The essay centers on a single important issue and does not attempt to solve this complicated bioethical reality in a facile way. It illuminates complexity to provide deeper understanding and then points toward a specific ethical goal (more trust of women) and a practice to help us make progress toward that goal (deep listening). This essay, in my view, achieves the aspiration set out by the editors of the volume to provide a clearer picture of what it could look like to imagine "alternative futures where we might live better together" (Perez Sheldon, Ragab, and Keel 2023, 4).

The introduction to the volume indicates that this political and ethical orientation is a key contribution that distinguishes it from what are seen as overly theoretical approaches to science and religion, and this is a needed reorientation in the field. As the editors state, "we intend to reorient the ethical trajectory of this field to a more overtly political framework that centers the racial, gendered, sexualized, and colonized natures of science and religion" (Perez Sheldon, Ragab, and Keel 2023, 4). But given this is expressed as a central goal of the work, I hoped for a more expansive account of the ethical and political implications to be drawn out in more concrete terms. In other words, I wondered, after finishing the book, if the editors and authors have a shared and clear vision of the varied ethical trajectories they hope to point us toward. Certainly, it is the case (as they acknowledge) that "there is no single vision of an alternative future," and this plurality is expected and desirable (Perez Sheldon, Ragab, and Keel 2023, 14). In many cases throughout the volume, however, the ethical, or political ideals readers are meant to be motivated to work toward are present in more impressionistic or inchoate ways rather than being clearly developed. For example, the editors speak at one point of a focus on "belonging, wholeness, and human flourishing" (Perez Sheldon, Ragab, and Keel 2023, 7), but these values are not treated again in explicit or systematic

ways in the subsequent essays. It is possible to interpret certain contributions in the volume as subtly or implicitly related to these values, but again, much of the positive content and potential in these terms is left undeveloped.

I focus on this issue since the editors clearly express a desire to produce "knowledge for social change" as a central goal of the project. This must not be change simply for the sake of change (i.e., from one mediocre or evil system to another equally mediocre or evil system) but rather change for the better or movement toward some good or desired ethical ideal. As mentioned earlier, for the editors, this is movement toward a "future that is more just and humane" (Perez Sheldon, Ragab, and Keel 2023, 1). In my view, it is important to be at least somewhat specific about what this more just and humane world must entail, since it cannot be taken for granted that readers will have the same background assumptions the authors and editors have about what such a world ought to look like. The question of ethics also raises the problem of how to ground a particular ethical vision in order to make a case for why some ethical norms should be preferred over others.

My desire to see a more concrete ethical vision developed in this project no doubt emerges from the inclinations and orientations of my own home discipline (theology), which tends to be more comfortable than other disciplines constructing normative frameworks or ethical ideals. I appreciate that most (but not all) of the contributions in this volume are historical in nature, and thus, as the editors note in the conclusion, this historical orientation can result in a "reluctance to participate in normative analyses" (Perez Sheldon, Ragab, and Keel 2023, 376). Certainly, critical historical scholarship can be an essential element in its own right of crafting a constructive vision for the future. A great strength of this project is its historical analysis, which illuminates the extent to which a variety of violent systemic sins (patriarchy, colonialism, slavery, etc.) have shaped—and, in some cases, continue to shape—the field of science and religion. Yet, as the conclusion argues, diagnosing what is wrong with the existing world is not sufficient to create a new one (Perez Sheldon, Ragab, and Keel 2023, 378). As a result, a tension exists in the volume between the desire of the editors to facilitate the work of constructively building this new world and the toolset of most of the contributors, who, given their disciplinary training, would be less inclined to make normative claims.

To return to the problem of grounding an ethical framework, it is crucial to remember that one always emerges from more essential beliefs about the nature of reality, or, in other words, ontology. Without some account of a fundamental ontology, it is difficult and perhaps impossible to construct an ethical vision that has any positive content. As Elizabeth Grosz (2017, 4) has argued, one's ontic commitments shape one's vision of the good life and formation of ethical ideals. Accordingly, the ethical ambitions expressed by the editors would have perhaps been aided by the insights of ethicists, theologians, and philosophers

to contribute to the valuable historical work contained within this project. At certain points in the volume, however, the editors suggest a resistance to, or even rejection of, the kind of metaphysical reflection that would have served to ground their ethical commitments. For example, the excellent essay by Perez Sheldon discussed earlier is described by the editors as advocating for a "postsecular theology that does not rely on metaphysical assertion or doctrinal authority" (Perez Sheldon, Ragab, and Keel 2023, 19). At the same time, in contrast to these rejected options, they claim her essay suggests "something more profound: making trust in women sacred in contemporary debates over abortion policy" (Perez Sheldon, Ragab, and Keel 2023, 19). It is not clear to me that the volume avoids metaphysical assertion. What would it mean for trust in women to be "sacred" outside of an appeal to metaphysical categories? Rather, I suspect there is an implicit metaphysics—even if untraditional—that is operative in the work, grounding the ethical orientation of the volume, even as metaphysics is held at arm's length by the editors. Said otherwise, it must be the case that the editors have some fundamental beliefs about the nature of reality, the divine, the possibility for human life to be meaningful, etc. that motivate and justify the ethics they want to direct us toward. In my view, their moral vision would be more effectively achieved if it were set within the context of a more explicitly articulated ontology.

The editors of (and contributors to) this volume express a profound awareness of the ways in which certain epistemologies, knowledge claims, and ethical systems can become tools of violence and oppression. As the historical analyses within this book demonstrate, all too often, claims to objectivity, rationality, and virtue have resulted in violence against those deemed wrong, irrational, or sinful. Disciplines like feminist science studies, Indigenous studies, and many other areas of critical thought have done important work to reveal the violence of many of the knowledge traditions that define the Western world. Nevertheless, despite the inherent risks involved, we cannot abandon categories like objectivity, rationality, and normative ethical claims. As Donna Haraway (1991, 579) argues, despite our historical conditioning and social construction, we still live in a shared world. There can be no collaborative work to pursue justice without real (even "objective") knowledge claims about the nature of reality (ontology) and ethical norms. As Haraway (1991, 580) argues, objectivity does not have to mean claims to omnipotence or transcendence of historical location, but "we could use some enforceable, reliable accounts of things not reducible to power moves and agonistic, high-status games of rhetoric or to scientistic, positivist arrogance." Objectivity, for Haraway, involves acknowledging one's situatedness and limitations as well as one's responsibilities to others. Objective knowledge for Haraway is accountable for its effects. In my view, something like Haraway's notion of objectivity as partial perspective or an account of critical realism as an epistemological frame would be useful for a

volume like *Critical Approaches to Science and Religion*, which has such an emphasis on illuminating the destructive abuses of power hidden in many (especially Western) knowledge traditions. Without an accompanying positive account of how knowledge claims are still possible despite the risk of corruption and violence, a strong critical focus risks nihilism.

I express these criticisms in the context of enthusiasm for the goals and hopes of the volume and a desire to see more of what it provides in the subfield of science and religion. In fact, the criticisms I articulate here emerge as a result of my agreement with the editors about the profound evil of patriarchy, racism, and colonialism, and a recognition of their ongoing destructive presence in this world. This volume calls us to see these evils more clearly, rebuke them, and insist upon a better and more liberative future. A stronger articulation of an ontology to ground ethical and political action would enable the editors to name the societal ills they identify as evil—morally wrong, everywhere, and for everyone. It would also provide content and motivation for their positive ethical vision. Without an ontological foundation, arguments about the immorality of patriarchy, racism, and colonialism fail to achieve coherence. Against what standard are these realities deemed immoral? A richer account of epistemology and objectivity would provide a way of understanding how knowledge claims and ethical norms can be both critiqued and deconstructed while also being meaningfully constructed. While this project moved me in profound ways, it also provides an opportunity to imagine (with and beyond this volume) new futures and practices that can help us build in those directions. In my view, the volume represents a very successful first step that will hopefully evoke/provoke further scholarly work to develop these seeds.

In reflecting on the tension between the potential violence of the creation of knowledge claims and norms alongside the seeming necessity to do so, I wonder if insights from aesthetics could provide a generative spark. In particular, Hans-Georg Gadamer's understanding of how a work of art dynamically "comes to presentation" could be useful. He expresses this in his *Truth and Method* (1960). For Gadamer, art is not static, it is a dynamic event that facilitates an encounter with difference. In order for the event of an artwork to be effective, it requires ongoing playfulness, as it evokes a "to and fro" movement between the viewer's own "hermeneutic horizon" and the encounter with difference as expressed in the work of art that challenges, provokes, and expands the limited horizon of the viewer (Gadamer [1960] 1989, 103). Interpreting a work of art is a dialogical, creative response. It is flexible and requires rhythmic movement within the context of a defined structure that leaves room for what Gadamer refers to as "leeway" (*Spielraum*). As Cynthia Nielsen (2022, 140) argues, "leeway is central both to Gadamer's account of play and his understanding of art. Without leeway, play's movement loses its creativity and is reduced to monotonous, mechanical movement. Without leeway, art has no play, and consequently, no movement."

