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8. Big Questions in Cosmology

Intersections between Science and Religion

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Introduction

In this paper, I attempt to point out that there are many areas in contemporary scientific cosmology that touch upon theological and philosophical questions. My perspective and that of many believing scientists is that our understanding of the universe will be enriched by a complimentary approach that incorporates the best science along with the most mature and reasoned theology. Each discipline may point to separate truths, but these truths are complimentary.

Since this is a paper published in a religion and society journal, let me lay out what I consider compelling reasons to do science and to consider the scientific perspective and why theologians should care about science. The usual approach to this question is to consider creation as a gift, hence worthy of study. As Michael J. Buckley, S.J. points out, "Does this sense of gift not mean that we should pay attention – even in the most disciplined and serious manner – to what God has entrusted us? Has not the church insisted since the attack of Manichaeism that the world is good and that matter and history are the stuff of salvation? Does not creation give obvious importance and even a religious dimension to the work of science?" (41). But as Buckley himself goes on to point out, these reasons are generic, have been repeated to death, and yet are somehow lacking. Is there a more compelling reason?

Alice Bourke Hayes tells us, "Scientific ideas are so powerful, and have such great significance for intellectual life. To not incorporate them into Catholic intellectual schema is to leave part of our minds in another century" (5). Buckley himself posits two theses that give a deeper and more compelling reason to study science and to integrate science and religion: 1. "In one way or another, contemporary scientific inquiry raises serious questions about ultimacies and so constitutes part of the present religious problematic"; and 2. "The scientific passion for the truth about the world is a part of that general passion for truth that makes faith – any vital faith – possible" (42).

My personal answer to this question is many-fold. In the Catholic tradition, Aquinas believed that both faith and reason were roads to the truth. As a scientist, I am profoundly appreciative of the medieval tradition of regarding the world as the "Book of Creation," and that one can discover truths about the ultimate mystery by studying the world around us. To paraphrase Rev. Michael Himes, when scientists study mystery, they are engaged in the God question whether they realize it or not. And finally, as a faculty member at a Jesuit university I am touched by the Jesuit charism of Finding God in All Things. This also harkens back to Himes's sacramental principle, that anything can be a sacrament as long as it "causes us to notice the love which supports all that exists, that undergirds your being and mine and the being of everything around us" (99). Thus joy in the beauty and perfection of the mathematical equations of general relativity can be sacramental and lead us to an experience of God.

Now, I would further argue, as do many others, that it is just as crucial for the scientist to study theology as it is for the theologian to consider the truths revealed by science. Hayes relates the following story:

> It reminds me of the triumphant announcement made by the Soviet Cosmonaut, Yuri Gagarin, when he returned from his historic orbit, that he had disproved the existence of God. He told reporters that he had been up there, and he had looked all around, and he didn't see God. I thought, how poignant that the quintessential 20th century man seemed to be searching for the quintessence, a pre-16th century notion that heaven was up, and a Michelangelo picture of God, the old man with the beard, reaching down from his cloud. One part of Gagarin's intellectual development was at the frontiers of science and technology, and the other part held a medieval world-view (53).

A more modern example of this phenomenon is the so-called Kola Borehole hoax. The Soviet Union in a scientific project had drilled a borehole more than 12 km deep. The drilling stopped in 1989 due to increasing temperatures and drilling expenses. A sensational hoax about the project was promulgated that stated that Russian scientists while drilling broke through into a cavern from which could be heard the tortured screams of the damned, as if Hell were a literal, physical place. The story was widely reported and even more widely believed! We will not be able to comprehend the mysteries of 21st century science if part of our minds and intellectual schemas are pre-16th century.

Pope John Paul II wrote, "Science can purify religion from error and superstition; religion can purify science from idolatry and false absolutes . . . The unprecedented opportunity we have today is for a common interactive relationship in which each discipline retains its integrity and yet is radically open to the discoveries and insights of the other." As I will mention in this paper, at times it seems like the science and theologies of the day are in conflict. What then? Cardinal Newman writes that we should approach such conflicts "with full faith in the consistency of that multiform truth, which they share between them, in a generous confidence that they will be ultimately consistent, one and all, in their combined results though there may be momentary collisions, awkward appearances and many forebodings and prophecies of contrariety" (375).

Let me end this introduction with what I believe is a beautiful example of such an integration of science and religion: the newly commissioned St. John's Bible. For example, the Gospel of Matthew, which begins with a genealogy of Jesus, is illustrated with DNA double-helices. As a cosmologist I was particularly moved by Acts, in which Jesus instructs the apostles to "Go and make disciples to the ends of the earth . . ." This passage is accompanied by a starry landscape, a comet, and geometric figures reminiscent of the discoveries of modern physics of the 20th century. To me it seems that science and religion can coexist and complement each other, and that it is possible to have both our scientific and theological minds in the 21st century together.

