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Lecture 3: The mystery of the constants of nature

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At the end of my second lecture, I began to explore the importance of counterfactual thinking for natural theology. This involves the recognition that the world could have been very different from that which we actually experience and know. Counterfactual thinking is an act of imagination – the construction and inhabitation of a world that did and does not exist, as a means of achieving a better understanding of the forces that shape the empirical world. An appeal to the "counterfactual imagination" is widely perceived to be a normal, natural and justified way of thinking. The starting point for counterfactual thinking is the belief that things need not be as they actually are (or have been as they actually were). By conducting "thought experiments", it is possible to construct alternative scenarios, which allow the roles of specific actors, factors and agencies and the generalities of happenstance in bringing about an existing situation to be better understood. What would have happened if Charles I had won the Civil War? If the Confederates had won the American Civil War? If Nazi Germany had defeated the Soviet Union during the Second World War? Or, to consider a more specifically theological issue, what difference would it have made to the religious history and intellectual development of the European church if the young Martin Luther had died – rather than merely been emotionally shaken – when thrown from his horse during the thunderstorm at Storterheim in June 1505? The question allows us to assess the importance of Luther as an individual to the emergence and shaping of the movement that is now retrospectively designated “the Reformation”.

Although counterfactual thinking has increasingly found a role in historical studies, the same is not yet true of the philosophy of science. Indeed, at first sight, it might seem that counterfactual thinking has little role to play in the natural sciences, in that these disciplines focus on the actual, observed world. The key issue concerns the explanation of what is observed, rather than speculation about what might have been observed. However, on reflection, the situation is not quite as straightforward as this naïve empiricism might suggest.

For example, consider the following question: What would have happened if the K-T meteorite had missed the earth? Would life have been very different from what we now know? For those of you who would like me to expand on this question, let me do so: what would have happened if the meteorite which is widely believed to have been responsible for the Cretaceous-Tertiary extinction event 65 million years ago had missed the earth? Would the dinosaurs still be here? More interestingly, would *we*?

Counterfactual thinking offers a highly productive framework for beginning to assess the theological significance of anthropic phenomena. The approaches to anthropic phenomena that have emerged in recent years have emphasised the significance of certain fundamental constants which, if varied slightly, would have significant implications for the emergence of human existence. Examples of canonical statements of the astrophysical “fine tuning” of fundamental cosmological constants include the following:

1. If the strong coupling constant were slightly smaller, hydrogen would be the only element in the universe. Since the evolution of life as we know it is

fundamentally dependent on the chemical properties of carbon, that life could not have come into being without some hydrogen being converted to carbon by fusion. On the other hand, if the strong coupling constant were slightly larger (even by as much as 2%), the hydrogen would have been converted to helium, with the result that no long-lived stars would have been formed. In that such stars are regarded as essential to the emergence of life, such a conversion would have led to life as we know it failing to emerge.

2. If the weak fine constant were slightly smaller, no hydrogen would have formed during the early history of the universe. Consequently, no stars would have been formed. On the other hand, if it was slightly larger, supernovae would have been unable to eject the heavier elements necessary for life. In either case, life as we know it could not have emerged.

3. If the electromagnetic fine structure constant were slightly larger, the stars would not be hot enough to warm planets to a temperature sufficient to maintain life in the form in which we know it. If smaller, the stars would have burned out too quickly to allow life to evolve on these planets.

4. If the gravitational fine structure constant were slightly smaller, stars and planets would not have been able to form, on account of the gravitational constraints necessary for coalescence of their constituent material. If stronger, the stars thus formed would have burned out too quickly to allow the evolution of life.

The important point to appreciate is that each of these four statements is framed *counterfactually*. We are asked to envisage alternative worlds in which these constants have different values, and compare these worlds with that which we actually know. Small variations in any of these constants would have led to very different outcomes. For a theist, the implications of such points are obvious: as John Leslie wryly observed, “God would need to be careful which physics he chose.” Yet at this stage, we are not concerned with offerings explanations of unusual observations – or even considering whether it is possible or necessary to offer any explanation in the first place - but with identifying features of the cosmos which appear to stand out as being significant, in that *they could have been different* – and a very different universe would have emerged as a result. Perhaps most intriguingly of all, there might have been no observers able to reflect on the significance of their observations.

