Cosmology

Cosmology is the study of the universe as a whole. It has a three-fold agenda; first to describe the universe, then to reconstruct its history, and finally to explain why things in the universe have the features that we find. It's been an enormously active field these last two decades, in part because of advances in technology. We can put telescopes in orbit outside the earth's atmosphere, and this has an enormous advantage. It turns out that the earth's atmosphere is opaque to most forms of electromagnetic radiation. For example, it's opaque to ultraviolet light. This is good; otherwise we would be fried; but we can learn a lot about stars and galaxies by looking at the ultraviolet light they emit. Satellites together with modern telescope technology make it possible for us to do this. What is true of ultraviolet light is equally true with x-rays, infrared radiation, radio waves, etc.

You might wonder what this has to do with religion. I find part of this answer in a remarkable passage from C. S. Lewis' novel *Perelandra*. The novel tells of an imaginary voyage to Venus in service of God who in this world is called Maleldil. It ends with a long prayer that presents a Christian vision of cosmology that I find profoundly true. I will quote one paragraph of a much longer prayer.

"That Dust itself which is scattered so rare in Heaven, whereof all worlds, and the bodies that are not worlds, are made, is at the centre. It waits not till created eyes have seen it, or hands handled it, to be in itself a strength and splendor of Maleldil. Only the least part has served, or ever shall, a beast, a man, or a god, but always, and beyond all distances, before they came and after they are gone and where they never come, it is what it is and utters the heart of the Holy One with its own voice. It is farthest from Him of all things, for it has no life, nor sense, nor reason; it is nearest to Him of all things for without intervening soul, as sparks fly out of fire, He utters in each grain of it the unmixed image of His energy. Each grain, if it spoke, would say, I am at the centre; for me all things were made. Let no mouth open to gainsay it. Blessed be He!"

There are two ideas here that seem to come directly from modern cosmology, "That Dust which is scattered so rare in Heaven…" and the image that is repeated over and over in the prayer that "Everything is at the center." This is a precise statement of what we call the cosmological principle, and I will have a lot to say about dust. Let me quote one more paragraph.

“Never did He make two things the same; never did He utter one word twice. After earths, not better earths but beasts; after beasts, not better beasts but spirits. After a falling, not recovery but a new creation. Out of the new creation, not a third but the mode of change itself is changed forever. Blessed be He.”

This seems to touch on the issue of emergence, which I will come to in the last lecture.

So the dust is worth studying for reasons that the prayer says so well, but I have a further agenda. It turns out that the universe is intricately contrived in such a way that our existence is possible. For example Bishop Ussher thought the world was created 6000 years ago. In fact the universe is 13.7 billion years old, and if it were much younger, we could not exist! There are many other respects in which, if the universe were only slightly different, we could not exist. The physicist Freeman Dyson said that it looked like “the universe knew we were coming.” My discussion of cosmology tonight will be very selective. I want to pursue all the different ways in which the universe might be said to know that we were coming.

Start with the sun. The sun is a very ordinary star. It gets its energy with a nuclear fusion reaction. It converts protons into helium via several intermediate steps. For each helium nucleus formed a certain amount of energy is released. This happens in the core of the sun. The energy released gradually rises to the surface and makes it hot. Hot things as you all know, glow. All this is well-understood physics, and since the sun is so close, we can study its properties carefully. We know that the sun has been burning for five billion years and has enough fuel for another five billion. After that a complicated sequence of events will occur, which I will talk about later. We know that the more massive a star is, the brighter it shines and the shorter it lives. On the other hand, large planets like Jupiter are “failed suns.” They don’t have quite enough mass to light the nuclear fires. As we look out at the night sky, we see a great variety of stars of all possible ages, sizes and compositions. Their distribution tells us a lot about the age and history of the universe and the galaxies that contain them.

Let’s talk about numbers. Light travels the same speed, 300,000 km/s, under all circumstances (that’s 15 times around the earth in one second), so it makes a handy way of describing large distances. It takes 8 minutes for light from the sun to reach us, so we say the sun is eight light minutes away. The nearest star on this scale is 4 light years away. Astronomical distances are so huge that the only way to get your mind around them is to think in terms of ratios. If the sun were the size of a grapefruit and everything else in the universe was scaled down accordingly, the earth would be one mm in diameter 10 yards away, and the nearest star would be 2000 miles away!