Big Questions in Cosmology

As is well recognized, interdisciplinary work is difficult because one is generally only an expert in one discipline. My goal in writing this paper is to bring to the attention of theologians and philosophers some questions in modern cosmology that seem ripe for collaboration and interdisciplinary work. Although I will mention work from the theological side, I will generally try to stay within my own disciplinary expertise, and leave those details outside my own area as fertile ground for collaboration.

To me there seem to be several "big" questions in cosmology that are motivated by current research. These are:

1. Was there a beginning to the universe?
2. What is the nature of time?
3. What is the fate of our universe?
4. Why our set of physical constants or laws?

These questions, of course, touch upon theology as well, particularly as it relates to the beginning and end of times and our conception of our role in the universe.

Was There a Beginning?

In the *Summa Theologica*, St. Thomas Aquinas states, "That the world has not always existed is held by faith alone, and cannot be demonstrated" (I, Q. xlvi, a. 2). This Christian doctrine of creation *ex nihilo* is a significant modification of Platonism and earlier Greek science. In this section let us examine what scientific evidence exists in modern cosmology for a beginning to space and time and if this article of faith is scientifically defensible or justifiable.

Prior to the Enlightenment, the universe was considered to be young (the 6,000 years old consistent with a literal interpretation of scripture) and unchanging. Newton, who unraveled the secrets of gravity in the 17th century, believed that the universe was a static and unchanging place (apart from local dynamics). Of the perfect balance he saw in nature, he said, "This most beautiful system of the sun, the planets, and comets could only proceed from the counsel and dominion of an intelligent and powerful Being" (208). However, Newton also understood that a finite, static space was not stable – any small imbalance in the cosmic distribution of matter would lead to the creation of succeeding dense regions that would lead to gravitational collapse. Of this he writes, "But hitherto I have not been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses" (210). Newton himself had no idea how stability was maintained except by divine intervention. Furthermore, in terms of a beginning, Newton simply assumes that there was a beginning but lacks any scientific evidence for his conclusion.

The modern era of cosmology and the first evidence for a "beginning" of the universe, I believe, come with the observations of Edwin Hubble that the universe is expanding. Continuing the work of Vesto Slipher, in 1929 Hubble found that most galaxies are receding from our own (with the exception of the Andromeda galaxy and other nearby dwarf galaxies to which we are gravitationally bound), and that the velocity of this recession depends linearly on the distance to the galaxy. This led Hubble to formulate his famous Hubble Law,

$$v = H\, d$$

where v is the recession velocity of the galaxy, H is a new constant called the Hubble Constant, and d is the distance to the galaxy in question. Hubble originally found a value of about 500 km/sec/Mpc for the constant, however, the modern value of this constant is closer to 76 km/sec/Mpc. What this law simply states is that the farther a galaxy is from us, the faster it is moving away from us. This result was interpreted through the lens of general relativity, established in 1915. The recession of distant galaxies was interpreted as the expansion of space-time itself; galaxies, themselves gravitationally bound systems, do not expand, but rather the space between them expands.

An analogy we can use to understand this expansion is that the universe is like a loaf of raisin bread. When the dough goes into the oven, the raisins, galaxies in our analogy, are spaced some roughly equal distance apart. As the bread rises in the oven, however, the dough between the raisins rises and expands, and raisins "see" themselves moving apart. Barring edge effects (the loaf of raisin bread is finite), each raisin sees itself as the center of this expansion, and raisins that are farther away from this central raisin seem to move away at larger velocities.

Another simple way to understand the Hubble Law is the following. Imagine three galaxies, A, B, and C that start at time t_0 a distance d apart as shown below.

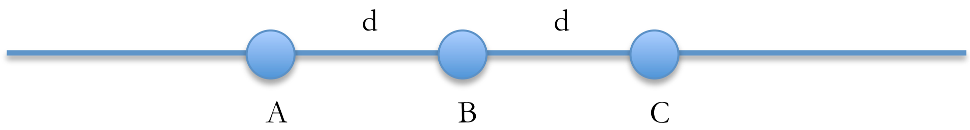

Figure 1. Imagine three galaxies in space separated by a distance d at some cosmological time t_0.

Now imagine that at time $2t_0$, the galaxies have been carried along by the expansion of space-time, such that distances have doubled. The new picture would look like Figure 2 below.

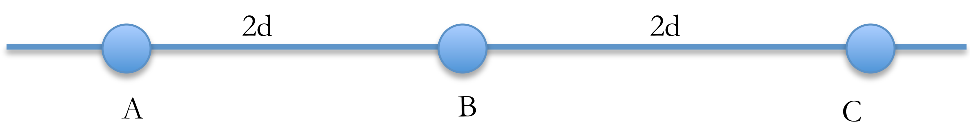

Figure 2. The same three galaxies of Figure 1 after a time t_0 in which the space between them has expanded.

What is the velocity of galaxy B as seen by galaxy A? Looking at Figure 2, galaxy B has moved a distance d in a time t_0, so its recession velocity would be d/t_0. But galaxy C is now 2d away from galaxy A, so its recession velocity appears to be $2d/t_0$, or twice that of galaxy B. The same would hold for the perspective of galaxy C (or B); both would see themselves as the center of the expansion.