In this lecture, I want to explore something of these observations, and ask what they might mean. The twentieth century saw dramatic changes in our understanding of the origins and development of the universe. Its first two decades were dominated by the assumption that the universe was static. Yet during the 1920s, evidence began to emerge suggesting that the universe was indeed expanding. Up to this point, it had been generally (though not universally) assumed that the nebulae observed in the night sky – such as M31 in Andromeda, or M42 in Orion – were part of the Milky Way, the galaxy within which our solar system was located. On the basis of observations at the newly-constructed 100-inch telescope at Mount Wilson, Edwin Hubble (1883-1953) proposed that these objects were galaxies in their own right, lying far beyond our own. Developing work on the spectral red-shifts of these galaxies, Hubble was able to propose that, the greater the distance between any two galaxies, the greater their relative speed of separation. The universe was expanding, with increasing speed and apparently irreversibly.

It was a difficult idea to accept at the time, as it seemed to suggest that the universe must have evolved from a very dense initial state – in other words, that the universe had a beginning. But this was merely a suggestion, one way of making sense of the observations. Other ways of making sense of astronomical observations were certainly possible. The best known of these was set out in 1948, when Fred Hoyle and others developed a “steady state” theory of the universe, which held that the universe, although expanding, could not be said to have had a beginning. Matter was thus continuously created in order to fill in the voids arising from cosmic expansion.

Opinion began to shift in the 1960s, chiefly on account of the discovery of the cosmic background radiation by Arno Penzias and Robert Wilson at the Bell Laboratories in New Jersey. They were experiencing some difficulties: irrespective of the direction in which they pointed the antenna, they found that they picked up an unwanted and obtrusive background hissing noise which they simply could not eliminate.

It was only a matter of time before the full significance of this irritating background hiss was appreciated. It could be understood as the "afterglow" of a primal cosmic explosion – a hot "big bang" – which had been proposed in 1948 by Ralph Alpher and Robert Herman. This thermal radiation corresponded to photons moving about randomly in space, without any discernible source, at a temperature of 2.7 K. Taken alongside other pieces of evidence, this background radiation served as significant evidence that the universe had a beginning, and caused severe difficulties for the rival "steady state" theory.

Since then, the basic elements of the standard cosmological model have become clarified, and have secured widespread support within the scientific community. Although there remain significant areas of debate, this model is widely agreed to offer the best resonance with observational evidence. The universe is now believed to have originated some 14 billion years ago, and that it has been expanding and cooling ever since. As the universe expanded and cooled, various processes began to take place. In a period of rapid inflation, the universe grew by a factor of 10^{35} in 10^{-32} seconds, from being smaller than a subatomic particle to roughly the size of a grapefruit. As the universe evolved, structure formation on the scale of galaxies emerged out of gravitational growth of small primeval departures from homogeneity. Matter started to form clumps, including stars, allowing the process of nucleosynthesis to take place within stellar cores, leading to the chemical enrichment of the interstellar medium.

An important observation needs to be made at this stage. The “big bang” generated little chemical diversity. The conditions that prevailed in the early universe led to the production of hydrogen (including deuterium), helium, and small amounts of lithium – the three lightest elements. Yet the thermonuclear processes which would lead to the formation of heavier elements could not occur under these conditions. The production of oxygen, magnesium, silicon, iron and sulphur – the chemicals that presently make up 96% of the earth’s mass – could not take place until and unless the vast amount of stellar material coalesced to form stars, which were able to initiate thermonuclear reactions in their cores.

