

Five Theocosmic Puzzles

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Cosmology is one of those branches of science that continually intertwines with the philosophical. It relies on metaphysical considerations for interpretation of its data, while simultaneously providing new constraints and new possibilities for those same considerations.

Such metaphysical considerations will inevitably involve theological reflection, since the study of the universe as a whole cannot help avoid questions associated with its particularity, its development, its origin, and ultimately, of its Originator. It is the nature of the subject to raise such questions, both directly and indirectly. This is one branch of science that cannot help influencing and being influenced by extra-scientific considerations, at least if one wishes to be intellectually honest.

Here I wish to present five conundrums raised by recent cosmological research. I have given each a title that classifies the issue involved: Boundaries, Selection, Direction, Quantization, and Life. Each of these has a distinctly theological character, as I hope will become clear from what is presented below. While some of the issues presented here have been given attention from a theological perspective before, there are some fairly recent developments that should move the discussion forward in new directions. My purpose here is to outline the issues involved and raise some of the questions, as opposed to providing a resolution to them.

Boundaries

Boundary conditions are an inevitable part of every scientific problem. In order to make progress in any experiment, any observation, or any theory it is necessary to specify the conditions governing the starting point (and implicitly the endpoint) of the endeavour. Which equipment was used in which particular arrangement? How much data was collected? What information is needed to solve the differential equations posited by the theory in question?

When it comes to cosmology, the issue of boundaries becomes particularly intriguing, since the subject under consideration is the entire universe. Of course cosmological boundary conditions can be accepted provisionally, and the subsequent science carried out¹. However this provisional acceptance ultimately must give way to pondering of deeper questions. What boundary conditions should be set? Indeed, should there be any boundary conditions at all? Should

not a proper and complete cosmological theory furnish its own boundary conditions?

These problems came into clear focus a little more than 25 years ago, as the Big-bang theory of cosmology² became generally accepted by the scientific community as the most effective paradigm describing the cosmos. Supported by its three main empirical pillars of galactic redshift³, uniformity of cosmic microwave background radiation⁴ and the interstellar abundance of light elements⁵, the Big-bang theory has shown that metaphysical considerations concerning the origin of the universe can be given quantifiable scientific referents. Its repeated observational confirmation has forced scientists to come to grips with the puzzle of boundary conditions, both conceptually and quantifiably, since the model unambiguously suggests that the universe had a beginning, now known to be (13.7 ± 0.2) billion years ago⁶. This is a truly remarkable discovery. Could there truly be an origin of time, a point beyond which causality breaks down?

The philosophical and theological ramifications of this discovery are still being absorbed⁷. What measure of significance should be attached to a cosmic beginning? Superficially this resonates quite well with the version of creation as revealed in the Abrahamic faiths⁸. Furthermore, if there is indeed a cosmic beginning, then it is not a creation of matter/energy within space at a particular time, but rather is a creation of space and time as well of energy. To ask what happened 15 billion years ago is quite literally a meaningless question if the big bang can indeed be understood as a beginning.

However most cosmologists – and indeed physicists in general -- take a rather different view, eschewing this initial boundary in favour of a more complete theory. There are several reasons for this. First, one might argue if the laws of physics "began" at the big bang, then there is no physics prior to that point, and so the laws of nature break down. But if they break down at some point in time, why do they not break down at other points in time (and possibly space)? Furthermore, to accept such a boundary condition is tantamount to stating that the universe is the way it is because it began in a particular state. This is generally regarded as not explaining much of anything at all – one is left with the question of why that state and not some other⁹.

However perhaps the strongest reason why cosmologists persist in entertaining what happened before the big bang is that to do otherwise is to admit defeat. A boundary condition at the big bang is viewed as a "science stopper" -- there is simply nothing more for science to do if this condition is accepted at any more than a provisional level. For this reason cosmic boundary conditions are not something that cosmologists have been happy to accommodate, and a fair amount of effort is being expended to seek a way out.

This is truly an instance where physics and metaphysics indissolubly blend

together. By definition all such theoretical efforts are describing places and times that are not accessible empirically -- they are out of our causal reach. One metaphysical escape route is that of eternity -- a cosmos of change can avoid a beginning by being perpetually reincarnated in some manner¹⁰. The big bang becomes a big bounce, one of infinitely many that preceded it and one of infinitely many still to come. These scenarios can either be cyclic or chaotic in nature, but the result is the same: there is neither a temporal beginning nor a temporal end to the universe. The eternal inflation models of Linde¹¹ are good examples of this. The other escape route is that of elimination -- providing a framework in which the temporal boundary dissolves, much in the same way that the endpoints of a line vanish when glued together to form a circle. The most famous version of this is "no-boundary" proposal of Hawking¹², of which more shall be said below.