What should immediately spring to mind (and did for many scientists) was that if all galaxies are moving apart, was there a time when they were at the same point, i.e. a "beginning" or a moment of creation? Hubble did a naïve calculation and found that this time corresponds to roughly 1/H (where H is his constant), and using his 1929 data he found a value of approximately 2 billion years or so. This is, of course, much too young for the age of the universe. For example, geologists in the early 20th century were well aware from radioactive dating that the Earth is much older than this. The error in Hubble's calculation was a Hubble constant that was much too large due to inaccuracies in determining distances to the galaxies he was observing. Using his 1931 data, Hubble was able to obtain a value much more in line with other forms of dating, such as the use of stellar astrophysical techniques (the universe could not be younger than the oldest stars).

Hubble's 1929 data did not have an immediate influence on cosmological model makers as we might think today. Rather, Hubble's data (as interpreted by Eddington) was added to the cosmological theory of another early 20th century thinker, Lemaitre, to essentially come up with the Big Bang Model as we know it. Georges Lemaitre, a Belgian Catholic priest, was heavily influenced by the development of quantum physics and by the phenomenon of radioactivity. Lemaitre was intrigued that the half-life of radioactive elements such as Uranium-238 and Thorium-232 were on the order of the age of the universe. As described by Kragh, this, to him, was a clear sign that "our present world might be looked upon as the nearly burned-out result of a previous universe . . . The universe had originated in a giant radioactive flash and hence could be ascribed a finite age" (2007: 153). Lemaitre imaged a "primeval atom" in which a spectacular explosion flung matter outward as space itself expanded. This is the essence of the Hot Big Bang Model, which was a term, incidentally, intended to be an anti-Catholic slur (coined by the authors of the competing Steady State Model). The model of Lemaitre, along with work by Friedmann, Walker, Robertson, and others, became encoded into the Standard Model of Cosmology or the Hot Big Bang Model. This model sat on firm theoretical ground by being coupled with Einstein's General Theory of Relativity. In fact, the FRLW metric (named after Friedmann, Robertson, Lemaitre, and Walker) is the most general solution for four-dimensional space-time in a universe that is homogeneous and isotropic (and which is necessarily expanding or contracting).

The Hot Big Bang Model

The Hot Big Bang Model is deceptive in its simplicity, yet incredibly rich in its descriptive power. It simply states that the early universe was hot and dense, the universe is expanding, and that on large scales the universe is homogeneous and isotropic. There are two primary pillars of observational evidence for the hot big bang model: cosmological abundances of light nuclei and observations of cosmic microwave background radiation. Much more observational evidence exists, of course, but lies beyond the scope of this paper; here I only wish to provide you a sense that the model is well supported by observational data.

Approximately three minutes after the event we call the Big Bang, the universe was cool enough to fuse protons and neutrons into heavier nuclei like deuterium, tritium, helium, lithium, and other light elements. In this process, most of the neutrons present in the early universe were fused along with protons into helium, which is an extremely stable atomic nucleus. Using nothing more than well-known nuclear physics and reaction rates that can be measured in the laboratory, it is possible to predict the elemental abundances of these light elements (all elements heavier than lithium were created in the crucibles of stars and not in the early universe). A generic prediction that emerges is that before the epoch of star formation, the universe should be approximately 75% hydrogen and 25% helium with trace amounts of deuterium, lithium, and isotopes of helium. This is exactly what is seen when observation tests of primordial abundances are carried out (Steigman; Cyburt). This gives cosmologists confidence that we understand the universe 1-3 minutes after the Big Bang (approximately 13 or so billion years ago).

The Cosmic Microwave Background Radiation (called the CMB or CMBR for short) was first detected by Penzias and Wilson in 1964, but was theorized to exist earlier (Penzias and Wilson). After the Big Bang, the universe was a hot, dense plasma of interacting subatomic particles. Nuclei formed one to three minutes after this event, but neutral hydrogen could not form until approximately 300,000 years after the Big Bang. Prior to this point, the universe was still too hot, and radiation would immediately ionize neutral hydrogen if formed. Once neutral atoms were able to form, the universe suddenly became transparent to radiation, and the leftover photons from the Big Bang (created in particle anti-particle annihilations) streamed free. The CMB is this collection of photons (radiation) left over from the hot dense past of the universe, a sort of echo of the past. No other competing cosmological theory in the 20^{th} century could explain the existence of this radiation field, and it is a unique fingerprint of the Hot Big Bang Model.

Problems with the Big Bang Model

Despite the overwhelming observational evidence for the Hot Big Bang Model, several unanswered questions remained and were debated in the 1980s. Four primary issues arose:

1. Why is the universe so old?
2. The Horizon Problem
3. The Monopole Problem
4. Where does the structure in the universe come from?

