there is a God whose nature defines 'truth' and 'good' and 'beauty'. C. S. Lewis applied this argument not just to science but to the question of why there is any good/evil orientation in the universe at all.

Nature fills us with delight and awe. It moves us profoundly in ways that are difficult to express or assess and leads us to ask questions science may never be able to answer. But does it point to God? Before Darwin, many of our forebears had no philosophical misgivings about singing a hymn set to the music of Haydn whose last stanza, after admitting that the stars and planets have no voices in the usual sense, nevertheless says that 'In reason's ear', they unmistakably declare, 'the hand that made us is divine.'[49] What sort of reason would we have to employ to hear that declaration today?

Kitty Ferguson
The Fire in the Equations
Grand Rapids:
Erdman's Publishing

4

ROMANCING THE CREATION

The evolution of the world may be compared to a display of fireworks that has just ended: some few red wisps, ashes and smoke. Standing on a cooled cinder, we see the slow fading of the suns, and we try to recall the vanished brilliance of the origin of the worlds.

GEORGES LEMAÎTRE

OUR LATE TWENTIETH-CENTURY PICTURE OF THE UNIVERSE IS dramatically different from the picture our forebears had at the beginning of the century. Today it's common knowledge that all the individual stars we see with the naked eye are only the stars of our home galaxy, the Milky Way, and that the Milky Way is only one among many billions of galaxies. It's also common knowledge that the universe isn't eternal but had a beginning ten to twenty billion years ago, and that it is expanding. We take all this so much for granted now that it's hard to believe how far we've come in the past ninety years in the quest to discover the origin of the universe.

In spite of our greater understanding, the universe has become in many ways even more mysterious to us than it was to earlier generations. It is not a familiar, cosy place. It stretches out to distances inconceivably vast and contains systems driven by incredible power. Earth now seems tiny and insignificant, a speck, a cooled cinder. It would appear that if we humans are of

any interest to the Mind of God, God carries to an absurd extreme the credo of Dr Seuss's elephant Horton: 'A person's a person, no matter how small.'[1]

The first part of this chapter is a short review of the chain of theoretical and observational discovery which led over a period of years to the conclusion that the universe began with a Big Bang. We will also look at the philosophical and religious controversy which greeted these astounding and sometimes unwelcome developments. Those to whom this story is already familiar may want to move quickly through these pages to the middle of the chapter and more contemporary debates.

THE UNCOMFORTABLE CONCEPT OF A BEGINNING

By the end of the First World War there was no concrete evidence that the turn-of-the-century picture of the universe was incorrect, but there were suspicions. Since the eighteenth century there had been speculation about fuzzy patches of brightness called the nebulae. It seemed most likely they were only gas clouds in our galaxy, but some people entertained wilder ideas: they might be newborn solar systems, or fissures in the universe where matter and energy pour in from another universe or another dimension, or remote, independent formations of stars and gases like the Milky Way. Perhaps the Milky Way was only one among many 'island universes'.

In the early years of the twentieth century, attention had begun to focus on those nebulae that had a spiral structure, because many astronomers thought these were protostars – clouds of collapsing gas on the point of giving birth to a star. Between 1912 and 1914, Vesto Slipher at the Lowell Observatory in Flagstaff, Arizona, discovered that most of the spiral nebulae he was studying showed a red shift: that is, a shift in the colours of the spectrum of light away from the blue end of the spectrum and toward the red end. Slipher interpreted this shift in the light coming from the nebulae to mean that the distance between us and them was growing greater, just as we interpret the drop in the pitch of an engine or siren to mean that a vehicle is moving away from us – the familiar Doppler effect. In both cases the shift is

caused by the stretching of waves that reach us from something as its distance from us increases. In the case of the siren, sound waves are stretched. Our ears interpret the length of a sound wave as pitch; we 'hear' longer sound waves as a lower pitch. In the case of the spiral nebulae, light waves are stretched. Our eyes interpret the different lengths of light waves as different colours, and longer light waves mean a shift to the red end of the spectrum. The sort of red shift Slipher was discovering is not detectable to the naked eye as reddening light. He based his conclusions on calculations made by studying the spectra of light from the nebulae and comparing them with the spectrum of light from something whose distance from us is not changing.

What Slipher had found was revolutionary. In 1914 he presented his findings to the American Astronomical Society. John Miller, who had been one of Slipher's professors, described the event: 'Something happened which I have never seen before or since at a scientific meeting. Everyone stood up and cheered.[2] The turn-of-the-century picture of the universe was on the brink of crumbling.

Clearly Slipher had made a discovery of enormous importance, but it wasn't immediately obvious what it meant. Slipher's interpretation was that our own drift through space was causing the increasing distance between us and the nebulae. Since we don't think of the universe in terms of absolute position, it might seem a moot point who is retreating from whom, but Slipher's 'drift' didn't take into account the more dramatic implications of his discovery. Those wouldn't emerge until many more observations had been catalogued.

One problem with interpreting the significance of the red shift was that no-one was yet able to determine how far away the spiral nebulae were. The difficulty with measuring distances to objects in space is similar to the difficulty we have in judging the distance between ourselves and a light shining at night: is the light a few feet away and very faint, or is it a few miles away and very bright? Though the distance of the nebulae was still in question at the time of Slipher's announcement, astronomers were not far from having the answer. Since the last decade of the nineteenth century, they'd been devising increasingly sophisticated ways of measuring such distances.

Meanwhile, what were the theorists saying? Einstein produced his Theory of General Relativity in 1915. Within the next two years, Dutch astronomer Willem de Sitter and Einstein himself began to see that solutions to Einstein's equations implied that the universe is expanding. Einstein, like most of his contemporaries, believed the universe is static, that is, not changing in size. When the implications of his equations began to emerge, he was chagrined. As he wrote in a letter, 'To admit such a possibility seems senseless.'[3] He decided to adjust his theory to cancel out the prediction of an expanding universe by putting in a new constant of nature – a 'cosmological constant', a mathematical term which corresponded to a force of repulsion or 'anti-gravity'. Einstein was later to dub this cosmological term – this concession to his own preconception and that of his contemporaries – 'the biggest blunder of my life'.

The Russian mathematician Alexander Friedmann was the first to buck the spirit of the times emphatically and insist on taking Einstein's theory at face value, not assuming that the 'cosmological term', if it had to be considered at all, was necessarily anything other than zero. What Friedmann found was not just one solution but a family of solutions to the cosmological equations of General Relativity, and each different solution describes a different sort of universe.

The Belgian astrophysicist and theologian Abbé Georges Henri Lemaître – with whose words we opened this chapter – found solutions to Einstein's equations which were similar to Friedmann's. However, unlike Friedmann, Lemaître was most intrigued with what the equations and their solutions could tell him about the origin of the universe. It was he who first envisioned something like what we now call the Big Bang, though he didn't give it that name. Partly because he was a priest as well as an astrophysicist, this idea was met with some derision from fellow scientists. Lemaître's suggestion was that there had been a time when everything that makes up the present universe was compressed into a space only about thirty times the size of our sun – a 'primeval atom'. As he put it, 'The primeval atom hypothesis . . . pictures the present universe as the result of the radioactive disintegration of an atom.'[4] By the time Lemaître wrote those words in the fifties, he was speculating that this primeval atom might be thought of as a single quantum.

While Friedmann's theoretical work remained largely

unknown except among mathematicians – he died in obscurity at the age of thirty-seven – Lemaître's gained the attention of observational astronomers, largely thanks to Eddington (whose student Lemaître had been at Cambridge) and another of Eddington's research students, George McVittie.

Meanwhile, back in Arizona, Vesto Slipher continued to design his own instruments for studying the nebulae and discovered that most he was able to study showed red shifts. In early 1921 he reported an enormous red shift (or what seemed enormous at the time) for a nebula called NGC584. According to Slipher's calculations the nebula's distance was increasing at a speed of approximately two thousand kilometres per second. In 1922 Slipher sent Eddington at Cambridge measurements for forty spiral nebulae, thirty-six of which were receding.

When Slipher first announced his findings about red shifts in 1914, a young man named Edwin Hubble had been in the audience. In the years that followed, Hubble began to see the connection between Slipher's observational discoveries and the solutions that de Sitter (and Lemaître and Friedmann – though Hubble may not then have known about their work) was getting from Einstein's equations. Hubble also turned his attention to the nebulae. In 1923 he realized that a faint spot of light in the Great Nebula in Andromeda was not a nova, as he had previously thought, but a Cepheid – a star that regularly changes its brightness. It was this realization that enabled him finally to settle the question whether the nebulae are something in our galaxy or remote, independent 'island universes'. Astronomers had learned how to calculate the distance to a Cepheid by timing these variations. Hubble's calculations showed that the Andromeda nebula is at a distance much greater than any star in the Milky Way. It is indeed another galaxy.

Hubble went on to establish that there are many galaxies besides our own, and in 1929 he made one of the most revolutionary announcements in the history of science, one that was to change forever our ideas about what the universe is like, about its history, and about ourselves. He and his associate Milton Humason, a colourful character who had begun not as a scientist but as a mule driver at the Mount Wilson Observatory, established that except for galaxies that are clustered closest to us every galaxy in the universe is increasing in distance from us.

Moreover, except for galaxies which are close together, every galaxy in the universe is increasing in distance from every other galaxy.

The observations continued, and more and more galaxies and red shifts were catalogued. By the early fifties the relationship between what astronomers were discovering with their telescopes and the theoretical predictions of Einstein, Friedmann, and Lemaître was clear. The red shifts become greater the farther away a galaxy is from us, which tells us that the farther away the galaxy is, the faster it's receding. As Friedmann had predicted, regardless of where we were to station ourselves in the universe, in any galaxy, we would see the other galaxies receding from us, twice as far away, twice as fast. A loaf of raisin bread rising in the oven is a homely analogy to illustrate this. Standing on any raisin while the dough rises and expands between the raisins, we would see every other raisin moving away from us – twice as far away, twice as fast. The raisin bread also reminds us that it is more accurate to think of the expansion of the universe, as Friedmann first suggested, not in terms of galaxies flying away from one another through space, but in terms of the space between them swelling.

One might easily jump to the conclusion that if the universe is expanding like a loaf of raisin bread, we ought, if we had the technology to do so, to be able to travel to the surface of the loaf and find the edge of the universe. What would be beyond? The question of what is beyond the edge unfortunately has no real meaning. Eddington suggested that we think of a balloon with dots painted on its surface. Imagine an ant crawling on the surface of the balloon. In order for the analogy to be helpful we must say that for this ant all that exists is the surface of the balloon. The ant can't look outward from the balloon's surface or conceive of an interior to the balloon. Those dimensions don't exist for the ant. Now if air is let into the balloon and the balloon expands, the ant will see every dot on the surface of the balloon moving away from it. Regardless of where the ant travels on the balloon, every dot will be moving away. The ant won't find an edge or an end anywhere. The same may be true in our universe, but with more dimensions than in the ant's balloon universe.

Another conclusion to which we might jump is that we ought to be asking where in the universe the expansion began. Where is

the point everything is retreating from? One way of thinking of the expansion of the universe is as an explosion outward. Even if there are no absolute directions in the universe, beings riding on a piece of debris from any explosion ought to be able to assume that there is an answer to the question: Where exactly did the explosion take place in relation to where we are now? Eddington's balloon analogy helps us understand why there is no such point of origin in the universe. On the balloon surface, there is no such point – or, if you prefer, any point could just as fairly claim to be the point of origin. Remember that the interior of the balloon is a dimension that doesn't exist. Modern cosmology accepts Friedmann's assumptions: the universe looks the same (on the large scale) in all directions; and regardless of where we were to stand in the universe it would look the same in all directions. There is no edge from which we would see galaxies in one direction and nothing in the other. There is no core toward which we could point and say, There it began.

We can, however, ask *when* the universe began.