The movement within an artistic encounter is structured, orderly, and reciprocal but allows for improvisation, which is where innovation and novelty occur.

We might consider the discernment of ethical norms and the construction of knowledge claims using the analogy of the "coming to presentation" of a work of art. Through practices of deep listening, as suggested by Perez Sheldon, we encounter difference that makes a truth claim, proposes an argument, challenges us, expands our horizons, and invites a response. Through a creative, noncoercive, and generous process of give-and-take and to-and-fro that is structured but not mechanical or rigid, we improvise our way—always imperfectly—to more compassionate, merciful, and just futures. The work of art, like a knowledge claim or an articulation of an ethical norm, is historically located, embodied, and expresses a partial perspective. It also, however, gives an account of some reality. This account may provoke anger, disagreement, enthusiasm, joy, or other responses from the community. The community that receives the artwork may also decide it does not reflect their shared perception of the world. Like a work of art, a knowledge claim provides a limited, embodied, historically conditioned but nevertheless real and even perhaps "objective" (as Haraway defines the term) account of reality. A claim/argument comes into contact with difference, and if it is received in a spirit of playfulness and openness that allows horizons to be expanded, deeper insight into reality can be achieved. I am sure there is much more that could be said about the rich body of insights provided to us by this volume, but I conclude my remarks here and look forward to the ongoing to-and-fro discussion this volume will continue to evoke.

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To Have Been a "Science": Theorizing Afro-Cuban Religious Knowledges through *Critical Approaches to Science and Religion*

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The editors of *Critical Approaches to Science and Religion*, Myrna Perez Sheldon, Ahmed Ragab, and Terence Keel, have assembled an extraordinary group of contributors to produce a rich source of inspiration for future research. As they demonstrate, modern science has provided accounts of the "natural world" premised on transhistorical appeals to binary oppositions between science and religion (and between nature and culture) that are far from methodologically rigorous or politically disinterested. *Critical Approaches* deserves not only to be lauded but, perhaps more meaningfully, to be placed in conversation with compatibly vital contemporary scholarship. To explain my appreciation for its manifold interventions in religious studies, I would like to consider one discursive phenomenon found in Afro-Cuban religions that has yet to be examined—the practice of referring to deceased initiatory elders as "sciences"—and analyze it through the prism furnished by *Critical Approaches*. I conclude my remarks by stating why this volume should come to occupy an enduring place in our classrooms.

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Science and religion are having a moment. A significant number of academic books on these intersutured subjects have appeared since 2020, and among those most aligned with the volume under review include John Lardas Modern's *Neuromatic: Or, A Particular History of Religion and the Brain* (2021), Donovan Schaefer's *Wild Experiment: Feeling Science and Secularism after Darwin* (2022), Aisha M. Beliso-De Jesús's *Excited Delirium: Race, Police Violence, and the Invention of a Disease* (2024), and Judith Weisenfeld's *Black Religion in the Madhouse: Race and Psychiatry in Slavery's Wake* (2025). These innovative monographs all mount significant challenges to outdated paradigms for understanding the entanglement of science and religion—namely, the conflict and complexity theses interrogated in *Critical Approaches to Science and Religion* (Perez Sheldon, Ragab, and Keel 2023)—which have tended to leave little room for the articulation or advancement of counter-hegemonic ethical commitments. The editors of *Critical Approaches*, Myrna Perez Sheldon, Ahmed Ragab, and Terence Keel, have assembled an extraordinary group of contributors to produce a rich source of inspiration for future research. It deserves not only to be lauded but, perhaps more meaningfully, to be placed in conversation with compatibly vital contemporary scholarship.

To wit, I recently reviewed Stephan Palmié's 2023 *Thinking with Ngangas: What Afro-Cuban Ritual Can Tell Us about Scientific Practice and Vice Versa*, and it was enormously illuminating to read it alongside *Critical Approaches*.[1] Through ethnographic vignettes and historical accounts, Palmié problematizes the shared logics that underpin Afro-Cuban rituals and such phenomena as transplant surgery, genomic ancestry testing, and early electroacoustic research. Both *Thinking with Ngangas* and *Critical Approaches* reveal that "Western" science has followed modes of reasoning comparable to those found in religious formations while defining itself against religion for the sake of institutional and ideological legitimacy. "Religion . . . is that discourse whose defining characteristic is its desire to speak of things eternal and transcendent with an authority equally transcendent and eternal," Bruce Lincoln (1996, 225) asserts in his thirteen-point manifesto "Theses on Method." "History . . . is that discourse which speaks of things temporal and terrestrial in a human and fallible voice, while staking its claim to authority on rigorous critical practice" (Lincoln 1996, 225). As the contributors to *Critical Approaches* demonstrate, modern science has provided accounts of the "natural world" premised on transhistorical appeals to "eternal and transcendent" binary oppositions between science and religion (and between nature and culture) that are far from methodologically rigorous or politically disinterested (Mayr 1982, 24).

In *Critical Approaches*, Keel (2023) thematizes the dichotomies of "human/nonhuman and animate/deanimate." His insights—along with those of contributor Kathryn Lofton (2023) on the foundational "scriptures" of the social sciences—set the tone and high intellectual standard for the subsequent chapters. To explain my appreciation for their manifold interventions in

religious studies, I would like to consider one discursive phenomenon found in Afro-Cuban religions that has yet to be examined—the practice of referring to deceased elders as "sciences"—and analyze it through the prism furnished by *Critical Approaches*. I conclude my remarks by stating why *Critical Approaches* should come to occupy an enduring place in our classrooms.

"Walking Sciences"

As a historian and ethnographer, I specialize in the study of the West African-inspired tradition of Lucumí (popularly called Santería) and the Central African traditions collectively termed *reglas de congo* in Cuba. But it was primarily as a practitioner that I learned about the Afro-Cuban convention of calling religious elders *ciencias* (sciences) after their deaths. During an informal chat within a Spanish-speaking house of worship, I first heard the adulatory formulation "*era una ciencia*"—they "were a science"—to eulogize an erudite, long-active, and dynamic elder. Elders are those ordained into the priesthoods of Black Atlantic traditions, usually with more than two decades of experience administering and assisting in elaborate rites of passage.[2]

Most Lucumí practitioners will probably have encountered the term *ciencia* while listening to the prayer called *moyuba*. Elders recite a *moyuba* prior to all ceremonial "macropractices" praising the supreme sources of sacred energy, locating ritual participants temporally and spatially within the frame of the cardinal directions, and activating the presence of religious ancestors (or *egún*) (Pérez 2016, 123). I have previously explored the *moyuba* as a model of ethical citationality, since it specifies the birth names, nicknames, and priestly titles of those within practitioners' initiatory lineages to honor them (Pérez 2024). Since the *moyuba* is spoken in the ritual language of Lucumí—an atonal, liturgical form of Yorùbá—*ciencia* stands out as a Spanish word, especially when modified by the Spanish adjective *todo* (all) or the equivalent Lucumí qualifier *bobo* (*gbogbo* in Yorùbá). A "highly respected and acknowledged elder," living or dead, is also called *alagba* or *alawa*, from the Yorùbá term for "revered elder"; more senior or deceased elders are called *algbalagba* or *agbalagba* (or any number of orthographic variations thereof) (Eyiogbe 2015). Such eminences are sometimes extolled as *gran ciencias* (great sciences) to underscore their lofty stature.

Although these terms have seldom appeared in publications, they have come to be used with some regularity on social media. I have documented over one hundred posts—and many more comments— that contain *ciencia* in a Facebook group created only four years ago (whose Spanish name roughly translates to "The Departed Afro-Cuban Ancestors"), and they indicate the prevalence of this epithet in everyday parlance.[3] Sometimes, *ciencia* and *alagba* are combined in phrases plucked from *moyubas*, particularly in posts commemorating the achievement of religious milestones, as in a 2023 Instagram post paying homage to "*toda esa ciencia alagba*" (all of those elder sciences) and another from 2024 in

which the author praises "*toda esa ciencia alagualagua que descansa al pie de araonu*" (all of those elder sciences who rest at the feet of [the residents of] heaven).[4] These expressions signal the adoption of an elevated oratorical register to communicate users' involvement in Afro-Cuban religions, even to outsiders unaware of their denotative meaning.

Practitioners of the *reglas de congo*, such Palo Monte Mayombe and Kimbisa, also refer to their elders as *ciencias*. I have always found it curious that *ciencias* are not extolled as *científicos* (scientists) instead, given that several areas of expertise in which practitioners aspire to develop proficiency—like herbalism, divination, Spiritism, and the execution of the Kongo cosmograms (or *firmas*)—have been described as "sciences" in popular instructional manuals, religious tracts, and polemics (Cabrera [1974] 1980, 181; Davis 1987; Agbaomola 2016; Àṣàbí 2023; Almanza Tojeiro, Pérez Linares, and Marín-Gutiérrez 2012; Camara 2010). In *Critical Approaches*, Eli Nelson (2024, 292) writes of "native science" as "a mode of epistemic production that is so structured by being a scientific object in an occupied state while simultaneously making space for—and cultivating elements of—Indigenous knowledge, relations, and history." While this concept is specific to Indigenous peoples, it bears a family resemblance to *ciencia* in the Othered and objectified traditions of the African diaspora.