Let me explain. 1. In the early universe one nanosecond after the Big Bang, it turns out that the difference of one gram per cubic centimeter of density of matter could have tipped the scales and forced the universe to collapse rather than to expand and grow. This incredible dependence on the absolute density of the universe is called the Oldness Problem – why is the universe so old? 2. The Horizon Problem refers to the fact that the Cosmic Microwave Background Radiation appears far too uniform across the sky. Take, for example, two patches one degree in size on opposite sides of the sky. These two patches should never have been in causal contact with each other, and hence their temperature should not be correlated. However, one finds that the CMBR on both patches of sky is exactly 2.73 K. Why? 3. In the early, hot, dense universe there should have been a unification of fundamental forces due to the high energies and temperatures. As the universe expanded and cooled, this unification should have been broken and the grand unified force would have splintered into the four fundamental forces of nature we see today. One generic prediction of such a breaking is the production of particles called super-heavy magnetic monopoles (which would act as a bare north or a bare south magnetic charge). These particles have never been detected, but should have been copiously produced. Where are they? 4. Why is the universe only approximately homogeneous and isotropic and not perfectly so? Where did the seeds of structure formation come from? In other words, why were some regions of the universe overly dense such that they collapsed to form structures like galaxies and clusters?

In 1980, Alan Guth proposed a new mechanism that acted in the early universe: inflation. In inflation, shortly after the Big Bang (at approximately 10^{-35} seconds when the universe was 10^{-60} cm large), the universe went through an exponential growth, eventually inflating by a factor of e^{70}. In an infinitesimal fraction of a second, the universe grew from 10^{-60} cm in size to approximately 1 cm in size. This exponential growth had several interesting effects and solved the problems that many had noticed about the Hot Big Bang Model. 1. The universe expanded so rapidly that collapse was impossible. 2. The entire sky that we see today evolved from one causally connected patch at the time of inflation, so all points on the sky should have the same CMBR temperature. 3. The exponential inflation of the universe washes out the density of super-heavy magnetic monopoles leaving approximately one monopole per observable universe (rather than 1 per 30 m^3). 4. Inflation provides the seeds for structure formation by stretching tiny ripples caused by quantum fluctuations that were the size of nuclei into density fluctuations that were the size of solar systems after inflation.

In order for inflation to occur, the universe must contain matter with negative pressure. Now what does this mean? Well, general relativity tells us that matter and pressure create gravity through the curvature of space-time, so matter with negative pressure will create a sort of "anti-gravity," a cosmic repulsion that will drive the expansion of the universe. With ordinary matter, say a gas, the more you squeeze the gas the higher the pressure gets. With a negative pressure material, the more you compress it the lower the pressure gets, and paradoxically if you let the material expand the pressure increases! This is not all that odd – if you think about it, a rubber band acts like this. I will speak more about a cosmic substance like this (dark energy) when I discuss the eventual fate of the universe. With approximately three times as much repulsion from "anti-gravity" as attraction from regular gravity, one can initiate and maintain an exponential expansion like that which inflation calls for. But where does the energy for this expansion come from? Interestingly enough, it comes from gravity itself in essentially the ultimate Ponzi scheme (Tegmark).

Of course inflation comes with its own set of problems. If the universe exponentially inflated (and washed out any density of magnetic monopoles), then why was the matter and energy density that we see today not washed out/diluted as well? The answer to this question introduces a remarkable concept: eternal inflation. Paul Steinhardt's landmark paper works out the conditions necessary for inflation to occur, continue, and eventually end (Steinhardt and Albrecht). He introduced the idea of the inflaton (a new particle/field) that slowly rolled down a potential (its kinetic energy increased slowly). As long as the kinetic energy component for this field is smaller than the potential energy, the particle exists in a slow-roll state and inflation continues. But once this condition is violated, the energy stored in the inflaton field decays and is transferred to radiation and the universe is re-thermalized. So, what we think of as the Big Bang (a hot, dense state of the early universe), is actually characteristic of a universe exiting from inflation. This re-thermalization of the universe from the decay of the inflaton field is what creates all of the energy and matter density we see today. If not for this process, called reheating, the universe would be cold and empty from seventy e-foldings of expansion.

In 1983 Alex Vilenkin showed that the end of inflation, if inflation ever ends, is itself an interesting question. We know that, at least in our observable universe, inflation ended. However, Vilenken showed that it is possible for inflation to be eternal, i.e. it continues in some regions and stops in others. The basic idea is the following: the negative pressure matter component (perhaps the inflaton) causes exponential expansion. Yet at the same time, this component is decaying, causing some regions to drop out of inflation and undergo reheating. Take, for example, as Max Tegmark does, a scenario where inflation triples the size of the universe per time period while one-third of the inflating substance decays away. I have reproduced Tegmark's figure in a slightly different way below (Figure 3) to get the point across.

In this way, inflation never really ends in the universe – it is always continuing somewhere, and there are always new regions dropping out of inflation through the process of reheating and generating new Big Bangs and new regions of the universe that look like ours. In this way the universe grows to infinite size in a finite period of time. It is also possible, though not currently well-understood, that each of these new regions that burst out of inflation might have different fundamental constants and behave differently based on quantum fluctuations and initial conditions.