Close examination of the cosmic narrative just outlined suggests that its shape and outcome was determined by some critically important factors. It is clear that there exist certain invariant properties of the natural world and its elementary components which make the gross size and structure of almost all its composite objects inevitable. The size of bodies such as stars and planets are neither random nor the result of any progressive selection process, but simply manifestations of the different strengths of the various forces of nature. We can thus imagine a mental experiment in which someone designs a machine that allows us to vary the values of some of the fundamental properties of the universe – such as the weak nuclear force – and see what would happen (at least theoretically) if they were significantly different from what is actually observed. The term “fine-tuning” is often – and, it must be said, somewhat controversially – used to refer to the often narrow window of possibilities that emerges from such mental experiments. The values of certain fundamental cosmological constants and the character of certain initial conditions of the universe appear to have played a decisive role in bringing about the emergence of a particular kind of universe, within which life is capable of developing. Although the term is clearly supportive of God as “fine-tuner”, I will use it here essentially in a neutral sense, referring simply to the surprisingly restricted range of values that certain fundamental constants must take to bring about the universe with which we are familiar.

Some landmarks along the way should be noted. In 1973 Barry Collins and Steven Hawking pointed out that, out of all the possible values of the physical constants, only a relatively narrow range of initial conditions could give rise to the observed isotropy of the actual universe. A quite extraordinary degree of constraint would have to be imposed on the initial cosmic energy density to give rise to the universe as we know it. They found this result puzzling, in that accepted theories did not offer any explanation for the fact that the universe turned out this way rather than another. Collins and Hawking reasoned along what would now be considered to be anthropic lines in their discussion of the "flatness problem." Basing themselves on the clearly anthropic assumption that galaxies and stars are necessary for life, they argued that a universe beginning with too much gravitational energy would recollapse before it could form stars, and a universe with too little energy would not permit the gravitational condensation of galaxies and stars. Thus, out of many different possible initial values of Ω (the ratio of the actual average density of the universe to the critical density), human life could only have emerged in a universe where the initial value of Ω was almost precisely 1.

A year later, Brandon Carter published a paper in which he introduced the term *anthropic principle*, which he stated in two forms. The *weak* anthropic principle states that "what we can expect to observe must be restricted by the conditions necessary for our presence as observers". The *strong* anthropic principle holds that "the universe (and hence the fundamental parameters on which it depends) must be such as to admit the creation of observers within it at some stage".

These speculative explorations culminated in 1986 with the publication of John Barrow and Frank Tipler's landmark book *The Anthropic Cosmological*

Principle, which propelled the “anthropic principle” from the pages of obscure journals to popular culture. In doing so, it raised many theological questions, including the apologetic value of the “anthropic principle”. Barrow and Tipler provided a comprehensive yet relatively accessible account of the fundamental role played by the constants of nature, and the astonishing great implications of seemingly small variations in their magnitude. *The Anthropic Cosmological Principle* set out the extraordinary, seemingly fortuitous coincidences that appear to have made life possible. Barrow and Tipler went on to present three possible ways of making sense of apparent “fine-tuning” of the world for biological life – the “weak”, “strong” and “final” forms of the principle. Although each of these models was already known within the scientific community, Barrow and Tipler made them intelligible and accessible to a much wider readership. It rapidly became the “Bible of anthropic reasoning” (Robert Klee).

It was, some felt, a risky book for both authors to write. By raising questions about the “design” of the universe, Barrow and Tipler were breaking scientific taboos that might have had a major detrimental impact upon their careers. For example, nearly two hundred pages of their text were devoted to a rigorous exploration of the notion of “purpose” and “design”. Yet the intellectual range and sheer brilliance of their exposition disarmed their critics. The book represents a landmark in the acceptance of “science and religion” as a legitimate, proper, and even necessary adjunct to scientific reflection, prompting some to suggest that it might be the greatest work of natural theology since William Paley. It has catalysed a new debate within Christian apologetics – and beyond – over the evidential basis of faith.

By setting the discussion about design in its proper intellectual framework, Barrow and Tipler challenged the popular secular myth that talk about “design” of the world was a recent innovation, associated with intellectual *arrivistes* such as William Paley. As they rightly pointed out, it is one of the oldest and most fundamental questions of all, deriving its legitimacy partly from its antiquity, and partly from its sheer intellectual importance.

