Design in Cosmology

Rodney Holder
CiS Durham Conference, 18.03.2006, 10.30-11.20 pm

The Big Bang

I wonder if you knew that Einstein spent some time in Oxford. Well, he did and they have the original blackboard on which he wrote in Oxford's Museum of the History of Science. When Einstein was boarding his train at Paddington, he is rumoured to have asked the guard, 'At what time does Oxford Station depart for this train?'

Now you may recognise the person on the right of this photograph. It is of course Einstein himself. The person on the left is less well know but he is one of the truly great figures in cosmology. He is the Abbé George-Henri Lemaître. He was a Belgian priest. In 1927 Lemaître solved Einstein's equations of general relativity for the universe as a whole. He came up with a solution which indicated that the universe should be expanding from an original 'creation event' which we now know occurred some 14 billion years ago. This is the Big Bang theory, though that phrase was only coined much later by atheist British cosmologist Sir Fred Hoyle, who hated the idea because he thought, if the universe had a beginning, then that implied God created it.

Einstein himself disliked the Big Bang idea and had come up with a solution to his equations which was static. He was later to call this his biggest blunder. Lemaître was proved right and Einstein wrong when the expansion of the universe was observed by Edwin Hubble just a couple of years later in 1929.

In fact the Big Bang theory is extremely well supported by the observational evidence. The expansion of the universe is the obvious piece of evidence. However, that wasn't enough for Fred Hoyle who proposed an alternative theory, the steady state theory whereby the universe has always existed, always looking pretty much the same, and the gaps caused by the expansion are filled by new matter continuously created at just the right rate to fill them. The steady state theory has been demolished and the Big Bang established by three subsequent pieces of evidence:

1. The theory predicts a uniform, remnant radiation field bathing the universe. On the Big Bang theory the universe would have been very dense and hot at the beginning, and has now cooled to a mere 3 degrees above absolute zero. This cosmic microwave background radiation has been observed, effectively eliminating the steady state theory which could not explain it.

2. The theory correctly predicts the abundances of the lightest chemical elements (notably helium and the deuterium isotope of hydrogen) which it explains as being formed from nuclear reactions in the first minutes of the universe's existence. Astrophysicists were unable to explain the production of these elements with models of nucleosynthesis in stars, the other great nuclear furnaces of the universe, so light element production in the Big Bang completes a satisfying account of how the elements heavier than hydrogen are manufactured.

3. Observations show a greater number of active galaxies at the greatest distances (which, because of the finite speed of light, correspond to earliest times in the universe's history).

The Big Bang theory would lead one to expect such signs of cosmic evolution, whereas, on the steady state theory, the universe would look the same at all epochs.

Now I must emphasize that the Big Bang theory is very well attested indeed and almost universally accepted by cosmologists. When I come to criticisms and areas of dispute they are not about the Big Bang itself but about the details, particularly about the details pertaining to the very tiniest fraction of a second from the origin.

Specialness of the Big Bang: Cosmic Fine-tuning

The Big Bang is very well supported by the evidence, yet it presents us with some puzzles. It seems to be set up in a very special way indeed, seemingly in order for us to be here to observe it. This specialness relates to two areas:

(1) First, the conditions right back at the beginning, at the earliest time we know we can sensibly speak of, have to be just right for the universe to give rise to life. This is some 10^{-43} seconds after the beginning when an as yet unknown theory of physics applies, which combines Einstein's theory of gravity with quantum mechanics, the theory of the very small.

(2) Secondly, the constants which go into the laws of physics have to be what they are, in order for the universe to give rise to life. These constants determine the relative strengths of the fundamental forces of nature like gravity, and the force which holds atoms together. They determine how key physical processes go at different stages of the universe's evolution.

There are many, many examples of this so-called fine-tuning, and I will just give you one of each kind now:

(1) First, the mean density of the universe has to be just right at the very beginning to 1 part in 10^{60}. If it is smaller than it is by this amount then the universe will expand far too quickly for galaxies and stars to be able to form. If it is greater then the whole universe will recollapse under gravity long before there has been time for stars to evolve. Either way you have a boring universe with no possibility of life. An accuracy of 10^{60} is that required to aim a gun at a coin 14 billion light years away at the opposite end of the universe and hit it.