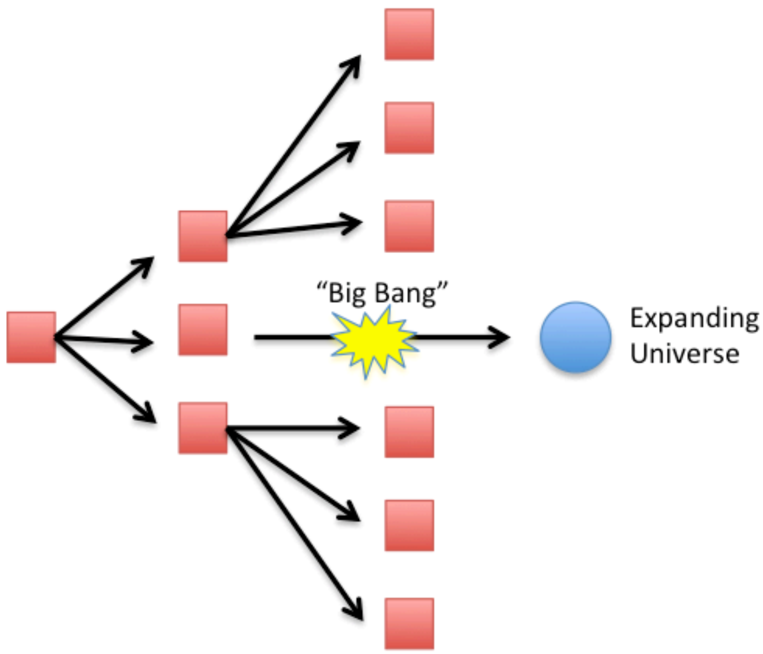

Figure 3: Each cube represents a volume of inflating space that triples in size per unit time. The decay rate of the inflating material is such that one-third of it "decays" producing a "Big Bang." The volume of inflating space is thusly always increasing. In the next time increment, one-third of the new inflating volumes would experience Big Bangs, while the regions that continue inflating would give rise to three new inflating regions (Tegmark).

So if inflation can continue infinitely into the future, can it continue infinitely into the past as well? In other words, can it be possible that the universe we are observing really had no beginning? Within the context of general relativity it seems that the answer is no. In 2003 Arvind Borde, Alan H. Guth, and Alexander Vilenkin used General Relativity to show that it is not possible for inflating universes to be past-eternal; this is now known as the BVG theorem. However, one must be cautious here: general relativity is surely broken at high energies and short distance scales where quantum gravity emerges, and quantum gravity is not yet well understood or formulated. In the same way, we can say we understand the universe extremely well up to a fraction of a second after the Big Bang, but are ignorant of what was before that because of a fundamental non-understanding of physics at these energy scales. A theory of quantum gravity such as string theory might invalidate the BVG theorem. As Vilenkin himself has said,

> If someone asks me whether or not the theorem I proved with Borde and Guth implies that the universe had a beginning, I would say that the short answer is "yes." If you are willing to get into subtleties, then the answer is

> "No, but . . ." So, there are ways to get around having a beginning, but then you are forced to have something nearly as special as a beginning (2010).

As odd as the inflationary universe sounds, new experimental evidence has recently provided a "smoking gun" for inflation. The BICEP2 experiment (*B*ackground *I*maging of *C*osmic *E*xtragalactic *P*olarization telescope at the South Pole) in 2014 recently detected the signature of gravitational waves consistent with inflation in the CMB). The presence of gravitational waves in the early universe (basically ripples in the fabric of space-time) would leave an imprint in the polarization of CMB – "a sort of 'curl' component or rotation that is known as the primordial B-mode polarization" (BICEP2). If true (and the careful analysis of the BICEP2 experimental team is so far holding up), this would provide evidence of the conditions in the early universe 10^{-30} seconds after the Big Bang, and would be one of the most amazing experimental results of the last century. One of the most poignant moments I have seen in science is when BICEP2 collaborators visited Andrei Linde, one of the pioneers of inflationary theory, at his home to give him the news that inflation has been experimentally validated.

To wrap up our consideration of the beginning of things, modern cosmology seems to point out that the creation of the universe is not as simple as envisioned in the Christian doctrine of creation *ex nihilo*. In particular, it seems unlikely that there is only one universe. Does this traditional Christian doctrine need to be reconsidered, and how central to Christianity is it? For example, if confronted with solid, experimental evidence of the existence of multiple-universes (or that our current universe did not have a beginning and instead is eternal) how should Christian theology react? Just as the Catholic Church and many other Christian churches have accepted biological evolution, how can Christian beliefs be reconciled with what the "book of nature" teaches us? This is a large and important question, and a full discussion is beyond the scope of this paper, but I offer one thought. Perhaps we should be thinking more along the lines of process theology, as begun by Alfred North Whitehead, and change our metaphysics to reflect what we know about physics. Perhaps, like the universe, God is changing and evolving and becoming (certainly a radical departure from the way we usually think about God). The notion of God as a continuous creator from process theology certainly seems to describe an eternally inflating universe where new regions undergo Big Bangs infinitely into the future.