It should be pointed out that pretty much all such scenarios involve giving up one of the sacred principles of known physics, typically either the positivity of energy or the locality of physical law (the notion that action-at-a-distance does not take place) or both. The least painful way of doing so is via some quantum-mechanical means, but there are other mechanisms as well¹³. Cosmological pragmatists would say that the end justifies the means. Cosmological optimists would stress that the ideal model would be one that cured the singularity affliction of the big bang model in a manner that yielded some observational imprint in our universe, and that such a model is conceivably within conceptual reach.

It seems germane to ask serious questions regarding these cosmological endeavours. Are such explanations an improvement? If so, how? Under what conditions -- if any -- will science accept an origin of the universe? Is there truly an origin of time? What would count as evidence in favour or against? What role should metaphysical considerations play? What role should theological considerations play?

There are other boundary issues raised by cosmology, namely that of space and that of energy. The former yields the familiar problem of what to make of an edge to space -- if it has one, what lies beyond? There are two ways to address this issue. One is to assume that space is topologically closed -- like the surface of the earth, or a doughnut, space would have no boundary but would be finite in size. In principle such a universe can leave an observational signature¹⁴. The other is to assume that the universe is infinite in its spatial extent. This latter view presents us with a different theocosmic puzzle as we shall see below¹⁵.

The problem of energy has received considerably less attention. Does the universe indeed have an energy budget? The law of conservation of energy -- perhaps the most sacred of all physical principles -- suggests that the answer is yes. One of the most perplexing results in modern cosmology is connected with the distribution of energy in the observable universe. The interpretive consensus -- increasingly buttressed by ever more precise observations -- is that the normal

matter of everyday experience (ie that described by the Periodic Table) is only 4% of the total. Another 22% consists of dark matter, which is known to gravitate in a manner similar to ordinary matter, but which is not luminous and apparently shares no other characteristics in common with ordinary matter. The remaining 74% percent of the energy budget is called dark energy, whose only known characteristic is that it anti-gravitates, causing a large-scale acceleration of the universe¹⁶. A cosmological constant is a form of dark energy that is constant everywhere in space and time, but the features of dark energy are not well-enough understood to conclude that it is indeed a cosmological constant (though observational evidence continues to point in that direction^{6,16}).

Theologians have tended to pay little attention to the energy balance in the universe, but surely it merits some form of theological contemplation. Normal matter has become special rather than typical – could there be anthropic effects associated with this situation? Furthermore, should the dark energy be either a cosmological constant or something else that does not decay in time, then the ultimate fate of the universe is that of a cosmic whimper, an expansion into a dilute nothingness in which no form of life can survive. Surely this is a cause for more specific eschatological reflection¹⁷.

Is the problem of boundary conditions one that is exclusively under the aegis of science? Or is this a problem that merits the employ of theological resources?

Selection

One of the remarkable features of our universe to have come to light in the last 50 years are its strong biophilic selection effects. While scientists might regard our cosmos as a typical specimen of all logically admissible cosmos, it is now quite clear that this is not the case. It is known that the conditions for life as we know are very special, sensitively dependent upon the values of a large number of constants of nature whose empirical values superficially appear irrelevant. Examples include the particle/antiparticle ratio, the relative masses of the proton and neutron. and the fine structure constant (the dimensionless strength of the electromagnetic force). Small changes -- typically less than one percent -- in any one of these parameters would make our universe inhospitable to life as we know it.

This situation concerning biophilic selection effects is more commonly known as the Anthropic Principle¹⁸, a subject of much controversy in modern physics. In its simplest form the Anthropic Principle states that the only kinds of universes we can observe are those that permit our kind of life to exist. This much is fine. What is puzzling is the strong selection effects noted above. It is not a-priori obvious that they had to exist. Initially one might expect that the existence of life as we know it would be highly robust to large relative changes in the fundamental

constants of nature. Indeed there would be no controversy if this were the case. But it is not the case, and ours is the first civilization in history to appreciate this fact. The question -- for theology, philosophy, and science -- is what we make of it.

One response is to conjecture that life can take on forms very different from that which we know. Perhaps such "other-life" is very robust under changes in the constants of nature, in which case our universe would indeed be a typical member of a set. Certainly the discovery of such novel forms of life -- a situation for which there is not a scrap of empirical evidence -- would be truly revolutionary. However it would only modify the form of the puzzle of biophilic selection and not its essential content. We would still be left with the question as to why our particular form of carbon-based life is so special. Our universe would still not be a typical universe in that it supported this rather unusual type of life¹⁹.

