Cosmology of Ultimate Concern Transcript

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THE FOURTH ANNUAL BOYLE LECTURE

Professor John D Barrow, FRS

Rector George Bush

A very warm welcome to St Mary-le-Bow and the Boyle lecture. In the newly-published history of this parish, there will be a substantial chapter detailing the inception and history of the Boyle lectures and, indeed, much else besides.

Seemingly, in the Middle Ages, it was impossible to resolve legal disputes involving foreign territories. A device was invented by which these territories were deemed to be in England, and often here at St Mary-le-Bow. I am rather pleased that, for a time in the reign of Edward III, Majorca was in my parish! We have remained resolutely international; however, in recent weeks, we at St Mary-le-Bow, after much thought, demurred from participating, *via* telecast, no international flights involved, and in real time, in a conference with our companion parish in New York, Trinity on Wall Street. This reticence was, despite collaborative intentions, technical expertise and the undoubted distinction of the participants, but partners here made us aware that a conference, although championing alternative contemporary readings, which was essentially about apocalypticism, would not 'run' in these Islands. It is several centuries since anyone here believed the world was coming to a divinely arranged end.

By contrast, a charity, Sense About Science, recently began a campaign to promote scientific evidence in the statements of celebrities when they stray into such areas. Joanna Lumley, usually free from criticism in these parts, has been taken to task for describing cancer as roaring ahead, whereas the prevalence of the disease is more to do with longevity. I had thought it was clerics who were most exasperated by inaccuracies made about or attached to our most cherished convictions and rituals. A corrective campaign to expose bad religion would require a strong nerve, but is of course essential. The revived Boyle Conversation with Science, physical and human, is a much to be desired corrective among much else to bad religion.

In espousing reasonable religion I note, and only from a review, that William Charlton, in a recent book of a similar name, states that: 'Science, having been mathematised, became identified with viewing the world as a closed mathematical system, and so people think that, if God exists, he would have to be a supernatural cause, interfering with such a system.' Most of us may not recognise this, but it informs a caricature of religion sensibility.

In welcoming you to this fourth revived Boyle Lecture, I am delighted to announce that Gresham College have most graciously agreed to record the proceedings and to make them available by webcast. There should, before long, be a link from Mary-le-Bow's own website, St Mary-le-Bow not normally numbered among those with overhead projectors and screens! I record a debt of gratitude to the Lecture's trustees for their guidance and enthusiasm, as to the worshipful Company of Mercers, and especially to the Grocers' Company, by turn patrons of this parish, whose interest and generosity has been imaginative and unstinting.

It is now my pleasure to introduce Dr Michael Byrne who, with energy and endless good humour, convenes, as indeed he has reinvented, these Lectures.

Dr Michael Byrne

Ladies and gentlemen, it is my great pleasure to welcome you once again to this annual Boyle Lecture at St Mary-le-Bow. As George has said, this is the fourth in the new series of Boyle Lectures to be held at this church. The original series ran from 1692 to 1731, and the original Boyle Lectures were recognised, even then, as marking an important episode in the relationship between religion and the sciences in this country. Most of those early lecturers used their sermons to stress that the new natural philosophy developed in the late 17th century was wholly supportive of Christian theology. Both theology and the sciences have moved on a good deal since that time, and our intention in reviving these lectures four years ago was to ask whether that 17th century aspiration was still valid today.

The work of selecting each year's Boyle lecturer falls to a group of trustees, who give generously of their time to make such a success of this enterprise. The presence among them of Julian Tregoning, a former Master of the Grocers' Company, and David Vermont, a former Master of the Mercers' Company, recalls the deep historical connections between this church and the wider City of London, as does the presence among the trustees of Sir Brian Jenkins, a former Lord Mayor. Canon John Polkinghorne, the distinguished scientist and theologian, has been of inestimable assistance in identifying interesting speakers for the series, and another trustee, Jonathan Boyle, the 15th Earl of Cork and Orrery, recalls the connection between this event and the Boyle family. Lord Cork's predecessor, Richard Boyle, the first Earl of Cork, was Robert Boyle's father.

This year, we are also very fortunate that the Earl of Selborne, chairman of the Board of Trustees at Kew Gardens and, like John Polkinghorne, a Fellow of the Royal Society, accepted our invitation to join the trustees, and we are honoured that the Bishop of London, Dr Richard Chartres, continues to be a member of the board. I reiterate the thanks of both the Rector George Bush and myself to these fellow trustees for their constant encouragements of this venture.

These new Boyle Lectures are also beginning to gain the attention of a wider audience. The first two lectures were published in the journal *Science and Christian Belief*, and last year's lecture by Philip Clayton and the response by Niels Gregerson, were both published in another academic journal, *Theology and Science*. We also plan, in 2009, to publish the first five of these new Boyle Lectures in book form, together with a debate on their relevance or otherwise by a number of critics and commentators.

I should also mention, as George already has, that the forthcoming History of St Mary-le-Bow, due for publication in September this year, will contain a chapter on the Lectures by a young German historian, Johannes Wienand. This History will mark the culmination of four years' work and will feature essays by a range of distinguished contributors on many aspects of the life of this Church since its foundation in or around 1080.

So let me conclude by introducing our speakers for this evening, both of whom can only have the time to do all the things they do by living in parallel universes, a concept which I expect both speakers will mention in their speeches this evening.

Responding to this year's Boyle Lecture is Professor Martin Rees, who became a member of the House of Lords as Lord Rees of Ludlow in 2005. Lord Rees is Professor of Cosmology and Astrophysics in the University of Cambridge, where he is also Master of Trinity, Isaac Newton's old college. Lord Rees is also the author of many books which introduce issues in cosmology to a wider audience. Finding that these various activities still leave him with too much time on his hands, he also serves as Astronomer Royal and, since last year, as President of the Royal Society. We are very honoured to have him with us this evening.

