Article


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Physics at the Theological Frontiers

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The rapid pace of progress in physics in recent decades has brought not only significant changes in our technology and economy, but has also provided us with new perspectives on reality, perspectives that have implications for Christian faith. I discuss five major points of contact in the relationship between physics and Christian theology: typicality, plurality, reduction, quantization, and eternity. These ideas influence thinking at the forefront of physics today, and have interesting implications for Christian faith. I shall outline the meaning of these ideas, relevant recent experimental and theoretical developments, and some new questions for theological exploration and reflection. The goal is to generate further dialogue and research in the science/faith endeavor. The essays that follow in this theme issue helpfully begin to address some of these questions and raise yet more related ones.

One of the more exhilarating aspects of being a scientist is the continual novelty of discovery. This most commonly takes place in very specialized ways, with advances being made incrementally in a multitude of subdisciplines. Yet, from time to time, all scientists step back to take a broader look at progress made in their discipline as a whole, assessing its implications and directions for further work. This big-picture perspective is taken with increasing frequency, primarily because scientific progress in many fields is proceeding at such a rapid pace.

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Such expansive overviews provide interesting points of contact with theology. New insights and new challenges for a theological perspective on the world are available for those willing to invest the time to reflect deeply on the broad meaning of existence. The mind-sciences, life-sciences, and physical sciences each provide their own particular forms of input for theological reflection.[1] Conversely, theology offers the prospect of enhancing one's worldview beyond the empirical and the quantitative in novel and refreshing ways.

This article is particularly concerned with physics, its latest developments, and how these might further enrich the science/theology dialogue. Rather than attempt to resolve the possible insights and questions, the purpose of this essay is to raise the issues in a context that encourages discussion. No attempt is made either to define the field or to claim mastery of it. Rather, the goal is to draw people who specialize in physics to think about the implications of some of the latest developments for the Christian faith and to pique interest from scientists in other disciplines to find out what is going on.

I shall proceed by discussing five major points of contact in the physics/theology interface—typicality, plurality, reduction, quantization, and eternity—that have been affected by recent experimental and theoretical developments. Each of the preceding five terms will be explained in context, describing the main issues at stake, the recent scientific developments pertinent to the topic, and the various theological questions and discussion points that emerge.

Typicality

One of the most fruitful advances in scientific thinking was the realization that our planet does not occupy a privileged place in the solar system. This idea, first proposed by Nicolaus Copernicus, asserted that the sun, instead of the earth, was at the center of the solar system.[2] Reasoning from this hypothesis provided a more coherent and technically satisfying explanation for the observed retrograde motion of the planets than did the Ptolemaic system.

The implications of this idea for both science and faith have redounded through the centuries, systematically revising our worldview.[3] So named by Hermann Bondi in the mid-twentieth century, the *Copernican principle* has had its greatest influence in cosmology, where it has been indispensable in providing a paradigm for interpreting observations concerning our universe.[4] For example, from the observation that our universe is isotropic (that it appears to have approximately the same large-scale structure in any direction), it is straightforward to reason, using the Copernican principle, that our universe is homogeneous at any given time, and so must be isotropic about any point in space (and not just our own earth-bound position). These conditions of homogeneity and isotropy are the primary testable consequences of the cosmological principle, which states that the properties of the universe, viewed on a sufficiently large scale, are the same for all observers.[5]

It is more or less folkloric that the Copernican principle is in conflict with Christian theology. While the high point of this conflict is generally regarded as being epitomized in the dispute between Galileo and the Catholic church,[6] the notion that the Copernican principle should be regarded as a demotion of humankind[7] (and by implication, undermining Christian theology[8]) was not asserted until a century after Copernicus's death by Cyrano de Bergerac, who associated (without citing evidence) the geocentric Aristotelian/Ptolemaic model with "the insupportable arrogance of Mankind, which fancies, that Nature was only created to serve it."[9] Bernard le Bovier de Fontenelle advanced this viewpoint further, praising Copernicus for demolishing "the Vanity of men who had thrust themselves into the chief place of the Universe."[10] By 1810 Goethe asserted, "No discovery or opinion ever created a greater effect on the human spirit than did the teaching of Copernicus, [since it required humankind] to relinquish the colossal privilege of being the center of the universe."[11] More recently, a classic textbook on general relativity by Hawking and Ellis asserts,

> Since the time of Copernicus we have been steadily demoted to a medium sized planet going round a medium sized star on the outer edge of a fairly average galaxy, which is itself simply one of a local group of galaxies. Indeed we are now so democratic that we would not claim that our position in space is specially distinguished in any way.[12]

Not only has this general perception persisted to the present day, but the Ptolemaic model is also still promoted in terms of representing humankind as "the pinnacle of God's creation," rhetorically linking monotheistic perspectives to backward scientific thinking.[13]

The Copernican principle is an irreducible philosophical assumption, one whose implications go well beyond cosmology. Indeed, many take it to mean that a core principle of science must be that of typicality, namely, that the outcome of any experiment must be interpreted using the assumption that we are typical observers.[14] This perspective motivates much modern work where details of its deployment in string theory, inflationary cosmology, and quantum physics are debated in the scientific literature.