Any direction in space we look, no matter where in the universe we are, we look toward the past. Even in so small a space as the room where I sit and write, what I see is old news. However, the delay with which the picture of the far wall reaches my eyes is not worth considering, because light – and thus any picture that comes into my eyes – does travel extremely fast.

When it comes to cosmic distances, the delay is decidedly worth considering. The light that reaches us from some distant quasars left them perhaps ten billion years ago.[5] Are the quasars still there? In give-or-take another ten billion years our descendants on the earth (if descendants and earth still exist) might find out whether these quasars, or the galaxies into which they may have evolved, were still there in the 1990s (earth time). From our own vantage point, we can only observe their existence ten billion years ago. Since the past is in all directions, then out there – some distance beyond the quasars – is the answer to the questions: Did the universe have a beginning, and, if so, when?

Fortunately, there are other ways of finding the answers to those questions besides actually seeing the split second of the origin of the universe – an observation which is not possible with our technology and perhaps not with any we could ever invent. If the universe is expanding, it would seem correct to think that it must at an earlier time have been, as Lemaître insisted, much denser than it is now. In fact it would seem correct to think that there was a time when everything we would ever be able to observe in the universe was in exactly the same place, and that this must have been the beginning.

Must that have been the case?

In 1948 Hermann Bondi, Thomas Gold, and Fred Hoyle introduced theories which allowed for the expansion of the universe but did away with the requirement that the universe must have a beginning. According to their 'Steady State' theory, the universe hasn't always contained all the matter it does today. As the universe expands, new matter continuously emerges to fill in the gaps, and the average density of matter in the universe remains the same. Galaxies such as ours reach the end of their life cycles – when the stars in them burn out and the galaxies die – but meanwhile new galaxies are forming from new matter.

A Steady State universe would have no beginning or end. This return to the possibility of an eternal universe was welcomed by many, including the theorists who invented it, as a way of eliminating the hint of 'creation' that was inherent in a universe with a beginning. For more than a decade the scientific and (to a lesser extent) the philosophical debate continued between those who favoured the Steady State theory and those who favoured the Big Bang.

It may be difficult from our vantage point to understand why the notion of a beginning presented a major philosophical problem for anyone. Today almost all scientists accept some version of the Big Bang theory, yet we still find atheists and agnostics as well as believers in God among them. Clearly having a Big Bang must not prove decisively that we have a God. As we will see a little later, having a Big Bang doesn't even prove we have a beginning. Why were Bondi, Gold, Hoyle, and some of their colleagues so concerned? We must try to see this from the point of view of those who debated it in the late forties and the fifties.

To a certain extent it was true that as the Big Bang theory began to look increasingly likely to be the correct one, the anti-God camp seemed to be losing ground to the pro-God camp, but that was not the whole story. In Chapter 3 we saw how Robert Jastrow, himself an astronomer and an agnostic, in his book *God*

and the Astronomers, chides his fellow scientists for their reaction to the Big Bang theory: 'the response of the scientific mind – supposedly a very objective mind – when evidence uncovered by science itself leads to a conflict with the articles of faith in our profession.' Jastrow describes the situation:

> This is an exceedingly strange development, unexpected by all but the theologians. They have always accepted the word of the Bible: In the beginning God created heaven and earth. To which St Augustine added, 'Who can understand this mystery or explain it to others?' The development is unexpected because science has had such extraordinary success in tracing the chain of cause and effect backward in time . . .
>
> Now we would like to pursue that inquiry farther back in time, but the barrier to further progress seems insurmountable. It is not a matter of another year, another decade of work, another measurement, or another theory; at this moment it seems as though science will never be able to raise the curtain on the mystery of creation. For the scientist who has lived by his faith in the power of reason, the story ends like a bad dream. He has scaled the mountains of ignorance, he is about to conquer the highest peak; as he pulls himself over the final rock, he is greeted by a band of theologians who have been sitting there for centuries.[6]

However, as Jastrow himself pointed out, the controversy was much more complicated than a simple competition between science and religion in which religion had apparently won a major victory. It isn't God that Jastrow's scientists find when they pull themselves over the final rock. It is a band of people, including presumably St Augustine, faced with a closed door at a beginning in time through which we are not allowed to pass in our search to know everything.

The irony in Jastrow's story is not that the theologians have had it all explained for a long time, while the scientists have not. The irony is rather that the theologians have been saying for many centuries that we are dealing with a mystery human beings will *never* be able to explain, and now the scientists, by dint of hard labour trying to find that explanation, have to their chagrin arrived at the same conclusion. It isn't the discovery of God, but

rather the discovery of the limits of human intellectual endeavour that rots everyone's socks on the mountaintop. The theologians have learned to live fairly comfortably with those limitations and put down roots and even enjoy the situation. The advantage they claim to have, and if it's true it is a very great advantage, is that they believe the end of human intellectual endeavour isn't necessarily the end of the quest for complete understanding.

For a while the Steady State theory that allowed one to believe that the universe was eternal held its own and seemed a powerful rival to the Big Bang theory. Both theories seemed equally capable of explaining what had been found by observation. However, in the sixties, new evidence came to light which the Steady State theory could not explain and the Big Bang theory could.

Back in the 1940s, George Gamow, a Russian-born physicist who defected to the West in 1933, had begun, with Americans Ralph Alpher and Robert Herman, to theorize about the early universe by running Friedmann's equations backward toward the event with which the universe began. They predicted that there should be left-over radiation – photons (messenger particles of the electromagnetic force) – surviving from about a thousand years after the origin of the universe. In that era the universe would still have been very hot, but the prediction was that the temperature of those photons should by now have cooled to about five degrees above absolute zero. Such radiation would be very difficult to observe, and the prediction was not tested. The evidence of that radiation was finally discovered by accident in 1965. The story of the discovery recalls our discussion of the interplay between theory and direct observation in Chapter 3. It is an instance in which theory didn't lead the way but rushed in with the spectacles needed to make sense out of otherwise puzzling data.

In the mid-1960s, at Bell Laboratories in New Jersey, there was a horn antenna designed to be used with the Echo I and Telstar communication satellites. The amount of background noise the antenna picked up hampered its use in the study of signals from space. Scientists working with the antenna had to make adjustments and confine themselves to studying signals that were stronger than the noise. It was an annoyance that was possible to ignore, but two young scientists, Arno Penzias and Robert

Wilson, took the noise more seriously. They noticed that the noise remained the same no matter which direction they pointed the antenna. If the noise were a result of the earth's atmosphere, that wouldn't be the case, since an antenna pointed toward the horizon faces more of the earth's atmosphere than one pointed straight up. The noise had to be coming either from beyond the earth's atmosphere or from the antenna itself. Wilson and Penzias thought pigeons nesting in the antenna might be causing the disturbance, but evicting the pigeons and clearing away their droppings made no difference in the noise.

Wilson and Penzias weren't aware of a current proposal from Robert Dicke at Princeton, who was in the process of building an antenna to search for the background radiation that Gamow, Alpher, and Herman had predicted in the 1940s. But when another radio astronomer, Bernard Burke, heard from Penzias and Wilson about their problem with the antenna, he proceeded to bring the two groups of researchers together. Penzias and Wilson had found by accident the radiation that Dicke, led by theory, had been hoping to find.

In 1973, balloon experiments of Paul Richards and others at Berkeley in California showed that the spectrum of the background radiation was the spectrum Big Bang theory predicted. The cosmic background radiation (as it is now called) has been confirmed by many experiments and is the most direct evidence we have that the universe was once very much hotter and denser than it is now. The radiation as it reaches us has a temperature of about three degrees above absolute zero, instead of the five degrees Alpher and Herman had calculated. Today we know that you don't need unusual equipment to observe the cosmic background radiation. The snow on a TV screen that appears when a station isn't broadcasting consists in part of this radiation – these photons which are artefacts of ancient light.

The discovery of the cosmic background radiation and its spectrum was dramatic support for the Big Bang theory. There was more. The theory predicts that, of all the elements making up the universe, about 25 per cent of the mass ought to be helium 4. . By the mid-seventies, measurements of the elements in external galaxies (a measurement which is possible by studying their spectra), as well as in our own galaxy, confirmed this prediction. They also confirm predictions of abundances of other elements that were made in the Big Bang, such as deuterium, helium 3, and lithium.

More support for the theory came from the fact that it suggests a solution to the mystery of why we find quasars only at such large distances from us. Most astrophysicists link quasars with galaxy formation. If galaxies were periodically dying and being replaced by new galaxies made from new matter, as the Steady State theory would have it, then we ought to find quasars fairly evenly scattered throughout the universe. On the contrary, we find no quasars near us. They are all far away, and, by virtue of that fact, long ago. It's understandable why this is so if galaxy formation occurred mainly during one era far back in the history of the universe, and is not a continually recurring process. Looking to the distance where the quasars are, we are seeing the universe in that era of galaxy formation. The information from there has taken a long time to reach us. Old news indeed, but it seems to indicate that we are in a universe that is evolving over time, a universe like the Big Bang universe, not the Steady State universe.

While observational evidence was confirming the Big Bang, theorists were providing further support and putting an additional padlock on the slammed door at the beginning of time. It had become clear that if general relativity is correct, it's overwhelmingly probable that the universe will be either expanding or contracting. A static universe in that theory is about as stable as a pencil standing on end. Nevertheless the question arose, If a universe is expanding, even if it isn't a Steady State universe, does that necessarily mean that everything in it was in the same place at some earlier time?

In 1963 Russian scientists Evgenii Lifshitz and Isaac Khalatnikov suggested another possible history for an expanding universe. Running time backward, imagine a scenario in which a universe something like ours contracts, with all its galaxies getting closer together, apparently on collision course. Looking more closely at the galaxies, we notice that they have other motion in addition to the motion that's drawing them directly toward one another. When the galaxies approach one another, this additional motion might cause them to miss one another, fly past – and the universe expand again without having reached a state of infinite density.

It was this possibility that interested Hawking and Roger

Penrose in the middle and late 1960s, about the same time Wilson and Penzias were puzzling over the cosmic background radiation. General relativity predicts the existence of singularities – points of infinite density and infinite spacetime curvature – but in the early sixties few physicists took this prediction seriously. Some thought that a star of great enough mass undergoing gravitational collapse might form a singularity at the centre of a black hole. No-one yet had claimed that it MUST.

Though some of John Wheeler's students say they heard him use the words earlier, 1967 is usually the date given for his coining the term 'black hole'. However, the study of black holes began well before that, as we learned in the story about Chandrasekhar in Chapter 3. In 1965 Penrose, building on earlier work of Wheeler, Chandrasekhar, and others, was able to show that if the universe obeys general relativity and several other constraints, when a very massive star has no nuclear fuel left to burn and collapses under the force of its own gravity it will inevitably be crushed to a point of infinite density and infinite spacetime curvature – a singularity. This will happen even if the collapse isn't perfectly smooth and symmetrical. No 'might' about it. It must.

Hawking took off from there. In his doctoral thesis at Cambridge in 1965, he reversed the direction of time and applied the concept to the entire universe. He suspected that what we would see if we could watch the expansion of the universe run backward was similar to what Penrose had found with black holes. Once the collapse (the expansion of the universe run backward) had gone far enough, the additional motions of galaxies would make no difference to the history of the universe. By 1970 Hawking and Penrose were able to show, in Hawking's words, 'that if general relativity is correct, any reasonable model of the universe must start with a singularity'[7], with everything we would ever be able to observe in the universe compressed not to the sphere Lemaître envisioned, but to infinite density. Spacetime curvature at the singularity would also be infinite. The distance between all objects in the universe (though calling them objects at this point would be inaccurate) would be zero.