Nature of Time

One of my favorite quotes from St. Augustine's *Confessions* is a response to the question of what God was doing before he made Heaven and Earth. Augustine responds, "He was preparing Hells for those who inquire into profundities" (XI, xii). Now, we could interpret Augustine's retort literally, and take the stance that it is not for Catholic scholars to ask these sorts of questions. However, Augustine himself used the modern science of his day (primarily Roman astronomy) as one of his many reasons to break with the Manicheans, and scholars of Augustine such as William Harmless, S.J. have explained to me that this comment is very much tongue-in-cheek. Augustine's point seems to be that we should ask these sorts of questions. So, let us ask them. Why does time exist? Did time exist before the event we call the Big Bang? Why does time seem to move in only one direction (the so-called "arrow of time")? Time is a slippery quantity. Within the *Confessions* Augustine also says, "*quid est ergo tempus? si nemo ex me quaerat scio; si quaerenti explicare velim, nescio*," which translates as "What is time? If you do not ask me, I know. If you ask me, I do not know."

We take time for granted and the classical viewpoint of time is to look at time as some external fixed reference. For example, in Newtonian mechanics, time is a constant for all observers. Velocities and positions are relative (and connected through Galilean transformations), but time is the same for all observers. In 1905, Albert Einstein shattered this paradigm and showed that a consequence of the constancy of the speed of light in all reference frames is the notion that time is a relative quantity. Different observers will measure different times, and in fact even the notion of simultaneity must be abandoned – different observers cannot even agree that an event occurred at the same time. Time, rather than being a fixed, eternal quantity, becomes a variable and part of a deeper structure called space-time. This viewpoint of time continues in Einstein's General Theory of Relativity.

But what is time and why does it only run in one direction? Was there a beginning of time? These questions are not new. Ancient philosophers such as Aristotle and Plato argued and disagreed here. But intriguing physical theories are being offered that are giving us new insights into the meaning of time. For example, John Wheeler and Bryce DeWitt were attempting to find a way to unify general relativity with quantum mechanics. General relativity describes the physics of the very large (stars, galaxies, etc.) while quantum mechanics describes the very small (sub-atomic particles and atoms). Both are well-tested theories that are amazingly accurate, but all attempts to unify them have so far failed. What Wheeler and De-Witt found was a formulation in which quantum mechanics and general relativity seem to unify, but in this formulation all time disappears from the equations. This is, of course, an issue since the universe clearly evolves and we see the passage of time.

In 1983, physicists Donald Page and William Wootters looked at this "problem of time" in another way. Quantum entanglement is a phenomenon where two particles may be separated by space but are still part of a single quantum state and hence "entangled." What Page and Wootters theorized is that entanglement could be used in a sense to measure time, but like many quantum effects, how this is measured makes all the difference. Relative to an external, absolute, fixed-clock system/observer, time would not appear to change for these entangled particles. But internally, if these particles are compared to the rest of the universe in which they exist, an internal observer would see the particles change and evolve and would in fact measure time. As the ArXiv blog puts it,

> This is an elegant and powerful idea. It suggests that time is an emergent phenomenon that comes about because of the nature of entanglement. And it exists only for observers inside the universe. Any god-like observer outside sees a static, unchanging universe, just as the Wheeler-DeWitt equations predict (Page and Wootters).

This is of course a very abstract and theoretical argument. However, in late 2013 an experimental group in Italy showed that quantum systems that were entangled could behave in precisely this way, giving an experimental confirmation of the ideas of DeWitt and Wheeler and of Page and Wootters (Page and Wootters).

Finally, why does time flow in one direction? The short answer is that we simply do not know. Newton's laws and the corrections provided by Einstein work just as well if time runs both forwards and backwards. Some theorize that the arrow of time has to do with entropy, the tendency of systems to increase in disorder. The universe began after the Big Bang in a very low entropy state, and as the universe evolves entropy increases.

But how is the puzzle of the unidirectional flow of time tied to our fundamental question of the origin of the universe? What are the implications to theological thought? It turns out that new, preliminary work done by Barbour, Koslowski, and Mercati proposes a twist to the standard solution to the arrow of time. They propose that "the origin of time's arrow is not necessarily to be sought in initial conditions but rather in the structure of the law which governs the Universe." Time, they propose, actually flows in two directions, although we experience only one. In essence, it casts doubt upon the Big Bang as a cosmic beginning; instead the Big Bang acts as only one phase of the Universe that may be infinitely old. However, this work is very preliminary and does not yet include general relativity or quantum mechanics. However, it is clear that the nature of time remains as one of the unsolved "big questions" in cosmology and physics.