Yet the Copernican principle evidently has limitations. Applying it temporally, Bondi and Gold used it to argue that the universe is homogeneous in time as well as space, the so-called "perfect" cosmological principle.[15] The steady-state cosmological model that is founded on this idea is in strong disagreement with observation, which indicates that our universe is undergoing cosmological evolution from markedly different conditions at a particular time (known as the Big Bang) to a future state whose conditions again differ radically from what we observe today. Is it time for a reassessment of the applicability of the Copernican principle and its theological implications?

There is a dynamic tension in Christian theology between typicality and uniqueness. The Savior who reminds us that it rains on the just and the unjust[16] also brings us the good news that the hairs on our heads are numbered by a loving God.[17] How do we effectively articulate a theology of God's love for each person in the light of the perceived secular "demotion" of humanity? To what extent should Christian theology humbly incorporate new scientific findings interpreted through the lens of typicality, and to what extent should a prophetic voice step forth to challenge the secular anthropological zeitgeist connected with modern cosmological thought? Can human significance be given a scientific basis? If not, then how can its refutation be founded on scientific findings? Is atypicality a testable concept? If so, what would be the implications for Christian faith? Conversely, is typicality falsifiable, or must we simply accept it as intrinsic to all of modern science? And if we do, whither is our understanding of God's relationship to humanity?

Dennis Danielson, who has pointed out that the Copernican principle does not carry the misanthropic interpretation that many modern scientists ascribe to it, has started some reassessment of this work.[18] Scientifically, there have been a few recent ideas suggesting how the Copernican principle could be subjected to new scientific tests, insofar as we might be able to discern more directly the extent to which the universe is indeed spatially homogeneous;[19] alternatively, if we are located at the center of a cosmic void, we would indeed be in a "privileged" location.[20] The outcome of such experiments and observations, should they be carried out, will surely have implications as profound as that of Copernicus's original insight. The ongoing implicit theological challenge of the Copernican principle is that of understanding our significance in a universe that can appear so harshly indifferent to human beings.

Plurality

The Copernican insight that our planet is one among several orbiting the sun inspired Giordano Bruno to propose that our universe is infinite, containing many suns and planets. The relative importance of this view (compared to other heresies Bruno held) as the rationale for the Roman Inquisition sentencing him to be burned at the stake, has been a point of historical debate.[21] Yet it is clear from the documentation of Bruno's trial that his cosmological ideas regarding the scope of the universe and the plurality of worlds were a nagging concern of his inquisitors.[22]

A number of cosmologists and particle physicists are reconsidering Bruno's idea in an extreme form, replacing the plurality of worlds with a plurality of universes. Known as multiverse cosmology, the idea that our observable universe is a small part of a much, much larger structure[23] raises new challenges for science, theology, and the relationship between them that go far beyond what Bruno and his inquisitors might have imagined.

Scientifically, the motivation for this idea emerges from the meta-observation that our cosmos is not a generic specimen from a warehouse of possible universes,[24] but instead has rather atypical features conducive to the existence of life and the cosmos as a whole.[25] Specifically, the physical laws, initial conditions, and particular structures of our universe are in a delicate state of balance: a small relative change in one parameter (e.g., the mass of the proton or the expansion rate of the universe[26]) results in a cosmos inhospitable to life,[27] looking nothing like the one we see.[28] A desire to ensure Copernican typicality has in recent years motivated an increasing number of scientists to consider the multiverse as the underlying scientific description of reality.[29] Its proponents generally rely further on string theory[30] and cosmic inflation,[31] regarded respectively by many as the best paradigms for uniting quantum theory with gravity and for describing our cosmos. String-theory calculations recently suggested that at least 10^{500} kinds of low-energy types of universes were possible (each with its own particular properties). Cosmic inflation, having indirect support from observations of the cosmic microwave background, is regarded by many as being most naturally described in a multiverse context.

This "super-Copernican" revolution merits a healthy dose of skepticism from both scientific and theological perspectives, as I have advocated elsewhere.[32] Scientifically, the necessary breadth of theoretical perspective, combined with the obvious empirical limitations of observing other universes, is implicitly redefining what is meant by science.[33] Theologically, it introduces a new question: why is there something instead of everything?[34]

These are interesting questions to pursue, to be sure. But one need not, and should not, accept at face value the ostensible merits of the multiverse without properly assessing its epistemic costs. From a scientific perspective, the relationship between observation and theory takes on a whole new character (since the idea relies on a wealth of empirically unverifiable precepts), and the distinction between potentiality and actuality becomes blurred, if not lost (since the ensemble of universes needs to be physically instantiated for our universe to have a chance of being a typical member). From a theological perspective, the theodicy problem becomes far more acute (since there can be unbounded replication of tragic events), and the possibility of ascribing any form of transcendent meaning or purpose in the context of a loving God becomes very remote (since existence itself actualizes otherwise exclusive possibilities).

There is a tension here between acknowledging God's sovereign ability to create in abundance with God's purposeful intentions for creation (as in Isaiah 46:9–10). A theory of everything is not the same as a theory of anything,[35] nor is a God that *can* create anything the same as a God that *does* creates everything.[36] A proper assessment of the merits of the multiverse will require a true blend of clear thinking in the overlap between science and theology.