This similarity notwithstanding, the normative usage of *ciencia* emphasizes practitioners' focus on the human body as the main site of knowledge production. Their epistemic orientation is utterly at odds with dominant constructions of knowledge as "out there," awaiting discovery; elders themselves are the facts worth knowing and the phenomena to be observed empirically. Elders are those for whom the sacred power they received in initiation has had time to settle—or, as practitioners say in Spanish, *asentar*, connoting "to consolidate" or "to be set down firmly"—in their bodies. Previous generations placed more emphasis on "oral apprenticeship" than practitioners do today, yet elders' gestures and words (filled with auspicious primordial energies like the Lucumí *aché*) are to be memorized. Indeed, they remain the principal catalysts for the sensorial enskilment of newcomers.[5] Erika Lorraine Milam's (2024, 207) *Critical Approaches* chapter begins with an epigraph by Mary Oliver, "[a] ttention is the beginning of devotion," and this sentiment is germane to my argument here. Even more so is the Simone Weil statement that might have inspired it: "Attention, taken to its highest degree, is the same thing as prayer. It presupposes faith and love" (quoted in Eggemeier 2014).

Dance scholar Yvonne Daniel (2005, 66) has referred to virtuosic dancers, singers, and musicians in Afro-diasporic traditions as "experiential librarians," such that their deaths are like "the burning of a library."[6] Elders do not simply possess wisdom but actually incarnate it; they are the living, breathing archives of Afro-Cuban religions. Practitioners sometimes dub deceased elders *ciencias caminantes*, or "walking sciences," a phrase that evokes the Muslim locution

"walking Qu'rān" (Ware 2014).[7] In ethnographic contexts, I have seen this understanding come to the fore in casual musings about eldership, as reflected in a 2005 online forum in which the moderator Eshu Tolu posed the question, "WHAT MAKES A 'TRUE' ELDER OR ALAGBA???"[8] To kick off the discussion, they offered, "These people usually are quite visible. They have a certain presence. No one need ask how many years that they have crowned because they walk with power and authority . . . I personally, with twenty-one years crowned, am not worthy of the title of 'Elder' or 'Alagba,' yet. Although I am very wise, I have not yet EARNED such a title. Very few have . . . When I know that I have earned such a title, the world will know, when I walk the walk of respect, power, and authority!"

Ciencias in the Age of Modern Science

In *Critical Approaches*, Katharine Gerbner (2023) and J. Brent Crosson (2023) address the role secrecy has played in constructions of Caribbean *obeah*, and "science" as a synonym for it. Their chapters have convinced me that *ciencia* is evoked in Afro-Cuban commemorative contexts (like the *moyuba*) precisely because secrecy attends the incorporation of privileged information in rites of passage. The ancestral knowledges elders personify are not unlike the *conocimientos* identified by Chicana feminist writer and theorist Gloria Anzaldúa (1999): forms of consciousness, intuition, and perception that do not register as ways of knowing within hegemonic interpretive frameworks, even as they combat the colonial *desconocimientos* (lack of awareness or ignored knowledges) that foster ignorance and denial about the past.

Historically, however, the knowledges embodied by *ciencias* were not recognized as such beyond their religious milieus. In genres of blackface minstrelsy, Afro-Cubans were lampooned as incapable of pronouncing medical terms and incompetent in the language of science, which is acutely ironic in light of the important role enslaved healers played on colonial plantations and the battlefield during the Wars of Independence (Lane 2017, 68; Gómez 2017). Scientific discourses in Cuba emerged in tandem with those of witchcraft and fetishism (the two categories to which African-inspired religions were relegated in the colonial and early Republican periods). The dissected corpses of Black Cubans who were labeled *brujos* (witches), unjustly accused of kidnapping and sacrificing white women and children, were housed in anthropological museums to further the ends of racial criminology; thousands of sacred objects exhibited alongside them were confiscated in police raids (Bronfman 2004). As Stephan Palmié (2002, 30) writes, "to the extent that a self-consciously modernizing science focused its gaze on the bodies and practices of Cuba's black lower-class citizenry, the indices of [their] wizardry began to multiply, calling forth ever more violent strategies of repression, celebrated in turn as triumphs of science and modernity."

It was in this era that the arguably anti-science speech genre of "unchosen choice" crystallized (Pérez 2013). In it, practitioners narrate their ordination into Afro-diasporic priesthoods as something they did only to heal themselves after reaching the limits of medical science to understand the illnesses that afflicted them. This foundational narrative mode marks the ascendance of scientific discourses at odds with *conocimientos* informed by West and Central African precedents. In inhabiting the speech genre of "unchosen choice" today, initiates share interpretations of their corporeal experience that forcefully contest those offered by representatives of a rightfully mistrusted allopathic and technoscientific establishment.

Among my contemporary African American interlocutors, "modern science" has frequently been cast as a species of volt sorcery. In Ilé Laroye,[9] the Lucumí community about which I have written most often, the kitchen was where practitioners sat or leaned against the wall to deliver pointed Afro-pessimistic critiques of white supremacist state terror. They also unspooled so-called conspiracy theories: histories of unauthorized medical experimentation—not only at Tuskegee but throughout the country—and the coordinated abduction and killing of Black people (Washington 2006). On one night in 2005, my interlocutor 'Tunde was moved to recall his horrific childhood experiences at segregated hospitals and an incapacitating spinal surgery that left him—at twelve years old—with a permanent limp.[10] His recollections gave way to a more far-reaching indictment of the medical, judicial, and military systems intertwined with the carceral state.

Later that evening, 'Tunde reiterated claims that the military had tested a vaccine for poison gas on soldiers that made their semen black, and the serum infected their wives when they came into contact with their husbands' sweat.[11] The United States military has conceded the testing of mustard gas, radiation, and LSD on soldiers—whom we may suppose were disproportionately Black and Latine—and 'Tunde's allegation conveyed his understanding that the military-capitalist complex turned the world upside down and inside out, corrupting the bodies of its victims and invading the innermost relations between intimate partners. For 'Tunde, the Lucumí deities, called *orishas*, did the very opposite: they healed bodies through cooling white substances like coconut meat, eggshell chalk, and their own perspiration, secreted in the course of possession performances and then smeared on the faces and limbs of devotees (Matory 2001, Ochoa 2020, 23–24).

As several contributors to *Critical Approaches* note, settler colonial scientific narratives have relied on the dehumanization of Black and brown people and the corresponding degradation of their lifeworlds. It thus seems significant that the elders of Afro-Cuban religions are customarily acclaimed as *ciencias* after they are gone. This implies that *conocimientos* are not cumulative but perpetually in danger of existential loss. There is no telos, no march toward progress that

positivist scientific discourses promote. There is only the continual extinction of prior knowledges. The absence of certain Yorùbá and Ewe-Fon deities in Cuba is sometimes blamed on elders who went to their graves without having handed down the procedures deemed necessary to consecrate them; this vividly illustrates practitioners' view of human participation in ongoing cosmological processes that have profound social and ontological implications (Vélez 2000). It is possible that—as a means of resisting "life- denying" modalities of "Atlantic modernity"—they have chosen to sidestep the questions of evidentiality and rationality in their appropriation of *ciencia* (Keel 2023, 46). Then again, as *Critical Approaches* suggests, assuming this might betray our failure to envision radically alternative approaches to organizing the universe.

I would like to end on a pedagogical note. Since 2012, I have taught the undergraduate course "Religion, Healing, and Medicine" numerous times. It surveys a range of therapeutic methods drawn from United States-based religious communities and cultural groups, including the Navajo/Diné nation, Hmong immigrants, and African American rootworkers. The course regards biomedicine as an enterprise with its own high priests, taboos, and rituals. While compiling the syllabus, I looked to other such courses, like "Introduction to Medical Anthropology," "Culture, Medicine, Body," and "Biomedicalization: The Body as a Social Problem." I can imagine profitably integrating *Critical Approaches* into all of these, especially given the editors' decision to split the book into four approachable parts, "Values," "Boundaries," "Narratives," and "Coherence." It is a text that will have students eager to talk and even debate, so daring are its provocations and so timely are its meditations on what modern science has made of—and taken from—our world.

Notes

[1] The review is forthcoming in *Religion and Society* 15 (2025).

[2] In my initiatory community and others, an *alagba* is a person initiated in Lucumí for sixteen or more years and/or who has undergone the rite of passage called *pinaldo*. In some communities, an *alagba lagba* is someone initiated for at least thirty-two years.

[3] I have left out the exact title of this group for reasons of confidentiality.

[4] See bejaranoscarlet3, https://www.instagram.com/bejaranoscarlet3/p/DEQnDmRtp3l/, September 7, 2023; yordanka.paseiro, https://www.instagram.com/yordanka.paseiro/p/DDunKR2uG06/, December 18, 2024; and denniys0315's citation of "*toda esa ciencia*" on Instagram, https://www.instagram.com/denniys0315/p/Cw4k8lystZT/, September 7, 2023.