“Aristotelian science was based upon presupposition of an intelligent natural world that functions according to some deliberate design”. The debate may have taken a specific form in the hands of William Paley in the early nineteenth century – yet Paley’s intellectual and theological misadventures, which are clearly specific to his age, cannot be allowed to negate the question of why things are the way they are – or, indeed, why they is anything at all.

Barrow addressed such issues in subsequent writings, making the fair point that two quite different forms of the design argument are used by theologians and philosophers. The first is that which is encountered in the larger, biological, section of Paley’s *Natural Theology*, and is based on “nice outcomes of the laws of nature”. The argument, though easily grasped, is severely vulnerable. God can easily be eliminated from the argument (a development which began long before Darwin published his theory of natural selection.) In my view, it amounts to little more than Deism, positing a somewhat attenuated notion of God, rather than the somewhat richer Trinitarian vision of God associated with Christianity.

Barrow’s second approach is based on “nice laws.” Where do the laws of nature come from? If the universe sprang into existence in an astonishingly short time *already possessing the laws that would govern its development*, the question of the origin and character of those laws becomes of major apologetic importance. As Barrow rightly points out, this latter version of the design argument is much harder to explain without reference to God. After all, the laws of nature clearly did not come into being by a gradual process of cumulative selection. The universe that emerged out of the Big Bang, on an anthropic reading of things, was already governed by laws that were fine-tuned to encourage the rise of carbon-based life forms.

The apparent “fine-tuning” of the universe has been considered in a large number of relatively accessible works, and does not require detailed exegesis in this lecture. For our purposes, it is enough to note several features that are illustrative of this phenomenon, rather than provide a more extended analysis. The debate in the literature mainly concerns the *interpretation* of these phenomena, whose existence is generally conceded. The essential point is that if the values of certain fundamental constants which govern the development of the universe had been slightly different, its evolution would have taken a different course, leading to a cosmos in which life would not have been possible. The element of surprise in this analysis relates to the impact on cosmic evolution of even a small variation of some of these constants.

A canonical statement of the importance of the fine balancing of the fundamental constants of the universe was provided recently by Martin Rees, currently President of the Royal Society. We may summarise his analysis as follows.

1. The ratio of the electromagnetic force to the force of gravity, which can also be expressed in terms of the electrical (Coulomb) force between two protons divided by the gravitational force between them. This measures the strength of the electrical forces that hold atoms together, divided by the force of gravity between them. If this were slightly smaller than its observed value, "only a short-lived miniature universe could exist: no creatures could grow larger than insects, and there would be no time for biological evolution."

2. The strong nuclear force, which defines how firmly atomic nuclei bind together. This force, which has a value of 0.007, "controls the power from the Sun and, more sensitively, how stars transmute hydrogen into all the atoms of the periodic table." Once more, the value of this constant turns out to be of critical importance. If it "were 0.006 or 0.008, we could not exist."

3. The amount of matter in the universe. The cosmic number Ω (omega) is a measure of the amount of material in our universe – such as galaxies, diffuse gas, and so-called "dark matter" and "dark energy". Ω tells us the

relative importance of gravity and expansion energy in the universe. "If this ratio were too high relative to a particular 'critical' value, the universe would have collapsed long ago; had it been too low, no galaxies or stars would have formed. The initial expansion speed seems to have been finely tuned."

4. Cosmic repulsion. In 1998, cosmologists became aware of the importance of cosmic antigravity in controlling the expansion of the universe, and in particular its increasing importance as our universe becomes ever darker and emptier. "Fortunately for us (and very surprisingly to theorists), λ is very small. Otherwise its effect would have stopped galaxies and stars from forming, and cosmic evolution would have been stifled before it could even begin."

5. The ratio of the gravitational binding force to rest-mass energy, ***Q*** is of fundamental importance in determining the "texture" of the universe. "If ***Q*** were smaller, the universe would be inert and structureless; if ***Q*** were much larger, it would be a violent place, in which no stars or solar systems could survive, dominated by vast black holes."