THE GORDIAN KNOT OF SINGULARITY

The slammed door was now locked indeed. Physical theories can't work with infinite numbers. When the theory of general relativity predicts a singularity of infinite density and infinite spacetime curvature, it is also predicting its own breakdown. In fact all the theories of classical physics become useless at a singularity. There's no way to predict what will emerge. Standing at a singularity we can only wait to observe what's to come. In addition, we have no way of finding out why a singularity suddenly ceases to be a singularity and becomes a universe. Any leap of imagination is as good as any other. And what if we turn around to study the past? What happened before the singularity? It's not even clear that these questions have any meaning. A singularity at the beginning of the universe means that the beginning is beyond the limits of our science. All we can say is that time began, because we observe that it did. Hawking and Penrose had tied a true Gordian knot.

The Big Bang scenario for the origin of the universe had come to this:

In the beginning was the Singularity. Everything that was to be the matter/energy of the universe that we might eventually be able to observe was packed together in a point of infinite density. Ten to twenty billion years ago (as 'time' is measured in the space-time frame which was to follow), this 'exploded'. That was the Big Bang. To imagine the infinite heat of 'time zero' of creation is as impossible as imagining the point of infinite density. To imagine the light of it is also a meaningless endeavour, because light as we are able to see it didn't exist. After a time, matter, instead of radiation, began to dominate the universe. The universe expanded and cooled enough for electrons and nuclei to form stable atoms. Matter could begin coming together by dint of its own gravity, starting the process that would eventually lead to stars and galaxies and planets. Ten to twenty billion years after the beginning, we find the universe we know today.

I find myself picturing this process as though I were standing on the outside, watching it take place. But such a position doesn't exist. There was no 'outside' where I could have stood at the beginning, just as there seems to be none today – no vantage point beyond the universe from which to observe the universe.

Everything was within the point of infinite density. Everything was within the explosion. Everything still is.

This was the Big Bang creation story as it existed in the mid-1970s, and on the face of it it was a congenial one for those who believed in God or simply found eternity monotonous and weren't too terribly concerned if humans couldn't know absolutely everything. Both sides of the God-or-not debate – when it has seemed in their interest – have argued with great ingenuity that whether or not there was a Big Bang singularity isn't really relevant to the question of whether or not there is a God. But hardly anyone felt there was nothing at stake in the answer. A very young friend of mine summed it up in a truism: 'If there was a beginning, and we can know about it but we can't ever explain it, that's just a whole different kind of universe.' If you don't like this whole different kind of universe, then the next step is to get busy trying to explain the beginning – or explaining it away.

We have two tracks we must take now to follow this adventure up to the present. In the years since the mid-1970s, theorists and researchers have continued trying to solve problems that still existed with the Big Bang theory. Theorists have also got busy undermining the singularity.

We've said that by the early seventies it was clear that the Big Bang theory could explain much of what we were finding by means of observation, much that the Steady State theory couldn't explain. However, the Big Bang theory could not at that time (nor can it now) explain all the observational evidence. Two of the remaining puzzles have to do with the nature of matter.

First, how can we explain the fact that the universe has matter in it at all rather than being empty? The production of matter is no longer a complete mystery to us. We know how to produce a particle of matter out of pure energy in the laboratory. But we don't know how to do that without at the same time producing an equal amount of antimatter. According to Big Bang theory, a great deal of matter was produced out of energy in the early universe. This raises the question: What has happened to all the antimatter that must have been produced at the same time?

If equal amounts of matter and antimatter appeared in the early universe, as they do in the laboratory, we have every reason to expect that by now there would be neither matter nor antimatter left around, because when matter meets antimatter they annihilate in a burst of pure energy. Every particle of matter would long ago have met an equivalent particle of antimatter and they would all have annihilated each other. The whole game would have ended disappointingly, cancelling out like a card game of Old Maid where the Old Maid card is missing from the pack.

One suggested solution to this puzzle is that most of the antimatter is elsewhere in the universe, while our neighbourhood is an area containing mostly matter. The trouble with this idea is that there would be borders between the regions that had matter in them and the regions that had antimatter in them. It would be difficult not to notice where these borders lay, because matter and antimatter would be annihilating each other there in a way we are able to detect with gamma-ray detectors. So far no such activity has been detected in the region of space accessible to such detectors.

Another suggested explanation goes like this. When matter and antimatter first evolved in the early universe, there was a lot more of it than we see around today, with an imbalance (perhaps very small in proportion to the total amount of matter and antimatter) in favour of matter particles. After the big annihilation scene, there were left-over matter particles which hadn't found an antimatter partner with which to annihilate. These left-over matter particles, these Old Maid cards, make up all the matter of our universe today. We said in Chapter 2 that for the universe to exist as we know it a certain amount of asymmetry is required. If everything balanced out perfectly and came out even, we wouldn't have the universe. In this explanation for the origin of matter we see a good example of that necessary asymmetry.

If that's the way it happened, we still haven't solved our problem completely. How do we explain the initial imbalance, be it ever so small, between matter and antimatter? Some of the theories which propose to unify the forces of nature provide conditions under which such a situation of imbalance could occur, but so far we have no clear evidence to show which if any of these theories is correct or that these conditions existed. Some of the ingredients are there, but not by any means all. This mystery still remains unsolved.

A second problem concerning matter was, until the spring of 1992, even more of a challenge to Big Bang theory. In repeated

measurements researchers had found that the cosmic background radiation is remarkably uniform in temperature. Taking readings out to the end of observability in every direction, they found the temperature the same. This was clear evidence that the early universe was smooth, without lumps, clumps, and irregularities that would show up as fluctuations in the temperature of the radiation. Yet we also know that the universe we live in today contains galaxy clusters, galaxies, stars, and planets, and even such small clumps of matter as people. How did a universe that started out so smooth get lumpy?

Recall that every particle of matter in the universe attracts every other by means of gravitational attraction. The closer to one another the particles are, the stronger they feel each other's gravitational pull. Wheeler suggests that we should think of the universe as a giant democracy in which every particle has a vote to cast in the form of gravitational attraction. A single particle has very little voting power. Only when particles band together in a voting bloc – the earth, for instance – do they manage to wield substantial gravitational clout. If we imagine a situation where all particles of matter in the universe are equidistant, with no areas in which even a few particles have drawn together more densely to form the loosest sort of voting bloc, then in that situation every particle will feel equal pull from every direction and won't budge to move closer to any other particle.

It looked for a while as though we had discovered this sort of gridlock in the super-smooth early universe – a gridlock where matter was distributed so evenly that it would never yield to form the universe we have today. That sounds like a highly unlikely situation, but if it weren't the case in the early universe, why weren't we finding even the tiniest fluctuations in the background radiation – our 'picture' of how matter was distributed in an era not long after the Big Bang? You can see that it would take only a minuscule variation in that smoothness to let gravity go to work and pull things one direction or another in ways that would show up in the background radiation. The smoothness of that radiation showed us there was a missing link in the history that would connect our contemporary universe with the Big Bang.

When George Smoot, an astrophysicist at Lawrence Berkeley Laboratory and the University of California at Berkeley, and his cohorts at several other institutions announced in April 1992 that

new data from the Cosmic Background Explorer (COBE) satellite had revealed wrinkles in the fabric of the universe, wrinkles that must have been created by the Big Bang itself and not evolved later, the *New York Times* headline read: 'Astronomers Detect Proof of Big Bang.' So, in a sense, they had. The wrinkles were the fluctuations in the cosmic background radiation which astrophysicists had been looking for in vain almost from the time of Penzias and Wilson's initial discovery of that radiation in the 1960s. They were fluctuations of no more than a hundred-thousandth of a degree, but enough, the discoverers felt, to explain what had happened to the universe. These tiny variations in the topography of the universe when it was 300,000 years old were sufficient evidence of a gravitational situation in which matter would attract matter into larger and larger clumps.

There are other mysteries that those who study the Big Bang have yet to unravel. One of them has to do with the uniformity of the large-scale structure of the universe. We'll discuss that and the inflationary universe theories which may solve it in Chapter 5 in another context. Nevertheless, a wealth of evidence points to the fact that we do indeed live in a Big Bang universe.

Does an expanding universe, even a Big Bang universe, necessarily have to be a universe with a singularity at its beginning? Hawking and Penrose's calculations had said it did, but they and their colleagues were not happy with this conclusion. The singularity was derived from theory, not observation or experiment. It is a prediction we have no way of confirming or denying from observational evidence with our present technology, and perhaps not with any technology we will ever be able to invent. The theorists had discovered this Gordian knot, so it was the theorists who went to work trying to untie it. They decided to look at the origin of the universe not only with the spectacles of relativity theory, which predicts the singularity, but with the spectacles of quantum mechanics, which may not allow it.

When we study the orbits in the solar system, we're able to measure a planet's position and momentum simultaneously and get a fairly precise measurement of both. This allows us to make predictions about where the planet will be found at a later time and where it would have been found at an earlier time. We can do nothing of the sort when it comes to studying an electron orbiting the nucleus of an atom. As we've seen, one of the frustrations of

quantum mechanics is that it's impossible to measure a particle's position and its momentum simultaneously and get a precise measurement for both. We don't find an electron orbiting the nucleus in the predictable way a planet orbits the sun. Quantum mechanics predicts that the probability of finding the electron is spread out over some region around the nucleus. In an article Hawking wrote in 1989, he expressed the hope – one he'd been harbouring at least since the early seventies – that in a theory of quantum gravity (a theory combining general relativity and quantum mechanics) we would find that singularities are also 'smeared out'.

As Hawking writes, 'There was a problem [in the early years of this century] with the structure of the atom, which was supposed to consist of a number of electrons orbiting around the central nucleus, like the planets around the Sun. The previous classical theory predicted that each electron would radiate light waves because of its motion. The waves would carry away energy and so would cause the electrons to spiral inward until they collided with the nucleus.' Obviously something was wrong with this prediction, because atoms don't collapse in this manner. Hawking continues:

> However, such behaviour is not allowed by quantum mechanics because it would violate the uncertainty principle; if an electron were to sit on the nucleus, it would have both a definite position and a definite velocity. Instead, quantum mechanics predicts that the electron does not have a definite position but that the probability of finding it is spread out over some region around the nucleus.
>
> The prediction of classical theory [that the electron must collide with the nucleus] is rather similar to the prediction of classical general relativity that there should be a Big Bang singularity of infinite density. Thus one might hope that if one was able to combine general relativity and quantum mechanics into a theory of quantum gravity one would find that the singularities of gravitational collapse or expansion were smeared out like in the case of the collapse of the atom.[8]

Hawking first applied this idea to the singularities in black holes, and then to the Big Bang singularity.

Hawking's theories put immense faith in the interpretation of quantum mechanics which sees the uncertainty principle as a limit upon what actually can happen in the universe, not merely a limit upon what we can measure. If we are to follow Hawking's logic, we must join him in assuming that what we cannot measure – in other words, a result at which we are incapable of arriving – cannot occur. The vast majority of physicists today are of the same mind as Hawking. Though it's not at all clear that we can apply quantum theory to the whole universe, it is possible to argue that we may need no other theory to erase the singularity, that finding everything at the same point, infinitely dense, would be simply too precise a measurement of position and momentum. The singularity is 'smeared out'. However, Hawking, with Jim Hartle, has proposed something a little more complicated than that. They and other theorists have attempted to find not only ways of ridding us of the slammed door of the singularity, but also answers to the questions which the singularity made unanswerable.

THE MAGIC OF IMAGINARY TIME

'Physicists today are not modest,' wrote physicist and astronomer Alan Lightman in *A Modern Day Yankee in a Connecticut Court.*[9] He recalls attending a lecture given by Hawking in 1984 at Harvard, where Lightman is a professor. This was shortly before Hawking had his vocal cords removed in an operation to save his life when he was suffering from pneumonia, and he could still talk in what sounded to most in the audience like low whines and moans. A student translated these sounds into words. The first shock when listening to Hawking, even with his more recent high-tech computer voice, is to find that this unlikely figure is saying anything coherent at all. The second is the supreme, understated confidence with which he ventures where others do not.