[5] For example, see Obá Ernesto Pichardo's moving tribute to his teacher Obá Oriaté Rafael Roque Duarte "El Jimagua" Tinubu (*Ibae*)—who has continued to be called a *ciencia* in many a *moyuba* I have heard, as recently as March 2025—on November 28, 2015: https://www.facebook.com/photo.php?fbid=1132872540138938&id=141467842612751&set=a.157768334316035.

[6] See also George Brandon (1993, 139); Ócha'ni Lele, "Aumbá Wá Orí, Song One," https://ochanilele.wordpress.com/2017/02/08/aumba-wa-ori-song-one/, February 8, 2017.

[7] For example, a TikTok user with the handle coqui commented that video poster Tata Nkisi Tronco E ceiba is "Una ciencia caminante," https://www.tiktok.com/@monanzotceibavititimenzu/video/7392394982994349318, July 16, 2024.

[8] Eshu Tolu, "WHAT MAKES A 'TRUE' ELDER OR ALAGBA???," https://www.tapatalk.com/groups/newlcocommunityboards/what-makes-a-true-elder-or-alagba-t790.html, April 26, 2005.

[9] This name, Ilé Laroye, and 'Tunde are pseudonyms.

[10] Fieldnotes, October 12, 2007.

[11] This has long been a trope of Otherness; see Tristan Samuels (2015).

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Critical Theories and the Question of Values

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This review of *Critical Approaches to Science and Religion* by Myrna Perez Sheldon, Ahmed Ragab, and Terence Keel welcomes this new collection and points to some of the ways in which it can, and has already, broaden(ed) and enrich(ed) the field. A particular focus is the editors' proposal that critical studies can bring a new normative perspective to the field—one that moves it beyond the models of conflict and complexity to offer prescriptions about shared values and how we should live. A distinction is made between the scholarly commitments typical of historians, which focus on neutrality and objectivity, and those in the fields of critical studies, which tend more towards advocacy. Questions are raised about the grounds of our normative commitments, especially in a post-liberal context, and the role they should play in our scholarship.

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I was delighted to see the publication of *Critical Approaches to Science and Religion* by Myrna Perez Sheldon, Ahmed Ragab, and Terence Keel (2023) and congratulate the editors on their efforts in compiling it. The collection advocates a new and potentially fruitful approach to the well-established field of science and religion and offers an array of individual studies that go a long way towards making good on its promise. Part of my enthusiasm owes to the fact that I think any well-established field benefits from the insights of new methodological approaches. But I also believe that in this particular case, the approach outlined in the introduction and many of the chapters can open up new avenues of investigation and inaugurate new conversations with the field of critical studies. Since the volume comprises fifteen chapters ranging over a fairly wide territory, my plan is to restrict my attention to some the methodological proposals laid out in the introduction and further elaborated in subsequent sections. I am particularly interested in Part 1, which deals with the theme of values, and to some extent Part 3, which addresses various narratives.

The introduction begins with a contracted survey of dominant approaches in the science–religion field, suggesting it can be characterized in terms of two themes: the conflict thesis and the complexity thesis (Perez Sheldon, Ragab, and Keel 2023, 1–2). The conflict paradigm traces its origins to the French Enlightenment, assumed its definitive form in the late nineteenth century, still attracts vocal advocates, and continues to command public opinion (Numbers 2009; Ungureanu 2019). The complexity paradigm was pioneered by historians such as John Brooke, Ronald Numbers, and David Lindberg, further developed by Bernard Lightman, and is now the standard orthodoxy among historians of science and many in the field of science and religion. It posits neither unremitting conflict nor harmony but rather local and contingent interactions that do not conform to any single overarching pattern (Brooke 1991; Lindberg and Numbers 2008; Hardin, Numbers, and Binzley 2018; Lightman 2019).

Setting up the field this way provides a rationale for a new trajectory of the discipline—a critical approach that moves beyond both of these paradigms. The conflict thesis, in spite of its ongoing popularity in certain quarters, has been rejected by virtually all informed commentators, and dispensing with it seems largely unproblematic. But the suggestion in the volume is also that the complexity thesis, while on the right track, suffers from significant limitations too. Its advocates are said to rest content with a corrective, descriptive approach, failing to move beyond this to offer normative prescriptions. This, then, makes for a difference with the proposed critical approaches:

> But our desire is not for mere characterization; nor are we content with telling histories determined by the values of liberal tolerance and social pluralism. In other words we are committing ourselves to proposals for what we might do, what our political lives must be, and what our collective values might look like.

> Each of these chapters takes on an urgent issue and, in the process, makes a claim about value commitments that ought to shape the thinking of religion and science scholars. (Perez Sheldon, Ragab, and Keel 2023, 17)

The difference here, to invoke Marx, seems to be that while historical approaches have described the world, the point is to change it.

At this juncture, it is worth identifying an additional difficulty with the complexity thesis that its own proponents acknowledge. As Numbers (2010, 63) once ruefully observed, complexity "seems to have little to recommend it beyond its truth." Mark Lilla (2007) has offered the related observation that "[h]istorians who offer 'multicausal explanations'—and use phrases like that—do not last, while those who discover the hidden wellspring of absolutely everything are imitated and attacked but never forgotten." The difficulty then is that a detailed and historically accurate picture of the past does not seem to add up to the kind of narrative that can motivate a change of attitude or opinion among nonspecialists. This is not altogether unrelated to the gap between description and advocacy the introduction proposes as an inherit limitation of complexity approaches. I revisit this issue later.

For now, let me briefly return to the way in which the book sets up the field in the introduction and make some additions to the exemplars of conflict and complexity that are used to establish the rationale of the new approach. Doing so, I believe, highlights additional opportunities for a new critical approach, linking it to ongoing historical work. At the same time, I think it also points to what, for me at least, are potential challenges to yoking the field to a more explicit normative advocacy and places in high relief the important question posed to the field of science and religion by this collection: What role should moral (or religious) judgments and commitments play in our scholarship?

Directly relevant to this question is what I think is a missing element in the initial description of the field, and that is works dedicated, with varying degrees of explicitness, to Christian apologetics (or, more broadly, a defense of theism against scientific naturalism). The work of one of the field's pioneers, Ian Barbour (1923–2013), fits this mold, as does, even more obviously, the contributions of Stanley Jaki (1924–2009), Arthur Peacocke (1924–2006), John Polkinghorne (1930–2021), and others.[1] These works are worth noting because they do in fact make normative claims that go well beyond simple advocacies of liberal tolerance or social pluralism. The existence of this genre of science–religion literature suggests the field does not suffer from any intrinsic lack of those willing to promote value commitments. But it does raise the questions of whose value commitments are taken be the right ones and how we might adjudicate between them, especially if appeals to liberal tolerance and pluralism are regarded as suspect. The claim here is not that moral and religious advocacy are directly equivalent but that both are normative. It is not implausible to

attribute a degree of universality to moral claims that many religious claims lack. But that attribution in turn needs some metaethical underpinning.

A second dimension that might be usefully added to the initial state-of-play analysis is the trajectory of historical scholarship, which I think has made some moves in the direction the editors of this volume suggest is desirable. Here, I think of attempts to expand the science–religion canon to consideration of other religious traditions and to take on board some of the implication of the roles played by both Christianity and the natural sciences in colonialism and racism. Brooke's *Science and Religion around the World* (2011), Marwa Elshakry's *Reading Darwin in Arabic* (2016), Lightman and Sarah Qidwai's *Evolution and Religious Traditions* (2023), and to some extent, Donald Lopez's *Buddhism and Science* (2008) and M. Alper Yalçinkaya's *Learned Patriots* (2015) fit this mold. To these we might add, from a more explicitly Christian perspective, Mike Brownnutt and Keith Fox's *Global Perspectives on Science and Christianity* (2024). These titles and others point to a growing recognition among historians that comprehensive histories of science must be global histories of science and that themes of empire, colonialism, race, modernization, and secularization are a necessary part of the story. In this context, we also encounter the issue of the status of traditional or Indigenous forms of knowing, another important theme of the present volume. There is another potential meeting point in the field of science and technology studies—Sandra Harding's *Objectivity and Diversity* (2015) offers just one example. All of this suggests an important point of contact and perhaps overlap between history and critical studies. Happily, the collection has already begun such conversations with inclusions by historians of science (Erika Milam, Joanna Radin, Suman Seth, and Ahmed Ragab). Further development of these connections, along with conversations with the more sensible manifestations of science and technology studies, would add an important new dimension to the science and religion field.

Related to this, the introduction also helpfully draws attention to the way in which the West's encounter with Islam shaped the former's conception of a secular, liberal neutrality—a conception that may be more historically contingent and less disinterested than we often imagine (Perez Sheldon, Ragab, and Keel 2023, 8). Others have also drawn attention to this issue (Mahmood 2015; Yalçinkaya 2015; Akan 2017; Asad 2018). But questioning liberalism, now under attack from both sides of the political spectrum, leaves us with the questions of how we arrive at shared moral values and how we assess what I think are the undeniable goods Western liberalism has delivered (while conceding that there have been downsides).