Our Boyle lecturer for 2007 is Professor John D. Barrow, who also inhabits multiple universes. John is Professor of Mathematical Sciences in the University of Cambridge, as well as being Professor of Astronomy at Gresham College here in London. He took his undergraduate degree at Van Mildert College in the University of Durham. I mention this in passing, because that College is named for William Van Mildert, the last of the Prince Bishops of Durham who helped found the University there in the 1830s. Before being appointed a Bishop, Van Mildert was in fact Rector of this Parish, from 1796 until 1820, and in the years 1802 to '04, he delivered the Boyle Lectures here in this Church. Professor Barrow has written some 17 books of popular science, and has lectured at Number 10 Downing Street, Windsor Castle and the Vatican. He is also a playwright, and in 2006, he won the distinguished Templeton Prize. We are greatly honoured that he accepted our invitation to lecture here this evening, and it gives me great pleasure to invite him now to deliver the Boyle Lecture for 2007 on the topic 'Cosmology of Ultimate Concern'.

Professor John D Barrow FRS, Gresham Professor of Astronomy and University of Cambridge

The years 1691 and 1692 were very eventful and significant for the subject of natural theology for the entwinement of theology and the natural sciences. Of course in 1691, Robert Boyle died, and his Will set up the series of sermons and lectures that we now call the Boyle Lectures. The first of those was given by the young Richard Bentley in 1692 at the age of 29. But also at that time, in those two years, two very influential volumes were being published by John Ray, based on lectures that he gave in Cambridge, so natural theology was something that was in the intellectual air as well as being in the religious air. It was only five years since Newton's *Principia* appeared in 1687, and what Bentley decided to do amounted to a sea-change in the way that natural theology was presented and fashioned.

Previously, the focus of natural theologians had been upon the multiplicity of the outcomes of the laws of nature, the fortuitous coincidences of those outcomes that appeared to create an environment tailor-made for life and for our sort of it in particular. But what Bentley decided to do was to take information that he had gleaned from more informal versions of Newton's *Principia* to create a form of design argument in natural theology that was based not upon the outcomes of the laws of nature but upon the forms of those laws themselves. Newton was the first to create an extensive system of universal laws of nature. Bentley engaged in correspondence with Newton in order to learn more carefully and more clearly what Newton's views were about the issues he intended to raise in his lectures. Newton clearly approved of this enterprise, and the famous *Letters to Bentley* are among the most interesting pieces of informal scientific intuition that exist from that period.

Bentley recognised the scope of Newton's creation for what his enterprise required. He was of course a classical scholar. Later on, he would go on to become Master of Trinity College, like Lord Rees; fortunately Lord Rees is a much more enlightened Master of Trinity College than Bentley ever was, and certainly will not be following the course of action that Bentley embarked upon in his engagement with the Fellows. They failed over many years to have him removed and, to their chagrin, he eventually died in his bed in the College. Well, they were probably pleased he died- but not in the College!

Bentley took his cue from, in effect, new physics of his time, and we are going to do the same: we are going to look at what some of the new ideas in cosmology have to say about our place in the universe.

Like Bentley, we know that the universe is big, but what Bentley did not know and we do is that it is also getting bigger. Since the late-1920s, we have known that the universe is expanding; that distant parts of the universe, distant clusters of galaxies, are receding away from one another at ever-increasing speeds. That introduces to cosmology a complexion of the universe which we might call an evolutionary one; that things are in a state of change. The universe is not like a watch in the sense that Paley once tried to persuade us in 1802 - it is not like a watch because it is not finished at the level of the astronomical phenomena. It is still changing, it is still developing, it is still exploring all the potential that is possible for it to visit.

We can measure the size of the universe as it expands against time in billions of years; the expanding universe and the unfolding trajectory of its history. That trajectory means that at different times, conditions are different. When the universe is small, it is hot and dense, and too hot in its first quarter of a million years for any atoms to exist. Today, it is relatively cool and sparse, just a few degrees above absolute zero. In between, as it has expanded, it has, first of all, allowed the first atoms to form, then molecules, then great islands of material condense out to form what we now call galaxies and, within them, stars, planets and ultimately people can form.

In the future, the long range forecast looks rather bleak. The Sun and the Solar System around it will undergo an irrevocable energy crisis. If our descendents wish to survive, they had better move elsewhere, but ultimately wherever they move to will suffer the same fate, and the long range forecast of the universe is bleak for habitation and for life. Similarly, if you look back early enough, the universe is not able to support life. There is a short interval of cosmic history, a niche of time during which conditions allow life as we know it and complexity in any chemical form to exist. The fact that we live within that habitable niche is of course no coincidence. We live about 13.7 billion years after the apparent beginning. Those enormous periods of time seem very strange. A few years ago, I was shopping in my supermarket and I discovered that these enormous periods of time had even infiltrated the commercial world of Sainsbury's. On the shelf there was a sachet of salt, and it had written on the side, 'This salt is over 200 million years old. Extracted from the mountain ranges of Germany. Best before April 4th 2003!'

This unfolding trajectory of evolution in the universe is linked to our own existence in unexpected ways. The elements of chemistry that you need for any type of complexity, things that are heavier than helium and hydrogen gases, do not appear ready-made in the universe; they do not come from the apparent Big Bang beginning. They are made in the stars by a sequence of nuclear reactions that are long and slow, and they amount to combining helium with helium to make beryllium, beryllium with helium to make carbon, and then carbon with helium to make oxygen and so on. When stars reach the end of their lifetime and explode and die, these life-supporting elements are dispersed around space, and ultimately find their way into rocks and debris and planets and you and me. So all the carbon nuclei in your bodies have, at some stage, been through a star, perhaps more than once.