If the multiverse is too speculative and extreme a realization of plurality, recent advances in astronomy are bringing Bruno's expectations much closer to home. Over one thousand extrasolar planets have been confirmed by observation, with more than 2,600 other objects as likely candidates. One hundred sixty-two different planetary systems analogous to our own solar system have been discovered so far. NASA's Kepler mission is making extraordinary advances, affirming the expectation that planetary systems are common in our galaxy (and presumably so in other galaxies).[37] At the end of 2011, discoveries of the earth-sized planets Kepler 20-e and Kepler 20-f were announced, along with the discovery of Kepler 22-b, a planet located in the habitable zone about its star. While these candidates fail other tests for habitability (20-e and 20-f being too close to their star, and 22-b being too large), it would seem only a matter of time—perhaps less than a few years—before a planet is found possessing all of Earth's habitable characteristics. As of this writing, there are twelve "superterran" exoplanets: considerably larger than Earth, though within what is thought to be the habitable zone about their star. There are no Earth-sized potentially habitable candidates at present.[38]

This would be the first empirical evidence that we may very well not be the sole inhabitants of our galaxy. Should evidence for life be found on such a world (or even perhaps elsewhere in our solar system), it would more strongly affirm the ubiquity of life throughout the universe. Such discoveries will have a profound impact on humanity's self-assessment of its place in the universe.[39]

While secularists will undoubtedly point to this as increasing evidence of a godless universe governed by blind evolutionary processes, such assertions miss the point that our quest for extra-solar life is of a deeply religious nature. There is an opportunity here for Christians to raise interesting ethical and theological questions, questions that go well beyond recognition of the generous creative power of God. How far can we extend the concept of the *Imago Dei*, that we are made in God's image? What proper social and ethical controls should be exerted over communication with alien species, should this be possible? What kinds of reinterpretations need to be made with regard to the creation/evolution dialogue? How do we interpret the plan of salvation in the context of life on other worlds?

While the exploration of alien life from a Christian theological perspective is not new,[40] the subject has, by and large, been left to secular writers and Hollywood filmmakers to shape our societal perspectives on this issue. The input of new information from the Kepler probe offers an opportunity to revisit the question of plurality afresh, seeing what genuine new insights and reliable truth the gospel might have to offer.

Reductionism

A key motivator underlying all scientific thought is unification: the notion that apparently disparate phenomena can be understood as different aspects of the same phenomenon at some deeper level. Historically, it has been scientifically quite fruitful to seek unification, particularly in physics, even though there is no proof that this strategy will work. Newton united terrestrial phenomena with celestial phenomena via his universal law of gravitation that governed the motion of both apples falling to earth and stars moving in the sky.[41] Maxwell united electricity and magnetism, once thought to be distinct phenomena, in a single theory describing them as a unified force that we now call "electromagnetism."[42] Four decades ago, weak interactions governing the phenomenon of radioactivity were united with electromagnetism in a single theory, "electroweak theory," that made a number of new predictions that have since been confirmed experimentally.[43]

We now have a Standard Model of particle physics,[44] a set of mathematical equations that describe all known subatomic particles (quarks and leptons) and their interactions due to the strong (or nuclear) force and electroweak forces.[45] High-energy accelerator and low-energy precision experiments have repeatedly confirmed this model. The last outstanding bit of information remaining was the Higgs particle, a particle whose interactions with all other known particles give rise to what we measure as their masses. In 2012, the Large Hadron Collider (LHC) announced the discovery of a particle with a mass 125 times heavier than the proton, a particle that has all of the expected properties of the Higgs particle.[46]

While further testing will need to be done to confirm that the interactions of this particle with other forms of matter agree with the predictions of the Standard Model, this finding is indeed a triumph for reductionistic science. Like a twenty-first-century version of the chemical periodic table, it leads, for the first time, to a fully comprehensive description of all known matter and forces. Nevertheless, particle physicists will remain much less than satisfied with this final confirmation of the Standard Model. For although the Standard Model self-consistently describes all that is known about particle physics, it depends on twenty-seven distinct parameters (twelve of which are the different masses of the twelve elementary subatomic particles, for example), each of which must be determined by experiment. No deeper principle explaining their values is known. Furthermore, cosmological observations of the orbital motions of galaxies in clusters and of the accelerating expansion of our universe have led to the view that only a little less than 5% of the mass-energy of the universe is composed of known (Standard Model) matter, most of which is gas and dust. The remaining portion is about 26.8% dark matter (matter that does not interact with light or electromagnetism and so cannot be directly observed by traditional astronomic means) and 68.3% dark energy (the name given to whatever diffuse energy source is causing the universe to accelerate).

For these reasons, most particle physicists believe that a deeper level of unification beyond the Standard Model is required. The search for a "Theory of Everything," a single theory describing all known (and currently undiscovered) particles and forces in a coherent unified whole, has occupied the attention of theoretical physicists for over three decades. The simplest model of a grand unification uniting the electroweak and strong forces predicted that the proton was not stable, decaying with a very long but feasibly observable lifetime.[47] No evidence for this decay was found in subsequent experimental searches. Instead, lower bounds were set on the proton lifetime.[48] Many more Grand Unified Theories (or GUTs as they are called) have since been constructed, each with its own predictions for low-energy (and sometimes early-universe) physics. Superstring theory was originally regarded as the most promising GUT,[49] as it held out the promise of also uniting gravitation with the other forces in a manner consistent with quantum mechanics.