This brings me back to the question of norms and the suggestion that we need to move the field beyond analysis to something like advocacy. Here is the proposal:

> Rather, we intend to reorient the ethical trajectory of this field to a more overtly political framework that centers the raced, gendered, sexualized, and colonized natures of science and religion. Ultimately, our hope is to use the study of science and religion as a venue for imagining alternative futures where we might live better with one another. (Perez Sheldon, Ragab, and Keel 2023, 4)

> Because of this, we lead the volume with a part on values. In it, the contributors ask, How do we live well with one another? By raising this question, they challenge existing expectations of what histories of science and religion are meant to do. We are inspired by the willingness of scholars like Ronald Numbers, David Livingstone, Janet Browne, and Peter Harrison to think beyond philosophy and polemics in their accounting of these categories. But our desire is not for mere characterization; nor are we content with telling histories determined by the values of liberal tolerance and social pluralism. In other words, we are committing ourselves to proposals for what we might do, what our political lives must be, and what our collective values might look like. (Perez Sheldon, Ragab, and Keel 2023, 17)

Without wishing to seem overly defensive, especially given the generous estimation of the contributions of historians of science, it is worth saying that historians do have normative commitments that are not simply reducible to liberal tolerance. Colleagues in the history of science, many of whom I have worked with on collaborative ventures of various kinds, may not have shared common religious or even political values but were nonetheless passionately committed to the truth, in the sense of wanting to provide an accurate account of what had actually transpired in the past. This approach was understood, perhaps tacitly, to require the adoption of a moral comportment that called for a bracketing of personal values, which is to say, a setting aside of any specific identity as Jewish, Catholic, agnostic, atheist, Protestant, etc., with the goal of producing an account of the past that, to the extent possible, was untainted by personal bias. An unspoken premise was that the ideological uses of history were a problem that had given rise to distorted understandings of our past in the first place, and that rectifying this would give us a better understanding of the present. Such distorted accounts would include both constructions of historical conflict in order to provide some legitimating account of secular modernity and its converse, the harnessing of history to support various forms of religious apologetics. I take this to be a different conception of how norms operate in the way we do history than that advocated in the collection.

That said, the actual histories in the "Narratives" section of the collection are not significantly at variance from the stance just outlined. The introduction to this section offers this characterization of its goals: "What ethical and political work has been done with narratives about science and religion? [The authors]

examine instances when a distinction made between science and religion animates different ethical and political agendas" (Perez Sheldon, Ragab, and Keel 2023, 12). I take this to be the work of history proper. Historians ought to be doing this and in many cases are. So, I wonder about the difference between the historical treatments in the volume and those we can already find within what we might call the "standard" history of science. This again goes to the question of whether history and critical studies operate on different (but perhaps equally legitimate) sets of methodological and/or ethical commitments. Alternatively, the suggestion may be that historians have largely accomplished their goals, and it is now time to move on.

All of this leaves me with four questions about critical studies approaches to science and religion. First is to ask whether there is a tension between the two kinds of moral comportment expected of the historical enquirer and whether the new critical approach advocated in this volume would not be simply a matter of building upon previous historical work and adding a normative component, or whether the proposed approach entails an actual rejection of the implicit normative stance of preceding historians of science, a stance I take to be an aspiration to a form of objectivity (all of this bearing in mind, as noted, that notions of neutrality and objectivity can themselves be subjected to critical scrutiny and that protestations of neutrality can be sometimes serve as a mask for covert normative agendas).

A second way of getting at this issue is to ask how we get from the history itself to "proposals for what we might do, what our political lives must be, and what our collective values might look like"? This is a kind of "is/ought" question. It is not clear to me whether the relevant values emerge from the scholarship or whether they are brought to the scholarship. I do not have a problem with the latter, but as already suggested, it does raise questions about the source of the relevant norms—especially if they are meant to be "collective values"—and how the scholarship is meant either to ground them or lend them legitimacy. Further, if scholarship becomes a form of moral exhortation, how does this differ in principle from the apologetic mode of scholarship we also see in the field of science and religion? To be sure, the values themselves are different, but is it possible to escape the line of criticism apologetic harmonizers faced—namely, that their historical narratives were fashioned in ways intended to support preexisting commitments?

I am not suggesting in all of this that normative positions have no place in the science–religion field, or in any academic discipline for that matter. But in historical terms, normativity has become a "known problem" within critical theory (at least of the Frankfurt School variety—and I would be interested, as side note, to understand how the critical theory represented in the volume situates itself in relation to this original form). It can be plausibly argued that critical theory in this previous register failed to provide a satisfactory account of

its own normative commitments, hence, the "normative deficit" to which the work of Jürgen Habermas (2003) and, more recently, Peter Gordon (2019) have alerted us. Habermas (2005), at one stage at least, resorted to a kind of non-transcendental Kantianism to ground his normative proposals. Leaving aside the question of whether this is a coherent enterprise, it is surely indebted to the tradition that was itself under critique. In this context, I wonder, in light of the editors' concerns about the limitations of "the values of liberal tolerance" (Perez Sheldon, Ragab, and Keel 2023, 17), what alternative normative grounding is being appealed to. How do the proposed "collective values" differ from the "liberal tolerance" beyond which it is suggested we move, and what is the justification for holding those values?

My third question follows on from this by taking up another way in which values have been introduced into historical enquiry. Both the idea of "immanent critique" (again adverting to the Frankfurt School) and historical genealogy offer potential (and related) ways of introducing normative judgments into historical enquiry, while at the same time avoiding some of the difficulties that attend the explicit advocacy of specific normative positions (Harrison 2023). The latter seems to call for some kind of meta-ethical justification, without which normative commitments would reduce to a form of emotivism and/or relativism, which would undermine their capacity to enjoy broad appeal. Immanent critique seeks to expose the inherent tensions within cultural movements that emerge from historical developments at odds with some original and perhaps forgotten normative stance. In simple terms, this could be an inability to instantiate in practice what are supposed to be fundamental moral commitments, or a failure to understand the full implications of such fundamental commitment. Critique in that register would imply, for example, that Christianity's implication in racism resulted from a failure to live up to *its own* moral standards—notwithstanding the fact that we can also tell histories illustrating how Christianity was at the same time the source of practices and narratives that contributed to modern racism. Critical genealogy can function in a similar way by showing how a culture's moral commitments have outrun an original rationale that is now ignored or denied. Think in this context of Friedrich Nietzsche's genealogical critique of utilitarianism, which, on his analysis, advocated what, content-wise, were indistinguishable from Christian values, even though the Christian foundations that would make those commitments coherent were denied by utilitarians. The advantage of immanent critique is that the critical work is done not by an overt moral advocacy (which then needs its own justification) but simply by highlighting the moral contradictions that inhabit particular cultural practices.

Fourth and finally, the volume helpfully broaches the question of Indigenous forms of knowledge and practice and rightly insists that the science–religion field must contend with them. I am fully convinced this is essential for our field. At the same time, it is not clear to me that we presently possess the analytic

tools that would enable this, and I wonder whether critical theory can help. Demarcation questions, I think, are directly relevant here: What gets to count as "science" and what as "religion"? I would like to think that historical work on the construction of these concepts in the West is pertinent—just as it is to the issue of religious pluralism. At present, however, it is difficult to see how the great diversity of Indigenous knowledges might be accommodated and given their due within our present frameworks, and how a situation of radical pluralism could be entertained without entering into a self-defeating relativism (how, e.g., might the creation stories of Indigenous traditions be granted a status some have argued is denied to Jewish and Christian creation narratives). This quandary parallels, to some degree, what I see as a normative difficulty within critical studies. The issue of the status of Indigenous knowledges is, in my view, a genuine and pressing question our field must confront. If critical studies can help, I would be interested to learn more.

In sum, then, this collection offers prospects for the expansion of the field of science and religion in exciting new directions. At the same time, it raises crucial questions that do not admit straightforward answers about the role values play in scholarship. These need not constitute a barrier to adopting the approach advocated, but I think they do need to be confronted. My focus on these normative questions has come at the cost of neglecting the good number of excellent and thought-provoking contributions to the volume. These have much to offer, whatever we might think about the more general methodological issues, and I would encourage readers of this journal to thoughtfully engage with them.

Note

[1] Two recent, and mostly theological, approaches could be added to round out the picture: "science-engaged theology" and "after science and religion." For the former, see John Perry and Joanna Leidenhag (2021) and Perry and Leidenhag (2023); for the latter, see Peter Harrison and John Milbank (2022) and Harrison and Paul Tyson (2022).

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The Place of China in *Critical Approaches to Science and Religion*

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This review of *Critical Approaches to Science and Religion* argues for a "critique from without" in the study of science and religion, specifically from the perspective of China's engagement with modernity. It contends that conventional Western paradigms of conflict and complexity, while valuable, are insufficient for understanding the unique ways science and religion function in a non-colonized context like China. Drawing on examples such as traditional Chinese medicine and Confucian sociopolitical thought, the article highlights how Chinese category thinking tolerates apparent contradictions and resists the dualistic, hierarchical logics of Western modernity. Engaging with these alternative category formations in cultures like China can offer a more profound critique of the racist and patriarchal underpinnings of colonialism than internal critiques alone. While China has embraced "science" in its modernization, it continues to articulate its own categories of knowledge, resisting Western scientific and political coloniality.