But this long process takes time, lots of time: nearly ten billion years of time is required to produce the building blocks of living complexity, and so we begin to understand why it is no accident that we find the universe to be so old. We need to live in a universe that is enormously old in order that it has had enough time to make the building blocks of any living complexity. A universe that was significantly younger than we find ourselves in today could not create the basic building blocks of life and mind of any sort. You might have thought a universe the size of our Milky Way galaxy, with its hundred billion stars and maybe as many planetary systems, would be a pretty good economy-sized universe, but a universe the size of that Milky Way galaxy with its hundred billion stars would be little more than a month old, barely enough time to pay off your credit card bill, let alone evolve complexity and life. So we should not be surprised by the enormous antiquity of the universe and those times in the of order billions of years; we could not exist in a universe that was significantly younger.

Because the universe is also expanding, its age is inextricably bound up with its size. The enormous size of the universe is seen at once to be another consequence of its age. A universe that has to be billions of years old has to be billions of light years in size. Paradoxically, we could not exist in a universe that was significantly smaller than the one in which we find ourselves. This is a consequence of the expansion. So although the enormous size of the universe may be a reason to suspect that life exists elsewhere, the universe would have to be pretty much as big as it is to support just one lonely outpost of life on Earth.

Philosophers of the past, such as Birch and Russell in the early 20th century for example, always regarded the vastness of the universe as an indication of its antithesis to the development and support of life. Modern astronomy turns this judgement on its head. We see that the vastness of the universe is the necessary condition for the development of life within it.

The great age and therefore size of the universe that we need, for these reasons, also gives it another very strange property: the universe is almost empty. There is nothing in it to speak of. It is just empty space. If you take any ball of material and you expand it greatly, it becomes more and more sparse, less and less dense, as it becomes larger. If you took all the material in the universe, smoothed it out into a uniform sea of atoms, there would be just one atom in every cubic metre of space. No laboratory of physics in the world could make a vacuum that is anywhere near as evacuated as that. So the universe is mostly just empty space. You and everything else within it, from that perspective, are just a minute trace element.

If we decide to lump that density together in more interesting combinations, instead of having an atom in every cubic metre, we would run into a planet like the Earth every ten light years, a star like the Sun every thousand light years, and a galaxy like the Milky Way every ten million light years. So you begin to see why extraterrestrials are not queuing up on our doorstep to talk to us. The enormous distances between planets, between stars, between galaxies, the insulation of different sites where life can develop from each other, is a consequence of the tiny density of material in the universe, which is another consequence of its enormous age and enormous size that are needed for life and complexity to develop.

Another property that follows is that our universe is cool. If you expand a lot, you will cool down a lot. So the very low temperature of our universe today is a reflection of the enormous amount of expansion that has taken place over 14 or so billion years. This low temperature has a dramatic consequence.

I have a picture of our next door neighbour galaxy, M81, taken by the Spitzer Telescope. Our own galaxy would look rather similar if we were to see it from outside. What is most interesting about this picture, if you are a cosmologist, is not the galaxy but the black, dark night sky all around.

The dark night sky is the first interesting cosmological observation that was ever made, and it was made at a time not too different from the inaugural time of these Lectures, by Edmond Halley. Halley asked the question, 'Why is the sky dark at night?' At first, you might tell him, 'Well, you need to get out more! You need to talk to people. Notice the Sun.' But the answer to the question is profound. Halley could not find the answer. It has nothing to do with the Sun. If you look out into the forest, for example, your line of sight everywhere ends on the trunk of a tree. Halley wondered why it was not the same when he looked out into the universe. Why did his line of sight end not everywhere on the surface of a star? Surely there are enough of them - maybe even an infinite number of them. The whole of the sky should look like the surface of the Sun all the time.

We only found the answer to this question when modern cosmology revealed the expansion of the universe. The enormous expansion, the tremendous cooling means that there is too little energy in the universe today to illuminate the night sky. If we turned all the matter in the universe into radiation just like that, all that would happen is the temperature would rise from three degrees above absolute zero to about 15 degrees above absolute zero, and nobody would notice. There was a time when the sky was bright, but it was a long time ago: it was when the universe was just a quarter of a million years old, greatly smaller than today, when the temperature was a thousand times greater, and then the whole sky was illuminated. But today, because of the age and the size that we need to find in our universe for you to be alive within it, we necessarily find the sky to be dark. So we have discovered, through the eyes of modern cosmology, a number of interesting and counter-intuitive things: that a life-supporting space, a life-supporting universe, besides being almost empty, big and old, dark and cold, these are the properties that we require if life of any complex sort is to be possible in the universe.

Long ago, before astronomy came on the scene in the 20th century, these would have been regarded as features of the universe quite antithetical to life, indicators that somehow life was a mere accident or trace element in the universe. Modern astronomy turns that perspective, in some sense, on its head. We see these strange features of the universe, that look so peculiar at first, are essential features if life of any sort is to exist within it. So things are often not quite what they seem. These life-averse features of the universe turn out to be essential pre-requisites for complexity of any sort.

There is more to the universe than just being big and getting bigger. Different sorts of universe are possible. You can have universes which are rather acrophobic, which expand and keep on expanding for ever; you can have ones that are a little more claustrophobic that one day stop expanding, reverse and start to contract back towards a big crunch. In between, there is a sort of 'British compromise' universe that just manages to expand fast enough to keep going for ever, and that is interesting to us because our universe is tantalisingly close to that critical divide.