(2) Secondly, the ratio of two of the fundamental forces [strong force and electromagnetic force] has to be just right for carbon and oxygen to be made inside stars. One of the great discoveries in astrophysics is how all the chemical elements are manufactured inside stars, where the temperatures reach hundreds of millions of degrees, through nuclear reactions. Sir Fred Hoyle, the atheist Cambridge astrophysicist I mentioned before, was foremost in this discovery, and he it was who discovered the particular 'coincidences' required for carbon to be made in the first place, and then for the carbon not to be destroyed in making oxygen. When he made this discovery he was moved to remark that a superintellect had monkeyed with physics, as well as with chemistry and biology, and that there are no blind forces worth speaking about in nature.'

As I say, there are a host of these examples of fine-tuning which I won't go into in detail. But just to mention a few: the universe needs to be the size it is, with a hundred thousand million galaxies in order for their to be life. A universe with only one galaxy, which you might think provided enough stars and planets for life, would be hopeless because such a universe would collapse to a black hole in the space of a month. The mass of the proton needs to be very close to 1840 times the mass of the electron, as it is in fact, in order for there to be any chemistry possible at all, let alone the development of life. And so on, and so on. Some more examples will crop up later in the talk. One very key example which I will come back to is the need for the universe to be incredibly highly ordered right back at the beginning so that any kind of structure can emerge at all, rather than all the matter collapse into black holes.

Explanations

This specialness of the universe, which is essential if there is to be life, just cries out for explanation. The most obvious explanation is that it was made that way; it was designed so that life would appear. Christians would say that God intended there to be living creatures with the capacity for reason and with free will, who would be able to have a relationship with him. Note, however, that this explanation is very different from the design arguments in biology put forward by the 'Intelligent Design' movement. Here we are talking about why the laws of physics and the initial conditions to which they are applied are as they are. We are emphatically not looking for explanatory gaps in the processes described by these laws when they are applied.

Many scientists, however, regard any kind of design hypothesis with loathing. They want to restrict their explanations, even for why the laws of physics are as they are, to within science itself.

So what alternatives have scientists come up with? I'm going to contrast two strategies which scientists have pursued in order to avoid the implication of design by God.

(1) The first is to seek an explanation from within science for the values taken by the various constants of physics—to derive them from some more fundamental theory, a so-called 'theory of everything' (TOE). Interestingly Einstein spent his later years in a fruitless search for such a theory: 'What I am really interested in is whether God could have made the world in a different way', he said—although this quote obviously indicates that he still saw no contradiction with God being behind it all. Connected with this search for a TOE is the aim to show that the initial conditions are not special: to argue that whatever they were, the universe would turn out much the same.

(2) The second strategy is diametrically opposed to this. It is to postulate a multiverse. A multiverse is vast infinity of existent universes, embracing the whole range of values of the constants and initial conditions. The idea is that if a multiverse exists you can then say: Hey presto! Given the vast ensemble, our universe with its suite of parameters is bound to exist, and we should not be surprised to find ourselves in it, because we simply couldn't exist in the overwhelming majority of universes which differ from ours in their parameter values.

In a moment I shall give a brief history of modern cosmology, showing how these strategies have been repeated a number of times, as theory has progressed. I shall also say something about them being repeated in the context of string theory, the latest and most popular candidate for a 'theory of everything'. But first does—can—either strategy provide the ultimate explanation?

Ultimate Explanations

The answer is that only God can provide the ultimate explanation. No scientific theory can do that. And neither atheistic strategy on offer in the context of the fine-tuning of the universe can do it.

The basic question is, ‘Why is there something rather than nothing?’ ‘Why is there any universe at all?’ God explains that. There is a universe because he freely created it. He wanted to bring about an environment in which free, rational creatures could flourish and have a relationship with him.

I’m now going to introduce two important terms from philosophy, the terms ‘necessary’ and ‘contingent’. Something is said to be necessary if it cannot be other than it is; something is contingent if it can be otherwise or if it needn’t exist at all.