Stars are grouped in vast clusters called galaxies. Our own galaxy is called the Milky Way galaxy. We can’t see it from the outside, of course, but if we could it would look something like this, our close neighbor, the Andromeda galaxy. These look like giant pinwheels, and indeed they are spinning. Our galaxy makes one complete revolution every 200 million years. Our sun is 25,000 l.y. from the center, which puts us out about half way along one of the spiral arms. There are roughly 100 billion stars in our galaxy, about as many sand grains as there are in a one meter cube. If you were to count them one at a time, it would take 3000 years. Think again in terms of ratios. If the earth’s orbit were the size of a pin, the nearest star would be 300 yards away, and the galaxy would span the entire United States.

Galaxies themselves are grouped together in clusters ranging from a few tens of galaxies to a few thousands. Our galaxy and the Andromeda galaxy are part of a small group called the Virgo cluster. An important fact is that these clusters are not uniformly distributed in space. They make strange patterns with walls, voids, strings and bubbles. Together these structures make up what is called the cosmic web. In the picture there are about 250,000 galaxy clusters. One final ratio. If our Milky Way were 20 yards across, Andromeda would be 600 yards away, and the farthest distance we can see would be the size of the United States and contain 100 billion galaxies.

This might make you feel inconsequential in terms of size, but there is another way of looking at our place in the universe and that is in terms of complexity. We are by far the most complex thing we know of in the universe. It’s hard to quantify complexity, but one way might be to compare it with light; things that are very complex are like a bright light. Simpler things are dimmer. On this scale a galaxy is like a light bulb, and a human being is like the brightest quasar ever seen! Think of this as our real place in the universe, but remember, on this scale your goldfish is only imperceptibly dimmer.

Now let's get back to the galaxies. It turns out they are all moving and in three different ways. Some are rotating as I have already showed you. All are moving relative to one another in various complicated ways. But the really significant thing for our purposes is that they are all moving directly away from us, and the farther away from us they are, the faster they are moving. It is if we committed some cosmic *faux pas*, and everyone is trying to get away from us as fast as possible! This was first discovered in the 1920's by an astronomer named Edwin Hubble. He made this now-famous plot with distance on the horizontal axis and recession speed along the vertical axis. Each galaxy is one point on this plot. The speed with which the galaxies are moving away from us is easy to measure. Light sources moving away from us appear redder than they really are. Those moving toward us appear bluer. This effect is called the cosmic red shift and it's very easy to measure. Distances, on the other hand, are very difficult to measure. Hubble's original measurements were wrong by a factor of ten! Now after 70 years of work we have these distances nailed down to something like 10% accuracy. How this is done is a very technical business which I don't have time to tell you about. Now the amazing thing is that if you get the distances right and if you restrict the plot to distant galaxies so that the other motions I told you about are negligible, then the points all lie on a straight line. The slope of this line is a famous number called the Hubble constant, H=22 km/sec/Mly, again plus or minus 10%.

The fact that this is a straight line has two amazing consequences. The first appears when we consider what happened in the past. Let's assume that H has always had the same value. That's not quite true, but it's OK for our purposes. If the galaxies are now moving away from us then in the past they must have been closer. Take any galaxy. It's easy to see that sometime in the past the distance between us and the galaxy must have been zero, and it's easy to calculate how long ago that was. The fact that the Hubble plot is a straight line means that no matter what galaxy you choose, the time when it would have been sitting right on top of us is the same, 13.5 billion years ago. We call this the Hubble time.

Now you might wonder what's so special about us, or maybe what's so terrible about us, that everyone is trying to get away **from us**. Now the second remarkable consequence of the straight line appears. Every observer in every galaxy will see exactly the same thing. Every observer can measure his or her or its Hubble plot and get the same plot. Everyone will conclude that the universe is rushing away from him or her or it in the same way. In other words, *everything is at the center*. So far as we know, this additional fact is true. If we average over sufficiently large regions of space, then the universe looks the same in all respects to all observers. This is called the cosmological principle. We will assume it is true remembering that it is an approximation, but as it turn out, it becomes a better and better approximation as we look farther and farther back in time. Incidentally, to the extent that the cosmological principle is true, there can be no "edge" to the universe. The universe must be infinite.