In the lecture that Lightman heard, Hawking was speaking about initial conditions – not, on the face of it, a startling subject. In an experiment, 'initial conditions' means the lie of the land at the beginning of the experiment. But, as Lightman wrote, 'I gradually realized what I was hearing: Hawking had traveled

back the whole distance. For the first time, a pre-eminent scientist was tackling the INITIAL condition of the UNIVERSE – not a split second after the Big Bang, as I'd heard about before, but the very beginning, the instant of creation, the pristine pattern of matter and energy that would later form atoms and galaxies and planets.'[10]

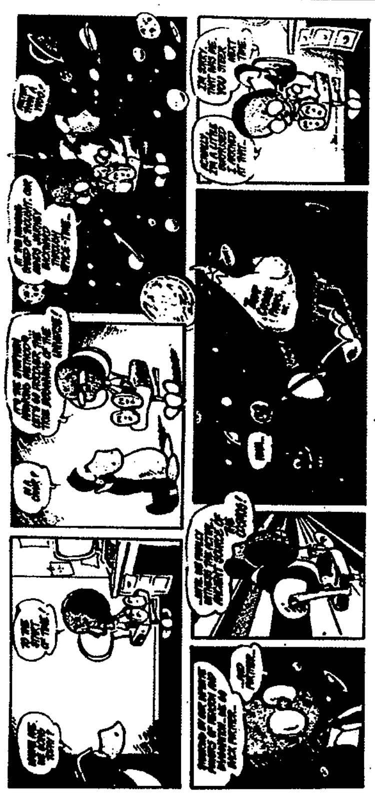
In *A Brief History of Time* Hawking tells of a conference he attended at the Vatican in 1981. Addressing the conference, the Pope had this to say about the search for an explanation of the beginning of the universe: 'Science cannot solve such a question by itself: this human knowledge must raise itself above science and astrophysics and what is called metaphysics; the knowledge must come above all from the revelation of God.'[11] Hawking, of course, would have none of that – though to describe this statement, as he does in *A Brief History of Time*, as a 'prohibition' against the search for the beginning of the universe seems an overreaction.

At the same conference, Hawking presented a proposal that there was no beginning of the sort the Pope was speaking of – a proposal that there were no boundaries for the universe. Hawking had decided that that holy of holies, the singularity, might not be a block to our knowledge after all. In order to arrive at this proposal, he and Hartle used the device of imaginary time.

Imaginary numbers, contrary to popular legend, were not invented by Hawking but have been around since the mid-sixteenth century. They deserve some demystification. They are a mathematical, not a metaphysical, concept, despite some early ruminations which might suggest the contrary. Gottfried Leibniz, the seventeenth-century mathematician who narrowly, and perhaps unfairly, lost the race with Newton to claim to be the inventor of calculus, saw imaginary numbers as a 'sort of amphibian, half-way between existence and non-existence'. He suggested that they were somewhat like 'the Holy Ghost in Christian theology'.[12] However, there is nothing mystical in the least about imaginary numbers.

Imaginary numbers are not even a very complicated mathematical concept, although the way Hawking and Hartle have applied them to the universe is not easy to understand. They are numbers which when squared yield a negative number. If you never went beyond the more elementary maths courses in school, you

Figure 4.1



Romancing the creation

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Berke Breathed

probably didn't encounter them. You were taught that the square of −4 is 16, just as is the square of 4. The square of any number, negative or positive, is a positive number. If this is true then you can't possibly ask what is the square root of −16. The situation is different with an imaginary number. The square of imaginary 4 is −16. Imaginary 3 squared is −9. The square root of −16 is imaginary 4; the square root of −9 is imaginary 3.

What then is imaginary time?

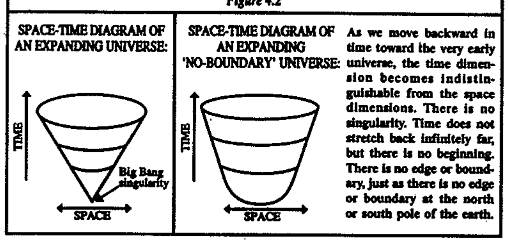
According to Big Bang theory, in the very early universe, space was extremely compressed. Here, Hawking suggests, the smearing effect of the uncertainty principle could erase a basic distinction, which still endures in relativity theory, between space and time dimensions. Allowing the time coordinate to be an imaginary number provides a new way of looking at this situation in which it is more accurate to talk not about three dimensions of space and one of time but, instead, of four dimensions of space. Time, in this approach, becomes indistinguishable from a space dimension. To quote Hawking, 'Calculations suggest that this state of affairs cannot be avoided when one considers the geometry of the universe during the first minute fraction of a second.'[13]

The idea of treating time as a space dimension is not new to physics. Physicists use this device for working out problems in quantum mechanics. What makes Hartle and Hawking's a radical approach is that they don't merely use this trick to solve a problem and then go back to the usual concept of time. They propose that time really was like space. As Hawking has said, 'I think these concepts will come to seem as natural to the next generation as the idea that the world is round. Imaginary time is already a commonplace of science fiction. But it is more than science fiction or a mathematical trick. It is something that shapes the universe we live in.'[14] We can't simply accept this statement from Hawking, or say 'Time really was like space', without recognizing that in doing so we leap-frog a great deal of discussion about the reality of mathematical models and about reality itself. But let us proceed for the moment and return later to quibble about that.

If Hartle and Hawking's proposal is correct, we don't have to worry about time and space beginning in a singularity, because here, the tiniest interval away from what we have been assuming was the beginning, in imaginary time it becomes meaningless to talk about 'past' at all. The concept of a beginning 'before' that is also meaningless.

The question then remains as to the geometry of this four-dimensional space. It has to join smoothly onto our familiar space-time as the universe expands and the quantum smearing effects subside. One possibility among many others – an infinite number of possibilities, says physicist and science writer Paul Davies, echoing Poincaré – is that the four-dimensional space curves around to form a closed surface, without any edge or boundary at all, a situation similar to our earth or to the balloon on which our imagined ant lived, but with more dimensions. The ant, you remember, found no boundary or edge. There are no boundaries to Hartle and Hawking's universe, no boundaries in space and – far more significantly – no boundaries in time. No beginning. The concept of 'past' ends in the early universe just as the concept of 'north' ends at the north pole, without a boundary or an edge off which to fall – without a beginning (Figure 4.2). What can we say then about 'initial conditions'? As Hawking puts it, 'The boundary conditions of the universe are that there are no boundaries.'[15]

Figure 4.2



As we move backward in time toward the very early universe, the time dimension becomes indistinguishable from the space dimensions. There is no singularity. Time does not stretch back infinitely far, but there is no beginning. There is no edge or boundary, just as there is no edge or boundary at the north or south pole of the earth.

'No boundaries' might seem to imply 'infinite', but in fact it doesn't. In the case of the surface of the earth, there are no boundaries in space, and yet the surface of the earth is not infinite

in size. So it is with Hartle and Hawking's no-boundary universe. Space is not infinite, nor is time.

Hartle and Hawking prefer this geometry for reasons of mathematical elegance. What possible reason do you and I have for believing with them that this proposal could represent physical reality, that time really might have been like space, and that this scenario is not merely a mathematical fiction or an article of faith arising from a yearning for mathematical beauty and an explanation of the universe which doesn't require a *deus ex machina*? The question is not only 'Could it really have happened this way?' but also 'If it could have, why should we think it did?'

Hawking is the first to point out that his idea is just a proposal. He doesn't even call it a theory. It's a spectacularly wild leap of imagination. He hasn't deduced these boundary conditions from some other principle. Of course it goes almost without saying that we have no direct observational data, but, having made the leap, Hawking and others have carried matters forward by asking what sort of universe would result from this particular 'no-boundary' situation. The calculations are extremely complex, and so far they've been carried out only in simple models, but they seem to demonstrate that the proposal can be linked by mathematical consistency to the real universe as we observe and experience it, that the universe that would result would indeed be a universe like our own. In real time, where we live, it would still appear that there were singularities in black holes and at the beginning of the universe. But in imaginary time there would be none in either place.

This isn't then just the Land of Oz. So far so good. However, mathematical and logical consistency do not demand this model of the universe as opposed to others. Nothing has so far shown that it is the only consistent model or one to be strongly preferred over others.

Could it have happened this way? It's far too early in the game to answer that question. Did it happen this way? Only on aesthetic and philosophical grounds, and because it upholds one of the assumptions of science, is it possible at present to prefer this theory over others. Hawking tells us that the proposal appeals to him because 'it really underlies science . . . it is really the statement that the laws of science hold everywhere.'[16] It is that – a statement, not a demonstration that they do or that

Hartle and Hawking have correctly described the manner in which they do.

Imaginary time also plays a large role in theories from Hawking and others about wormholes and baby universes, perhaps an even more spectacular leap of imagination, though in this case the concept arises from previous ideas, particularly those of Wheeler.

Once more, picture a balloon – an enormous one – inflating rapidly. This is the cosmic balloon, our universe. Picture also dots on the balloon's surface to represent stars and galaxies, and picture them causing tiny dimples and puckers in the surface. These are the curving of spacetime caused by massive objects, which Einstein predicted. Imagine also that, in spite of these little puckers, the surface is relatively smooth, even when we look at it through a not very powerful microscope. If we look at it through a much more powerful microscope, we find it isn't smooth after all. The surface seems to be vibrating furiously, creating a blur, a fuzziness.

We've encountered such fuzziness before. The uncertainty principle causes the universe to be a blurry affair at the quantum level. The surface of the cosmic balloon is uncertain in a similar way. Under high enough magnification the quantum fluctuation becomes such that Hawking claims there's a probability we'll find it doing – as he puts it – *anything*. Specifically, he thinks there's a probability that the cosmic balloon will develop a little bulge in it. On rare occasions you see this happen as a party balloon is inflated. On even rarer occasions the bulge doesn't cause the balloon to burst, but instead turns into a miniature balloon attached to the surface of the larger balloon by a narrow neck. If you saw this happening with the cosmic balloon, you'd be witnessing the birth of a baby universe. The little neck would be a 'wormhole'.

Is there data to support this supposition? Surprisingly, that isn't such a ridiculous question when it comes to wormholes and baby universes, although it won't be direct observational data. Several experiments have been proposed. However, Hawking himself doesn't think these tests will succeed in determining whether or not wormholes and baby universes exist. When we speak about seeing all this through a microscope we're being fanciful. If anything can be said to start small, it's a universe. The most probable size for a wormhole connection between our universe

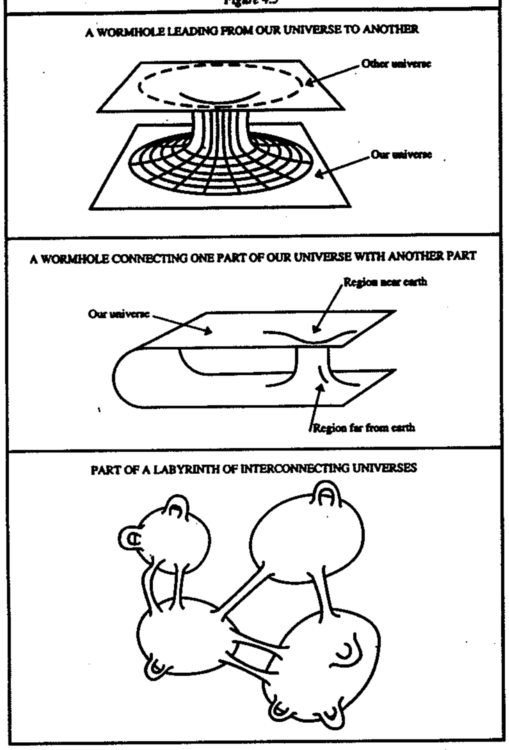
and the new baby is only about 10^{-33} centimetres across. If you want to write that out as a fraction you do so by using 1 as the numerator and 1 followed by thirty-three zeros for the denominator. A wormhole is like a tiny black hole, flickering into existence and then vanishing after an interval too short to imagine. Another reason why we can't witness the birth is that it all happens in imaginary time.