Theologically it is tempting to regard these selection effects as being the result of a choice made by an extranatural superintelligence out of the vast range of available possibilities. Much in the same way that being dealt a set of 29-hands of cribbage three times in a row might lead a person to guess that the dealer had stacked the deck, the biophilic selection effects are the result of a Selector that has made a particular choice. Superficially this is a very tempting possibility. However it is only a first step on a theological journey, for it leaves unanswered the question as to how such a selection is instantiated into the universe that we know. What, if any, are the philosophical and theological constraints on this instantiation? Is this indeed a question that can be philosophically addressed? Is it a question about which science can have anything to say?

A scientific response to the question of selection effects involves arguments of either chance or necessity. The latter alternative is generally regarded as the more attractive option. The idea would be that some fundamental theory of physics would explain the values of the observed constants of nature from considerations of symmetry and dynamics alone, relying on the smallest number of input parameters possible (ideally one or zero). This was the original hope of string theory 20 years ago, following a moderately long tradition of such thinking in particle physics. String theory aspires to be the fundamental theory of everything, uniting all forces and particles into a single comprehensive whole. In this context the constants of nature would have the values we observe because the (presumably unique) fundamental theory of everything makes no sense otherwise. Such a view -- while often regarded as atheistic by its protagonists -- in fact has strong monotheistic resonance. God's blueprint for the universe -- what physicists would call the theory of everything -- would contain the seeds of life.

An alternate explanation is that of chance -- the constants of nature have the values that they do for statistical reasons¹⁹. A person playing cribbage for thousands of years might expect a set of 29-hands three times in a row, simply

because they had been playing for so long they eventually must get dealt this unlikely combination. Much in the same way, if most (if not all) members of the set of possible universes are actually physically instantiated (ie they exist somewhere and/or somewhen), then even the rare members of the set must exist, our universe included. If there are many repetitions of the physical processes that gave rise to our universe and those like it, then with enough repetitions the universe we observe with its particular biophilic selection effects must occur. Hence biophilic selection could possibly be explained by making our universe a small part of a much larger multiverse, in which the observed constants of nature are just part and parcel of our local multiverse environment²⁰.

This seemingly rather strange explanation is gaining more and more acceptance within the scientific community today²¹, though not without resistance. There are several reasons for this. One is that an enormous amount of effort has been expended in computing the constants of nature from first principles without any appreciable success. Indeed, while the existence of life sensitively depends on some constants of nature, there are other constants with seemingly arbitrary values whose alteration would apparently have no effect on the existence of life whatsoever. Examples would include the masses of the heavy quarks. The second reason is that string theory -- rather than singling out a unique vacuum state that would presumably describe our low-energy universe -- instead has been shown to have well over 10^{500} possible vacuum states²². There is nothing in the theory that indicates preference for any one of these states over any other, though conservative voices claim that non-perturbative effects might play a role here. Third, recent cosmological evidence from WMAP is suggestively supportive⁶ of cosmic inflation, the idea that our observable universe underwent a very rapid expansion early in its history²³. The purpose of cosmic inflation was to reduce (ideally eliminate) sensitive dependence of our universe's development on initial conditions (as noted above). It naturally (but not necessarily) suggests that our observable universe is a small part of a much larger structure, ie a multiverse.

Many scientists -- indeed the majority -- have felt that recourse to a statistical explanation for the anthropic principle is less than satisfactory. It means giving up on theories that can be tested by experiment in favour of those that can't, at least in any direct way. Furthermore it seems to be a violation of Occam's principle in the worst possible way, since it posits the existence of an unbounded well of unobservable resources to explain what is proportionately a very small effect. Yet more and more scientists are accepting the multiverse as the least possible evil.

Our biophilic corner of the multiverse is simply a small part of a much larger structure that is hostile to life, and the observed selection effects are explained on statistical grounds. So the argument goes. Unfortunately this cure may be worse than the disease. For if a multiverse can support one biophilic region, why not two? Indeed why not many? Why not infinitely many? If the laws of physics

permit life to occur somewhere, then what prevents this occurrence from being infinitely repeated?

This infinite replication paradox¹⁵ is an endemic problem with the multiverse: once you start making biophilic regions you can't stop, at least in a multiverse with no constraints other than logical consistency. Our universe has been repeated infinitely many times, either in space, in time or both. Furthermore, all of its nearby variants undergo similar infinite repetition. Anything that can happen, does happen, and infinitely often at that.

It seems to me that this concept is theologically toxic. While one could certainly argue that God could create all logically admissible things, it is quite another story to contend that this is what happened. To be creative is to make choices from a range of alternatives. Is a god that created a multiverse a god worth believing in? A God of love and justice that permits evil seems to me far more preferable to a god that permits all things to exist. It is the ultimate in purposelessness²⁴.