This would be incomprehensible without Einstein and the general theory of relativity. The mathematics of the general theory is truly terrifying, and it's even hard to get your mind around the qualitative ideas, but I will try to explain them. Imagine you are an airline pilot flying from New York to Tokyo. You would like to conserve fuel so you map out the shortest distance between the two cities. This turns out to be what we call a great circle route. For (almost) any two points on the earth there is one unique path that is the shortest distance between them. In geometry class you learned that the shortest distance between two points is a straight line. These great circle routes are straight lines in the generalized sense of lines drawn on a spherical surface. In geometry class you used flat pieces of paper, and on flat paper the sum of angles of a triangle is always 180 degrees, and the Pythagorean Theorem is always valid. If you learned geometry on a curved surface like the surface of the earth, you would have to learn new rules. The sum of angles in a triangle is always greater that 180 degrees, and the square of the hypotenuse is always greater than the sum of the squares of the other two sides. One more thing about the surface of the earth, it's a two-dimensional surface in the sense that it takes just two numbers to specify where you are on the surface. We call these two numbers latitude and longitude. All this is easy to understand because we can step back and see how this two-dimensional curved surface is imbedded in three-dimensional space.

Now here’s the hard part. Einstein says that three-dimensional space itself could also be curved, except now we can’t step back into four-dimensional space because there ain’t no such thing. All you can go on is that the sum of angles of a triangle might be greater or lesser that 180 degrees, and the square of the hypotenuse might be greater or lesser that the sum of the squares of the other two sides. Moreover, the deviation from equality would be immeasurably small unless your triangles were made up of cosmic distances.

Why is this important? It all gets back to gravity. According to Einstein, gravity isn’t really a force like for example magnetism. Rather gravity curves space slightly, and what seems to us like an object falling under the influence of the force of gravity is really an object following the shortest path in this curved space.

One more new concept and then I’m done playing with your minds. Space can not only curve, it can also stretch. To visualize this, imagine a balloon. Paint some dots on the surface. Name one of them earth and name the others after you favorite galaxies. Now slowly inflate the balloon. It remains a sphere (more or less), but the distance between any two points increases; and the farther apart they started, the more rapidly the distance increases. If fact, if you were a little two-dimensional astronomer on “earth” looking at the other dots with your two-dimensional telescope you would observe Hubble’s law! If you could deflate the balloon until it was nothing but a point, then all the galaxies would lie exactly on top of one another. This is what is frivolously called the “big bang” model of the universe. The entire visible universe started when all of space was compressed to a single point. Since then the galaxies have not been moving any more than your dots moved on the surface of the balloon. Rather space itself is stretching and carrying the galaxies along with it.

Now let’s take the cosmological principle and make the drastic approximation that all the matter in the universe is smoothed out so that it’s completely uniform. You might call this a toy model of the universe. In this case we can use Einstein’s terrible mathematics and get a rather simple pair of equations that describe the complete history and structure of the universe. We call this the Friedman model after the Russian mathematician who first worked it out. It makes some fascinating predictions. First it predicts that the universe must be either expanding or contracting. It simply cannot stand still. Here is a good analogy. Suppose you throw a stone into the air. It will come back down **unless** you throw it very fast, faster for example than a rifle bullet. Then it will escape the earth's gravity and keep on going forever. If you throw it at **exactly** the right speed it will escape the earth's gravity and after an infinite time coast to a stop. We call this the escape velocity. That speed turns out to be 11.2 kilometers per second, about ten times the speed of a rifle bullet. (We're ignoring air friction.) The point is that you can calculate this speed just knowing the pull of gravity. In this case you would need to know the radius and mass of the earth. So it is with the universe. It will either fall back on itself and collapse again, or it will continue to expand forever. It all depends on the pull of gravity. There is still the exceptional case in which it expands at exactly the right velocity and eventually coasts to a stop after an infinite time. It is not possible to have a static universe any more than it is possible to have a stone stand still in mid air. The universe is expanding, and in this case the Friedman model predicts Hubble's law. Furthermore, if we knew the density of the universe we could calculate the Hubble constant.

The model makes one other prediction; in general we expect space to be curved. If the density is large enough so that the universe will eventually contract, then the space will have a positive curvature. If you travel in a straight line in any direction you will eventually come back to where you started. If on the other hand, the density is small enough so that the universe will expand forever, the curvature will be negative. There is the all-important exceptional case in which the density is exactly right so that the universe will expand but eventually coast to stop, in which case the geometry is flat, and what you learned in high school geometry class is in fact true even over cosmic distances. This is called the critical density. It turns out to be a very small number, about equivalent to six hydrogen atoms per cubic meter. This is much smaller than the best vacuum we can achieve here on earth, but as it turns out, much greater than the density of ordinary matter in outer space.