However, the baby universe attached to this wormhole umbilical cord may not be so short-lived. Nor must it necessarily continue to exist only in imaginary time. Eventually the new universe may expand to become something like our present universe, extending billions of light years. Perhaps not only something like ours, but exactly like ours, with galaxies, stars, planets, life. In fact the suggestion Hawking makes is that our universe did originate that way, as a baby universe bulging off the side of another universe. According to the theory, there may be many universes, a never-ending labyrinth of them, connected by wormholes in more than one place. There might even be wormholes connecting one part of our universe with another part, which would allow for rapid travel between very distant locations – travel in space or even in time – if we were small enough and if we could travel in imaginary time (see Figure 4.3). It does seem that among elementary particles it's not completely unreasonable to quote e. e. cummings:

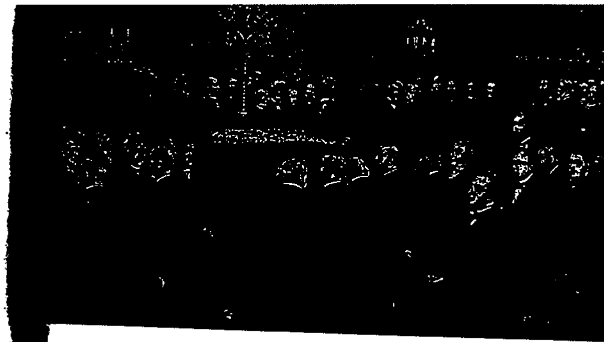
> Listen, there's a hell of a
> good universe next door:
> let's go![17]

Wormhole theory not only proposes to rid us of the problem of singularities and explain another way the universe may have begun, it also attempts to solve a puzzle we call the cosmological constant problem. We'll save that for Chapter 5. Meanwhile, the no-boundary proposal and wormhole/baby-universe theory are not the only suggestions for unravelling the Gordian knot of the singularity.

Figure 4.3

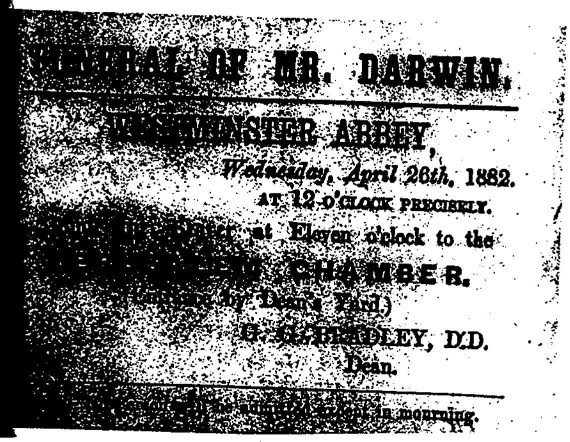


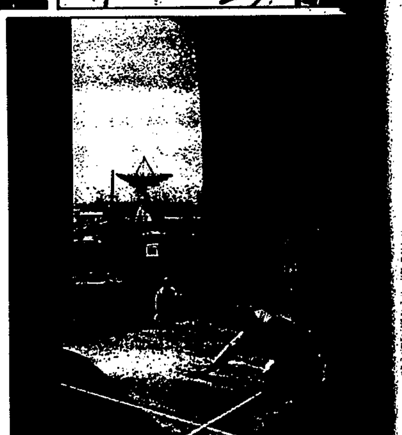
Drawing by Andrew Dunn



E: The funeral of Charles Darwin, Westminster Abbey, 26 April 1882, with leaders of ce, Government, and Church in attendance. The *Manchester Guardian* reassured its s that they should not have 'any misgivings lest the sacred pavement of the Abbey d cover a secret enemy of the Faith'. (*The Mansell Collection*)

W: A ticket for a better seat at the funeral. (*By permission of the Syndics of ridge University Library*)





ABOVE: Vesto Slipher at the Lowell Observatory, c.1912. (*Lowell Observatory Photograph*)

ABOVE RIGHT: Edwin Hubble in the 1920s with the 100" telescope at the Mount Wilson Observatory. (*Henry E. Huntington Library and Art Gallery*)

RIGHT: Robert Wilson (on ladder) and Arno Penzias inside the horn antenna at Bell Laboratories in New Jersey, 1965. (*AT&T Archives*)

THE PULSING UNIVERSE AND THE ELUSIVE CLUE OF DARK MATTER

Will there come a time when the universe stops expanding and begins to contract again? Friedmann's solutions to Einstein's equations suggested the possibility of three types of universe. In one model, the universe expands to a maximum size and then recollapses. In a second model, the universe expands rapidly and never stops expanding. In a third model, the universe expands at exactly a critical rate to avoid recollapse (see Figure 4.4).

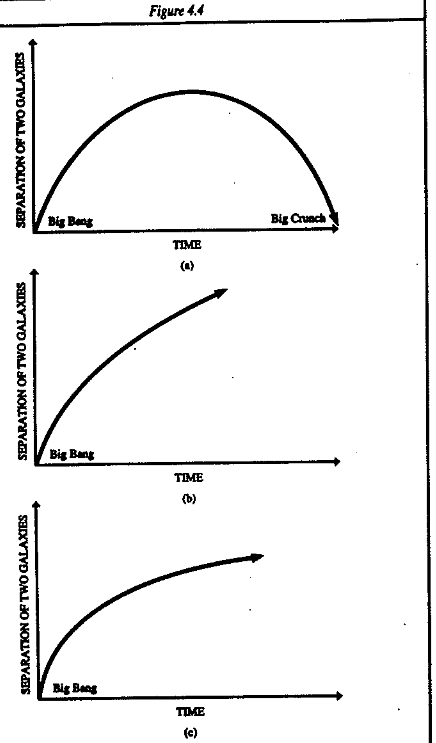
How can we find out which model fits our universe? To do so, we have to compare the current rate of expansion with the current average density of mass in the universe. There are problems with measuring the current average density of mass.

The amount of gravitational attraction between objects depends upon the amount of their mass and their distance from one another. We ought to be able to add up the voting power (as Wheeler thinks of it) of all the matter in the universe and be able to calculate at least roughly whether that will produce enough gravitational attraction to stop the expansion and close the universe. When we do this calculation, we find that the amount of matter in the universe that we can observe directly isn't nearly sufficient to stop the expansion. You might expect the discussion to end there, but it doesn't.

We have good reason to suspect there is mass in the universe that we can't observe because it isn't radiating in any part of the spectrum – hence its name, 'dark matter'. First, we have indirect evidence that many galaxies are surrounded by halos of dark matter. We determine this not by observing the dark matter itself but by observing the movement of visible matter such as stars and gases within the galaxy. For instance, the mass and distribution of visible matter in our own galaxy is not enough to account for the way our galaxy rotates. The rotation indicates that the mass of the halo must be much larger than the visible mass of the galaxy.

In June of 1993 Douglas Lin of the University of California announced that study of the orbit of the Large Magellanic Cloud, a satellite galaxy of the Milky Way, provides additional evidence that a dark-matter halo surrounds our galaxy. His calculations indicate that the Milky Way galaxy must weigh 600 billion solar masses (600 billion times the mass of our sun). That is five to ten

Figure 4.4



Three models of the universe: (a) The universe expands to a maximum size and then recollapses. (b) The universe expands rapidly and never stops expanding. (c) The universe expands at exactly a critical rate to avoid recollapse

times the mass of all the visible material in our galaxy. The visible part of the Milky Way is about 120,000 light years in diameter. The total diameter of the visible galaxy and the dark-matter halo might be 800,000 light years in diameter or more.

There are other observational clues. Observations of distant stars and galaxies show us effects that can best be explained as lensing effects, where light from these remote sources is bent by massive objects or accumulations of mass nearer to us – in the way the sun bends the paths of light from distant stars. By studying these effects, astronomers are able to calculate how much mass is there, even though the mass is invisible. These studies continue, and obviously will take some time. There is a great deal of universe out there. Until we can find out more precisely how much dark matter exists, we can't determine which Friedmann model of the universe is correct. The case is not closed, and neither, necessarily, is the universe.

However, let us suppose for the moment that the Friedmann model in which the universe will some day contract again is the correct one to describe our universe. What's to keep it from expanding again after it contracts? Indications coming from quantum physics and supersymmetric string theory are that the universe wouldn't necessarily contract all the way to a singularity. Instead, just short of that, it might 'bounce' and start the cycle all over again. How would we know whether this model of a 'pulsing' universe is correct?

First, of course, the universe can't bounce or pulse if it doesn't fit the Friedmann model in which it contracts. A second consideration has to do with entropy.

To measure the amount of entropy in a system means to measure the amount of disorder. The Second Law of Thermodynamics says that entropy (disorder) in any closed system cannot decrease, it can only increase. This law can in rare instances be broken, and we will see in Chapter 6 that there are theories which call into question the universality of the trend toward disorder; but it is generally accepted that entropy in the universe as a whole is inexorably on the increase.

This may seem to defy common sense. Obviously if we have marbles of two colours in a box separated by a partition, with all the reds on one side and all the greens on the other, and if we remove the partition and shake the box, there is only the tiniest of

probabilities that at a future time the marbles will again sort themselves out by colour as they were before the partition was removed. However, all we have to do is reach into the box ourselves and re-sort the marbles. Haven't we defeated the Second Law of Thermodynamics? No – we haven't. Our reaching into the box means it isn't a closed system. Similarly, we can put some bit of the universe in order, perhaps wash the dishes, stack them neatly on the shelf, and sort the garbage and recyclables, but the bad news is that in the physical and mental effort of doing all this we convert energy to a less useful form and this adds to the overall entropy of the universe. You can combat entropy by never doing anything at all, but merely staying alive converts some energy.

A way to understand this situation is to consider the fact that in any system, the start-up conditions which would allow things to progress from disorder to order are vastly more rare than the start-up conditions which would allow them to progress from order to disorder. For example, all the marbles in the box would have to be rolling at precisely the right speeds and in precisely the right directions to get back to their sorted positions on the two sides of the box. For that to happen is not impossible, but it is far from likely in view of all the other speeds and directions that would not get them there.

This Second Law of Thermodynamics is one of the great organizing principles (though perhaps it would seem more appropriate to call it a disorganizing principle) of the universe, and it appears to have a great deal to do with our distinguishing the past from the future. Remember those kindergarten exercises in which someone asked you to take four pictures and put them in order? Even at age three or four you knew that the one showing the bull entering the china shop doorway with all the china immaculately displayed in the showcases was most likely going to be picture number one, not picture number four.

Why should entropy cause a problem with the model of a universe that pulsates? The problem is that when one cycle of expansion and collapse is finished, the universe must surely be at a much higher level of entropy or disorder than it was at the beginning of that cycle. Penrose, whose work with Hawking, you will recall, led to the theoretical confirmation of the Big Bang singularity, insists that entropy at the beginning of the universe

Figure 4.5

The proverbial bull in the china shop. We never see the time-reversed process in which B would occur before A and entropy at the end would be 'ridiculously different'.[18] The universe at the Big Bang is so highly organized that if it were cut in half it would show almost no structure. The universe at the Big Crunch will be a great mess. The upshot is that, unless there were some as yet unexplained way of putting things back in order very quickly before the next expansion, the next expansion would begin with a much higher state of entropy and would produce a different sort of universe. We may be living in the only recurrence of the cycle in which it would be feasible for us to live.