It may also be the ultimate in scientific impotence, since any experiment yields all possible outcomes that are logically possible²⁴. If we take a multiverse seriously, what job is it that science is performing for us? If it is to provide us with information about our particular corner of the multiverse, then why make use of scientific arguments to infer the existence of a multiverse? What epistemically efficacious function does the multiverse perform?

Clearly there is some philosophical work to do here. One is in need of placing constraints on the multiverse to prevent the situations described above. However it is not clear what constraints these should be, and what criteria should be employed to judge their relative merits. Indeed, it would not be surprising if the metaphysical criteria employed were split along theological lines.

The puzzle of biophilic selection is one that raises fascinating meta-questions, ones that merge science, philosophy and theology. It is a hope of the science/faith dialogue that progress might be made in addressing these questions.

Direction

Our most everyday experience – that of the passage of time – is one of the least understood cosmic phenomena. It is clear – from sociology, psychology, biology, physics, and cosmology – that there is a direction of time. The thumbprint of this phenomenon is the cosmic expansion of the universe.

A moment's consideration is enough to indicate that this need not be so. The cosmos could have been a static unchanging place, and indeed was thought to

be so by the ancients. It could also have been a place of directionless change, with galaxies move randomly toward and away from one another. While an arrow of time is certainly compatible with a beginning of time, the two need not be connected. Random change need have no temporal origin, and a cosmos with a temporal origin could easily have settled into a steady state.

For many cosmologists time's arrow is a troubling annoyance, in large part because the laws of nature are time-reversible at microscopic scales²⁵. An arrow of time necessitates that the past is in a different state from the future, raising the question of the origin of that state as opposed to some other. A key problem is that the entropy of our observable universe is about 33 orders of magnitude smaller than it could be on general thermodynamic grounds (ie if all matter in the universe were in one black hole). Factoring in a rather generous estimate of the number of black holes in the universe reduces this discrepancy to about 22 orders of magnitude, still a very large discrepancy. The entropy of our universe is evidently quite tiny, and seems to have evolved from an era where it was significantly smaller since there were few (or no?) black holes in the early universe. An increase in entropy is correlated with an increase in time (that is the 2nd law of thermodynamics) but this leaves unanswered the question as to why our universe began in a state of such low entropy.

Returning to the question raised earlier, is this a natural state for the universe? If so, one might invoke a "double-standard principle" – anything that is purportedly natural about an initial condition should also be natural for a final condition for a given physical system²⁶. From this perspective the conventional big-bang model is unnatural since it implies our universe began in an extremely homogeneous configuration, a state we would not expect it to be in should it recollapse in the distant future. Various proposals have been made to comply with the philosophy of the double-standard principle²⁵, by either invoking the same boundary conditions for the final state of our universe as for the initial state (so that entropy would increase for a time, reach a maximum, and then decrease in the future), or by embedding our universe in a much larger multiverse so that it is statistically time-symmetric (with our observable universe being a statistical fluctuation in the ensemble. Observationally the former approach appears not to be in accord with current observations of an accelerating cosmic expansion, whereas the latter approach must carry with it all of the difficulties associated with a multiverse explanation for things²⁴.

At a deeper level it is desirable to know whether a cosmic arrow of time is reflective of some telic process. This view would be in accord with accepting that the initial low-entropy state for our universe is indeed unnatural. An arrow of time is quite congenial to a theological outlook reliant on a God of process²⁷. It is very tempting to regard the arrow of time as evidence that the universe is "going somewhere", particularly when one takes into account the emergence of conscious beings such as ourselves within it. The experience that each of us has as causally efficacious agents within some limited sphere of influence is a

fact of existence that demands some form of explanation. The relationship between this small-scale arrow of time with the cosmic arrow of time remains scientifically unclear. Theological resources can perhaps bring a deeper level of insight here²⁸. The universe can be understood to be a place of fruitful development, with increasingly more novel structures emerging as time marches on. The past really does seem to be different from the future.

Yet before getting too theologically comfortable, it is important to reckon with the implications of the energy budget for the universe noted above. The dark energy of the universe implies a very bleak future over long cosmic time scales. If the ratio of its pressure to its energy density (a parameter known as w) is negative and less than unity, then the cosmos is almost certainly doomed to accelerate to a heat death. However if this ratio is greater than unity then the outlook is even more bizarre. A cosmic singularity – popularly known as the “big rip” – will literally tear the universe apart at some finite time in the future¹⁶. All bound states – galaxies, stars, planets, atoms -- will ultimately be fodder for this cosmic paper shredder, with the largest structures coming apart first²⁹. Eventually space and time will cease to exist³⁰.