So what will it be; an open or closed universe, negative or positive curvature, infinite expansion or eventual collapse? The answer turns out to be none of the above. The universe as far as we can tell, and this to about 1% accuracy, is flat! It seems to follow that the density of the universe must be the critical density. Now here's the big surprise. We can measure the density of ordinary matter fairly well, and it’s only 4% of the critical density! We are really missing something here! 96% of the matter and\or energy of the universe is in some form about which we know nothing. If, as is conjectured, some of this mass is in the form of sub-atomic particles, then there must be a billion of them passing through your body at this very moment!

There was still one more surprise in store for cosmologists. The Friedman model seems OK for the average properties of the universe, but in the 1990’s it became possible to look at very distant galaxies and measure their distance and velocity fairly well. It turned out that they were receding at a faster rate than Hubble’s law would predict. There is some force, a sort of anti-gravity that is tearing the universe apart! So in addition to the sort of matter and radiation that we know about, there are two more components of the universe. One is called dark matter. So far as we can tell, it must be in the form of sub-atomic particles that have mass and thus respond to and create gravitational forces, but interact with ordinary matter so weakly that they have never been detected. Their presence does have several indirect effects that can be measured. For one thing they affect the rotation of galaxies. This is big effect that has been known, if not understood, for a long time. Not only that, but because dark matter has mass it can curve nearby space. As a consequence light from distant galaxies doesn’t follow straight lines but is deflected in small random ways. This effect can be used to map out the distribution of dark matter as the next slide shows. It is ironic that even though we have no idea what dark matter is, we can “see” it in the above sense, and although I can’t go into the details here, we can measure its density. It turns out that it is 23% of the critical density.

So ordinary matter comprises 4% of the critical density and dark matter comprises another 23%. What about the missing 73%? That’s the part we call dark energy. It is a sort of negative gravity. It’s negligible over short distances, but over very large distances it has a repulsive force. It has another peculiar property. Its density is always constant, **even while space itself is expanding**. Consequently, as space expands it contains more and more dark energy. For the first ten billion years or so there was insufficient dark energy around to have any effect, but recently it has begun to take over. The expansion is accelerating and the acceleration is accelerating. The universe is destined to be ripped to shreds.

So let's review the plot so far. The universe is infinite so far as we know, it has flat Euclidean geometry, and it's expanding. If it always expanded at the same rate at which it expands now, then there was a time, about 13.5 billion years ago, when the visible universe was compressed to a single point. Now what happens when you compress something? For example, what happens when some air and gasoline vapor are injected into the cylinders of your car and then compressed by the piston? They heat up. The universe works the same way; in the past it was denser and hotter. There are simple relationships between density, time, and temperature, so we can specify the age of the universe by saying how many years elapsed since the big bang or we can specify its temperature. That raises an interesting question; what is the temperature of the universe today? Suppose you took a thermometer into outer space, what would it read? Remarkably that question has an answer. There is a great flood of radiation left over from the creation of the universe. We call it the cosmic microwave background. There are perhaps a billion of these leftover photons passing through your body this very instant. If you have an old-fashion black-and-white television set with an antenna and set it to a channel where there's no signal, then some of the little flecks of "snow" you will see come from photons left over from the big bang. These photons have exactly the energy distribution of radiation coming from an object with a temperature of 2.73 K above absolute zero. So that's the temperature of our universe now, 2.73 K. It's a famous number.

Now with this number firmly in hand we can "run the clock backwards" and watch what happens as the universe heats up. At a few hundred degrees above room temperature molecular bonds begin to break up. This is what cooking is all about. Now run the clock backwards a long time until the universe is only 350,000 years old and its temperature is 3000 K. At this temperature atoms begin to break up and lose their electrons. In particular, hydrogen, which is the major atomic ingredient of the universe at this time, ionizes. Since light travels with a finite speed, when we look out into space we look backwards in time. When we see a galaxy 10 billion light years away, we see it as it was 10 billion years ago. Following this line of reasoning, you might think that we could look back even further to the beginning of the universe. Alas, it's not possible. When the hydrogen is ionized and there are free electrons around, light can't penetrate, or more correctly, light travels through a free electron gas the way light travels through a fog bank. The light comes through, but you can't see into the fog. So that's what we see when we look back in time with the right kind of telescope, a huge glowing object with a temperature of 2.73 K, which is the infant universe. To look back in time further than this we need the eyes of theory. The next milestone occurs when the universe is only three minutes old and its temperature is one billion degrees. At this point, atomic nuclei break up, or, running the clock forward, atomic nuclei form. This is a very important event from the point of view of our existence, and I will come back to it in a moment.