Fate of the Universe

In the classic Hot Big Bang model, the presence of matter in the universe means that due to gravitational interactions the universe should be decelerating in its expansion. Of course, the amount of deceleration depends on the amount of matter in the universe, but cosmologists were so confident in this fact that the acceleration parameter for the Universe was always written with an explicit negative sign (called the deceleration parameter). Cosmologists received a huge shock in the late 1990s when two groups, the High-Z Supernova Search Team and the Supernova Cosmology project, reported that the universe was in fact accelerating in its expansion (Reiss; Perlmutter). In a nutshell, these groups studied distant supernova (explosions of massive stars that can briefly outshine their entire host galaxy), and used them as "standard candles" to estimate distances to their host galaxies. Distances, as it turns out, are notoriously difficult to measure in cosmology; one cannot simply run out the tape measure to a distant galaxy! The supernova results showed evidence that these supernova were dimmer than expected for their given redshift (how much light is stretched by the universe's expansion), and hence the universe had been accelerating rather than decelerating recently.

Before the supernova data of the late 1990s, the fate of the universe was always tied solidly to matter and geometry. Einstein's field equations of General Relativity model the universe on the whole as an isotropic (the same in all directions) and homogeneous (roughly the same at all points) space, and have three possible solutions: 1. Four dimensional space-time could be positively curved (parallel lines meet) and eventually collapse in on itself, 2. Four dimensional space-time could be negatively curved (parallel lines diverge) and expand forever (while always decelerating in that expansion), or 3. Four dimensional space-time could be geometrically flat (parallel lines never meet) and the universe's expansion would asymptotically approach zero at large times. When originally confronted with these solutions (note all of them are dynamic), Einstein, a believer in a static universe, tried inserting a corrective term in his field equations that he called a "cosmological constant." This constant served essentially as a form of "anti-gravity" and balanced the attractive force of gravity so that stationary solutions could be formed. However, when Hubble showed Einstein his evidence for the expanding universe, Einstein removed his cosmological constant and called this endeavor "his greatest blunder."

How can an accelerating universe be explained? It turns out that Einstein's "greatest blunder" may not have been a mistake after all. It turns out that a term very much like Einstein's "cosmological constant" can model an accelerating universe. Here the interpretation of this constant is a bit different, but the mechanics are the same. In this case Einstein's cosmological constant refers to energy intrinsic to space-time itself. As space-time expands, so does the total amount of energy locked in this cosmological constant component. Because this energy acts as a sort of "anti-gravity," once the universe is large enough, it becomes the dominant form of energy in the universe (albeit the actual density of this energy is very low but the universe is very large). This leads to an accelerating expansion of the universe. Cosmologists call this vacuum energy associated with space-time itself "dark energy." Notice that dark energy has very similar properties with the negative pressure matter that caused the universe to undergo inflation; the connection, however, is not well understood.

The connection with theology (in this case eschatology) lies in examining the ultimate fate of the universe. If dark energy remains unchanged (it does not begin to act differently at some distant cosmological epoch), then the universe will simply accelerate faster and faster. There will come a time when all galaxies outside our own cluster will have receded from our view, leaving our universe an empty place. As stars exhaust their supply of nuclear fuel and star forming regions stop producing new stars, our universe will be a cold, dark, empty place. The universe will simply sputter out.

Another frightening possibility, worked out recently by physicists Robert Caldwell, Mark Kamionkowski, and Nevin Weinberg, examines the possibility that dark energy could change form into what they dub "phantom energy." In this scenario, the universal acceleration of the universe becomes so large, that the effective amount of dark energy becomes infinite in a finite time. The amount of dark energy becomes so large that even gravitationally bound systems like galaxies, stars, and planets cannot survive and are torn apart by expansion. Eventually, even atoms are disassociated until the universe as a whole ends in what they have termed the "Big Rip." This is the utter destruction of the universe as we know it.

The notion of a cold, dark, empty universe or a universe that destroys itself in a Big Rip is problematic in light of traditional Christian Eschatology. Of course, there is no single Christian Eschatology. However, many Christian Eschatologies understand the end of the universe as the end of physical existence followed by the creation of some new "heaven." The cold, lonely, empty dark energy dominated universe has no physical end and will continue to expand forever. More traditional Christian Eschatologies see divine intervention in the material and physical world, but again, staged at "the end." Physical cosmology in most scenarios does not predict such an end (aside from the Big Rip scenario which is highly speculative). The best predictions of physical cosmology today predict a universe that continues to accelerate in its expansion forever. Such a fate of the universe seems at odds even with non-traditional thinking like that of process theologians, who see God as continuously creating. Currently, the chief aim of scientific study of dark energy is to determine if it is constant in time or if it in fact changes and evolves. Perhaps such studies will give us clues to the ultimate fate of the universe and banish the pictures of the cold, dark, empty place we saw earlier.