The big-rip scenario can only be realized if the positivity of energy is not satisfied on cosmic scales (technically the dominant energy condition is not satisfied). This causes profound predictability problems for general relativity, and as a consequence there are those that believe observational confirmation that $w < -1$ is a signal that qualitatively new physics governs the universe at large scales, such as the presence of extra dimensions of space.

The arrow of time and its itinerant cosmological conundrums should be of increasing interest in the dialogue between science and theology. By implication it raises the question as to whether or not there is a telic character to the cosmos, for a cosmos with no large-scale distinction between past and future is difficult (or perhaps impossible) to understand as a creation. To the extent that science can shed some light on this issue, the dialogue is enriched.

Quantization

It is abundantly clear that ours is a quantum universe³¹, one in which strict determinism has had to give way to a somewhat more flexible probabilistic understanding of causation. Specification of the initial state of a system will yield in classical physics a completely predictable evolution for this system (provided all known boundary effects are taken into account), whereas in quantum physics, only the probability that it will undergo a given evolution can be calculated. All attempts at ferreting out a deeper underlying structure to quantum mechanics

have so far shown that quantum theory is quite robust, despite its highly counterintuitive features, such as wave-particle duality, contextuality, and entanglement.

Some 20 years ago physicists began seriously considering applying quantum mechanics to the universe as a whole, and the subject of what is now known as quantum cosmology came into being³². The driving intellectual idea behind this subject is that the creation of our universe is the result of some kind of quantum fluctuation from some primordial state. Briefly it works as follows. One can understand the evolution of our universe to be that of a (3-dimensional) space that is changing in time; it is well-known that the equations of general relativity can be cast into this form. The relevant physical quantity is then space itself. Retrodicting from current conditions, it is clear that space was considerably “smaller” in the distant past than it is now; technically one says that the cosmic scale factor decreases as one moves to the past. Quantum cosmology posits that quantum gravitational effects – whatever their correct theoretical formulation – will be able to produce space (technically a spatial geometry) in a manner analogous to the way that a strong enough electric field can quantum-mechanically produce a particle-antiparticle pair.

But what is the analogue of the strong electric field in quantum cosmology? Originally it was a spatial geometry of 4 dimensions, whose boundary was the beginning of our three-dimensional space³³. Think of a sphere sliced in half – its 1-dimensional circular boundary is the analogue of our 3-dimensional universe at its creation, after which point the classical equations of cosmology take over and this space expands. Black holes can be produced in the early universe via a similar mechanism³⁴. Unfortunately this formalism is not adequate for describing the open universe that observational cosmology evidently requires. An open universe requires for the analogue of the strong electric field a false vacuum (a classically stable excited state that is quantum mechanically unstable). The idea then is that our lower-energy observable open universe quantum mechanically nucleated out of this false vacuum, forming a bubble of true vacuum inside it. Remarkably enough the equations permit the interior of such a bubble to be an infinite open universe in which inflation may occur³⁵.

Such a scenario cries out for some kind of theological – or perhaps anti-theological – response. Is quantum cosmology indeed a way to explain creation out of nothing in scientific terms? The most intriguing feature of this approach is that the concept of time does not arise in the process of universe creation. The 4-dimensional spatial geometry (an example of what is called an instanton) that describes the quantum emergence of our 3-dimensional space cannot be located in time. It describes the spontaneous appearance of a universe from literally nothing. It is only once the space of our universe exists that quantum cosmology can be approximated by general relativity, inducing the appearance of time. This kind of creation ex-nihilo has a distinctly Augustinian flavour to it, and it quite congenial to the notions of an origin of time³⁶. However the probabilistic

character of quantum mechanics (the “spontaneous appearance” of our universe) has perhaps for atheistic than theistic overtones. Of course a theist can justifiably say that the entire formalism rests on the presumed eternal validity of quantum mechanics, and can ascribe a theistic origin to this. However the nature of quantum fluctuations is such that there is no reason why this process – and all other logically possible variants – cannot have occurred arbitrarily often, raising the spectre of the multiverse²⁴.

Another issue connected with this subject has to do with the role of the observer. Quantum mechanics is most straightforwardly formulated in the context of classical measuring apparatus, whose setup and data collection depend upon the contrivances of observers. One learns from nature only that information that can be gleaned from the choice of experimental setup. If the apparatus is configured to reveal wavelike properties of an electron, then that is what will be seen. Any attempt to measure particle-like properties of an electron will result in a loss of information about its wavelike character. There is a necessary tradeoff in measurement-taking that appears to be intrinsic to the character of reality.