At least since the time of St Thomas Aquinas in the thirteenth century theologians have argued that the idea of God as ‘necessary being’ provides a stopping point for explanation. To say that God is necessary means that he cannot but exist. He must exist. He cannot not exist. This is what the concept ‘God’ means. Another way of saying it is that there is no possible universe in which God does not exist. It follows from this that God was not himself created. He couldn’t have been or else there would have been a time when God did not exist but something else did, namely whatever or whoever created God. Anything created is not God. Now someone could doubt that such a being exists - we know that many do doubt it, but it follows that if he does exist then he has always existed and will always exist and everything else that exists depends on him.

That is because everything else is ‘contingent’. The word contingent means the opposite of necessary. Something which may or may not exist is contingent. It didn’t have to exist. It might not have existed.

Now you see that things are very different with the universe. The universe might or might not have existed. Stephen Hawking famously asked, ‘What is it that breathes fire into the equations, and makes a universe for them to describe?’ That is a fundamental question. The universe cannot explain its own existence. It cannot create itself, by lifting itself up by its own bootstraps, as it were, into existence. The question ‘Why is there something rather than nothing?’ has no answer on the basis of either strategy 1 or strategy 2.

Now strategy 1 doesn’t explain why anything exists, why there is a universe, but it does explain why the universe is like it is, given that it exists. It couldn’t have been different, so, with the big proviso that it exists, then it is necessarily the way it is.

If that is so, then there is still a massive puzzle because we can now ask, ‘Why does the only self-consistent set of physical laws give rise to life?’ It could have given rise to an isolated amorphous lump of rock and nothing else. Why on earth did it give rise to a universe with all the rich complexity including living creatures that we see? Given the infinite variety of outcomes we can imagine it is desperately puzzling why the only possible set of laws gives a universe with human beings in it.

Coming to strategy 2, the multiverse hypothesis says that the universe certainly can be different and indeed different universes actually exist. And it could be the case that the more universes you have the more chance there is of getting one with life. But there is a pretty big puzzle here too, namely, ‘Why does this particular multiverse exist as opposed to another?’ We now have a choice of equations into which fire somehow gets breathed, and we have a choice about how many sets of equations give rise to universes and how many universes they give rise to. What determines these choices?

One cosmologist, Max Tegmark, has proposed in answer to this that all possible mathematical structures have physical existence. That would certainly guarantee our universe’s existence. But it takes us way beyond what physics can tell us and most mathematicians and physicists think the idea doesn’t make sense. You soon run into problems and paradoxes when you actually start to try and write down ‘all possible mathematical structures’. Certainly there seem to be conflicts in what actually exists as opposed to what can possibly exist. For example *I* can’t simultaneously deliver a talk on ‘Design in Cosmology’ at the CiS Durham Conference and sit at home watching TV. Some copy of me in another universe could conceivably have taken a different course, but *I* couldn’t simultaneously do both.

A Brief History of Cosmology

In the search for the ‘ultimate theory’ physicists and cosmologists are driven by two considerations. The first is the specialness of the Big Bang and the laws of physics we have discussed. The second is the need for a more fundamental theory in any case to describe the physics at the earliest epochs in the universe’s history and, purely from the point of view of physics, to combine the four fundamental forces into one.

Back in the late 1960s the chaotic cosmology programme sought to show that the initial conditions at the Big Bang didn’t matter. More or less any initial conditions would lead to a smooth universe as we observe today. This idea was demolished by Stephen Hawking and a colleague of his Barry Collins in a paper written in 1973. Now in order to give rise to life the universe must quickly approach a state in which it looks the same in all directions [technically it is isotropic]. If that isn’t the case then shear and rotational distortions will prevent the formation of galaxies and stars. Collins and Hawking showed that the probability of a universe like ours emerging from the Big Bang—looking the same in all directions in the sky to a high degree of accuracy—is actually zero. You can’t have greater precision in the way the universe is set up than that.

Collins and Hawking turned to a multiverse to solve that problem. There are several ways of conceiving a multiverse. The simplest, and that I shall concentrate on, is as an infinite space in which there are enormously large regions, each region having its own set of parameters. A second way is as successive expansions and contractions of a single universe, and a third arises if one adopts a policy of realism to all the possible outcomes of chance events in quantum theory.