As we turn the clock back and turn the temperature up, there is a point when the protons and neutrons themselves break up into quarks. Beyond this even the eye of theory fails. The universe attains temperatures corresponding to energies higher than anything we can produce with particle accelerators. Beyond that we reach the ultimate limit to our present knowledge. At times on the order of 10^-42 seconds there is a realm where both gravity and quantum mechanics are relevant. No one has been able to construct a theory in which these two realms of physics are unified. This is the ultimate barrier to seeing back to the moment of creation.

That's the basic plot. Along the way at least five things happened, or didn't happen, which are crucial to our existence as carbon-based life forms. These things are all so remarkable I need to tell you about them in some detail. The first is that the universe emerged from those early moments with exactly the critical density. If the density were ever so slightly greater than critical, the universe would have re-collapsed long before we came along. If it had been slightly less, the universe would have flown apart so fast that galaxies and stars could not have formed. The amount of fine tuning required to get the universe just right is truly remarkable as the next slide shows.

The next milestone occurs at three minutes when the first stable nuclei are formed. It happens in several steps. First deuterium is formed from a neutron and a proton. Then another nucleon is added to make He3, then another to make He4. A similar process occurs in stars. Four protons are fused together to make helium. This reaction releases energy. This is how most stars get their energy. This is how our sun shines. But the whole chain of events depends very sensitively on the strength of the force that holds neutrons and protons together. If it were slightly weaker, helium could never form. Stars would have no source of energy, and the universe would be cold sterile and dark. If the force were ever so slightly stronger, protons could stick together. Rather than forming deuterium, the early universe would have formed di-protons. The neutrons would then have decayed away. The di-protons would all have repelled each other so stars could not even form let alone shine.

Let me tell you some more about stars. The early universe produced deuterium and helium but not much else. Stars get their energy by converting hydrogen to more helium. But there are no helium-based life forms. Where did all the carbon and oxygen come from? It turns out that all the heavier elements are produced in the death throes of old stars. It works like this: when stars use up their proton fuel there is no longer enough heat energy to resist the force of gravity, and the star is gradually squeezed to death. But when the core of a star become dense enough it becomes possible to convert the helium “ashes” into carbon, the carbon into oxygen, the oxygen into calcium, and so forth. Each step up the periodic chart releases a little more energy, which postpones the death of the star. Eventually the star produces iron, and that leads immediately to its violent death. The problem is that creating elements heavier than iron absorbs energy rather than releasing it. Gravity has finally won the battle. The star collapses into itself, and then explodes hurling its spent nuclear fuel – all the heavier elements that make up our world – into space. The detritus of such explosions eventually coalesces with primordial hydrogen to form new stars and the cycle repeats.

Let’s think about this for a moment. First, all the elements in your body except hydrogen were forged in the last few days or minutes of a dying star. It is doubtful that one star cycle would have produced enough heavy elements to make a solar system like ours. It must have taken several cycles, and this all takes a long time. The universe has been working on this for billions of years. It took nine billion years to make our solar system and another 4.5 billion years to make us! Only in a universe this old are we carbon-based life forms possible.

There is a fine point here that is especially remarkable. I said glibly that the stars converted helium to carbon. You might think this would happen in two steps. First stick two helium nuclei together to make Be8, then add another helium to make carbon. The trouble with this scenario is that there is no such thing as Be8! In order to make carbon, three helium nuclei have to fuse together simultaneously. This in turn requires that the nuclear forces have to be exquisitely fine-tuned. I won't go into the technical details here, but some people have claimed, naively perhaps, that this alone was a sufficient proof of the existence of God!

I mentioned that when we look out into space with radio telescopes we see the faintly glowing remains of the primeval fireball with its famous 2.73 K. There are at least two remarkable things about it. One is that the temperature is almost exactly uniform throughout. The other is that the temperature is not quite exactly uniform throughout; some parts are warmer than others by about one part in a hundred thousand. This number, one part in a hundred thousand, is another one of these famous numbers often called Q. We have some vague ideas about how these fluctuations came about but no idea why Q has the value it has. Why is this significant? Over the next few hundred million years these non-uniformities grew and seeded the formation of galaxy clusters, galaxies, and eventually, stars. If Q were larger by a factor of ten, for example, the universe would be a turbulent and violent place. Regions far bigger than galaxies would condense early in its history. They wouldn't fragment into stars but would instead collapse into vast black holes, each much heavier than an entire cluster of galaxies in our universe. If Q were smaller by a factor of ten, Galaxies would be anemic structures in which star formation would be slow and inefficient, and 'processed' material would be blown out of the galaxy rather than being recycled into new stars that could form planetary systems.