There's another possibility. Perhaps when the universe reverses itself and contracts, the arrow of entropy also reverses itself. Perhaps in a contracting universe entropy decreases, broken teacups reassemble, bulls run tail-first through china shops leaving once-shattered china sitting whole upon the shelves. A further implication might be that the universe would reverse itself not only in space dimensions, but also in the time dimension. We can imagine a science-fiction-like scenario in which everything that had happened in the expanding phase would happen backward in the contracting phase. The cycles would be endless repetitions. If that's so, I'm not sure I want to know about it – nor would I, according to astronomer Thomas Gold, who first proposed the idea. He suggests that intelligent beings might have their thought processes reversed in the contracting phase so they would not notice the difference. They would still see themselves as living in the expanding stage.

Both Hawking and Penrose think that the arrow of entropy would not change in the contracting phase. Entropy would continue to increase. If they're correct, then some calculations indicate that the cycles of expansion of a pulsing universe would get bigger and bigger, and endure longer and longer, and that there would be no end to this process. Other calculations suggest a different picture: a pulsing universe might not be any more eternal than the successive bounces of a rubber ball, gradually running down. Although with the model of a pulsing universe we may have circumvented our own particular singularity, we haven't necessarily erased the notion that somewhere, perhaps several pulses back, there might have been a beginning that is still waiting to be explained.

It's possible that a universe that did not contract again might also be a cyclical universe.

THE MYSTERIOUS WOBBLING OF NOTHINGNESS

It was Alan Guth of the Massachusetts Institute of Technology who applied the attractive phrase 'free lunch' to the universe. Like Wheeler, Guth has a reputation for thinking up catchy names. His comment was: 'I have often heard it said that there is no such thing as a free lunch. It now appears that the universe itself is a free lunch.'[19]

The idea predated Guth's christening of it. American physicist Edward Tryon proposed in 1973 that quantum mechanics and relativity, fused in a quantum theory of gravity, might show us a mechanism for creating the universe out of nothing – *ex nihilo*. Beginning in 1978, cosmologists at the Free University of Brussels provided a series of suggestions along those lines. The idea originated as a way of explaining the creation of matter, and only later led to something more fundamental, an explanation for the creation of spacetime itself. Let us first see how it might apply to the creation of matter.

Suppose it all began with a vacuum where spacetime was empty and flat. The uncertainty principle doesn't allow an emptiness of complete zero. We've seen earlier that it rules out the possibility of measuring simultaneously the precise momentum and the precise position of a particle. It also rules out other simultaneous measurements. The one that concerns us here has to do with fields, such as a gravitational field or an electromagnetic field. If we measure the value of a field, we can't at the same time measure precisely the rate at which that field is changing over time, and vice versa. The more precisely we try to measure the one, the fuzzier the other measurement becomes.

In complete emptiness, the two measurements would read exactly zero simultaneously – zero value, zero rate of change – both very precise measurements. The uncertainty principle doesn't allow both measurements to be that definite at the same time, and therefore, as most physicists currently interpret the uncertainty principle, zero for both values simultaneously is out of the question. Nothingness is forced to read – something.

If we can't have nothingness at the beginning of the universe, what do we have instead? A continuous fluctuation in the value of all fields, a wobbling a bit toward the positive and negative sides

of zero so as not to *be* zero. But these are energy fluctuations. How do we get matter out of this process?

According to Einstein's equation $E = Mc^2$, there can be no increase of E (that is, energy) on one side of the equal sign unless there is also an increase of M (mass) on the other side. (The c is the speed of light and that can't change.) Because of this equivalence of mass and energy, a quantum energy fluctuation would produce the equivalent mass of particles. These particles would attract each other by means of gravity, causing flat spacetime to become curved.

In this scenario, it would seem that the creation of matter violates the generally accepted rule that energy or matter cannot be added to or subtracted from the universe. Some have argued that such a violation smacks of divine intervention. But we really have no violation in this case. The gravitational attraction is negative energy, which offsets the positive energy of the particle masses – leaving a net gain of zero. Thus the instability and unpredictability of the flat spacetime quantum vacuum seeds the birth of the universe.

This leaves open the possibility of another kind of cyclical universe. Suppose the universe that emerged from this process turned out to be the sort of universe that goes on expanding for ever. The matter in the universe would spread out thinner and thinner and would eventually become extremely dilute – a situation very like the flat, 'empty' spacetime with which this story began. Perhaps the entire drama would then repeat itself on a far grander scale.

Either this process has been repeated an infinite number of times in the past, or else we still need a way to explain how it began the first time. An even more basic version of this free lunch creation proposes how spacetime itself came into being. We've seen that events we observe on the quantum level can be 'uncaused events' – happenings without a certain history. Physics theorists are still in the process of trying to explain gravity in a quantum mechanical way, but some think that doing so will show us an even more fundamental uncertainty which might allow the creation of space and time to occur spontaneously, without cause. There may be a mathematically determinable probability that a snippet of spacetime would emerge from nothing at all.

We've observed such uncaused events only on the super-microscopic level, and so we assume that is the only level on which they occur, but we needn't think that just because we are applying this process to the creation of the universe we are operating on a size level larger than that studied by quantum physics. The size of the seminal bit of space would probably be the size of Hawking's wormhole, 10^{-33} centimetres. We've already seen that such a tiny speck of creation can grow to be a universe.

As the saying goes, 'Nothingness is unstable, and tends to decay into something.' Calculating the probability of there being something rather than nothing, it seems that there is more likely to be something. Thus physics attempts to update Thomas Aquinas's assertion in the thirteenth century that 'We cannot but admit the existence of some being having of itself its own necessity, and not receiving it from another, but rather causing in others their necessity. This all men speak of as God.'[20] The 'free-lunch' argument is that it may not be God which has 'of itself its own necessity', but simply a highly likely snippet of spacetime – which might also answer Hawking's question 'Why does the universe go to all the bother of existing?'[21] Because it would be considerably more bother not to exist!

If any of the proposals we have been discussing is correct, the origin of the universe is no longer beyond the laws of physics or unknowable to us. There is no slammed door – at least not just *there*. But at first glance, to those not accustomed to considering mathematics such a powerful guide to reality, these theories seem like ripping science-fiction yarns rather than science fact. We can get quite carried away reading about them. We envision the wormholes, or we imagine time swooping in to join the space dimensions, or we fancy the wobbling of nothingness and the minuscule morsel of somethingness destined to expand and be the entire universe. But then we raise our heads from the book, glance around at the four walls and the trees outside the window and perhaps a chair like my Texas chair, solid and quiet over there against the wall, and we think we have returned to reality. What claim does all this science which borders on science fiction have to being 'real' in the way the familiar objects around us seem to be 'real'? What actual relevance does any of this have to whether or not we believe there is a real God?

We hear the argument that the Big Bang supports the biblical view of creation and is a threat to atheism. We hear the argument that Hawking's no-boundary proposal abolishes the need for God. In order to support anything or be a threat to anything, a theory must have some claim to being the correct model of what really is.

We'll begin this discussion with the Big Bang theory, asking: How valid is the claim that this theory is an accurate retelling of the history of the universe?

The Big Bang was never a purely mathematical theory. It arose out of a combination of observation and theory. Though it doesn't have as firm an underpinning of observational data, and certainly not as much fruitfulness for practical technology, as relativity and quantum mechanics have, it is not a speculative theory like the no-boundary proposal. In line with the criteria we discussed in Chapter 3, Big Bang theory, far more than its erstwhile competitor the Steady State universe, accounts for a wealth of available evidence in a relatively simple, efficient, and unartificial way; and it ties in with other strong theories in such a way as to make eminent sense and suggest further meaningful lines of inquiry and thought.

The theory does still leave us with mysteries and loose ends. However, we can say that the Big Bang is currently regarded as a well-established theory, the 'standard model' acceptable to most physicists, and that the questions that remain do not cast serious suspicion on it. They are more a matter of settling which specific version of the theory is correct – shall we accept inflation theory, for example (we'll get to that in Chapter 5) – working out details, improving, and refining. What claim does the Big Bang theory have to being the real history of the universe? A good claim. What actual relevance does the theory have to whether or not we believe there is a real God? If one's atheism or agnosticism rests on the hope that the Big Bang theory is not the correct version of history and will eventually be replaced by a different model entirely, it would be best to look for other support. But it's doubtful, in spite of some earlier panic, whether anyone's atheism or agnosticism is threatened by this theory in the 1990s.

'In the beginning, God created the Heavens and the Earth.'[22]

In line with Big Bang theory (with singularity), that might more specifically read: 'In the beginning, God created everything that was later to become what we now call the Heavens and the Earth, as well as the laws that directed that outcome, and God caused it all to begin happening.' For those who accept the Genesis account as metaphoric or symbolic, or see it as a beautifully poetic but inadequate human description of events whose magnitude defies any human description – even a scientific explanation – the connection is significant. The Big Bang singularity, by slamming the door in our faces, puts us in the uncomfortable position of not being able to explain how the universe began. It doesn't necessarily follow that the unknowable explanation is God, but it would seem that God is at least as good an explanation as any other. Nevertheless, the Big Bang account does not support a word-for-word acceptance of Genesis.

There are those who believe in God who see no philosophical advantage in the Big Bang over Steady State theory. They point out that the Judaeo-Christian God creates and sustains the universe continually and perhaps eternally (if the universe is eternal), and that whether or not there was a beginning of time has no relevance for the question of whether or not God is the creator.

We must now inquire with regard to those proposals which attempt to undermine the singularity – the no-boundary proposal, wormhole and baby-universe theory, the pulsing universe theories, and the free-lunch universe: What claim do these have to being descriptions of something that really happened ten to twenty billion years ago, and what relevance do they have for whether or not we believe there is a God?

These proposals were not developed in direct response to observational data, and they have so far no direct experimental or observational data to support them. It is correct to say that some things we have been able to observe *suggest* . . . but not to say we have direct supporting evidence. We've detected what seem to be uncaused events in observation of the quantum level, but it is not yet clear that we can apply what we know about quantum mechanics to the entire universe. In any case, observing the quantum level in the way we are capable of observing it is not the same as looking at the universe when it was 10^{-35} seconds old or

even younger. Before reaching the temperatures and densities of that era, we run out of physics which has been tested in any laboratory.

These proposals began as flights of fancy, though some of them have become more than that. Their claims to being correct rest primarily upon arguments of mathematical and logical consistency and the elegance of that consistency. However, it has not been established to everyone's satisfaction that Hartle and Hawking's no-boundary proposal is indeed internally consistent. Whether it is consistent with well-accepted, well-established knowledge about the universe, whether calculations and simulations based on the theory produce a universe like our own, and whether it is consistent with other speculative but highly regarded theories such as superstring and inflation theory – these are questions which have been answered only in a very preliminary way. Superstring theories are at present the favoured candidates for unifying the forces of nature – though string theory is arguably as difficult to verify through experiment and observation as the origin-of-the-universe proposals are. There are still many versions of string theory, and it is difficult to decide with which version compatibility would be meaningful.

If we claim we are approaching an ultimate theory of the universe, we must remember that the closer we get to such a theory the more significant the question becomes: Is this the ONE theory which succeeds in being mathematically and logically self-consistent, encompassing all the data and all approximate theories, explaining constants of nature, and producing a universe like our own, while all other theories fail to do so?

We are not even remotely near establishing that any present theory is unique in these ways. The proposals we've seen concentrate on initial conditions. Only in combination with other theories (superstring theory, perhaps) might they approach anything like Theory of Everything status. But even when it comes to describing initial conditions, no-one has been able to show, with any of these proposals, that mathematical consistency looks likely to constrain us to this model and this model alone. Davies has pointed out that there are infinite possibilities for the geometry of four-dimensional space in the early universe. Hartle and Hawking picked one geometry over the others because of its mathematical elegance. But they have not eliminated other

possibilities by showing that theirs is the only geometry that is mathematically and logically consistent.