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The authors of the impressive collection of essays in *Critical Approaches to Science and Religion* (Perez Sheldon, Ragab, and Keel 2023) share a conviction that the conventional paradigms for understanding the relationship between science and religions, those of conflict and complexity, need further critical reflection. The paradigm of conflict and its converse, that of Stephen Jay Gould's nonoverlapping magisteria, regard science and religion as essentially different domains of knowledge based on the opposite sides of the fact/value distinction. Science deals with the empirical world, and religion deals with values and meanings. The paradigm of complexity demonstrates how the absolute distinction between science and religion, or the production of facts and values, is historically and intellectually untenable. An examination of how science and religion are in fact socially produced reveals a set of entanglements, or overlapping social forces, that show how "science" and "religion" are mutually implicated. As Jason Storm (2023, 150) writes in his essay *Dark Gods in the Age of Light*, "the histories of religion and science are not two independent narratives but rather the tale of conjoined twins born late and in the moment of their mutual contrastive self-definition." Rather than viewing the categories of science and religion as "ahistorical abstractions," we should view them as "historically conditioned, unfolding processes" (Storm 2023, 150).

But as the editors of this volume note, the mere acknowledgment of complexity, of noting that "science" and "religion" are terms by which modernity denominates and ascribes value to certain social processes, is not enough. A critical approach to this complex entanglement "reveals how science and religion emerged alongside—and, indeed, constitute—modern power structures and identities, and, in turn, undergirded the emergence of race, gender, sexuality, class, and nationality in the modern world" (Perez Sheldon, Ragab, and Keel 2023, 2). Just to make the point more explicit, we should go one step further and clarify that the power structures and identities produced by the dualisms of the ideology of modernity are those that enable white supremacy, patriarchy, colonization, and genocide. Delineating how, historically and theoretically, the production of science and religion as mutually entangled categories both contributed to and was enabled by the social construction of racism, etc. is the significant achievement of the essays in this book.

For more than thirty years since Bruno Latour's *We Have Never Been Modern* (1991), Western thought has been digesting the culturally constructed nature of the chief dualisms of modernity such as nature/culture. More recently, we have been aware that the hierarchical nature of these dualisms and the universalization of these hierarchies has produced, as Terence Keel notes, "the history and values that established what [Sylvia Winter] calls 'the overrepresentation' of the white European as the universal 'Man'" (Perez Sheldon, Ragab, and Keel 2023, 45). Man, science, reason, white, etc. are deemed to be universals, while their corollaries are local, transitory, or ephemeral.

This produces a chief distinction between Western science and what Eli Nelson describes in his chapter as "Native science." In his comparison of Indigenous and European geographies, he quotes David A. Chang: "Kānaka understood geography from points of view. Kānaka did not describe the world as an abstract truth but as a world seen from a perspective" (Perez Sheldon, Ragab, and Keel 2023, 288). Where Western geography sought an Archimedean vantage point from which to order all knowledge, Indigenous science produced knowledge from the context of the particular relationship between people, places, and things. As a result, "universal science" presumed the right to order the world for everyone and thus "overran" Indigenous science without even realizing what it had done.

But to what end this critique? In his essay, Keel quotes Cornel West's criticism of contemporary postmodern American philosophy as a "culturally lifeless rhetoric mirroring a culture (or civilization) permeated by the scientific ethos, regulated by racist, patriarchal, capitalist norms and pervaded by a debris of decay" (Perez Sheldon, Ragab, and Keel 2023, 55). The danger is that the critique of the categories has the paradoxical effect of continuing to inscribe them within our apprehension of the world rather than managing to subvert or transcend them. Critique as it has been developed within contemporary philosophy has been largely an internal process, that is to say, reflecting critically on the categories modernity has produced. Modern Europeans produced the categories of race and gender that have enabled the colonial construction of science and religion (and vice versa), and the solution to this problem, as presented in this volume, is to attempt to undo this from within.

But what if we think about knowledge not from the perspective of these dualisms? What I would like to present is a complementary strategy to the internal critique of the construction of science and religion, which is to propose a critique from without, namely, a critique from the perspective of the Chinese engagement with modernity.

China ought to be an important voice in the discussion of the production of science and religion, not least because it was never subject to a complete colonization by the West. As such, it retains a strong cultural identity difficult for Europeans and Americans to digest. China does not fit neatly into the category of colonial power or colonized subaltern. China is difficult to read because the West has consistently and to this day been unable, despite its best efforts, to bring it to heel, to subject China to the West's privileged claim to universal orderings. Science functions differently in China. Religion functions differently in China. The internet functions differently in China. Economics functions differently. And as much as we in the West try to bring China into view using our own theoretical lenses and cultural critiques, we are continuously obstructed by China's refusal to defer to our systems of meaning.

It is beyond the scope of this short reflection to articulate in full what an engagement with Chinese views of science and religion might contribute to the ideas voiced in *Critical Approaches to Science and Religion*, but I would like to point to a theoretical issue regarding the question of borders, or boundaries between categories, an issue very well explored in section two of the book.

The Chinese approach to knowledge production has not proceeded in ways readily digestible by Western approaches to knowledge production. This gap was famously described in the preface of Michel Foucault's *The Order of Things*. Here, he presents a passage from Jorge Luis Borges's (1984, xv) *Ficciones* that cites "'a certain Chinese encyclopedia' in which it is written that 'animals are divided into: (a) belonging to the Emperor, (b) embalmed, (c) tame, (d) sucking pigs, (e) sirens, (f) fabulous, (g) stray dogs, (h) included in the present classification, (i) frenzied, (j) innumerable, (k) drawn with a very fine camelhair brush, (l) et cetera, (m) having just broken the water pitcher, (n) that from a very long way off look like flies.'" The categories in the fictional Chinese encyclopedia are not simply different from how we imagine knowledge to be ordered in the West but rather defy logic. By what sense can "frenzied" and "drawn with a very fine camel-hair brush" be considered the same category of thing such that they could be placed in a series? Though humorous and fictional, Foucault, via Borges, makes the point that taxonomies of knowledge create different perceptions of reality that combine to render one culture illegible to another. Although universal science was capable of overrunning Indigenous knowledges in the lands conquered by European empires, this process of colonial erasure did not fully take hold in China.

To give a concrete example from contemporary China, let us consider the case of what is called "traditional Chinese medicine," or TCM. TCM functions in China as a hybrid between what actually was Chinese medicine and modern scientific biomedicine. Chinese medicine, as a category of knowledge production about the human body and practical treatments for disease, in principle defies universalization. The basic principle of Chinese medicine is that the whole body should be treated as a system, and treatment for one person's symptoms might not be the same as treatment for another person's symptoms, given the holistic understanding of that individual's body. For this reason, Chinese medicine cannot in principle be subjected to the double-blind, randomized trials that are the foundation of modern biomedicine.

At the same time, Chinese medical theory in its classical form is based on a series of correlations between categories. Seasons, flavors, colors, and times of day all interact to produce a constellation of effects within the body. Ailments are to be treated with regard to all these correlations. Scientific biomedicine, on the other hand, is based on the principle of linear causation. It should not matter for controlling a virus whether the season is humid or one eats sour foods. These correlative factors should have nothing to do with scientific causation. But these factors are taken seriously in Chinese medicine diagnosis and treatment.

In twentieth-century China, the status of Chinese medicine was hotly debated because of its association with traditional culture and its apparent incompatibility with modern science. A compromise arose with the creation of what is known today as TCM, in which the methods and principles of Chinese medicine continue, but subject to a process of rationalization and scientization. It is difficult for me as an outsider to appreciate on a theoretical level how and why this hybrid form of medicine exists and functions well in China today, but it does. The fact that TCM functions in China alongside scientific biomedicine is testament to the power of Chinese category thinking to hold apparent contradictions in tension without the overwhelming need to collapse a tension into a singularity.

A second example of the different nature of Chinese cultural thought lies in its ability to tolerate difference at different levels of sociopolitical reality. Confucian thought imagines the sociopolitical context as a series of concentric circles radiating from the self to the family, the broader community, the nation, and the totality of human polity, understood as "all under heaven" (*tianxia* 天下). What I think is difficult us to appreciate about Chinese polity is that these layers are not to be understood as isomorphic copies of each other, like Matryoshka dolls. Things may function one way at the family level and in a different way at the community level. Although the smaller realities are inscribed within the larger realities and subject to downward pressures from those larger contexts, there is no sense that the absolute identity between these levels is an ideal to be aimed for. This is why, for example, a directive issued at a national level may be implemented in different ways in different locations in China. Higher levels of government do not generally prescribe the ways lower levels of government should implement the policy directives they issue. This even applies to issues such as national security or border controls, where policies and processes may differ in different cities in China (see Donaldson 2017). This is quite different from the federal political model, where federal governments and state governments have clearly demarcated and different areas of responsibility.