Fundamental Constants and the Anthropic Principle

Although the physical constants of our universe can be measured and tabulated, it is extremely profitable from the viewpoint of theoretical physics to ponder why exactly these constants have the values that they do. For example, the photon (the carrier of the electromagnetic force) has exactly zero mass because it is protected by a U(1) gauge symmetry. Questions such as why is the electron neutrino so much lighter than the electron are unsolved puzzles in high energy particle physics. Similar questions can be asked about other fundamental constants such as the fine structure constant (the strength of the electromagnetic force), the speed of light, etc. Why do these constants have the value that they do? Are they simply assigned their current values by random chance in a multiverse that contains all possibilities? Are the values of the fundamental constants simply accidents caused by quantum fluctuations in a region of inflating space that led to our universe?

Although it is not a scientific principle, the Anthropic Principle continues to fascinate scientists and philosophers. Simply put, the Anthropic Principle states that simply by our very existence, we can say something about the nature of the universe. In other words, the physical conditions of the universe must be compatible with the conscious life that observes it. The Anthropic Principle exists in several formulations:

1. Strong: This formulation was devised by Brandon Carter and presented at the 1973 Krakow Symposium honoring the 500th birthday of Copernicus. It can be summed up as "cogito ergo mundus talis est" or "I think therefore the world is as it is." It is referred to as the strong anthropic principle because it essentially states that the universe *must* have the properties necessary to bring forth intelligent observers.
2. Weak: This formulation comes from John Barrow and Frank Tipler. It essentially states that, yes, we can say something about the universe from the fact that we exist, but there is a selection bias here and the universe in no way *must* be this way.

How is the Anthropic Principle useful? The best (and perhaps only scientific) example of this phenomenon comes from astronomer Fred Hoyle of B^2FH fame (stellar nucleosynthesis). Hoyle reasoned that because we are made primarily of carbon, there must be an efficient mechanism to produce carbon in stars. He postulated the existence of an undiscovered resonance that would allow stars to fuse helium into carbon. Shortly after his prediction, such a resonance was in fact discovered. However, there is some debate among historians of science as to whether or not Hoyle was in fact influenced by the Anthropic Principle or if his prediction was a purely scientific one divorced from anthropic reasoning (Kragh 2010).

Although the Anthropic Principle is not strictly scientific, it can be a good "common sense" principle that leads us to ask interesting questions. Science, of course, must make testable and falsifiable predictions, but there remains the critical issue that we have only one universe to observe. How much of what we see is simply selection bias? But the Anthropic Principle can lead to interesting questions and issues like the following: the universe seems "fine-tuned" for the existence of life. For example, if the strong nuclear force grows too strong, nucleons will bond too easily leaving no hydrogen (and hence no fuel for stars). If the strong nuclear force grows too weak, then heavier elements cannot form and life cannot develop. Another example is the following: stars are a constant battle between outward radiation pressure and the inward gravitational force. If gravity were only a little bit stronger, stars would be smaller and would burn through their nuclear fuel faster, leaving little time for life to develop. If gravity were weaker, stars would be larger and burn more coolly, shrinking drastically the habitable zone in which liquid water might exist on the surface of a planet.

The essential question is have the fundamental physical constants been fine-tuned in such a way that life can develop? Or, as critics of the Anthropic Principle argue, perhaps we exist in a multiverse and in this particular universe the conditions are right for life but not in many others. I am personally skeptical of the multiverse explanation. Consider a set of infinite numbers. One might be sure that the number three is part of this infinite set. How could it not be? The set of numbers is infinite, after all. But what if I told you my infinite set of numbers was the set of all even numbers; this set clearly does not contain three, even if it is infinite. This is essentially the argument of the multiverse: given an infinite set of universes there must be at least one universe that has exactly the right combination of physical constants to allow life to develop. However, as we just discussed, infinity is a tricky thing. I always say that when a physicist or mathematician or philosopher begin arguing with infinities, the best course of action is to slowly back away with one hand on your wallet!

Conclusion

Big questions are not the intrinsic property of science; in fact, the big questions do not belong to any single discipline, and a complete understanding of these questions requires a multi-disciplinary approach. I have tried here to point out areas of current research in modern cosmology in which a theological and/or philosophical approach would be useful. The beginning of the universe, and whether or not there was a beginning, is an active area of cosmological research, and it might be that a rethinking of the Christian doctrine of creation *ex nihilo* is necessary. The fate of the universe, as understood in the paradigm of dark energy, does not seem to match the understanding of Christian eschatology (though nothing is certain about dark energy except for the fact that it exists now). Similarly, the very nature of time and the values of the fundamental constants are an interesting puzzle. It would profit us all to examine these issues through more than one lens, and multi-disciplinary collaboration on these topics is called for.

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It is difficult for a theologian or philosopher to know where to begin when attempting a serious study of contemporary cosmology. Here are a few resources I would suggest. Helge Kragh, a historian of science, has a marvelous book that gives a very thorough account of the development of cosmology from ancient times to today (2007). Robert Spitzer's latest book, *New Proofs for the Existence of God*, studies the new cosmology from a theological and philosophical perspective and may serve as a bridge between the disciplines (although the scientific level of the book itself is high). Alexander Vilenkin has a general-audience level book titled *Many Worlds in One* in which he discusses many of the issues we have raised here (2007). I would also highly recommend any book by science popularizer John Gribbin.

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