A more recent attempt to solve some of the problems with the standard Big Bang is the theory of inflation. This postulates that the universe underwent an incredibly rapid period of accelerating expansion—called inflation—from 10^{-35} to 10^{-32} seconds after the origin. In that time the universe expanded from being 10^{-25} cm to 10 metres across. At that point the much slower deceleration of the classical Big Bang took over. Now it is the case that such a rapid period of accelerating expansion, even if that short, drives the density of the universe to the critical value and smooths out the differences between different parts of the universe, solving the problem to do with the universe looking the same in all directions.

That sounds wonderful, but there were some serious problems with inflation. One serious problem from our point of view is that inflation itself needed fine-tuning, ie parameters to be chosen specially! That is not very satisfactory for a theory which was meant to solve the problem of the need for fine-tuning. The upshot is that there has been an enormous inflation in the number of inflation theories—well over a hundred at the last count.

Now the inflation era is also the era when three of the forces of nature are supposedly united, and at the end of the inflationary period the forces split into two. They split again at about 10^{-10} seconds after the origin. That is about the time when we actually start to be confident about the physics. We can do experiments in the laboratory and the standard model of particle physics applies.

But back to inflation. The next step was to propose that this force splitting occurs at different rates in different parts of the universe. This is a turn to strategy 2, namely a multiverse with different regions having different parameters. This picture was proposed by a Russian cosmologist now working at the University of Stanford, California, Andrei Linde. His idea is known as eternal inflation and he imagines infinitely many different bubble universes forming by inflation with bubbles forming within bubbles ad infinitum.

Now we are still not quite at the Theory of Everything (TOE). That is the theory which is said to apply to the very first 10^{-43} seconds from the origin. During that time one needs a theory which combines all the forces of nature. That is to say, it combines Einstein's general theory of relativity, which is the theory of gravity, with quantum mechanics, which applies to the other forces and describes the very small.

We don't know what that theory is but the leading contender is string theory. String theory postulates that the ultimate building blocks of matter are not point-like particles but tiny, one-dimensional objects called strings. By tiny I mean really tiny, some 10^{-33} cm across. String theory aims to solve some of the problems with the standard model of particle physics, especially the existence of infinite quantities like mass and charge. The elementary particles we observe are actually different modes of vibration of the strings. An important complication is that these vibrations occur in more than the three dimensions of space that we are used to. The reason we only see three extended dimensions is that these other dimensions get curled up very small. Quite why this is so remains something of a mystery.

Now the original aim of string theory was to calculate particle masses, ie strategy 1 was pursued. The theory has always been dogged by its lack of connection with observation and experiment so the main motivation has been that it is beautifully mathematically elegant and it solves some theoretical problems. It is still the aim of some string theorists to calculate everything and some believe that is possible in principle, though some parameters (like the cosmological constant) still seem to need strategy 2. Nevertheless nothing has been calculated in practice so some string theorists, notably Leonard Susskind, have taken the turn to strategy 2.

Susskind and his colleagues talk about the 'landscape of string theory'. They find that there is not just one but many solutions of the theory, anything from 10^{100} to 10^{1000} solutions. The further claim is that a universe can 'tunnel' between solutions. The solutions are stable for billions of years, then another universe pops up as a region moves to another solution of the equations. This feeds in very neatly to the eternal inflation idea. If it works, and it is a big if, it would provide a better motivation than we have had for eternal inflation. It is also true that if there is a theory which in some sense naturally gives rise to many universes, then that gives plausibility to the idea of a multiverse. However, there are lots of problems as I shall now explain.

Problems for multiverses

The whole idea of multiverses, including the latest stringy landscape idea is fraught with problems and I'm just going to list a few of them.

1. It is important to recognise that the physics is speculative, to say the least. Even the string theory community is divided over whether the landscape exists. Some think the solutions are really different theories and therefore to talk about tunnelling from one to another is quite wrong. The trouble about many universes is that they cannot even in principle be observed. That is a very important difference from the many planets comparison that is sometimes made. Given billions of planets there is bound to be one like ours the right distance from its parent star, and so on, for life to arise. Well, we can observe other planets; we have detected planets outside the solar system. There is nothing strange or startling about that. But other universes? Well, they cause no effect whatever in our own because no signal from them can ever reach us.