6. The number of spatial dimensions, ***D***, which is three. String theory argues that, of the 10 or 11 original dimensions at the origins of the universe, all but three were compactified. Time, of course, is to be treated as a fourth dimension. "Life", Rees comments, "couldn't exist if ***D*** were two or four."

These six points can easily be expanded to include a series of observations about the values of fundamental constants, or the initial boundary conditions of the universe. As Freeman Dyson once remarked, "the more I examine the universe and study the details of its architecture, the more evidence I find that the universe in some sense must have known that we were coming."

So how are we to assess these new developments in cosmology, which are clearly of considerable theological significance? Though there are dissenting voices, it is widely agreed that the “new cosmology” is consonant with theism. Some would go further, and argue that the phenomenon of fine-tuning gives new life to more rigorous forms of inductive or deductive argumentation for the existence of God, such as the teleological and cosmological arguments. The realization that the universe as a whole, and not simply life on earth, has a history has major implications for our understanding of the emergence of life, often ignored in biological works. For example, many accounts of biological evolution often seem to assume that it is utterly unproblematic, and perhaps even uninteresting, that the critical chemical materials required for life are present in the universe, with physical properties that facilitate both the emergence and development of living forms.

For the issue of fine-tuning is no longer being limited to a discussion of cosmology. Since about 1990, there has been growing awareness that other scientific disciplines are generating material that is open to a similar interpretation. In particular, there has been a growing realization of the interconnections between certain fundamental principles of biology and astrophysics. As we have already seen, the early universe produced nearly nothing other than hydrogen and helium, yet biochemistry requires and uses almost all of the chemically active, reasonably abundant elements in the upper half of the periodic table. The time required to manufacture abundant biological elements and stars with earthlike planets is determined by the formation and evolution times of galaxies and stellar populations, setting a minimum age of billions of years. It is widely believed that the origins of life require the formation of small planet-like bodies, with chemistries and surface temperatures that are capable of supporting living organisms. The earth is believed to have been formed by a process of accretion from the solar nebula, leading to a series of defining characteristics – such as its chemical composition, atmosphere, and distance from the sun – which made it suitable for life. The significance of these observations is a matter of intense discussion at present.

The main point to make is that biochemically critical elements such as carbon, nitrogen and oxygen did not form, and could not have formed, in the early history of the universe. Their existence is the consequence of the "clumping" or "accretion" of material into stars, with the subsequent initiation of nuclear fusion reactions. The ratio of the gravitational binding force to rest-mass energy is such that it permitted the gradual "clumping" of material into larger bodies – the stars. Stars form as a result of turbulence in giant clouds of matter within the tenuous interstellar medium. All the heavier elements of the universe, from carbon upwards, are believed to be the result of nuclear fusion within stars, and not to be a direct outcome of the primordial fireball. Without the formation of stars, the universe would have been limited to hydrogen and helium, with only a tiny percentage of other elements, such as lithium and beryllium.

The nucleosynthesis of carbon, nitrogen and oxygen must therefore be regarded as essential to the emergence of life. The formation of carbon requires the fusion of three helium nuclei (or alpha-particles), through a two-fold process involving beryllium as an intermediate.

$$^{4}He + ^{4}He \rightarrow ^{8}Be$$

$$^{8}Be + ^{4}He \rightarrow ^{12}C$$

This fusion process occurs rapidly only at temperatures above 10^{8} K and in stellar interiors having a high helium abundance. The probability of such a double fusion is very low, as ^{8}Be is a very unstable nucleus, with a half-life of 10^{-17} seconds. This could lead to a "beryllium bottleneck", preventing the production of heavier nuclei, including oxygen, which would result from the fusion with a further helium nucleus:

$$^{12}C + ^{4}He \rightarrow ^{16}O$$

Yet if all the ^{12}C was converted to ^{16}O, carbon would not be produced in sufficient quantities to allow for the emergence of life.