In some sense, this is not entirely surprising. Universes that try to deviate too far in one direction or the other from the critical divide end up lifeless and uninteresting. You could expand so fast that material cannot beat the expansion to condense to form stars and galaxies and carbon. At the other extreme, you could run into a big crunch before the show even opens. So, in a general way, we understood why it is not surprising that we live close to that divide, but such an argument is not enough to explain why we live so tantalisingly close to the divide that we are unable really to tell on which side we lie, and have not been able to for a long, long time.

Another feature of the expanding universe that puzzled people for a long time, particularly until 1967, is that if you look at this expansion in different direction, it proceeds at the same rate in every direction to very high precision. When this was first discovered in 1967, the precision was a part in a thousand, at least; we now know the precision is about two parts in a hundred thousand. So you can think of the universe as an expanding sphere to very high precision. This is a puzzle, because it is so much easier to make universes that expand very, very differently in different directions. There are many more ways to be irregular than there are to be regular.

Lastly, although there is that regularity in the universe, it has a certain smoothness from one place to another and from one direction to another. There is also a graininess, and that graininess is present at a level of about a few parts in a hundred thousand. It is, again, essential to the whole story that leads to us, because it is those grainінesses that amplify and turn into the galaxies and the stars, the lumps and bumps which we reside upon and around. Without some graininess, those lumps and bumps will never form.

That physical process was first revealed in those letters from Newton to Bentley. Newton pointed out the tendency of gravity to make things that are a little bit lumpy become a lot lumpy. In fact, in the last of those Boyle sermons that Bentley gave in the first year, he departed in a very interesting way from his general focus upon the regularities and the laws of nature to discuss the problem of the irregularities of nature - mountain ranges, things that do not fit the patterns of symmetry and perfection, and how they are important in the make-up of the world, and also appreciated by our aesthetic sense. So, in the structure of our universe, we are interested both in regularity and irregularity, in the laws of nature and the flaws of nature.

These puzzles - the puzzle of the special expansion rate of the universe, its blindness from one direction to another, its overall smoothness, and its little degree of graininess - were features that all suddenly appeared to have a single explanation in a new perspective on the universe that emerged at the beginning of the 1980s. That perspective has become known as the inflationary universe. The word of course derived from economic conditions that existed in the world in the early 1980s, and the idea of this theory is very simple.

Earlier, we considered a universe expanding in a concave sense, the trajectory moved over in an arcing sense, indicating the universe was decelerating. Inflation is a simple idea, that there are some brief interludes in the very early history of the universe where its deceleration switched to acceleration. There was a surge in expansion that resulted in the universe becoming much larger than it otherwise would have become by any given time and, in so doing, the expansion is driven tantalisingly close to that critical divide and provides a natural explanation as to why we find it so today.

This idea was not an arbitrary one. At that time, particle physicists had begun to explore new varieties of theory in which unusual types of matter field were predicted to exist which, if they were in the universe in this early time, would exist for a while and then decay away into ordinary radiation and material but, while they were around, they would indeed produce a surge of expansion. After they decay away, normal service is resumed, and the universe continues to expand in the way that we see today.

We today at St Mary-le-Bow, with a perfect telescope, could see only out to a distance of about 14 billion light years. There has not been time since the beginning of the expansion for light to reach us from further away. So we call that region within our cosmic horizon the 'visible universe'. There is much more universe no doubt beyond, and tomorrow we would be able to see another light day's worth of universe.

If we run the plot backwards in time, we can ask how small is the region out of which our entire visible universe has expanded? The problem with the old pre-inflationary picture of the universe was that that patch out of which our whole universe emerged was always required to be far too large for us to make sense of what resulted, so large that there was never time for light signals to travel from one side to the other, for smoothness to be produced, for the expansion rate in different directions to be co-ordinated, and no way for any process to seed little grains and fluctuations in a similar way everywhere within it. Inflation solved that problem. Its surge of expansion enabled the whole of our visible universe to be grown out of the image of a region that was small enough for everything to be co-ordinated by light signals, for there to be enough time for one side of the region to be co-ordinated with another.

This theory gave us at once an explanation as to why our whole visible universe, on the average, is so smooth. It carries with it, as it were, the genetic code of a single fluctuation which is co-ordinated by signals, by radiation moving from one side to the other. The acceleration drives it close to that critical divide and, in so doing, it ensures that the expansion proceeds at the same rate in every direction, with very high precision.

But what happened next was really rather fascinating, and brings us to the heart of the topic of this lecture. First of all, it was recognised that this tiny patch that would create our whole visible universe will not be perfectly smooth. There must always be some fluctuation, some little statistical variations, perhaps of quantum origin, present, and we know what they are. We can apply our mathematical understanding of high energy physics to predict their form and also then to predict what will happen to them when the expansion stretches them, and they will show up in the radiation in the universe today. They will leave their footprint in the temperature variations of the radiation that comes towards us from every direction in the sky when we point our satellites from above the Earth. In the last few years NASA, and in coming years the European Space Agency, have been hunting for those fluctuations, at enormous expense and with great skill.

I have a map of the pattern of temperature variations found by the Wilkinson Microwave Anisotropy Probe (WMAP) telescope on the sky. The variations in colour represent deviations above and below the mean temperature of the radiation in the universe. If you are a statistician, an analysis of this picture will give you a detailed statistical description of the appearance of our sky, and that is what you require to test whether this extraordinary idea about the inflationary phase of the universe is something that ever happened.

It shows the variations in the temperature from place to place, and a measure of their angular size on the sky, or how big they are. You can see that the predictions of this theory lead to a very characteristic ringing like the bells of St Mary-le-Bow we heard beforehand: there is a great peak, and then a dying away of the oscillations of the variations in the radiation temperature and energy. There are black dots that show you the state of the data gathered by the satellite. The impressive thing is that there really is a remarkable correlation between the predictions and the theory, so there is surprisingly good observational evidence that, in the past of our observable universe, there was an experience of this surge of rapid expansion that we call inflation. These observations are allowing us to test directly a theoretical prediction about what the universe must have been like when it was ten to the minus 35 of a second old.