   I must say I find it rather intriguing that there is almost a 'law' at work here too. As theories progress towards 'ultimacy', as we get closer and closer to the final theory of everything (TOE), so the observational and experimental support diminishes to nothing. We are after all talking about régimes where the energies exceed what is attainable in the laboratory, in particle accelerators, by factors of billions. It is almost as if God is having a bit of fun at our expense, putting the ultimate just beyond our grasp. History might caution us too, since we thought we have been here before. At the end of the nineteenth century some physicists thought physics was all tied up bar some loose ends, which were to determine the constants experimentally to ever more decimal places. They couldn't have been more wrong!

2. There is a problem about the existence of actual infinities in nature. Mathematicians happily talk about and manipulate different degrees of infinity but there are lots of paradoxes when you think about infinite numbers of things existing in the real world. Hilbert's Hotel has infinitely many rooms all of which are full. Even so, you can very easily make room for infinitely many more guests! All you have to do is tell the person in Room 1 to move to Room 2, the one in Room 2 to go to Room 4, the one in Room 3 to go to Room 6, and so on. Then all the even numbered rooms are full but the odd numbered ones are all free!

   One problem is that, if there are infinitely many regions with varying parameters there will be infinitely many identical copies of me. There will also be copies who differ very slightly. Some of the 'Is' will be talking about multiverses, other will decide to stay at home and watch TV instead. It is quite bizarre even to begin to think about this. Some philosophers and mathematicians think infinitely many universes are ruled out because of the paradoxes. I don't quite see the paradoxes as logically precluding them, but a theory without paradoxes is surely to be preferred.

3. The multiverse hypothesis is not a simple hypothesis. Scientists normally go for the simplest of competing hypotheses and this doesn't seem to be that. As I said earlier

another question one needs to ask is 'Why this multiverse?' That applies to the stringy landscape idea as much as any of the others and already to produce the landscape some choices within string theory have been made.

4. In any case the turn from strategy 1 to strategy 2 implies a move away from predictability, which had been a cornerstone of the scientific method. This is not just predictability of physical parameters, but predictability in general based on the existence of order in the universe. Suppose some unexplained feature arises in the universe. Instead of trying to explain it rationally using science, the temptation is now to say, 'We just happen to be in a universe which exhibits that feature'. Such theories are not falsifiable (though see 6 below).

5. Possibly the most outstanding problem in cosmology is the fine-tuning of the cosmological constant, Λ. This is the term originally introduced into his equations by Einstein to make the universe static. If he had put it to zero he would have predicted the expansion and arrived at the Big Bang theory.

   Until very recently it had been thought that Λ was zero. More recently observations have indicated that Λ might take a very small, but positive value.

   Now physicists think they know where Λ comes from. In quantum theory the vacuum is not empty but a hive of constantly fluctuating activity, and possesses energy. Λ is believed to be the energy of the vacuum. The unfortunate thing is that when Λ is calculated it gives a value 10^{120} times that which is compatible with observations. If Λ really took the calculated value you would be pulled apart in an instant with your body parts flying away to the ends of the universe.

   The answer cosmologists have come up with to this one? You've guessed it. A multiverse. And in the string theory landscape the different universes represent different values of Λ. If a universe starts with a very high value of Λ it will tunnel billions upon billions of times until a universe eventually arises with the small value of Λ that our universe has.

   Now this looks like a great success. But now there is another question we need to ask. According to the multiverse theory, the universe is now to be regarded as typical of those with Λ values which permit life. It is a random member of the subset of universes which give rise to life. The question then is, 'Does it look like it is that or is it more special than that?'

   Now calculations show that the average value of Λ which would be compatible with life is quite a bit more than the value we observe. The first calculations showed that it could be a hundred times more; that figure came down with more recent calculations but it still looks a bit too high. Thus we seem to be observing a value of Λ that is a bit too special, though not enormously so by astronomical standards.

   Of course there could be many other parameters of our universe besides Λ which are more highly tuned than is strictly required for our own existence. It looks as though there are and I shall return to one of them in a moment.