If the success of one theory depends in such great part on the failure of competing theories, then there must be some way competing theories can fail – which brings us to the question of falsifiability. None of these proposals is at present falsifiable by direct experiment or direct observation. Their falsifiability lies primarily in the possibility of finding flaws in the internal mathematical logic, discovering that the proposal is incompatible with other more well-established theory, or showing that the model is incompatible with the universe as it has actually evolved – that is, showing that you can't start the universe as the theory proposes and have it eventually turn out to be the universe we know today.

If evaluation of these theories must rely heavily upon mathematical consistency, it behoves us to ask whether we are willing to think of mathematics as so infallible a guide. We saw, in Chapter 3, Barrow's point that mathematics is not in all cases self-consistent but is capable of producing contradictory solutions. He goes on to say that it seems not possible to discover these inconsistencies except by accident. We cannot go about systematically finding out where they lurk and how to avoid them. They may lie hidden in the mathematics that underpins many modern-day physics theories. We are not being incorrigible sceptics to wonder whether we can arrive at any reliable conclusions about the real universe by means of mathematics alone.

REALITY IN THE ABSENCE OF APPLES

When Hawking wrote that a mathematical theory 'exists only in our minds and does not have any other reality (whatever that may mean)',[23] he was not simply being lazy about defining terms. What 'reality' means is precarious in anyone's language. In the language of scientific theory, defining 'reality' becomes even more complicated. There is mathematical reality in the sense of mathematical logic and consistency, but does that reality necessarily translate to reality as we know it on the common-sense level, or to reality on the ultimate chair-as-it-is-in-itself level? We know that math says that 2 + 2 = 4 and we can see that having two apples and adding two more will indeed give us four apples, and that is 'real' in common-sense terms. But what reality does this actually allow us to assign to the equation 2 + 2 = 4 in the absence of apples and all other objects we can count?

Although most of us don't think of ourselves as espousing one philosophy of mathematics or another, to a certain extent each of us does – not, admittedly, a philosophy that is often consciously or rigorously worked out or one we advertise on our bumper stickers. To a surprising degree, your attitude or mine toward a mathematical theory as a guide to the history of the universe, and even how that attitude may affect our personal religious beliefs, depends on our philosophy of mathematics. A short perusal of the philosophical possibilities on offer is clearly to be recommended.

Most of us, when we first learned mathematics in school, probably assumed it was something that had been invented by humans. Mathematics was a way people had devised to make sense of things, put them in order, and keep track of them – a brilliant system, improving all the time as mathematicians worked on it. But mathematics wouldn't have existed if human beings hadn't existed.

If we are correct to think of mathematics as a human invention, then we are on shaky ground to assume that it will always and in all circumstances allow us to predict what physical reality will be like. We must go on discovering physical reality and inventing mathematics to describe it, and avoid the temptation to use what may be inappropriate mathematics to predict far ahead of discovery.

I remember clearly when it first dawned on me that human beings might have discovered mathematics, not invented it; that it might lie waiting in nature; that mathematical truth might be a part of independent reality. It wasn't in mathematics class, but in music theory, when I studied the harmonic series. It seemed to me that this pattern could not be a human way of sorting things out. It would have existed even if human beings had never existed. If I was right about mathematics being inherent in nature, then human mathematics could be successful only insofar as it accurately reflects the situation which is already there in nature. I didn't take this to mean that mathematics as we know it

actually does adequately capture reality. But if nature is inherently mathematical, that did seem to imply that *some* fundamental form of mathematics, as we know it or have yet to discover it, does. The concept of mathematical truth being transcendent, objective truth is expressed by Penrose in his book *The Emperor's New Mind:*

> How 'real' are the objects of the mathematician's world? . . . Can they be other than mere arbitrary constructions of the human mind? . . . There often does appear to be some profound reality about these mathematical concepts, going quite beyond the mental deliberations of any particular mathematician. It is as though human thought is, instead, being guided towards some eternal external truth – a truth which has a reality of its own, and which is revealed only partially to any one of us.[24]

The philosophy which sees mathematics as inherent in nature, rather than invented by human beings, is compatible with thinking God is First Cause of the universe, in the sense summed up by Aquinas – 'having of itself its own necessity, and not receiving it from another, but rather causing in others their necessity'. God would then be the divine inventor of mathematical truth.

However, it is this philosophy of mathematics, as discovered, not invented by humans, which also allows us to consider mathematical and logical consistency as a more powerful concept which God had no choice but to adhere to in creation. It even allows us to consider mathematical and logical consistency as a strong contestant for First Cause, not only constraining the universe to be what it is but making its very existence inevitable. Is it perhaps mathematically and logically *in*consistent for the universe *not* to exist precisely as it does? The answer to Hawking's question 'What is it that breathes fire into the equations and makes a universe for them to describe?'[25] might be that the equations are the fire.

An even more extreme form of the philosophy which sees mathematics as ultimate, objective truth is to believe that existence as a mathematical model IS reality. Maybe the equations aren't just the fire. Maybe they are the universe. As

Barrow explains this point of view, 'Life *must* exist in every sense because there exists a mathematical model of it.'[26]

We'll round out our list of philosophies of mathematics by mentioning two more. Some see mathematics as nothing more nor less than a system of logical deductions and connections, a great network of self-consistency, making it something like a game and side-stepping questions about its meaning or reality. However, Kurt Gödel's incompleteness theorem (that in any mathematical system rich enough to include the addition and multiplication of whole numbers, there must exist mathematical statements whose truth or falseness can't be decided from within the system) showed that mathematics can never be bundled up in any such neat, self-contained package.

A fourth philosophy confines mathematics to sequences of step-by-step logical constructions, much the way a computer operates. There was a time when we thought computers would be able to carry out all mathematical operations, but we now know that mathematics contains non-computable functions. This fourth way of looking at mathematics has nothing to say about whether, when functions of mathematics are non-computable, they maintain any practical link with reality. We know that there are mathematical operations which can't be simulated by a computer program, and we need some of these operations to understand the physical universe.

In the light of these four interpretations, it is interesting to find Hawking dodging the issue of reality in the following statement:

> If you take a positivist position, as I do, questions about reality do not have any meaning. All one can ask is whether imaginary time is *useful* in formulating mathematical models that describe what we observe. This it certainly is. Indeed, one could even take the extreme position and say that imaginary time was really the fundamental concept in which the mathematical model should be formulated. Ordinary time would be a derived concept that we invent as part of a mathematical model to describe our subjective impressions of the universe.[27]

In other words, ordinary time is a partial or approximate description which is useful for coping with common-sense experience, while imaginary time may be a more fundamental

description, useful to explain the universe. Hawking prefers to avoid questions about what is real. To his way of thinking, discussions about things we can never know – such as the question of which kind of time is more 'real' or whether there is a God – are not 'useful' and cannot possibly be relevant to a decision about reality. Perhaps he is right.

However, when we adopt that way of thinking, we run a risk of redefining reality rather than avoiding discussion of it. We fall into a habit of adopting 'what is useful' and 'what we can know' as our new 'reality'. It is this risk that Hawking's wife Jane was referring to when she told an interviewer in 1988, 'There's one aspect of his thought that I find increasingly upsetting and difficult to live with. It's the feeling that, because everything is reduced to a rational, mathematical formula, that must be the truth.'[28] The suspicion that we may end up with a straitjacketed and distorted picture of reality if we cling unwaveringly to a belief that truth is intrinsically mathematical has been shared by some of our greatest physicists and mathematicians, among them Ludwig Boltzmann and James Clerk Maxwell.

Nevertheless, mathematical consistency and beauty are an exceptionally effective pointer in science. We know so not from philosophy or as an article of faith, but from long experience. As Davies wrote in his book *The Mind of God*, 'much of the mathematics that is so spectacularly effective in physical theory was worked out as an abstract exercise by pure mathematicians long before it was applied to the real world . . . and yet we discover, often years afterward, that nature is playing by the very same mathematical rules that these pure mathematicians have already formulated.'[29] Whether it necessarily follows that nature in all contexts, even at the split second of its origin, played and will continue to play by those rules, we don't of course know. If mathematical truth is discovered, not invented, that would seem to give us greater cause for confidence, but even so we can't assume we're reading nature's mathematical rules aright, and aren't merely over-confidently projecting known rules upon regimes where they no longer apply, while failing to account for nature's deeper mathematical reality.

Theoretical physicists, however strong their belief in mathematics, do feel obliged to show the connections between their mathematical theories and the world most of us more readily regard as 'real'. Until those connections are clear, no-one, including the theorists, pretends that any of these proposals we've been discussing are 'scientific knowledge' in the way relativity theory or quantum mechanics is.

In addition to their mathematical beauty and consistency, what makes these origin-of-the-universe proposals particularly attractive is their ability to circumvent the singularity, and this is a more dubious argument. Listening to Hawking, it sometimes seems that the strongest support for his no-boundary proposal lies in the fact that it upholds the assumptions of science that there are laws of physics which apply everywhere and that it is not beyond human capacity to discover what they are. As dearly as we may hold those assumptions and as well as they've served us in the past, when it comes to arguing for the validity of a proposal for the origin of the universe, these are self-serving arguments – good arguments maybe for hoping a theory is correct, but no arguments for deciding it is. Such a decision would be an act of faith.

WHAT PLACE FOR A CREATOR?

John Polkinghorne, Cambridge theoretical physicist and theologian, wrote in *The Cambridge Review:*

> Those who essay a quantum cosmology are necessarily skating on intellectual thin ice, however pretty the arabesques they perform. Needless to say, Stephen Hawking is well aware of this problem. He believes that sufficient of the lineaments of an eventual theory of quantum gravity can be discerned to make at least general sense of the cosmological programme. Doubtless Steve's speculations deserve to be taken more seriously than those of many other practitioners, but they remain speculations nevertheless.[30]

To say that Hawking or any other theorist has shown us there is no God is premature to say the least. Nevertheless, that doesn't end the discussion of the relevance of these theories for religious belief. They exert great power over our thinking about God and

the universe. Why, if they are so unproven, such acts of faith themselves? Because they undermine one reason for believing that there is a God – that only by having a God is it possible to explain the universe. By offering a plausible competing explanation, they make unbelief a reasonable alternative. To do that, a theory doesn't have to show that it is correct, only that it is as likely to be correct as the 'theory' which says God created the universe. If all explanations for the origin of the universe are equally unfalsifiable, all acts of faith, then one may be as good as another. Physical explanations offer the promise of confirmation by future scientific study and discoveries – all of which sounds more enlightened to late twentieth-century minds than the promise that Christ will return and falsify all competing theories.

Proposals we have been discussing have managed to suggest that we could after all have a universe we can eventually explain and understand all on our own, without need for the idea that there is a creator. If we reduce arguments having to do with 'Is there a God?' to 'Is God necessary?' these proposals give an edge to agnosticism. Where we could have expected to hear the words 'The hand that made this is divine' – the origin of the universe itself – we hear instead 'There doesn't necessarily have to have been ány divine hand in this.' Not quite so promising for setting to music.

The question which looms over all this discussion is whether any of these proposals does indeed offer serious competition to the 'theory' that there is a God. Would any of them, if it turned out to be correct, be a complete explanation for the beginning of the universe? Is God, for that matter, a complete explanation?

When a theory requires that we take for granted pre-existing laws or a pre-existing situation or context, and especially when we know what that situation or context would have to be, we haven't really found a complete explanation or a candidate for First Cause which-has-not-itself-been-caused. A pulsing universe needs a previous pulse. And it has to be a universe that obeys a set of laws that cause pulsing to take place. Why should it necessarily be that sort of universe? Where do those laws come from? For 'something' to be more likely than 'nothing' requires a context in which the statistics say this is so. The 'free lunch' requires that the uncertainty principle be in operation. As Polkinghorne asks, 'Who created quantum theory? You don't get

it for nothing.'[31] This is no 'free lunch' after all. In all these cases, prior laws or events or boundary conditions – things we don't get 'for nothing' – are necessary. We haven't found a First Cause, and we haven't banished the question of how things just happened to get set up this way. We may succeed in moving the creator back a few steps, but we don't banish the need for a creator – or at least a cause.