However, this theory that we can test in this way, we hope with ever-greater precision - although we can do other things besides - also leads to much more outrageous and unusual predictions about the structure of our universe and our place within it. The first lesson it teaches us is that geography is a much more complicated subject than when we were at school. You see, we focused just now on one little patch of the universe, the piece that was once the small, contracted image of the whole observable universe that we see today. We know, from what we saw earlier, we require that patch to have expanded a lot and for a long time in order that it gives rise to a region here that is old enough and large enough for stars to form, explode, die, produce carbon and other life-supporting elements.

But in reality the whole universe may be infinite, certainly a good deal bigger than that one patch, and so we might envisage the situation when inflation occurs as rather like a tiny foam of bubbles that is then randomly heated. Some of the bubbles expand a lot, some only a little, some not at all. We have to find ourselves in one of the bubbles that has expanded enough to allow enough time for the stars to make their carbon, but what we predict is the geography of the universe is extraordinarily complex, that if we could see beyond our visible horizon, if we could take a God-like view of the whole, and were not limited by the finite speed of light, we would find the universe to be extraordinarily different in structure compared with how we find it within our horizon.

There have always been sceptical philosophers who would warn you against extrapolating from what we see in the visible universe to what it might be like in the parts that we cannot see but, for the first time, we have a positive reason to expect the universe to be quite different in structure beyond our visible horizon than it is within it, and by different we do not only expect things like the density, or the temperature, or the graininess of the universe to be different, but rather fundamental things, like the number of forces of nature, even the number of dimensions of space that become large, the values of some constants of nature. Some of these quantities, some versions of this theory, are predicted to fall out differently in different regions.
Well, so much for geography. What we are seeing is that once upon a time, when we thought there were many different disjointed regions of the universe that we could not access beyond our horizon, that they were probably all essentially the same, like the early Warhol picture of a collection of Beef Soups - they were all the same cans, but just as, later on, Warhol became much more imaginative and expansive in his imagination, and produced soup cans where they were all different - some mushroom, some beef, some cheese, some chicken - we face the situation where different bubbles in that chaotic version of the inflationary universe have quite different structures.

It is bad enough finding out that geography has changed since you were at school, that it is not enough to know six rivers of Africa to pass, that we discover also that history has become an extraordinarily more complicated subject because of cosmology. After that chaotic spatial consequence of the inflationary universe was recognised, it was then realised by Alex Vilenkin and Andrei Linde in the United States that inflationary universes possess an instability that renders the whole inflationary process apparently eternal and self-replicating. If we were to focus on one of those little bubbles, one of the patches that has undergone inflation, then it necessarily creates within itself the conditions needed for little sub-regions of itself, themselves to undergo explosive inflationary expansion. So the process is self-replicating: those regions inflate, they produce within themselves the conditions for further inflation to occur, and the whole process continues, apparently without end, to the future. Each one of those little bubbles in this process is allowed to take on rather different conditions to the others. How do we see ourselves in this scenario? We inhabit one of those bubbles in this so-called multi-verse of possibilities. Our universe is one region in a potentially infinite universe that is very diverse and different from place to place and also from time to time.

The issue of the beginning of the universe is also muddied by this scenario. You see, if we asked, 'Did the universe have a beginning?' it is quite possible for our piece of the universe to have a beginning. It can be a dramatic Big Bang type beginning out of infinity, or a more quiet one out of finite fluctuations, but it would still be possible for the whole multi-versal process to have neither a beginning nor an end. So each piece of the multi-verse may have a beginning, some parts may have an end, yet the whole process would be eternal.

This is a strange scenario which this inflationary universe impresses upon us. It was not looked for; it is a by-product of the successful study of what happens to one of those patches. One of the concerns about it is, can you test such an idea? Well, you might be able to. It could be that a theory which gives rise to this replication process leaves a particular observable stamp upon each member of the multi-verse, and if that stamp is not present, then the replication process could not occur. So in that sense, just by looking in our patch, and not finding that stamp, we would falsify such a replication process on all the other parts of it.

On the other hand, perhaps there is no way to test whether we are part of this infinitely more complex scenario. After all, you do not have to not like Karl Popper to regard it as really extremely anti-Copernican if you regard the universe as having been constructed for our convenience. So we can test and try out every theoretical idea that we might have about it. There is no reason why every true theory of the universe should allow us, at this time and in this place, to be able to critically test it.

One of the things that we see from this developing picture of the multi-verse is that it greatly muddies this distinction between the laws of nature and the outcomes of those laws, which that first Boyle Lecture by Bentley sought to distinguish. The laws of nature, we are in the habit of recognising, are typically surprisingly simple, highly symmetrical and really rather few in number. We think that just four fundamental laws, of electricity/magnetism, radioactivity, nuclear forces and gravity, are enough to explain the rules of cause and effect that dictate what goes on in the universe. May be one day there will be only one such law, a so-called 'theory of everything', perhaps of a string-theoretic variety. But the simplicity of the laws of nature is really something that is a little deceptive. You see, the outcomes of the laws of nature are much more complicated, far less symmetrical, far more difficult to understand than the laws themselves. Sometimes, in science, we find that we can find a theory, we can find the laws, but we cannot find the outcomes, we cannot find the solutions.