To the frustration of the scientific community, no evidence whatsoever has thus far been found in their favor; instead, only various empirical bounds and limits on GUTs have been set. While many still pin their hopes on the final round of LHC experiments as revealing some new phenomenon, there is no guarantee that anything beyond the Standard Model will be found.

Reductionism elicits extreme responses within the scientific community. Nontheists generally regard this approach (affirmed at least by the success of the Standard Model) as closing off any last gaps in which hopeful believers might want to place evidence for a deity. Theists have generally regarded the deep mathematical intelligibility that has emerged from reductionistic physics as evidence in favor of a Creator, partially reflecting the mind of God for those willing to see.[50]

Must science and theology stand on opposite sides of such a wide intellectual chasm? Or is it possible to build a bridge of new understanding here? What, if any, are the limits of reductionism? How does science proceed in the face of such limitations? What metaphysical interpretations might be drawn in this case? Alternatively, is it possible to go beyond intelligibility in understanding a Creator who values mathematical elegance to One who loves creation sacrificially? How is the God of the Standard Model the God of Calvary?

Quantization

One of the central lessons of twentieth-century physics resulting from a reductionist paradigm was that the natural world is not fully atomized. Localized atoms, nuclei, and subatomic particles can behave as extended waves, and delocalized wavelike phenomena, such as light, can behave as particles. This schizophrenic wave/particle behavior is described by quantum mechanics.[51] The Standard Model is a quantum theory, more properly, a quantum field theory that regards point-like particles as quantum excitations of fields; the photon, for example, may be treated as a quantized excitation of electromagnetic field, or more simply, a tiny bundle of light.

Indeed, the foundational laws governing nature blur the distinction between individual things and their surroundings. This blurring of distinction between the subsystems of a system is called "entanglement," and the theory describing this is called "quantum mechanics." It has surprising implications for how we understand the natural world. It is so powerful that it alters the laws of probability from the everyday world as we know it. Consider two fair coins, one given to Alice and the other to Bob. Let each flip their respective coins repeatedly for many trials and then keep track of the results. If Alice gets heads, Bob has a 50/50 chance of getting heads or tails, no matter what Alice gets. And vice versa. Such is the normal behavior of random processes in the everyday world.

Now consider what would happen if it were possible to quantum mechanically entangle the coins. The results would be strikingly different. In one possible form of entanglement (there are many), Alice still has a 50/50 chance of getting heads—but whenever she gets heads, Bob also gets heads. And whenever she gets tails, Bob also gets tails. It is as though each coin "knows" what the other is doing, even though the coins send no signals to each other. Each coin maintains its individual integrity—for each coin, heads comes up as often as tails, with a 50/50 chance. Yet there is no chance of a head/tail or tail/head combination. The pair of entangled coins does not behave as two distinct coins, but rather as a system that exhibits "togetherness in separation." The whole truly is greater than the sum of the parts.

This holistic feature of quantum entanglement can be shown to imply a certain degree of ambiguity or indefiniteness to existence itself, overturning not only commonsense, but all conventional ways of thinking about science as well.[52] It troubled many physicists, most notably Albert Einstein, who refused to believe that nature could be like that.[53] Yet this spooky form of interconnectedness has been repeatedly verified in laboratories around the world, most commonly with polarized photons as the quantum coins, "heads" being a left-circularly polarized photon and "tails" being a right-circularly polarized one.[54] By shining light of a particular frequency through a nonlinear crystal, a pair of light rays of reduced frequency can emerge (a process known as spontaneous parametric down-conversion), and a percentage of the photons in these rays can have their polarizations entangled, affording a verification of the strange coin-flip scenario above.[55]

The implications of quantum entanglement are profound. At a practical level, it can be exploited to encode and transmit information in completely novel ways. This realization has given rise to a whole new research field known as "quantum computing," whose goal is to exploit the properties of quantum theory to transmit, encode, and process information. So far the field is still rather young, though rapid progress is being made. The stakes are high, with unbreakable security codes, teleportation, and solving otherwise unsolvable math problems as prospective outcomes of the endeavor.[56]

Quantum entanglement also has profound philosophical consequences, implying that interconnectedness is a central feature of existence. It is so central that the relationships between the bits and pieces of nature can produce effects that each bit or piece on its own cannot produce. Nature is intrinsically relational. Here the discussion can take a theological turn, insofar as this feature is what we might expect from a creation reflecting the character of its Creator, who, as Father, Son, and Holy Spirit, is most profoundly a personal and relational God.

Theologians for centuries have struggled with a problem similar to that faced by scientists confronted with quantum entanglement, namely, that of understanding the nature of the Trinity. Known as perichoresis, it is a dazzlingly paradoxical concept, and refers to the mutual indwelling and interpenetration of the Persons of the Trinity. The eighth-century Syrian Christian monk, John of Damascus, described it as a cleaving together in a fellowship of mutual love.[57] The Persons of the Trinity are not simply different aspects of one Person, a perspective that would not do justice in understanding, say, the baptism of Jesus. Nor are they so distinct as to be a sort of stripped-down polytheism, a committee of three gods. Perichoresis rather asserts both the individual integrity of Father, Son, and Spirit and the indivisibility of the one true God.