In what is recognizably an anthropic argument, Fred Hoyle argued during the 1950s that there had to be a yet undiscovered aspect of the nuclear chemistry of carbon that would allow the production of carbon and oxygen in comparable biophilic quantities. The only way this critically important carbon-forming reaction could occur more rapidly if there is a excited 0^+ state in ^{12}C just about the threshold at 7.65 MeV that would make a resonance reaction possible. This mechanism was subsequently discovered by William Fowler, who investigated the matter at Hoyle's request. It also turned out that a resonance reaction did *not* take place in the case of the ^{16}O level at 7.12 MeV, since this is just below the combined energies of ^{12}C and ^{4}He at 7.19 MeV. The resonance level which assisted the formation of ^{12}C thus did not exist in the case of ^{16}O, preventing the immediate conversion of carbon to oxygen through alpha-capture. In a later reflection, Hoyle mused about the theological implications of this remarkable observation:

> From 1953 onward, Willy Fowler and I have always been intrigued by the remarkable relation of the 7.65 Mev energy level in the nucleus of ^{12}C to the 7.12 Mev level in ^{16}O. If you wanted to produce carbon and oxygen in roughly equal quantities by stellar nucleosynthesis, these are the two levels you would have to fix, and your fixing would have to be just where these levels are actually found to be. Another put-up job? Following the above argument, I am inclined to think so. A common sense interpretation of the facts suggests that a superintellect has monkeyed with physics, as well as with chemistry and biology, and that there are no blind forces worth speaking about in nature.

The origins of life are thus unquestionably anthropic. They depend upon the fundamental values of constants of nature being such that the universe is able to progress beyond the formation of atomic hydrogen, and bring about the nucleosynthesis of biologically critical elements. Had they been otherwise, this process might never have begun. No life forms are known that are based solely upon hydrogen, helium, or lithium – the three lightest elements, all of which were created in the primordial big bang. The big bang, in itself and of itself, was not capable of producing carbon, nitrogen or oxygen. Stellar nucleosynthesis is required, which in turn depends upon the clumping of matter after the "big bang" to form stars. The formation of stars depends upon the value of the gravitational constant, which is regularly cited as an example of fine-tuning. Similarly, the strong nuclear force, whose value is 0.007, defines how firmly atomic nuclei bind together and hence the extent to which stars can transmute hydrogen into atoms of the heavier elements. Its value is of critical importance if nucleosynthesis is to take place in stellar interiors. As Martin Rees points out, “if the strong nuclear force were 0.006 or 0.008, we could not exist.” It is thus beyond reasonable doubt that the origins of life depend upon the fundamental constants of the universe.

So how are these observations to be explained? For the theist, unsurprisingly, these observations point to the inherent potentiality with which the Creator has endowed creation. The relatively recent and unexpected discovery of anthropic phenomena has led to considerable discomfort on the part of some cosmologists, who are uneasy that a new lease of life has been given to discussion of apparent design in the cosmos. This has led to intense discussion of possible explanations of these observations, sometimes driven as much by the hope of eliminating the new styles of natural theology that have emerged in recent years as by the yearning to understand the cosmos better.

It is quite clear that anthropic phenomena fit easily and naturally into a theistic framework, especially its Trinitarian forms. Theologians do not hold that the Christian doctrine of God allows us to predict the specifics of the universe; the general view has always been that, since God made the cosmos with no constraining influences other than the divine will and nature, it could have been created in a variety of manners. René Descartes (1596-1650) thus argued that we must use empirical evidence to determine the structure of the world. There is no question of predicting the form of the world on theological grounds; rather, the form of the world is a contingency which is to be determined empirically, and then shown to be consistent with the known will of God.

The observation of anthropic phenomena is thus situated within a long tradition of theological and metaphysical reflection on *theologia naturalis*. It holds that the general phenomenon of fine-tuning is consonant with Christian belief in a creator God, arguing that the nature of things is such that the most appropriate outcome for a natural theology is to demonstrate that observation of the natural world furnishes conceptual resonance with, not deductive proof of, the Christian vision of God. On this approach, theism offers the best "empirical fit" of the various theories which set out to account for anthropic phenomena. Yet it must be emphasised that Christian theology has never seen itself as charged with the task of inventing an explanation for these observations; rather, they fit within, and resonate with, an *existing* way of thinking, which proves capable of satisfactorily incorporating such observations.