One of the most puzzling of these cosmic coincidences has to do with the existence of antimatter. According to quantum theory, for every particle there is a corresponding antiparticle. For every electron there is an anti-electron (usually called a positron). For each proton there is an anti-proton, etc. If you put a particle together with its antiparticle, they annihilate one another in a burst of photons. All this is well known and can be duplicated in the laboratory. We keep track of protons and antiprotons using a quantity called baryon number. Each proton carries one unit of baryon number and each antiproton has baryon number minus one. So far as we know, this number is always conserved. By this we mean that whatever happens to a group of particles, the total baryon number remains constant. One proton plus one anti-proton have total baryon number zero. Put them together and out comes a burst of photons all of which have baryon number zero. So what is the baryon number of the universe? Well it’s just equal to the number of protons plus the number of neutrons. It seems like a very big number. But is it? The very early universe would have been so hot that protons and anti-protons would have been produced in equal numbers. The same is true for all the other particle-anti-particle pairs. As the universe cooled down, all the particles and anti-particles should have annihilated one another leaving a vast number of photons. This is more or less what we see. There is no anti-matter (except that which we produce artificially) and an enormous number of photons. But why are there still protons and neutrons around. There are really not many of them; one proton for every ten billion photons. But why is the number not zero? Why does the universe have some net baryon number? It seems that the laws of physics, as we currently understand them, are violated once in every billion annihilations. If they were not, we would not be here.

One last puzzle – why do we live in a three-dimensional space? You might think this an odd question. What other kinds of space are there, you might ask. But mathematically we can describe a space in any number of dimensions. One dimension or forty-two; it’s all the same to a good mathematician. But life is not possible in two dimensions. For one thing, you can’t have complex networks without getting your wires crossed. Try drawing a circulatory system in two dimensions. Higher dimensions won’t work either, because there are no stable planetary orbits. The universe came into existence in three dimensions, and we have no idea why. I can’t even think up a theory that would give the wrong reason, let alone the right one.

I hope I have convinced you that the universe is exquisitely fine tuned in such a way as to make our existence possible. What are we to make of this? One response is that if the universe was not so adjusted we wouldn’t be here to discuss the matter. End of discussion! This is called the anthropic principle. It may seem like a truism, but think again. The following example comes from the philosopher, John Leslie. Imagine that you are condemned to die in front of a firing squad. Fifty of the finest marksman line up and on command fire. A second later you find that you are still alive! What’s going on here? You might argue, in keeping with the anthropic principle, that if you weren't alive you wouldn't be wondering about it. End of discussion. But you are alive, so there must be something more to the story. Perhaps it's a sham execution. Perhaps they are all drunk. Perhaps they were given blank ammunition by mistake. I agree with Leslie. When it comes to the universe, there must be something more to the story.

So what is the more to the story? Let's say that the universe was created this way by God for our benefit and for His. I have no objection to bringing God into the picture, but I find this answer unsatisfying. The problem is that it explains too much. Why is the moon made of green cheese? Because God made it that way. If it turns out the moon is really made of salami, then God must have created it that way. As we physicists like to say, a theory that explains everything, explains nothing. In more high-faulting terms, the theory isn't falsifiable.

The currently fashionable explanation among physicists is that there are many, perhaps an infinite number of other universes. The parameters we have been discussing, perhaps the very laws of physics, are different in the various universes. We, quite naturally, live in the one in which life is possible. As an explanation I find this even worse. First, it's wildly extravagant. An infinite number of universes, for heaven's sake. I suspect that scientists are so unwilling to get into theology that they champion this desperate hypothesis. It is possible in a vague way to imagine theories that would allow multiple universes, but there is no evidence at present that such universes exist. Again the theory is not falsifiable. Our universe must have whatever properties it has. End of discussion. Finally, it doesn't really solve the God problem. It just pushes it back one step. The multiple universes must have developed from some prior conditions according to some physical laws. These laws and these conditions must have been adjusted so that at least one of the many universes might contain us. Second thought – I like this idea. Perhaps God's labor in creating us was even more prodigious than we could have possibly imagined!

Or perhaps we should heed the advice of the philosopher, Ludwig Wittgenstein,

"Whereof one cannot speak, one must be silent."