You could understand rather easily why this is the case. If I balance a pointer vertically on my hand, then it is very symmetrical in its position. If I let go, it becomes subject to the law of gravity. The law of gravity is symmetrical and highly democratic, and in perfectly vacuum-like conditions, at zero temperature, there is an equal probability that the pointer will fall in any direction. Pointers do not tend to fall in the direction of Bow Bells or towards the Bank of England or Paris; there is an equal probability, in perfect conditions, that it will fall in any direction. But once it falls, the symmetry of the law is broken, and this outcome has picked out a particular direction in the universe. What we see, in this type of multi-verse picture, is so many of the things that were once regarded as irrevocable, unchangeable laws of nature - features like the values of the constants of nature, the number of forces of nature - have suddenly become outcomes rather than fundamental laws.

Let us turn to some of the symmetry-breakings, some of the outcomes of that inflationary production of different regions of the universe. You might imagine that there is a collection of different resting places, rather like a corrugated iron roof, and when you throw a ball in the air, like the National Lottery selection process, the ball will end up falling into one or other of those resting places. As the universe expands in different places, at different rates, in different parts of the universe, the ball will fall into different resting places, different ground states, as physicists call them, but those ground states are really very different in what they require of the universe where that happens. They will determine how many forces of nature there are. One world may have just gravity and no other forces. One world may have six dimensions. One may have three.

So this process creates a vast diversity of possibility in the outcomes of the chaotic and eternal inflationary process, and we see ourselves as part of a vastly more complex process. We appreciate that the conditions that are needed to allow life to develop in one of these patches, say the one that we reside in, are really very special and unusual indeed. So we then recognise that, in this type of scenario, in modern cosmology, that all we can ever hope to predict about our situation in the universe is something that involves probabilities. We might like to know how likely is it that things fall out in a way that allow planets like the Earth to develop, elements like carbon to exist, or consciousness to develop. That creates a big problem for us, because you might have imagined that mathematicians could simply go away and take these theories and compute those probabilities, but the situation is, again, not quite what it seems. So far, nobody has been able to compute such probabilities. We do not know how to do it. May be one day we will, but even when we do the answers that we determine are really likely to be somewhat confusing.

Suppose that we make a prediction about some quality of one of those patches in the universes that undergoes inflation. What would you be interested in about that prediction? Would you be interested in the sort of bubble that is most likely? Would you be interested in the bubble that is least likely? You see that if this was the outcome of the calculation, universes in a particular place would be the most probable, but suppose that we graft on to this picture what would be the probability of universes that allow complexity of any sort to develop? So suppose we ask which are the universes where stars as possible, or any elements at all? We might find, indeed, that this is a very, very narrow range indeed, and it may be a highly improbable part of the probability distribution but, no matter how improbable it turned out to be, we would have to find ourselves inhabiting that narrow niche of possibilities because we could exist in no other.

I have mentioned already, and will ask again in closing, did the multi-verse have a beginning? We do not know. We have got all sorts of different options. Our own universe within the multi-verse may have had a beginning; it may not have had a beginning. It could be that the multi-verse itself had no beginning, or it could have had a beginning, or neither need have a beginning. We have these three curious options. In all cases, the idea of a beginning is a rather tantalising one for cosmologists, just as for everybody else. A conventional beginning to our universe always seemed to require some physical infinity in Aristotle's ancient sense, an infinity of a physically measurable quantity, like temperature, or density, or interaction strength.

What is our view of that today? If you are a physicist of a more conventional sort, whenever an infinity pops up in your calculation, you take it rather like the remark on your old school report: 'Must try harder,' that it is a signal that somehow something has gone wrong in the formulation of the theory, that if you had only included some extra detail, the infinity would be exorcised and it would become simply a very, very extreme but entirely finite effect. That would still be the attitude of people working in fundamental particle physics to the appearance of a beginning to the universe in time.

Cosmologists are more accommodating to infinities. They are generally more willing to admit the possibility of singular events, and what could be more singular than the beginning of the universe? The centres of black holes and the beginning of the expanding universe might be the one place where you would be happy to allow something infinite to occur that would begin the expansion of everything out of nothing. So we have a number of completely different attitudes towards those sorts of beginnings to the universe which you will find on offer amongst cosmologists today.

What is the relation of all this to the big questions of ultimate concern that these lectures focus upon? That, within the last 20 years or so, there has been a dramatic change in cosmologists? perspective on the universe. I showed you how, by a careful consideration of what is going on in the expanding universe, you discover that the huge distances of space and extents of time are by no means divorced from ourselves here on Earth. We are intimately entwined with the conditions within the universe that gave rise to the building blocks of living complexity, and that insight enables us to understand why the seemingly life-averse features of our universe are actually critical requirements for complexity and life of any sort, including our own. Then we have seen, in a less parochial way, how the inflationary perspective on the universe, underpinned by its careful observational testing within the part of the universe that we can see, leads to quite dramatic reconsiderations of our place within the universe as a whole, and indeed, a vast enlargement of our perspective of the universe as a whole. We see it as more complex in space, more complex in time. Our position within it is likely to be rather particular, rather special, and one that we might hope to understand more fully in the future.

I hope Dr Bentley, were he here, would feel that we were continuing to learn more about the universe, that the successors of Newton's perspective on the laws of nature have given us a perspective which is richer and more fascinating, more spectacular in many ways; that the universe is as complex as we can imagine even today. I predict that it will turn out to be even more unpredictable and spectacular in its ultimate structure than we have even imagined.

Professor the Lord Rees, President of the Royal Society, Astronomer Royal and former Gresham Professor of Astronomy

Ladies and gentlemen, it is a great privilege for me to have the chance to offer some footnotes, as were, to this wonderful lecture from my friend and colleague John Barrow.

We are both cosmologists and I can assure you, from having observed many of my colleagues, that a preoccupation with near infinite spaces does not make any of us especially philosophical in coping with everyday life! Indeed, a cosmic perspective, in some respects, strengthens ones concerns about the here and now, and at the end of my remarks, I want to try and explain that.

