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BIG BANG TO BIG CRUNCH

A Lecture by

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1 March 1996

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BIG BANG TO BIG CRUNCH

Professor Heather Couper

Here follows a truly brief history of time. In this talk, I'm proposing to cover the entire story of our Universe from Creation to Doomsday - a story that couldn't be told until now. New technologies, new telescopes, even new advances in particle physics have all played their part in unravelling the mystery. But there are still huge blanks to be filled in. Thanks to particle accelerators on Earth, we know more about the first few seconds of the Universe than about the following half-billion years. And what happens in the future - no matter how much we try to extrapolate from present knowledge - will always involve some crystal ball-gazing.

The story begins in 1917, when Albert Einstein proposed a description of the Universe based on his new theory of General Relativity. It inspired many other theorists, including Willem de Sitter in Holland and the Russian Alexandr Friedmann. Einstein's equations predicted that the Universe should be expanding, and at the time, there was no evidence that this was the case. So Einstein added a 'fudge factor' - the 'cosmological constant' - to keep the Universe stationary.

A few years later, in the mid-1920s, the great observational astronomer Edwin Hubble discovered that the galaxies were moving apart from one another. Although he at first refused to read any great significance into this, cosmologists - scientists who study the Universe as a whole - gradually realised the importance of his findings. On the largest scales of all, the Universe *is* expanding. Einstein rapidly removed the cosmological constant from his equations, calling it his "greatest mistake".

At this point, a young Belgian Abbé - Georges Lemaître - came onto the scene. Inspired by Einstein's description of the Universe, he developed his own. Lemaître proposed that the Universe had begun as a "primeval atom" - something hot and dense that had exploded, causing space to expand. It was a very daring suggestion for the time. But later research has proved Lemaître right: our Universe was born in circumstances of unimaginable violence. Today, we call it the 'Big Bang'.

Many of you will have grown up with a theory of the Universe's evolution called the 'Steady State'. It was proposed in the late 1940s by physicists Fred Hoyle, Hermann Bondi, and Tommy Gold, and it taught the Universe was changeless, with no beginning and no ending. Yes, the Universe was expanding, but this expansion was kept 'topped up' by matter which was being continuously created in tiny quantities - just as an overflowing washing-up bowl is kept filled to the brim by a dripping tap.

By the mid-1950s, cracks started to appear in the Steady State theory, when radio astronomers found that distant galaxies - galaxies far back in time - were more tightly packed together. If the early Universe looked different, it was not changeless.

The final death-blow occurred in 1965, when physicists Arno Penzias and Robert Wilson discovered radiation from the sky - the 'Background Radiation' - that could only be the afterglow of creation itself. Even the Steady State supporters (but not Fred Hoyle) were forced to conclude that the Universe had a definite beginning in time.

The Big Bang, which took place about 13 billion years ago, was the beginning of both space and time. It came out of nowhere: an almost infinitely-hot fireball that started expanding as soon as it appeared. There was no 'before' the Big Bang, for time only kicked into play when the creation took place. Inside the fireball was the whole of space. The young Universe was a seething cauldron of radiation. Its energy was so enormous that matter and antimatter appeared spontaneously - just as Einstein had predicted in his famous equation '$E = Mc^2$', which says that energy and mass are interchangeable. But these 'virtual particles' annihilated instantaneously, and radiation reigned supreme.

Although we call the instant of creation the 'Big Bang', it was actually a fairly small one - equivalent to exploding a 1kg bag of sugar. But then the Universe got serious. Fractions of a second after 'ignition', it literally blew up. In this period of 'cosmic inflation', the Universe increased its size a hundred trillion trillion trillion trillion times. Inflation explains why the Universe is so big and so smooth today. Inflation made nearly all the mass there is in the Universe. It also spawned the four forces, flooding the Universe with energy. Virtual particles no longer needed to annihilate at once, so that real matter and antimatter began to appear.

The period immediately after inflation was the busiest in the Universe's history. The temperature rocketed to 10^{28} degrees, and the huge energy surge fuelled an explosion of particle and antiparticle creation. Because energy was so abundant, massive, exotic particles could come into being, along with oddities like miniature black holes and thin but massive cosmic strings. A snapshot of the particles present during this era would include lightweight quarks and leptons swimming amongst the massive WIMPs, X-bosons, Higgs particles and magnetic monopoles, "Force-carrying" gluons, photons, bosons and gravitons also abounded. There would also be copious quantities of 'dark matter', now known to make up something like 90% of all the matter in the Universe - although we still don't know what it is.

Next, the massed forces of particles started to fight. Closely-matched armies of matter and antimatter mutually annihilated in floods of radiation. Intense radiation all around created reinforcements in the form of new particle-antiparticle pairs. But in the end, radiation weakened too far to create new pairs, and the slight surplus of matter won out. By the end of the era, the building blocks of our Universe - protons, neutrons, electrons and neutrinos - were in place. A few massive particles like WIMPS may have come through, but it was the small ones that triumphed.