Here is new territory for science and Christian faith to explore.[58] Indeed, a fruitful and stimulating dialogue is taking place between scientists and theologians as to the consonant relationship between perichoresis and entanglement. Scientists such as Anton Zeilinger and Jeffrey Bub, and theologians such as Sarah Coakley and John Zizioulas, have gathered under the leadership of the Anglican physicist-turned-priest Sir John Polkinghorne to carry out research in these matters. A genuine theological and scientific dialogue is going on, one that is far removed from the more traditional conflict/apologetic stances.[59]

At a more prosaic level, the economic and societal impacts of quantum entanglement are novel and potentially far reaching. Quantum computation will radically change how we store, transmit, and process information. How we make use of this new technology is a question that necessarily goes beyond science. Insofar as we will be faced with new choices presented to us, we have new opportunities to be the salt of the earth and the light of the world. A science/faith dialogue on the proper uses of such new information technology is (as with any application of science) of perhaps even greater import than advancing our theological understanding.

Eternity

All attempts thus far to understand gravity in quantum mechanical terms have failed. While a majority of theoretical physicists still regard string theory as the most promising approach for addressing this problem, there are a number of competing ideas. Indeed, an understanding of quantum information in the context of gravitation has become a subdiscipline in its own right. Although at this point far removed from experiment, such ideas raise questions about the foundations of reality, a subject never far from a theological worldview. They suggest that the relationship between creation and the Creator is exceedingly subtle and complex.

Perhaps the most difficult conundrum here is that of time.[60] Every civilization throughout history has had to come to grips with how it marks the passing of the seasons and the advancement of years. However, it is at the birth of modern science that a debate takes place concerning the nature of time and its relevance to scientific understanding. One view, expressed by Newton, is that time is an external "thing" that clocks measure, flowing like an inexhaustible river.[61] The other view, articulated by Leibniz, is that time has no ontic reality of its own, but rather serves as an ordering parameter, with its sequencing of events bearing no more significance than the alphabetical ordering of names in a telephone book.[62] The Newtonian notion of time best corresponds to everyday intuition, and, for the most part, held sway in the practice of science. However, the twentieth-century revolutions of quantum physics and relativity have modified our understanding of time, both pragmatically and philosophically.

The key lesson of relativistic physics is that measurement of time is observer dependent, differing between observers having different relative speeds and/or different locations in a gravitational field. Time and space are woven together in a structure called "spacetime," whose properties and behavior are very accurately described by Einstein's theory of general relativity. Contrary to everyday experience (which is the way it is only because relativistic effects require high speeds and/or intense gravitational fields to be significant), both the duration of events and their simultaneity (the notion of "now") is not something universal. This is perhaps the hardest thing to understand about relativity.[63] Yet the Einsteinian theory that describes such effects has been repeatedly verified in many high-precision experiments, and today their proper incorporation into the rest of physics is required in order for the global positioning system to function properly.

The situation stands in stark contrast to the quantum-mechanical perspective, in which time is an ordering parameter demarcating the change of quantum systems (or states) from the past into the future. Quantum mechanics is highly compatible with a Newtonian nonrelativistic view of time. The paradoxical quantum effects of tunneling, wave-particle duality, and entanglement are all most straightforwardly explicated in this context. The union of quantum mechanics with special relativity took several decades to fully achieve, and led to what is now called "quantum field theory." Its early triumph was to successfully predict the existence of antimatter. Quantum field theory is the underlying mathematical structure of the Standard Model (discussed above). All particle physics experiments make use of it to interpret their data, and so far they have yet to contradict the Standard Model's predictions.

However, as noted above, all efforts to incorporate this same mathematical structure with general relativity have failed. This, in large part, is due to their very distinct conceptualizations of time. For example, quantum theory cannot be formulated without a clear and sharp distinction between past, present, and future. Yet one expects that a quantum gravity theory will yield a kind of wave/particle duality description of spacetime itself, blurring this distinction. To make matters worse, all predictions emerging from quantum field theory entail a systematic removal of infinite quantities that appear in calculations of various scattering processes (e.g., if an electron scatters off a muon), a procedure known as "renormalization." This troubling feature of quantum field theory is one its original practitioners were never happy with, though it did yield results that agreed with experiment. However, the same procedure applied to gravity fails miserably, yielding a theory with no predictive power. While there are many ideas as to how these problems can be addressed (string theory being the most popular), there is no clear resolution to this issue at present.[64]

A biblical picture of time yields a similar tension between dual concepts: we read of God being eternal, the Alpha and the Omega, transcending time in a manner that we can only dimly grasp.[65] Augustine proposed that time itself is created, something subservient to God as is the rest of creation.[66] Yet we also read of God lovingly interacting with the creation and its human inhabitants, conversing with them, challenging them, directing them, and providing them with a prophetic message. We puzzle at the notion of a God with foreknowledge who appears to change his mind.[67]

The active discussions in the theoretical physics community today on the nature of time can provide fertile ground for theological reflection. Properly treated, dialogue between theology and science can perhaps provide a deeper understanding or a more creative perspective on the nature of reality. In what follows, I shall sketch out some of the points of contact between science and theology on the nature of time.