John Barrow described how our concepts of space and time have enlarged over the centuries, how our galaxy, with its hundred billion stars, is itself one of billions. One of the most amazing images from the Hubble Space Telescope shows a small patch of sky, a patch of sky so small it would take a hundred patches like it to cover the Full Moon in the sky, and each of the little smudges in the image is actually an entire galaxy, which appears so small and faint because of the huge distance. The light from those galaxies set out about ten billion years ago. The entire domain accessible to our telescopes is governed by identical laws, and the atoms in those galaxies are just like the ones we study in the lab. There is very strong evidence, as John said, that this immense domain evolved from dense amorphous beginnings: a Big Bang nearly 14 billion years ago. But it is possible, as John said, though it is still speculation, that even this domain may be only a tiny fragment of physical reality. In a grander perspective, what we call the laws of nature could be just parochial by-laws in our cosmic patch, but that patch is large enough to stretch for tens of billions of light years.

If my research group were to devise a logo, I would choose an aura boras. The image depicts the interconnectedness of the micro world and the cosmos; the inner space of atoms and the outer space of the universe. Things are interconnected. There are links between small and large, left and right. Our every-day world of life and mountains is determined by atoms and by their chemistry. Stars are powered by nuclear fusion. This process generates from pristine hydrogen the elements of the Periodic Table. All the atoms in our bodies are the ashes from long-dead stars. We are the nuclear waste from the fusion power that makes stars shine

There is another link. Galaxies are seemingly held together by swarms of sub-nuclear particles, which make up the so-called dark matter. There is the domain of the quantum, and Einstein's theory holds sway. Einstein's Theory of General Relativity and quantum theory are the two great pillars of 20th century physics, but at the deepest level they contradict each other. They have not yet been meshed together into a single unified theory. In most contexts, this does not impede us, because their domains of relevance do not overlap. Astronomers can ignore quantum fuzziness when they are computing the motions of planets and stars. Conversely, chemists can ignore the gravitational force between the atoms in a molecule. They are nearly 40 powers of ten feebler than the electrical forces. But at the very beginning, when everything was squeezed smaller than a single atom, quantum fluctuations could, as it were, shake the entire universe. To confront the overwhelming mystery of what banged and why it banged, we need a unified theory of cosmos and micro world.
Einstein famously spent the last half of his life searching for such a theory. In retrospect, his efforts were doomed. Little was known then about the forces inside atoms, and he was famously dissatisfied with quantum

theory. But there is now much effort on these theories: the quest is no longer premature; it engages some young scientists, not just grand aging figures who can afford to risk over-reaching themselves and achieving nothing. But there is no guarantee that even a new Einstein would succeed in this unification. It is remarkable that our brains, which evolved to cope with the every-day world, can make so much sense of the cosmos and the micro world, but perhaps our brains will hit a limit. Even if there is a unified theory, it could be beyond humanity's mental grasp, just as quantum mechanics is beyond the mental powers of my dog.

A unified theory would be the culmination of an intellectual quest which dates back to Newton, who realised that the force that holds us to the ground is the same as the force that keeps the planets in their courses. Such a theory would exemplify what the physicist Eugene Wigner called 'the unreasonable effectiveness of mathematics in the physical sciences.' But I hope it is not curmudgeonly to point out that a final theory of that kind would be of zero help to 99 per cent of scientists. Calling it a 'Theory of Everything', as some popular books do, is hubristic and misleading. It would indeed unify two great scientific frontiers, the very big and the very small, but there is a third frontier, the very complex, and the most complex things we know about, we ourselves, are mid-way between atoms and stars. It would take about as many human bodies to make up a star as there are atoms in each of us. To understand ourselves, we need to understand the atoms we are made of, and also the stars that made those atoms. I like a quote from D.H. Lawrence: 'I am part of the Sun, as my eye is part of me; that I am part of the Earth my feet know perfectly, and my blood is part of the sea.'

Our every-day world, neither micro nor cosmic, presents intellectual challenges just as daunting as those of the cosmos and the quantum. The weather is harder to predict than celestial orbits are. The smallest insect is harder to understand than a star, its multi-layered structure is far more intricate.

Newton and Einstein are the iconic physicists. The complexity also has its intellectual icon, Charles Darwin. Darwin showed how, in the famous concluding words of *The Origin of the Species*: 'Whilst this planet has been cycling on, according to the fixed law of gravity, from so simple a beginning, forms most wonderful have been and are being evolved.'

Cosmologists aim to trace things back before Darwin's simple beginning, to set our Earth in a broader cosmic context, and to understand the origins of planets, stars and the atoms they are made of. The starry sky is part of our environment; indeed it is the most universal part. It has been shared by all humanity at all historical eras, although of course it has been interpreted distinctively differently by different cultures.

We have recently learned something that has made the night sky far more interesting. Stars are not mere twinkling points of light. They are orbited by retinues of planets, just like our Sun is orbited by its planets. So far, we have only detected these planets indirectly, and the techniques can only detect big planets, the counterparts of Saturn and Jupiter, the giants of our Solar System, but we may not have to wait long before it becomes possible to detect planets the size of the Earth orbiting other stars.

To imagine what you would learn, suppose that some aliens were viewing the Earth from 30 light years away, the distance of a nearby star. Our Earth would seem, in Carl Sagan's nice phrase, a pale blue dot, very close to a star, our Sun, that outshines it by many billions, a firefly next to a searchlight, but the shade of blue would be slightly different depending on whether the Pacific Ocean or the land mass of Asia was facing us. So even though these aliens could not resolve surface detail, they would be able to infer that our Earth had continents, the length of the day, and something of its climate and atmosphere. We will be doing that for other planets around other stars within 20 years.