So goes the Copenhagen interpretation of quantum mechanics. In quantum cosmology this necessary raises a theological issue, for who is the observer when one is speaking about the entire universe? While a Creator naturally comes to mind, theoretical physicists have generally had a disdain for invoking this concept. Instead there has been much effort expended toward finding a formulation of quantum theory that does not demand the presence of classical observers with their accompanying measurement apparatus³⁷. Here we see another example of the “science stopper” phenomenon at work, since reliance on a Creator as the Observer of a quantum creation of the universe would appear to be a scientific dead-end. Whether or not this is the case is a matter for metaphysical and theological consideration.

Another connection between quantum phenomena and the cosmos has to do with my own recent work on entanglement³⁸. This ubiquitous property of quantum theory implies that nature has a strong holistic character, in which two quantum particles are “together in separation”, and that isolatability is not a universal property. The intuitive notion that particle attributes have definite values independent of the act of observation (and that physical effects have a finite propagation speed) does not hold in a quantum world. This strange feature of quantum theory was first appreciated³⁹ in the 1930’s and was given a precise quantitative formulation in the 1960’s in terms of a set of inequalities (known as Bell’s inequalities) that can be expressed in terms of measurements made by observers (often called Alice and Bob) on entangled pairs of particles that have interacted and then separated. A non-quantum mechanical theory (ie one for which isolatability – or local realism – holds) limits the correlation of subsequent measurements of the particles. However in quantum mechanics this correlation limit may be violated due to quantum entanglement of the particles, whose states are defined only after a measurement is made on either particle.

Experiments for the last 25 years have repeatedly shown that these inequalities are violated⁴⁰, and that the quantum-mechanical predictions for correlation are upheld.

Recently physicists have come to appreciate that entanglement is an important resource for carrying out computational tasks – it can actually speed up computational tasks relative to those carried out in a context where entanglement is not operative⁴¹. The newly founded subject of quantum computing is dependent on this property. However entanglement is not limited solely to particles, but actually involves spacetime itself. An accelerating observer necessarily finds that the particles he observes are inextricably entangled with the structure of spacetime, and it is possible to show that the amount of entanglement shared between two quantum particles is increasingly degraded with increasing acceleration³⁸. Since the equivalence principle implies that gravity and acceleration are not distinguishable locally (ie. over small enough distances and short enough times) it must be that quantum entanglement between any two particles cannot be divorced from the entanglement those particles share with a curved spacetime. In the everyday world this effect is tiny enough that it can be neglected, but in extreme situations (eg. near a black hole) it could be significant.

To my knowledge, neither the metaphysical nor the theological implications of this phenomenon have yet been given any consideration, so I shall offer my own preliminary assessment. At the very least these results demonstrate a deep interconnection between all the constituents of our universe. We see again a further confirmation of the Einsteinian insight that space and time are not a theatrical backdrop for the universe, but in fact are participants in the ongoing cosmic process. Spacetime itself can – at least in principle – place limits as to the amount of information that a given observer can garner about reality. It has been proposed that the future is unknowable even to God, since God created a universe of intrinsic temporality. Might the limits spacetime places on the ability to exchange quantum information imply further constraints on the omniscience of God?

Life

This is a topic about which much more can be said than there is space available. My only point here is that any theological or metaphysical reflections about reality connected with cosmology will be incomplete without considering the implications of extraterrestrial life. It is surely one of the most profound questions we can ask about our place in the universe.

It is generally popular to expect that life does indeed exist on other worlds. The reasons for this have to do with the vast size of the cosmos and our understanding (incomplete though it may be) of the evolutionary development of

life on our world. It seems likely – to laity and expert alike – that we are not alone in the universe⁴².

It must be pointed out that there is no guarantee that this expectation will be realized. It may indeed be the case that the conditions for life to emerge are so special that the universe needs to be as large as it is for life's appearance to have a decent chance of happening just once. Attempts to quantify the uncertainties of the factors that determine the likelihood of life on other worlds (and the number of extraterrestrial civilizations) have a history of more than 40 years. However at this point in time we are still quite ignorant of the probabilities involved. Furthermore we have to contend with the observational fact that we have no positive evidence at this point in time that life exists anywhere but on earth. We may indeed be alone in the universe.

Whether or not we are alone is question with profound theological implications. If we are indeed alone, then surely this raise questions about the character of the Creator. Would it be reasonable to conclude that the cosmos was designed for our appearance? Is the size of the cosmos relative to ourselves reflective of the Creator's generosity? Or might we discover (as stated above) that only a universe as large as our own can support life just once?