6. Some multiverse models require an element of fine-tuning for there to be a multiverse in the first place. An example is that the overall mean density must be less than or equal to the critical value so that the universe as a whole is infinite and expands forever. And that may not be likely given that in principle the density can take any value from an enormously large range. It might well be greater than the critical value, in which case the universe is not infinite, but finite.

It may be that the landscape and other multiverse theories are already faced with the possibility of observational falsification for this reason. The latest satellite data (WMAP) on the cosmic background radiation which I mentioned near the beginning as confirming the Big Bang has examined this radiation in detail. The very tiny fluctuations in it have been taken to confirm the predictions of inflation. But there is a discrepancy, namely that the fluctuations disappear at certain points. That could mean that we are living in a finite universe which is closing back in on itself. What this would be saying is that we could almost be seeing right round the universe and there simply wouldn't be other regions 'outside' ours. This is very tentative and controversial, but the model which is proposed here at least has the merit of contact with observation and openness to empirical enquiry—and would avoid all the paradoxes of infinity.

Suppose this particular finite model were eliminated by observation. It would still be the case that we could never be sure that we really inhabited an infinite universe. John Barrow in a recent book (*The Infinite Book*, p 144) makes just this point. In fact either of two options is possible. We may think we are in an infinite universe when we just inhabit an underdense part of a finite universe *or* we think we are in a finite universe when we inhabit an overdense part of an infinite universe.

7. Now Sir Roger Penrose, former Professor of Mathematics at Oxford and outstanding cosmologist, poses a massive problem to inflation and indeed all attempts to explain the specialness of the Big Bang on the basis of a multiverse.

Penrose is concerned with the amount of order there was at the beginning. Order can be measured (by a quantity called entropy) and it decreases over time. Penrose puts it like this concerning the entropy of the universe. He says that the Creator had something like $10^{10^{123}}$ possible universe configurations to choose from, only one of which would have the order which ours does. That is the order necessary to produce a cosmos with all the galaxies, stars and planets that our universe possesses.

Now Penrose points to the fact that, for a universe to have life, you actually need a great deal of order but much less than this vast amount. You could create the entire solar system with all its planets and all its inhabitants by the random collisions of particles and radiation with a probability of 1 in $10^{10^{60}}$. This is a tiny probability but much greater than 1 in $10^{10^{123}}$. The implication is that our universe is vastly more special than required merely in order for us to be here. It is much, much more special than a universe randomly selected from the subset of universes which are conducive to life. It is virtually a nail in the coffin for the multiverse idea but totally consistent with design.

Comparing the explanations

So how do we choose between the multiverse explanation and design? I have just listed a host of problems with the multiverse explanation in addition to the fact that no purely physical explanation will ever be ultimate. So here a just a few of the problems with the multiverse:

1. It doesn't provide an ultimate explanation. You can always ask, 'Why is there something rather than nothing?'

2. It is also a complex explanation. Simpler explanations involving the least number of entities and kinds of entities are preferred in general in science, so scientists ought to be sceptical about the gigantic multiplication of entities involved in multiverse theories. There is also the question for any particular multiverse, 'Why does this particular multiverse exist and not another?'

3. A multiverse doesn't explain why there should be life. There is no reason in principle why a multiverse should do so. The question is always, 'Why does this particular set of laws, which gives rise to the multiverse in question, give rise to life?'

4. This universe looks too special. It is more special than is required for life to develop and that speaks of design more than of any kind of random selection.

In contrast creation and design by God does provide an ultimate explanation because God, if he exists, exists necessarily—that is at least part of what we mean by 'God'. In addition design by God is a simple explanation, and much more economical than the multiverse. One is not invoking a whole multitude of complex entities with which one can have no possible interaction, but one intelligent being, like ourselves in some ways but so much greater, who designed the universe with the deliberate intention of its bringing forth creatures for a relationship with himself.

Design by God explains why there should be intelligent life and why the universe should be special, even extra special as we find it. That is because it is the good creation of an all powerful, all knowing, perfectly good being. Is not modern cosmology pointing to God as designer?[1]

---

[1]The argument is explored in much more detail in Holder, R. D., *God, the Multiverse, and Everything: Modern Cosmology and the Argument from Design* (Ashgate 2004), where a full set of references is also provided.