The difficulties in obtaining a quantum description of gravity have led to the notion that time itself is perhaps "atomized." The idea here is that quantum gravitational effects will make it impossible to measure any time shorter than 10^{-43} seconds, a quantity known as the Planck time. Simply put, any clock attempting to measure time intervals shorter than this will be subject to gravitational effects so powerful that it will collapse into a black hole. A similar argument can be made for attempting to measure distances shorter than the Planck length of 10^{-35} meters (the Planck time multiplied by the speed of light). Perhaps it is simply not meaningful to consider time intervals shorter than the Planck time.

Yet, if this is accepted, what happens "in between" these intervals? Indeed, what sustains the existence of the universe in such intervals? Such an idea resonates with the notion of *creatio continua*, the ongoing activity of the initial creation out of nothing. The coherence of physical law over times (and distances) larger than this quantum limit is reflective of the integrity of nature and its ability to autonomously exercise its God-given causal powers, whereas the existence of such intervals perhaps speaks to the intimate moment-by-moment dependence of the creation on the Creator.

The directionality, or arrow, of time is another great puzzle at the roots of physics.[68] The laws of Newtonian physics are unchanged if the direction of time is reversed, so why does time "move forward"? In seeking to understand the arrow of time, physicists have identified seven different arrows—cosmological, thermodynamic, radiative, gravitational, metrological, subatomic, and psychological—whose deep explanations are still elusive. While we cannot rule out that they are all different aspects reflecting some underlying principle, each has its own distinctive manifestation in our world.

The cosmological arrow refers to the observation that the universe is expanding as time increases. That entropy, a measure of disorder, never decreases in any physical process constitutes the thermodynamic arrow. The radiative arrow refers to the observation that sound, light, and any other radiative phenomena always diverge outward (think of waves rippling outward after a pebble is dropped in water) and never converge inward, though the latter situation is permitted by the equations of physics. That black holes absorb all forms of matter and emit nothing but random thermal radiation is indicative of a gravitational arrow. The metrological arrow refers to measurement of any quantum system—once carried out, quantum superpositions irreversibly separate, a process whose ontic meaning is still an active subject of debate. The laboratory observation that subatomic particles known as kaons disintegrate more slowly than their antiparticle counterparts (a phenomenon also seen more recently for other subatomic particles) implies a subatomic arrow of time. And, of course, the most common temporal arrow is that of our own psychology: we remember the past and anticipate the future.

Temporal directionality is congruent with a theological notion of purpose—that history, writ large and small, is "going somewhere."[69] While the cyclic rituals of time—seasons, festivals, and high days—play an important role in all religions, the notion of ultimate purpose is one that is indispensable to Christianity. The Bible is replete with examples of a cosmic purpose, whose origin and culmination reside in God. From the Alpha, who formed the earth to be inhabited, to the Omega, who will make all things new, God's cosmic purpose unfolds along time's arrow for those having eyes to see. And this same testimony of faith also affirms that ultimately this cosmic purpose is one of love, in which God works all things together for good for the ones who love God, for each individual called according to his purpose.[70] There is certainly theological consonance between an arrow of time and the destiny of the cosmos. To the extent that scientific inquiry can provide information about interesting new connections between the various arrows of time, there is potential for deepening our theological understanding. Conversely, further theological reflection on the cosmic *telos* has the potential to broaden our appreciation and insight into the natural world and its directionality.

The notion that there is an ultimate destiny for the cosmos leads to the scientific question as to what the ultimate fate of the universe shall be. Here the picture from science over the past two decades has been considerably refined, amplified, and revised, pivoting around the observation that our cosmos is accelerating in its expansion. The source of this cosmic acceleration is referred to as "dark energy," whose structure and origin are currently under active investigation. Notwithstanding the outcome of such study, the long-term picture is one of puzzling gloom: puzzling because evolved carbon-based life can only exist in the earliest stages of the history of an accelerating cosmos, leading to the anti-Copernican implication that we live at a special time in cosmic history; and gloomy because no known laws of physics permit any other reasonable form of life to survive in an accelerating universe over any substantive fraction of its history—all sources of energy eventually become inaccessible. In the long run, we really are all dead.

Such notions require a considerable degree of unpacking, both scientifically[71] and theologically.[72]

It has already been noted that our scientific understanding of the destiny of the cosmos is considerably more threatening theologically than our corresponding understanding of its origins. How can we understand cosmic purpose in a universe condemned to dilute itself into virtual nothingness? What message of gospel hope can be proclaimed in such a context? In what manner might we expect a new heaven and a new earth?

Of course, any answers to such questions need to be quite tentative and speculative. However, I am optimistic enough to think that appropriate theological reflection on the nature of time might provide new approaches for sharing the light of the gospel for the scientifically—and perhaps not so scientifically—inclined.

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Notes

[1]For a broad overview of how these kinds of issues offer a broad range of science, see N. Murphy and G. F. R. Ellis, *On the Moral Nature of the Universe* (Minneapolis, MN: Fortress Press, 1996).