The questions become even more profound if we discover life on other worlds. We might find that there is no sentient life anywhere else, which would single out humans as unique insofar as this capacity is concerned. If there is sentient life elsewhere, will it be hostile or friendly toward our world and us? Will we be regarded as partners, pets, or provisions for some advanced alien species? Or will we find all other alien species to be less technologically advanced than ourselves? All of these scenarios raise interesting questions about the role and character of God relative to our cosmos.

Of course it appears to be very unlikely that we will know in any foreseeable future whether or not there is life in other galaxies. However we may be on the observational threshold of determining if there is life on other worlds in our galactic neighbourhood. Observationally technology and methods for determining the existence of other planets has enormously improved over the past decade, and today more than 200 extrasolar planets have been discovered through a variety of means⁴³. The ubiquity of such planets should comfort the optimists about extraterrestrial life. However no habitable planets have been found yet, where Habitable planets are defined as having a temperature of about 300K to allow for liquid water. It is conceivable that in the near future we will either detect habitable planets or else be able to set bounds on the rate of their occurrence.

In this sense science can be expected to provide theology with further empirical information. Theologians have generally been reluctant to address the implications of extraterrestrial beings (or lack thereof)⁴⁴. When asked their response has generally been a superficial "God can create anything" kind of

answer or a more conservative “wait and see” stance. There is now good reason to believe that we might not have much longer to wait.

Summary

Cosmology is one of those disciplines that push the boundaries of scientific knowledge at the most fundamental level possible. The puzzles presented here capture some of that flavour. They simultaneously frustrate us with their seemingly intractable character and delight us by motivating us to tap into deep wells of creativity to make progress in our understanding.

On the scientific side there is a broad range of ideas being tried that are increasingly speculative in character. It is quite in vogue now to give up formerly held sacred principles in physics – basic symmetries, positivity of energy, locality of physical interaction, direct observability of phenomena – to achieve some sort of computational means of addressing the above problems. The sole unifying feature would appear to be that of reliance on mathematical calculability stemming from the initial premises. Whether or not this is sufficient to sustain an acceptable basis for a cosmological framework remains to be seen.

On the theological side it seems to me that perhaps there is too much reticence (perhaps due to intimidation) with regard to seriously critiquing the various cosmological concepts that are in vogue. It would be helpful to have greater measures of candidness and clarity in discussing such ideas. My own view is that not all cosmological ideas and models are theologically positive (if this were not the case then it is difficult to see how any progress could be made in understanding some of these basic issues). However this means that reasonable criteria need to be established in making judgments as to the importance of a cosmological finding for theology and as to what counts as evidence for or against a given theological concept.

¹ For a readable introduction to modern cosmology see *Foundations of Modern Cosmology*, J.F. Hawley and K.A. Holcomb (Oxford University Press 1998); for a more technical introduction see *An Introduction to Modern Cosmology*, A. Liddle (J.F. Wiley & Sons, 2003).

² G. Lemaître, *Annals of the Scientific Society of Brussels* **47A** (1927); G. Gamow, *Nature* **162** (1948) 680.

³ E. Hubble, *Proceedings of the National Academy of Sciences of the United States of America*, **15** (1929) 168; D.N. Spergel et.al. astro-ph/0603449

⁴ N.W. Boggess, et al. *Astrophysical Journal*, **397** (1992), 420.

⁵ A. Alpher, H. A. Bethe, G. Gamow, *Physical Review* **73** (1948), 803; S. Burles et. al., *Physical Review* **D63** (2001) 063512.

⁶ D. N. Spergel, et al. *Astrophysical Journal Supplement Series*, **148** (2003) 175.

⁷ *Before the Beginning: Cosmology explained*, G.F.R. Ellis and P.H. Collins (Hawley Marion Boyars Publishers, Inc.)