The relevance of this polity issue for the science–religion discussion concerns the relationship between the categories whereby we organize knowledge and society. The logic of modernity is predicated on dualisms that are "either/or." Critical theory seeks to demonstrate how the dualisms of modernity function as hierarchies in which one element seeks to dominate and even negate the other: mind/body; male/female; universal/local; science/religion, etc. Chinese thought is based on a different set of logical processes in which, famously, "a white horse is not a horse" (白马非马也), and yin and yang do not dominate, erase, or contradict each other but function codependently as a process of transformation.

This is all to make the relatively straightforward point that cultures do not vary based on how they instantiate a set of universal categories (gender,

race, class, etc.) but rather on the way their different taxonomies function, so as to create different epistemological realities. Criticism, therefore, does not only have to operate by means of showing the outworkings of the racist and patriarchal logics of colonialism. It can also operate by means of engaging the alternative category formations that exist in cultures, like China, that have not been completely dominated by the logics of Western modernity.

The terms "science" (*kexue* 科学) and "religion" (*zongjiao* 宗教) did not exist in China before they were created in the nineteenth century engagement with Western thought, but this does not mean science and religion did not exist; it was just that they were not conceptualized via the dualistic framework of modernity. There is a plausible argument to be made that "by conventional intellectual criteria, China had its own scientific revolution in the seventeenth century," though it was not categorized by Chinese people as such (Sivin 1982, 46). This historical question, however, is almost impossible to answer, given the fact that we are attempting to make judgments about the development of Chinese history based on a set of categories that are alien to it. "Science" and "religion" or "civilization" are not explanatory categories but rather the "ideologies of the historical protagonists" (Hart 1999, 109). While China has wholeheartedly embraced "science" and dismissed "religion" in its quest for modernization, this does not mean Chinese society is conforming to the logics of European modernity. Chinese medicine, Confucian mores, and popular superstitions continue to resist the project of Western scientific and political coloniality through the continued articulation of Chinese categories of knowledge, even as China rushes headlong to create the most technologically advanced society in the world.

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Roundtable on *Critical Approaches to Science and Religion*: Response to Commentaries

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This roundtable conversation reflects on the aims and implications of *Critical Approaches to Science and Religion* (Columbia University Press, 2023), edited by Myrna Perez, Ahmed Ragab, and Terence Keel. The discussion responds to four critics—Megan Loumagne, Elizabeth Perez, Peter Harrison, and James Miller—who engaged the volume at the American Academy of Religion's "Author Meets Critics" panel in 2024. In this dialogue, the volume's editors consider how the study of science and religion might move beyond disciplinary reform toward more urgent forms of political and intellectual work. They question whether transforming academic fields remains a meaningful site of democratic practice amid the erosion of university infrastructures, the rise of authoritarian politics, and the vocational turn in higher education. The exchange revisits the legacy of the New Left, the status of basic research in the humanities and social sciences, and the relationship between research, teaching, and social transformation. Together, the participants articulate both the necessity and the limits of academic critique, proposing a renewed ethics of scholarship attentive to institutional fragility, epistemic inequality, and the moral imagination required to sustain democratic knowledge.

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As the editors of *Critical Approaches to Science and Religion*, we convened this conversation to clarify what is at stake in the project and where it all leads. The volume proposes vocabularies for analyzing science and religion as entangled with race, gender, and colonialism and models scholarship historically grounded and politically alert. What follows responds to the American Academy of Religion's "Author Meets Critics" session "Critical Approaches to Science and Religion" presided by Donovan Schaefer. Authors Myrna Perez Sheldon, Terence Keel, and Ahmed Ragab respond to the comments by Megan Loumagne (Boston College), Elizabeth Perez (University of California, Santa Barbara), Peter Harrison (University of Queensland), and James Miller (Duke Kunshan University). Our reflections here take up questions prompted by their responses to the volume, especially about whether changing a field—its language, archives, and institutions—remains an urgent site of political work or whether the present demands other commitments alongside and beyond the university.

Myrna Perez: Hello friends, let's get right into it!

I felt like we brought together the critical approaches project because we had a shared intellectual interest—giving vocabulary to an intuition we each had, sometimes independently and sometimes collectively—that there had to be a different way of talking about science and religion. A way of naming and voicing how science and religion are entangled with race, entangled with gender, come out of colonialism. It is almost hard now to remember how hard it felt to find that vocabulary, because through the project, the vocabulary has become clear and intuitive.

But the other reason we started the project was to make scholarship useful in pressing political situations. The book was published in 2023, and now when I reflect, that second part seems so much more pressing. That first part, that intellectual interest, I'm not even sure I care about anymore. I can't find it in my heart to be committed to changing the field of science and religion.

When I look at this book, I feel like it could reshape the field of science and religion, but I'm not sure that I care. And the second part—making scholarship useful—feels even more necessary, but maybe we're beyond that point.

I think the belief that changing a field of scholarship is the necessary work in the world is not something I can feel committed to. It probably has always been self-indulgent, but it feels incredibly self-indulgent to me now. I can't get up every day and think, "The thing I want to do in the world is change the way people study science and religion." Maybe it's a refusal of academic work in general. Also, the field's institutional legacy would require so much political work to reshape, and I don't feel that's where my political energy should go.

Terence Keel: I completely understand these sentiments, Myrna. Do you think the current political crisis facing American democracy might make this

a different proposition? That we are in a moment of praxis, not pure theory? Since the 1960s, the left has had to convince established intellectual traditions of the value of feminist studies, ethnic studies, postcolonialism, the Global South, all in the face of conservative forces that saw these claims as threatening the university and democracy itself. Now, the cat's out of the bag—democracy has been eroding since the '60s. People are disappeared through ICE raids, die in police custody, women's rights are under assault, Republicans are blocking affordable health care.

This political moment makes intellectual work different—not easier, but different—because it's not just abstract. There are real, material things eroding. I've always thought the subtext of the science and religion debate is: we can't have people denying the validity of science, believing in superstition and myth, endorsing creationism at the expense of evolutionary science. Irrational people are difficult to control, and that makes governance hard. The job of the intellectual is to do a kind of intellectual policing of minds.

Yes, the left has made some inroads—Black studies, feminist studies, Chicano studies, Asian studies—but the larger university apparatus has remained embedded in the Enlightenment tradition. Even still, democracy has eroded. So I can no longer endorse the project of turning young minds into one-dimensional, predictable people. That got us where we've been for sixty years. We need something different.

Myrna: Thinking about the New Left is helpful and gives texture to my refusal. New Left politics and fields—Black studies, women's studies, postcolonial studies—had confidence that knowledge is a site of political transformation. If you could speak about the world differently, remember history differently, give voice to more experiences, this would make a more democratic world.

Now, my university has eliminated the LGBTQ Pride Center, Women's Center, and Multicultural Center. It's against the law in Ohio to have places that work on behalf of diversity. It's made me reflect: Is knowledge the place for transformation? Is the university the place? Do we need another kind of left?

Five years ago, I'd have given a different answer about the value of teaching postcolonial feminist theory. I feel less confident and more humble about what changing an academic field can do in the world.

Terence: I agree. The New Left's integration into the academy came with concessions that defanged it, distancing it from communities and local organizations. Once it was integrated into the university, reward structures shifted to publications and prestige.

We've moved further from the people and the problems that should be the focus of our intellectual work. This distance is more like a cosmic-sized gap when you think about conventional approaches to science and religion.

Ahmed Ragab: Since the 1960s, the university's role has been to create governable subjects. The expansion of higher education shifted who it serves. "Local truth" taught to the governing builds political structure. Taught to the governed, it depoliticizes. The New Left exaggerated the university's role, investing too much in changing it.

The university is a centrist institution. We all teach to the right of our research and research to the right of our public views. I've never met people going into classrooms to indoctrinate students—except on the right. So when we talk about science and religion, are we talking about research or teaching? Each plays a role. Changing teaching and research can still have political impact because that's the infrastructure for political positions.

Myrna: Yes, I think the New Left overinvested in the university. It turned political work into structures for building prestigious academic careers. I don't care about being a leading voice in the field because that's not where I want my political work to be. It's hard for me to separate what I care about intellectually and politically and what I need to establish myself as a thinker and wage worker.

Ahmed: I think that's where I'd disagree. If I use your sentence and talk about mathematics or physics or computer science, it's just not possible. If I write a paper in abstract mathematics or programming language theory and it doesn't directly impact AI or make AI better—even ethically—you wouldn't accept that. Because if you don't do that work, there's no chance of ever doing serious programming language research or climate science or developing medicines.

The argument that you require basic scientific research is not really up for debate. One of the main things structuring the current global economy of knowledge and technology is that places with the capacity and luxury to do basic scientific research—mostly in the Global North—dominate. The Global South may produce chips, but without basic scientific infrastructure, it's still buying computers designed in California and made in China. This absence of infrastructure keeps the Global South secondary.

I think the same logic applies to the humanities and social sciences. We shouldn't buy into the devaluation of basic research in these fields. Basic research in humanities and social sciences is necessary to do applied research. If we don't talk about theoretical constructions of fields like science and religion, or about archival methods, we won't end up with meaningful applied research.