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[3]T. Kuhn, *The Copernican Revolution* (Cambridge, MA: Harvard University Press, 1957).

[4]H. Bondi, *Cosmology* (New York: Cambridge University Press, 1952), 13.

[5]W. Keel, *The Road to Galaxy Formation* (UK: Springer-Praxis, 2007).

[6]For a recent biography of Galileo, see J. Reston, *Galileo: A Life* (New York: Harper Perennial, 1994).

[7]D. Danielson, "The Bones of Copernicus," *American Scientist* 97 (2009): 50.

[8]C. Sagan, *The Varieties of Scientific Experience: A Personal View of the Search for God*, ed. A. Druyan (New York: Penguin Press, 2006).

[9]Quoted in D. Danielson, "That Copernicanism Demoted Humans from the Centre of the Cosmos," in *Galileo Goes to Jail and Other Myths about Science and Religion*, ed. R. L. Numbers (Cambridge, MA: Harvard University Press, 2009), 57.

[10]Ibid.

[11]Johann Wolfgang von Goethe, *Materialien zur Geschichte der Farbenlehre* (Hamburg: Christian Wegner Verlag, 1810).

[12]S. W. Hawking and G. F. R. Ellis, *The Large Scale Structure of Space-Time* (New York: Cambridge University Press, 1973), 134.

[13]P. C. W. Davies, *Cosmic Jackpot: Why Our Universe Is Just Right for Life* (Boston, MA: Houghton Mifflin, 2007), 129.

[14]For example, see R. Bousso, B. Freivogel, and I-Sheng Yang, "Boltzmann Babies in the Proper Time Measure," *Physical Review* D, vol. 77, no. 10 (2008): 103514.

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[16]Matthew 5:45.

[17]Matthew 10:31.

[18]D. Danielson, "The Great Copernican Cliché," *American Journal of Physics* 69, no. 10 (2001): 1029.

[19]J. Uzan, C. Clarkson, and G. F. R. Ellis, "Time Drift of Cosmological Redshifts as a Test of the Copernican Principle," *Physical Review Letters* 100 (2008): 191303.

[20]R. Caldwell and A. Stebbins, "A Test of the Copernican Principle," *Physical Review Letters* 100 (2008): 191302.

[21]See, for example, R. L. Numbers, ed., *Galileo Goes to Jail and Other Myths about Science and Religion* (Cambridge, MA: Harvard University Press, 2010).

[22]L. Firpo, *Il Processo di Giordano Bruno,* Document 51 (Rome: Salerno Editrice, 1993), 247–304.

[23]A recent overview of this subject is given in B. J. Carr, ed., *Universe or Multiverse?* (New York: Cambridge University Press, 2007).

[24]For the first comprehensive discussion of this, see J. D. Barrow and F. Tipler, *The Anthropic Cosmological Principle* (New York: Oxford University Press, 1988).

[25]For a philosophical analysis of these issues, see J. Leslie, *Universes* (New York: Routledge, 1996).

[26]W. J. Kaufman III, *Universe*, 4th ed. (New York: W. H. Freeman, 1993); S. Weinberg, "The Cosmological Constant Problems," in *Sources and Detection of Dark Matter and Dark Energy in the Universe*, ed. D. B. Cline (New York: Springer-Verlag, 2001), 18–26.

[27]B. Carter, *IAU Symposium 63: Confrontation of Cosmological Theories with Observational Data* (Dordrecht: Reidel, 1974), 291–8.

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[29]Davies, *Cosmic Jackpot*.

[30]M. B. Green and J. Schwarz, "Anomaly Cancellation in Supersymmetric d=10 Gauge Theory Requires SO(32)," *Physics Letters B* 149 (1984): 117; for some readable introductions to string theory, pro and con, see respectively Brian Green, *The Fabric of the Cosmos: Space, Time, and the Texture of Reality* (New York: Vintage, 2005); and Lee Smolin, *The Trouble with Physics: The Rise of String Theory, the Fall of a Science, and What Comes Next* (New York: Spin Networks, 2006).

[31]A. H. Guth, "Inflationary Universe: A Possible Solution to the Horizon and Flatness Problems," *Physical Review D* 23, (1981): 347–56; A. Linde, "A New Inflationary Scenario: A Possible Solution of the Horizon, Flatness, Homogeneity, Isotropy, and Primoridal Monopole Problems," *Physics Letters B* 108 (1982): 389; see also, A. Guth, *The Inflationary Universe* (New York: Basic Books, 1998).

[32]R. B. Mann, "The Puzzle of Existence," *Perspectives on Science and Christian Faith* 61, no. 3 (2009): 139–50.