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- ⁸ See for example E.A. Milne, *Modern Cosmology and the Christian Idea of God* (Clarendon Press, Oxford 1952)
- ⁹ More technically, one could ask if the initial state is ‘natural’ – begging to a certain extent the question as to the meaning of this term.
- ¹⁰ For a recent version of this idea, see P. Steinhardt and N. Turok, *Science* **26 May 2006**: 1180.
- ¹¹ A. D. Linde, *Physics Letters* **B175**, (1986) 395.
- ¹² For a popular introduction, see S.W. Hawking, *A Brief History of Time* (Bantam, 1988)
- ¹³ These include ideas such as discretization of spacetime, non-commutativity of geometric quantities, and the introduction of a minimal length. These concepts are not mutually incompatible and may in fact occur together in some combination.
- ¹⁴ For an early example of this see G. F. R. Ellis and G. Schreiber, *Physics Letters* **B115**, (1986) 97.
- ¹⁵ For a review of a history of ideas on this subject see J. Barrow, *The Infinite Book* (Pantheon, New York 2005).
- ¹⁶ For a review see S.M. Carroll’s contribution in the *SNAP (SuperNova Acceleration Probe) Yellow Book* (report EFI-2001-27).
- ¹⁷ One scientist-theologian that has given this some consideration is John Polkinghorne; see J. Polkinghorne, *The God of Hope and the End of the World* (Yale University Press, 2002).
- ¹⁸ For a review see J. Barrow and F. Tipler, *The Anthropic Cosmological Principle* (Oxford University Press, 1986).
- ¹⁹ For a discussion of this point see J. Leslie, *Universes* (Routledge, 1989).
- ²⁰ For an overview see M. Tegmark, *Scientific American* (May 2003).
- ²¹ See for example S. Weinberg, hep-th/0511037; F. Wilczek, hep-ph/0512187; to be published in *Universe or Multiverse?*, ed. B. Carr (Cambridge University Press).
- ²² M. Douglas, *JHEP* **0305** (2003) 46; S. Ashok and M. Douglas, *JHEP* **0401** (2004) 060.
- ²³ For an introduction see S. Tsujikawa, hep-ph/0304257.
- ²⁴ For a more complete discussion see R.B. Mann, *Perspectives on Science & Christian Faith*, **57** (2005) 302.
- ²⁵ For a review see S.M. Carroll and J. Chen, hep-th/0410270.
- ²⁶ H. Price, in *Time’s Arrows Today*, ed. S. Savitt (Cambridge: Cambridge University Press, 1994).
- ²⁷ For an introduction see Robert Mesle’s *Process Theology: A Basic Introduction* (1993; ISBN: 9780827229457).
- ²⁸ For a discussion see J. Polkinghorne, *Exploring Reality: The Intertwining of Science and Religion* (Yale University Press, 2005)
- ²⁹ P.H. Frampton and T. Takahashi, *Astroparticle Physics* **22** (2004) 307.
- ³⁰ For other perspectives on the ultimate fate of the universe, see *The Far-Future Universe: Eschatology from a Cosmic Perspective* ed. G.F.R. Ellis (Templeton Foundation Press, 2002).
- ³¹ For an introduction to this subject see T. Hey and P. Walters, *The New Quantum Universe* (Cambridge University Press, 2003).
- ³² For an overview see L.Z. Fang, R. Ruffini, *Quantum Cosmology* (World Scientific Publishing, 1987).

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- ³³ For the early work in this subject, see J. B. Hartle and S. W. Hawking, *Physical Review* **D28** (1983) 2960; S. W. Hawking, *Nuclear Physics* **B239** (1984) 257; A. Vilenkin, *Physical Review* **D33** (1986) 3560; A. Vilenkin, *Physical Review* **D37** (1988) 888; A. Vilenkin, *Physical Review* **D50** (1994) 2581.
- ³⁴ R.B. Mann and S.F. Ross, *Physical Review* **D52** (1995) 2224.
- ³⁵ S. W. Hawking and N. Turok *Physics Letters* **B425** (1998) 25.
- ³⁶ See the article by C.J. Isham in *Physics, Philosophy, and Theology -- A Common Quest for Understanding* eds. R.J. Russell and C.V. Coyne (Notre Dame Press, 1988).
- ³⁷ For the mainstream conventional viewpoint on this see W.H. Zurek, *Reviews of Modern Physics* **75** (2003) 715.
- ³⁸ I. Fuentes-Schuller and R.B. Mann, *Physical Review Letters* **95** (2005) 120404; P.M. Alsing, I. Fuentes-Schuller, R.B. Mann, and T.E. Tessier *Physical Review A* (to be published; e-Print Archive: quant-ph/0603269).
- ³⁹ For a complete overview see J.S. Bell, *Speakable and Unsayable in Quantum Mechanics* (Cambridge University Press 1987); see also J.F. Clauser, M.A. Horne, A. Shimony and R.A. Holt, *Physical Review Letters* **23** (1969) 880.
- ⁴⁰ A. Aspect et al. *Physical Review Letters* **47** (1981) 460.
- ⁴¹ M. A. Nielsen and I. L. Chuang *Quantum Computation and Quantum Information* (Cambridge University Press 2000)
- ⁴² For an overview see F. Drake and D. Sobel *Is Anyone Out There? The Scientific Search for Extraterrestrial Intelligence*. (New York: Delacorte Press 1992).
- ⁴³ For a recent review see G. Marcy, R. Butler, D. Fischer et.al. *Progress of Theoretical Physics Supplement* **158** (2005) 24.
- ⁴⁴ Notable exceptions include C.S. Lewis and J. Polkinghorne; see ref. 28 above.