An iconic image from the 1960s was the first photograph from space, showing our home planet of oceans, land and clouds, its fragile beauty contrasting with the sterile moonscape where Neil Armstrong and astronauts left their footprints. Within 20 years, we will be able to hang on our walls a poster with even more impact: a telescope image of a point of light that could be another Earth orbiting a distant star. But will this planet have a biosphere? Could some of these distant planets harbour life forms far more interesting and exotic than anything we will find on Mars, even something that could be called intelligent? The key questions here are not astronomical, they are biological, and biology is a far harder subject.

To answer them, we need to know how life began. I think there is a real chance of progress here so we will know whether life was a rare fluke here on Earth, or whether it is near-inevitable in the kind of initial soup expected on a young planet. But to the second question, even if simple life exists, what are the odds against it evolving into something that we recognise as intelligent? This is a far harder question. Even were primitive life common, we do not know how likely might be the emergence of advanced life.

Research has been carried out for signals from other stars that could reveal extraterrestrial intelligence - the string of prime numbers or something like that. Even if you could not make much sense of such signals, it would be a momentous discovery, showing that concepts of logic and physics were not restricted to the hardware within human skulls. But perhaps the emergence of intelligence requires such a rare chain of events that it has not happened even around one of the trillion billion stars within range of our telescopes. Were that the case, and it is a possibility, searchers for artificial signals would then be doomed to fail. This outcome would, in a way, be disappointing, but it would have a compensation: it would raise our cosmic self-esteem, because our Earth, though tiny, would then acquire deepened significance, not just for what it is now, but for its cosmic potential.

A word now about the far future: the stupendous time spans of the evolutionary past are now part of common culture. It is surely a culture of depravation to be unaware of the marvellous vision of nature offered by Darwinism and modern cosmology, the chain of emerging complexity leading from the still mysterious beginning to atoms, stars, planets and biospheres, and human brains that can ponder their origins. We are the outcome of four billion years of evolution on Earth's biosphere. But most people, although aware of that, somehow think that we humans are the culmination of the evolutionary tree, and that is surely unlikely to be so. Our Sun is less than halfway through its life, and after the Sun dies other stars will be born and the universe will go on expanding, perhaps for ever. To quote Woody Allen: 'Eternity is very long, especially towards the end!'

Darwin himself noted that, I quote: 'Not one living species will transmit its unaltered likeness to a distant futurity.' Any creatures that witnesses the Sun's demise six billion years hence will not be human; they will be as different from us as we are from our protozoan ancestors in the primordial slime three billion years ago. In the eons that lie ahead, life or its artefacts, seeded from Earth, could diffuse through the entire galaxy.

But even in this concertinaed time line, extending billions of years into the future as well as into the past, this century may be a defining moment. It is the first in our planet's history where one species has Earth's future in its hands and could jeopardise life's immense potential.

Suppose some aliens had been watching our planet for its entire history; what would they have seen? Over nearly all that immense time, four and a half billion years, Earth's appearance would have altered very gradually: the continents drifted, the ice cover waxed and waned, successive species emerged, evolved and became extinct. But, in just a tiny sliver of Earth's history, the last one millionth part, a few thousand years, the patterns of vegetation altered much faster than before. This signalled the start of agriculture. The pace of change accelerated as human populations rose. Then there were other changes, even more abrupt: within 50 years, little more than one-hundredth of one-millionth of the Earth's age, the carbon dioxide in the atmosphere began to rise enormously fast; the planet became an intense emitter of radio waves, the total output from all TVs and cellphones, etc. Something else unprecedented happened: small projectiles lifted from the planet's surface and escaped the biosphere completely. Some were propelled into orbit around the Earth, some journeyed to the Moon and to the planets. If they understood astrophysics, the aliens could confidently predict that our biosphere would face doom in a few billion years when the Sun flares up and dies, but could they have predicted this unprecedented pulse less than halfway through the Earth's life, these human-induced alterations occupying overall less than a millionth of the elapsed lifetime and seemingly occurring at a runaway speed?

If they continue to watch, what might these hypothetical aliens witness in the next hundred years? Will a final spasm be followed by silence, or will the planet itself stabilise, and will some of the objects launched from the Earth spawn new oases of life elsewhere? The answer depends on us. The challenges of the 21st century are more complex and less tractable than humans have ever faced. Our actions could initiate the spread of life beyond the Earth, indeed through the galaxy, or they could, if complex life were indeed now unique to the Earth, foreclose the creative potential of our entire galaxy. That would then be a cosmic disaster, not just a terrestrial one. So our location in space and time, on this planet, in this century, is crucially important not just for us but for the cosmos itself. Cosmology offers wonder and mystery, but it motivates action too.

Rector George Bush

Professor Barrow and Lord Rees have visited upon audience, parish and trustees unusual and great distinction, and we are vastly in their debt tonight. We thank them very much indeed.

It remains for me to announce that the 2008 Boyle Lecture will be on Wednesday, the 23rd of January, and will be delivered by the eminent neuro-psychologist Malcolm A. Jeeves, past President of the Royal Society of Edinburgh and Professor Emeritus of Psychology at St Andrew's University. He was the foundation Professor of Psychology there, and established the University's acclaimed Psychology Department. His own research has focused on brain mechanisms and neuro-plasticity. Having focused on evolution in the first two Boyle Lectures, on emergence theory in the third, and on cosmology this evening, the trustees thought it would be interesting to widen the scope of the series to incorporate human sciences as well. Professor Jeeves' distinguished academic record in psychology, together with his interest in the interface between theology and the human sciences, make him a very appropriate and welcome choice as the fifth Boyle lecturer. You will be very welcome here again next year.

To obtain a copy of *St Mary-le-Bow: A History*, published Autumn 2007, please contact Dr Michael Byrne, Editor, The History Project, St Mary-le-Bow, Cheapside, London EC2V 6AU
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