[33]For a recent critique, see G. F. R. Ellis, "Does the Multiverse Really Exist?," *Scientific American* 305 (2011): 38.
[34]R. B. Mann, "Inconstant Multiverse," *Perspectives on Science and Christian Faith* 57, no. 4 (2005): 302–10.
[35]Or as John Polkinghorne put it, "If you allow yourself to hypothesize an almost unlimited portfolio of different worlds, you can explain anything," quoted in an article by T. Folger, "Science's Alternative to an Intelligent Creator: The Multiverse Theory," *Discover Magazine* (December 2008): published online November 10, 2008, available at http://discovermagazine.com/2008/dec/10-sciences-alternative-to-an-intelligent-creator.
[36]R. B. Mann, "Thinking of Everything," *Irreconcilable Differences*, ed. Jason Robinson (Toronto, ON: University of Toronto Press; forthcoming).
[37]W. J. Borucki et al., "Kepler Planet-Detection Mission: Introduction and First Results," *Science* 327, no. 5968 (2010): 977–80.
[38]A variety of websites provide weekly updates on the search for extrasolar planets. See http://phl.upr.edu for up-to-date lists of habitable planets, and http://exoplanetarchive.ipac.caltech.edu for the complete archive of all extrasolar planets.
[39]Similar questions presented themselves (at least implicitly) in the sixteenth–eighteenth centuries when European explorers and colonists encountered people of different languages and cultures in the Americas, Africa, and Australia. In this case, the "alien" encounter was between different cultures, too often producing tragic results.
[40]C. S. Lewis, *The Seeing Eye* (Grand Rapids, MI: Eerdmans, 1995).
[41]S. Chandrasekhar, *Newton's Principia for the Common Reader* (New York: Oxford University Press, 2003).
[42]J. C. Maxwell, "A Dynamical Theory of the Electromagnetic Field," *Philosophical Transactions of the Royal Society of London* 155 (1865): 459–512.
[43]S. L. Glashow, "Partial Symmetries of Weak Interactions," *Nuclear Physics* 22 (1961): 579; S. Weinberg, "A Model of Leptons," *Physical Review Letters* 19 (1967): 1264–6; A. Salam, "Elementary Particle Theory," *Nobel Symposium* 8, ed. N. Svartholm (Stockholm: Almquist and Wiksell, 1968), 367.
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[48]C. Amsler et al., "2008 Review of Particle Physics," *Physics Letters* B 667, no. 1 (2008).
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[51]For an introduction at an undergraduate level, see D. J. Griffiths, *Introduction to Quantum Mechanics* (Harlow Gate, UK: Pearson Education, 2014).
[52]For a professional account of some of the interpretive issues, see B. d'Espagnat, *Conceptual Foundations of Quantum Mechanics*, 2nd ed. (Boulder, CO: Westview Press, 1999).
[53]For an account of these issues, see J. Bub, "The Entangled World: How Can It Be Like That?," in *The Trinity and an Entangled World: Relationality in Physical Science and Theology*, ed. J. C. Polkinghorne (Grand Rapids, MI: Eerdmans, 2010), 15–31.
[54]Polarization refers to the kind of vibrations an electric or magnetic field undergoes when a body emits light. Any form of light can always be decomposed into two distinct kinds of polarization, known as left- and right-circular.
[55]A. Aspect, P. Grangier, and G. Roger, "Experimental Tests of Realistic Local Theories via Bell's Theorem," *Physical Review Letters* 47 (1981): 460–3.
[56]For an introduction, see M. A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information* (New York: Cambridge University Press, 2004).
[57]See J. Zizioulas, "Relational Ontology: Insights from Patristic Thought," in *The Trinity and an Entangled World*, ed. Polkinghorne, 146–56.
[58]J. C. Polkinghorne, *Quantum Physics and Theology – An Unexpected Kinship* (New Haven, CT: Yale University Press, 2007).
[59]J. C. Polkinghorne, "The Demise of Democritus," in *The Trinity and an Entangled World*, ed. Polkinghorne, 1–14.
[60]For an introduction to some issues for nonspecialists, see P. C. W. Davies, *About Time: Einstein's Unfinished Revolution* (New York: Simon & Schuster, 1995).
[61]I. Newton, *Principia: Mathematical Principles of Natural Philosophy* (1687), 3rd ed. (1726), trans. I. B. Cohen and Anne Whitman (1999), "Definitions: Scholium," 408–9.
[62]G. W. Leibniz, "Third Letter to Samuel Clarke," February 25, 1716, http://www.phas.ubc.ca/~berciu/PHILIP/TEACHNG/PHYS340/EXTRA/FILES/Leibniz-ClarkeA.pdf.
[63]For a fairly nontechnical introduction at an undergraduate level, see J. B. Hartle, *Gravity: An Introduction to Einstein's General Relativity* (Reading, MA: Addison-Wesley, 2003).
[64]For an introduction to some of the issues, see L. Smolin, *Three Roads to Quantum Gravity* (New York: Basic Books, 2002).
[65]Revelation 1:8.
[66]St. Augustine, *Confessions*, bk. 11, chap. 13.
[67]Genesis 18:23–33.
[68]H. D. Zeh, *The Physical Basis of the Direction of Time* (Berlin: Springer-Verlag, 2001).
[69]J. Templeton, ed., *Evidence of Purpose* (New York: Continuum, 1994).
[70]Romans 8:28.
[71]G. F. R. Ellis, ed., *The Far-Future Universe: Eschatology from a Cosmic Perspective* (West Conshohocken, PA: Templeton Foundation Press, 2002).
[72]J. C. Polkinghorne, *The God of Hope and the End of the World* (New Haven, CT: Yale University Press, 2002).