God, then, unquestionably represents a plausible explanation of anthropic phenomena. But is this the *best* explanation? Alternative perspectives certainly exist, even if they are generally of very recent origin. For example, some argue that apparent cosmic fine-tuning is nothing more an interesting happenstance. The fundamental constants in question had to have *some* value – so why not these ones? They need possess no further significance. To give an example: the population of the United States of America is 300 million. There is only one president. The odds of any one American becoming president are thus one in three hundred million. But so what? Someone has to be president. It may be highly improbable that any given individual should be president, but it is a certainty that someone will be. At one level, it is impossible to refute this argument. Yet it is clearly inadequate to account for the actualization of a highly improbable scenario – namely, the emergence of a universe adapted for life.

A second, and much more significant, approach argues that anthropic phenomena appear significant only on account of the bias or location of the observer. Nick Bostrom, for example, argues that any special features of the universe which we might observe are ultimately illusory, a necessary consequence of our restricted viewpoint. Since we could not exist in other situations (for example, those in which there is no resonance in ^{12}C nucleus, enabling formation of elements heavier than helium), we will not observe these places, no matter how real and common they are. Bostrom thus argues that the central error of much anthropic thinking concerns a failure to appreciate that it represents nothing other than an *observational selection effect*.

A third approach has generated considerable interest – the multiverse. On this view, there exists a multiplicity of universes, so that the one we inhabit is an inevitability. We happen to live in a universe with these biologically-friendly properties; we do not observe other universes, where these conditions do not pertain. Our insights are restricted by observation selection effects, which means that our location within a biophilic universe inclines us to propose that the entire cosmos possesses such properties, when in fact other universes will exist which are inimical to life. Indeed, such biophobic universes are predicted to be the norm. We happen to exist in an exceptional universe.

On this model, the observable universe is therefore to be conceived as a miniscule region or "bubble" within this vast spatial structure, consisting of multiple universes. This "multiverse" consists of a vast ensemble of existent universes, in different spatial domains of varying sizes and structures. Within each domain, the constants of nature could take on distinct values as a consequence of the different ways that inflation begins and ends in that cosmic region. Current interpretations of string theory suggest that the multiverse may consist of as many as 10^{500} sets of constants. In most of these domains, the set of values inherited would be expected to be biophobic. However, on probabilistic grounds, there will be some region in which the set of values are biophilic. We happen to live in one such universe. It may be fine-tuned for life. But what of the 10^{500} others? That's a *lot*.

It is important to appreciate that at present the multiverse hypothesis remains little more than a fascinating yet highly speculative mathematical exercise. It has, perhaps unwisely, been adopted by atheists anxious to undermine the potential theological significance of fine-tuning in the universe. Thus part of the attraction of the multiverse hypothesis to atheist physicists such as Steven Weinberg and Leonard Susskind seems to be that it appears to avoid any inference of design or divinity. In fact, however, it seems that substantially the same arguments can be brought to bear for the existence of God in the case of a multiverse as in that of a universe, with the multiverse hypothesis being consistent with, not the intellectual defeater of, a theistic understanding of God. Yet the multiverse, at the time of writing, remains a speculative scientific theory, raising some difficulties in its own right, suggesting that a more detailed theological response should await further clarification of its status within the scientific community.

Now clearly I have done nothing more than to sketch a framework within which our quest for the "best explanation" of these phenomena could be set. Yet before beginning to explore how we might arrive at this "best explanation" of what is observed, we need to expand our discussion of fine-tuning in the natural world. I have already hinted at the importance of considering anthropic phenomena beyond the realm of cosmology. In the next lecture, I want to begin to explore the growing evidence that other fields – especially bioinorganic chemistry and biochemistry – also exhibit anthropic characteristics. So what are these characteristics, and what is their significance? I hope you will join me on Thursday, as we explore these questions.

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