Although the young Universe was still a frenzy of activity, it was cooling fast. This meant that it could now embark on feats of construction, rather than destruction. By the end of its third minute, it had succeeded in welding protons and neutrons - its basic building-blocks - into the nuclei of the first elements, hydrogen (single protons), helium and a smattering of lithium. To begin with, protons and neutrons were around in equal numbers. But neutrons are slightly unstable, and decay into protons - so protons got the upper hand. This is reflected in the proportions of the early elements created: 77% hydrogen, 23% helium.

After the hurly-burly of its extreme youth, the Universe relaxed. It continued to expand and cool: a foggy, opaque mass of radiation and particles. But inside the expanding fog, the Universe was busy. Invisible dark matter was gathering into the beginnings of galaxies. And when the temperature dropped to 3,000 degrees, electrons suddenly combined with nuclei to make atoms. Light, until then apprehended by electrons, had free passage - so the Universe cleared. Looking back to that instant, 300,000 years after the Universe's birth, with a sensitive radio telescope, astronomers can see the divide - and the opaque wall of the dying fireball itself.

As the cosmic fog cleared, matter was 'curdling' like milk turning into cheese, imprinting distinctive 'ripples' - discovered in 1991 by the COBE satellite - in the radiation background. Freed from the domination of radiation, matter was now in charge of its own destiny. It heralded a new era in the cosmos: huge structures - galaxies and clusters of galaxies - could start to emerge. Many galaxies had a violent youth, going through quasar outbursts before settling down to become placid star-cities.

The stars in these young galaxies picked up the baton of element-creation from the Big Bang. Deep inside their central cores, it was hot and dense enough to build hydrogen into helium; helium into carbon; and carbon into a succession of still-heavier elements. When these stars died, their 'ashes' were scattered across space, to create a new generation of 'enriched' stars. As time went by, the elements in space linked up to make increasingly complex molecules. Some of these now form the basis of life itself.

4.6 billion years ago - in a quiet suburb of one particular galaxy, the Milky Way - an ordinary star was born. But it was special to us: the Sun, with its planets, had come into existence. And the rich cocktail of molecules present by then ensured that one of the Sun's planets, at least, was able to develop life forms that would seek to comprehend the Universe around them

Today, the Universe is in its prime, with abundant raw materials in hand to make many more generations of stars. But the stars' days are numbered. In 5 billion years, our Sun will use up all its fuel and end its days as a dim white dwarf. Bigger stars will end up as neutron stars, or even black holes. Galaxies will become stellar graveyards, comprising star-corpses orbiting a massive black hole.

What happens next? The long-term future of the Universe depends on how much matter it contains. If it has enough matter - and remember that over 90% of the matter in the Universe is believed to be invisible 'dark matter' - then it possesses good 'gravitational brakes'. These will gradually slow down the expansion of the Universe, and ultimately reverse it. Such a collapsing Universe is called a 'closed Universe'.

But even with all the dark matter thought to be present, there may not be enough mass to halt the expansion of the Universe. A Universe like this is called 'open', and it will expand forever. The galaxies will continue to recede from one another, and the Universe will grow steadily emptier. In each dying galaxy, the star-corpses either fall into the central black hole, or are whirled out into space. They will eventually decay into radiation, while the supermassive black holes will explode. Nothing larger than subatomic particles will remain. At the very end, the tiny particles born in the Big Bang will have the last say. The infinite future will be one of a bitterly-cold expanse thinly-populated with electrons, positrons, neutrinos and the elusive WIMPS.

A closed Universe, on the other hand, will expand, reach a limit, and then shrink back. At first, stars live out their lives as they do in an open Universe. But about 3 million years before the 'Big Crunch', approaching galaxies - now huge black holes - start to merge with each other. As the collapse proceeds, the temperature of the background radiation climbs to that of the stars. At 3 minutes to go, the black holes merge. Rather than a death by cold, we now face a death by fire as the Universe races to oblivion. In this time-reversal of the Big Bang, space will disappear and time will come to a halt.

The Big Crunch, final though it is, does have some appeal. For it's possible that a Big Crunch could 'bounce' - and generate a new Big Bang. The 'oscillating universe' theory means that the Universe never really dies, but is constantly reborn from its own ashes. However, even if it is possible to create a new universe in this way, it would not be the same as *our* Universe. Our Universe has a unique mix of very particular particles and forces. Another universe would have a completely different mix - and we would certainly not be able to exist in it. So it's wise to get to appreciate the Universe we've got - for whether it's open or closed, we have an awful lot of time ahead living inside it.