Precisely because this link has been severed, the former left has bought into the idea that basic humanities and social science research is not important—and so it hasn't produced a single new idea in decades. How can you develop new ideas with zero interest in basic research? If computer scientists stopped learning math and physics and only learned programming languages, they'd hit a wall in five years.

This is connected to the changing university structure. If plans like the Heritage Foundation's continue, we won't have universities without humanities and social sciences—we'll have elite ones that still teach them, often in a very white, Western-canon way. But most schools will become glorified technical schools. The backlash to mass university education has been: "Let's just make it all vocational."

State schools won't have money to teach history, gender studies, or basic sciences like math theory. They'll just teach programming and engineering at a technical level. Everyone else gets vocational schools; Harvard, Yale, and Princeton students still get humanities, social sciences, and basic sciences. It's a return to the 1940s–50s order.

That's why I think there's significant value in keeping basic research in humanities and social sciences. I understand why it feels far removed from immediate outcomes—but mathematicians feel the same way. They could "just invent a new car," but that's not how it works.

Terence: I agree. We're returning to a vocational model of education that existed in the 1930s and earlier with land grant models, including for historically Black colleges after 1865. Then, the ethic of education was tied to local industry but with a very limited and problematic vision of social science and humanities. The goal was to train Black physicians, lawyers, social workers, and construction workers to build local economies and communities.

Now, it's: get a degree in medicine, computer science, or engineering, maybe get picked up by a tech or biotech company, become an entrepreneur. The entrepreneur is libertarian politically, uninterested in broader democracy. They might want campuses in Silicon Valley to sustain themselves, but they're not creating citizens invested in democratic governance.

It's like we've returned not just to the 1930s but to colonial models of learning—training bodies and minds to be productive for an economic project that's not invested in democratizing power, knowledge, or truth. It feels like a movement to return this country to a colony. Democracy isn't part of the equation.

Ahmed: And the aspiration is to become an entrepreneur—but not even 1% will. Most people will be glorified line workers. With class mobility foreclosed and education stripped of anything beyond the practical, the ideology sold is libertarianism: dress for the job you want, think for the job you want. You think like an entrepreneur while you're actually a line worker who should be thinking about unions and weekends.

Myrna: So, I want to go back to the core question: Does it matter to put political energy into changing the field of science and religion—whether conceived epistemologically or institutionally?

I've voiced disillusionment, and Ahmed, you've given a resounding commitment to the value of basic research in the humanities. I agree. Every colonial or oppressive structure has used knowledge as integral to its project. There are no politics without ideas. If you're not going to have ideas, others will.

But I keep returning to how to separate that work from the temptations of power and prestige in the academy. There's this sense: "We'll make the world more democratic—and to do that, I need power." It feels like a political conundrum.

I genuinely think it's transformational to understand science and religion as about reproductive technologies, surveillance shaping immigration, or knowledge used to architect cities along racial lines. But what do we do with that realization? Who do we offer it to?

When I teach or speak in media spaces and say "science and religion is about reproductive politics," people light up. That feels transformational. I'm not sure I need to argue with the old guard to have that moment. I'm not sure I need to call what I do "science and religion scholarship" or be the authority in the field to make that impact. The fight over disciplinary labels feels like a distraction.

Terence: I feel similarly. What we mean by "science and religion" doesn't look like what previous generations meant. More and more, young people aren't shaped by formal religious institutions, even though they continue to live in a Christian culture inundated by symbols they don't recognize as religious.

We're dealing with religion's remainder in conservative legislative arguments against women's rights, for example. Religious scholars should be able to unpack the patriarchal Christian symbols in those arguments, even when they're not explicitly invoked. That's where the work is.

Unfortunately, religious studies has also been a victim of neoliberal logic: humanities only matter if they're linked to capital accumulation or the creation of one-dimensional subjects that are easily governable. The field has taken the deal by doubling down on "literal" religion, where what scholars are supposed to do is study obvious religious institutions and religious practices. This sort of work is valuable in many respects. But it doesn't help young minds or the public more generally recognize, for example, Christian values hidden within state policy, criminal justice, or the ideology of the free market. In other words, this approach to religious studies keeps alive the distance between scholarship and changing our society. Without a critical approach to the study of religion or science, our students can't recognize the strange, twisted world we live in, where white supremacists invoke Christian supersessionism to legitimate their takeover of federal policy decisions on vaccines, access to abortion technologies, climate change, etc. That's the problem.

Ahmed: I agree. I feel strongly that we need to maintain consistent investment in basic research in the humanities and social sciences. But I don't feel strongly about maintaining disciplinary structures as they are.

Terence: I agree with what you're saying, and I think the disillusionment we're describing is about the assault on democratic institutions and democratic belief—ways of thinking and being that are oriented toward freedom, equity, and self-governance. We've seen an accelerating collapse of those institutions.

And with Trump's attempt to strong arm and infiltrate UCLA, USC, Columbia, and other R1s, we are seeing how easily the liberal democratic values of the university can be abandoned or repurposed to extend authoritarian politics—suppressing student protests, denying genocides, targeting academic freedom. That creates a deep sense of institutional betrayal that heightens the feeling of disillusionment.

But as Ahmed says, we can't just concede academic institutions to the right. Defending them still matters, even with all their contradictions. And part of this is about who we've been formed to be as intellectual subjects: people who value slow learning, slow thinking, time in the stacks. That's a gift, but we have to ask what it means to offer that gift now.

On the one hand, this humanistic practice is exactly what the world needs. On the other, neoliberal conditions and the distraction economy make it harder to sustain them. If getting a degree is the only path to social and economic mobility, why spend hours with Kafka, Audre Lorde, or Sheldon Wolin?

So, how do we teach slow thinking in a world structured to obviate it? But also, how do we teach slow learning in a world where the crises facing our democracy require dynamic and experimental thinking that cuts across established disciplines? Perhaps what we mean by "basic research" is what we have been grappling with. But what is "basic research" in the humanities, or in science and religion, during an economic, climate, political, or moral crisis?

I think the entries we published in our volume made it clear that being critical is part of the answer. But this conversation has also made it clear that working outside the university needs to be a part of this critical orientation.

Ahmed: I don't fully disagree, but I want to separate two kinds of work: research and teaching. They're connected, but they're not the same. Think of the natural sciences: a researcher might be teaching undergrads basic cell structure but running a cutting-edge lab on curing cancer. Their teaching lags behind their research, and that's expected. I don't need to translate everything I do into something my students immediately grasp. My teaching should lag behind my research. The research itself is what enables us to build political, social, and technological solutions in the long term. When I teach medieval medicine, I don't care if students memorize every detail of Galenic or Chinese

medical systems. If they leave with an understanding of pluralism and epistemic diversity, that's enough. My cutting-edge research doesn't have to fit neatly into a 200-level course.

Myrna: I don't think we actually disagree there. My question isn't about research needing to be immediately teachable. It's about what you mean by "value." If by value you mean moral or spiritual worth—the intrinsic human good of engaging with ideas—then yes, I'm deeply committed to that. I teach at a state school, in a Classics and Religious Studies department, where students read Homer in Greek. I want that kind of intellectual richness to be available to everyone, not just the wealthy.

But if we're talking about why universities pay for research—that's a different story. They invested during the Cold War because they saw basic research as essential to global power. Before that, only the wealthy could afford to do it. So yes, I believe in its transcendent worth. But expressing that worth in a democratic society is another question entirely.

Maybe we've simply played out the hand of investing our political energy in the university. The right has invested more effectively in other institutions—churches, think tanks—and treated universities as a problem to be subdued. If they can't reshape them, they'll crush them. Even Harvard's been pushed around. So it's not the worth of the research I'm questioning. It's where we place our political energy.

Ahmed: That helps clarify it. I also want to complicate the distinction I made between research and teaching. What counts as valuable research is determined by our colleagues, by gatekeeping. When I started publishing on deaths in custody, reviewers dismissed it as unworthy because the sample size was "too small." That's exactly the problem: universities exclude certain forms of knowledge production.

We've seen similar resistance in public health research around environmental violence and health outcomes. Brilliant work gets marginalized as "not bench science." And as we rise within the institution, we become those gatekeepers. Whether consciously or not, we'll inherit that power to define value.

And this ties back to value. Terence's early historical work or yours, Myrna—it might look politically inert at first glance. But its value is foundational. One reason the left struggles to articulate a coherent science policy—something that isn't colonial or technocratic—is that we haven't done or taken seriously the basic research that would allow it.

We talk about intersections all the time, but we haven't built politics capable of acting on them—around race, empire, or global decline. The value of our research isn't always immediate, but it's indispensable. Like pure mathematics leading to new technology decades later. Not everyone has to take the work from

A to Z, but we do need a different politics of knowledge—one that recognizes and sustains that value.

Myrna: Two quick things before we end. First, my hot take on why the left can't articulate that kind of politics: because we keep compromising with liberals, and the right doesn't.

Terence: Nancy Fraser would definitely agree with you.

Myrna: Second, what you just said reminds me of the image in Ephesians—the body of Christ. All the parts are different, but they work together. We don't all have to do the same kind of work; we just need a shared sense of purpose.

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