Might an underlying system of laws, a situation, or a context itself be the First Cause? Maybe there is something so compelling about the set of laws, the situation, or the context that it brings about its own existence and makes obedience inevitable. If so, by what standard 'compelling'? The answer could be: by the standard of mathematical and logical consistency, only these conditions, laws, or guidelines would satisfy, and these conditions, laws, and guidelines make the universe inevitable. We are far from showing this is the case in any proposal we have reviewed, but let's imagine we could. *Then* perhaps we could say we have reached a First Cause. Mathematical and Logical Consistency dictates that the universe began and developed in this way and no other. Any other way it might have happened – or for it not to have happened at all – is illogical and inconsistent; there is no other choice.

The hope of some who seek a Theory of Everything is just that – that it will be more than a unification of the forces and particles and a set of initial conditions, more even than a unification that will show how forces, particles, and initial conditions are linked. They hope that in the end the only assumption we will need is that there is a fundamental mathematical logic, which could not be otherwise and which makes everything that is real also inevitable.

Could we still insist on asking who invented mathematical and logical consistency? Do we get those for nothing? We could ask that, but we must also remember that we can ask who invented God. At this point it seems we do, indeed, reach a stand-off. If our faith requires that the First Cause be 'scientific' rather than 'religious', it would seem that Mathematical and Logical Consistency is the First Cause candidate of choice.

Could we still believe that God created the universe? Yes, but if God had no choice but to create according to a logic more fundamental than himself, then is God really First Cause of

everything there is? We might argue so, if God still had the choice *whether* to create. Perhaps we could have both First Causes simultaneously: God by nature both being and defining 'mathematically and logically consistent'. On the other hand, if God is stronger than any system of logic, if God invents all logic and mathematical consistency, then God is First Cause.

The discussion doesn't end here, but if we confine ourselves to what we've seen so far in this book, we do have a genuine stand-off between two First Cause candidates – God, and Mathematical and Logical Consistency. One can continue speculating, but the bottom line would seem to be that at present we have no scientific way of proving or falsifying either of them, nor are we likely ever to determine the answer by means of the scientific method. To vote for either candidate is a matter of faith.

THE THIRD CANDIDATE

Have Hawking and Hartle now had the temerity to nominate a third candidate . . . the Universe? In their no-boundary model, the Universe just IS, nothing had to create it or cause it. Let us consider the universe as a candidate for First Cause, to find out whether it can join the previous two in this exercise of cosmic one-up-man-ship.[32]

'If the universe has no boundaries but is self-contained . . . then God would not have had any freedom to choose how the universe began', writes Hawking.[33] However, if God didn't have a choice, why is it that Hartle and Hawking DID? Hawking has said that 'the boundary conditions of the universe are that there are no boundaries.' It's true his proposed universe has no boundaries in space or time, but in a sense it still has boundary conditions. One conventional definition of boundary conditions (initial conditions, in this case) is that they are the conditions at the beginning of an experiment – the initial state of everything that's going to be involved in the experiment. But we've also seen other meanings of boundary conditions. Boundary conditions can mean the underlying context of logic and laws, the specification required in order for the proposed situation to exist at all, with no reference to time or a beginning. A universe like the no-boundary universe, without boundaries in time or space but in which neither time nor space is infinite, could in fact exist only if Hartle and Hawking presupposed some rather specific boundary conditions of this second sort.

Hartle and Hawking provided their boundary conditions by giving a specific mathematical formulation which severely restricts the quantum state of the universe – a mathematical formulation which appeals to them on aesthetic and other grounds: it is mathematically elegant, it seems plausible rather than contrived, and it is able to circumvent the need for a singularity. As Hawking has said, this mathematical formulation was not deduced from some other principles of physics. No-one has been able to show that it is the only possible mathematical formulation that is self-consistent and could explain the universe we observe. Hartle and Hawking chose boundary conditions which would apply within their no-boundary universe, which make it possible for such a no-boundary universe to exist. In what way, then, is the no-boundary proposal any different from, or more fundamental than, the other origin-of-the-universe proposals we've discussed? Surely this no-boundary universe also presupposes a context, a situation, a mathematical formulation, without which it couldn't exist. We can still ask: Why this context, this mathematical formulation?

The difference is subtle. Hartle and Hawking's abolition of a 'beginning' becomes a key issue. Their universe needn't be considered as part of a continuum of space, time, or causality which includes anything except itself. If it should turn out that only the mathematical formulation Hartle and Hawking use could have produced the universe as we find it, and if this universe is completely self-contained and self-consistent in both time and space, then the context this universe presupposes is – itself. The question 'Why this context, this mathematical formulation?' can be reasonably answered 'Because this is obviously what IS.' The universe dictates the boundary conditions necessary for its existence – because it exists. What IS, physical reality, becomes a stronger concept than God.

To summarize this complicated argument: Hartle and Hawking are suggesting that we may find that the only way the universe could have got to be the way it is is to have been a universe in which at an instant in imaginary time the time dimension became

identical with space dimensions in precisely the way they describe. If this could only happen using the specific mathematical formulation they used, then God didn't have a choice how to create THIS universe, and neither did Hawking and Hartle. If there is additionally no time when the universe didn't exist, then God didn't have a choice of when to create the universe or whether to create it. There are no choices at all.

Before proceeding, we should ask whether a wormhole universe is also a no-boundary universe. It can be considered that, because although there must be a parent universe, the 'time' in which the wormhole forms and the baby universe is born is imaginary time. According to some of its proponents, wormhole theory is a triple threat Theory-of-Everything candidate because it draws together the laws of physics and the initial conditions and even takes a good shot at explaining the constants. We'll see more about that in Chapter 5.

THE MOTHER OF ALL CHICKEN-AND-EGG STORIES

We'll allow those who favour God as the candidate for First Cause to have a first go at knocking this third candidate – the Universe – out of the running.

Don N. Page, a close friend of Hawking's who has collaborated with him on several papers and who lived with the Hawking family in the late 1970s when he was a postdoctoral student at Cambridge, is now a professor at the University of Alberta, Canada. Page is a devout Christian, and he has tried to answer Hawking's question 'What need then for a creator?' According to Page, Hawking has not banished the need for God. In the Judaeo-Christian view, 'God creates and sustains the entire universe rather than just the beginning. Whether or not the Universe has a beginning has no relevance to the question of its creation, just as whether an artist's line has a beginning and an end, or instead forms a circle with no end, has no relevance to the question of its being drawn.'[34] The argument that God not only creates but also continually sustains the entire universe is expressed in the New Testament in a verse in Colossians: 'By him

[Christ, in this case] all things were created . . . He is before all things, and in him all things hold together.'[35]

A circle *does* have a beginning – the moment the artist draws it, or stamps it, or whatever method he or she uses. It is a beginning in the dimension we call 'time', a dimension not contained in the circle itself. For that reason, a circle is probably not a good analogy for the no-boundary universe – a universe which has no time dimension outside itself, such as Page's circle has, in which the 'drawing', or 'stamping', or 'beginning' can occur. Davies indirectly supports Page's view by suggesting that 'Although Hawking's proposal is for a universe without a definite origin in time, it is also true to say in this theory that the universe has not always existed.'[36] Davies is right in the sense that time in the no-boundary universe is not infinite. However, 'always' is a misleading word, for, like many of our words, it has meaning only where there is a time dimension. Hawking insists it's meaningless to talk of a time other than when the universe was in existence. As St Augustine of Hippo said with regard to discussions about a time before time began, 'Let them cease to talk such nonsense!'[37] There was no such 'time'. We might, following Augustine, suggest that God exists outside of both space and time, and *could* create and sustain a universe like the no-boundary universe in which time does exist without a beginning. But it seems the no-boundary universe also *could* exist without there being such a God.

Another question: Even if we find that Hartle and Hawking's scheme is the only way to achieve THIS exact universe – who chose that this exact universe should be the goal? The best rejoinder is that we have this universe and no other, which makes the idea of a choice meaningless. This response wouldn't really counter the proposal that God made the choice in order to have a universe suitable for human beings. In Chapter 5 we'll discuss the anthropic principle, which suggests that even this remarkable suitability is not necessarily a good reason to assume there is a God.

Another idea favouring God as First Cause comes from physicist Karel Kuchar, himself not a believer but a person who obviously enjoys controversy. Not to give himself a choice – perhaps THAT was God's choice.[38] Why should God choose not to give himself a choice, and thus hide the fact that he did? Perhaps

God preferred a universe in which he seems superfluous because such a universe leaves us no gaps, no mysteries where we must assume divine action. Maybe God's choice was to allow us freedom as to whether we will believe in him; God simply doesn't want to be found in the physical universe, because that would intimidate us and abolish our freedom of will. The no-boundary proposal would have been an ever-so-clever way of setting up the universe, if God wished to keep us from discerning his divine hand in creation. But it seems the no-boundary universe *could* exist without there being such a God.

Next, an objection to the Universe as First Cause from those who favour Mathematical and Logical Consistency as the First Cause. The no-boundary proposal presupposes something more fundamental than a particular mathematical formulation. It presupposes that the universe obeys mathematical and logical consistency. Or does it?

There is a way of thinking about it in which the universe-that-just-IS might be a stronger concept than mathematical and logical consistency – might constrain mathematical and logical consistency to be what it is. This is a rather obscure notion which we can best approach by recalling what may be an analogous situation. Space and time were once thought to be absolutes. Then Einstein transformed our thinking about them by showing that massive objects cause a warping of spacetime. As Hawking says, 'Our perception of the nature of time changed from being independent of the universe to being shaped by it.'[39] This statement doesn't sufficiently reflect the fact that this influence is a two-way street. Some lines from one of John Wheeler's poems sum it up: 'Spacetime grips mass, Telling it how to move; And mass grips spacetime, Telling it how to curve.'[40] What is clear is that space and time and the arrangement and movements of objects in the universe can no longer be thought of except as linked. Perhaps that allows us to speculate that, though we may now view mathematical logic as an absolute, we might find that it is not – that it can't be thought of except as linked to this particular physical universe. It could be that mathematical and logical consistency itself is somehow shaped by the way the universe IS.

God just IS. Mathematical and Logical Consistency just IS. The Universe just IS. We might suppose that three First Causes are really one – God, Mathematical and Logical Consistency, and the

Universe existing in perfect unity – all defining one another. Short of such an unorthodox trinity, it seems one of the three must be the uncaused First Cause, with no answer to the question why or how. As we end Chapter 4, we can only say that none of the three seems able to knock the others out of the competition. For that matter, have we met the entire slate of candidates?

In Chapter 5 we'll change our approach and try to bring science and religion onto the field in a way which will not allow for a stand-off.

5

THE ELUSIVE MIND OF GOD

In every true searcher of Nature there is a kind of religious reverence; for he finds it impossible to imagine that he is the first to have thought out the exceedingly delicate threads that connect his perceptions. The aspect of knowledge which has not yet been laid bare gives the investigator a feeling akin to that of a child who seeks to grasp the masterly way in which elders manipulate things.

Albert Einstein[1]

WE'VE ALLOWED PHYSICS THEORY TO SPIN OUT FIVE TALES OF THE origin of the universe. God hasn't figured in any of them. Instead we've found two candidates to compete with God for First Cause – and no way to cast an objective vote. Since there is probably no person on the face of the earth who *could* make an entirely objective decision among the three – even with much more knowledge than we presently have – without allowing some hidden or not so hidden agenda to weight the decision, let us invite an alien who has never seen our universe to survey this field of candidates. Could the alien, having familiarized himself or herself with our way of doing science and our human assumptions and logic, and then having looked at all the scientific findings and theories and arguments we've seen so far in this book, decide that God is the First Cause of our universe? Surely not. Nowhere in this science have we, with reason's ear, heard the words clearly