A brief history of cosmology

Four thousand years ago the Babylonians were skilled astronomers who were able to predict the apparent motions of the moon and the stars and the planets and the Sun upon the sky, and could even predict eclipses. But it was the Ancient Greeks who were the first to build a cosmological model within which to interpret these motions. In the fourth century BC, they developed the idea that the stars were fixed on a celestial sphere which rotated about the spherical Earth every 24 hours, and the planets, the Sun and the Moon, moved in the ether between the Earth and the stars.

This model was further developed in the following centuries, culminating in the second century AD with Ptolemy's great system. Perfect motion should be in circles, so the stars and planets, being heavenly objects, moved in circles. However, to account for the complicated motion of the planets, which appear to periodically loop back upon themselves, epicycles had to be introduced so that the planets moved in circles upon circles about the fixed Earth.

Despite its complicated structure, Ptolemy produced a model so successful at reproducing the apparent motion of the planets that when, in the sixteenth century, Copernicus proposed a heliocentric system, he could not match the accuracy of Ptolemy's Earth-centred system. Copernicus constructed a model where the Earth rotated and, together with the other planets, moved in a circular orbit about the Sun. But the observational evidence of the time favoured the Ptolemaic system!

There were other practical reasons why many astronomers of the time rejected the Copernican notion that the Earth orbited the Sun. Tycho Brahe was the greatest astronomer of his the sixteenth century. He realised that if the Earth was moving about the Sun, then the relative positions of the stars should change as viewed from different parts of the Earth's orbit. But there was no evidence of this shift, called parallax. Either the Earth was fixed, or else the stars would have to be fantastically far away.

It was only with the aid of the newly-invented telescope in the early seventeenth century that Galileo could deal a fatal blow to the notion that the Earth was at the centre of the Universe. He discovered moons orbiting the planet Jupiter. And if moons could orbit another planet, why could not the planets orbit the Sun?

At the same time, Tycho Brahe's assistant Kepler discovered the key to building a heliocentric model. The planets moved in ellipses, not perfect circles, about the Sun. Newton later showed that elliptical motion could be explained by his inverse-square law for the gravitational force.

But the absence of any observable parallax in the apparent positions of the stars as the Earth rotated the Sun, then implied that the stars must be at a huge distance from the Sun. The cosmos seemed to be a vast sea of stars. With the aid of his telescope, Galileo could resolve thousands of new stars which were invisible to the naked eye. Newton concluded that the Universe must be an infinite and eternal sea of stars, each much like our own Sun.

It was not until in the nineteenth century that the astronomer and mathematician Bessel finally measured the distance to the stars by parallax. The nearest star (other than the Sun) turned out to be about 25 million, million miles away! (By contrast the Sun is a mere 93 million miles away from the Earth.)

Most of the stars we can see are contained in the Milky Way - the bright band of stars that stretches across our night sky. Kant and others proposed that our Milky Way was in fact a lens shaped "island universe" or galaxy, and that beyond our own Milky Way must be other galaxies.

As well as stars and planets, astronomers had noted fuzzy patches of light on the night sky, which they called nebulae. Some astronomers thought these could be distant galaxies. It was only in the 1920's that the American astronomer Hubble established that some of these nebulae were indeed distant galaxies comparable in size to our own Milky Way.

Hubble also made the remarkable discovery that these galaxies seemed to be moving away from us, with a speed proportional to their distance from us. It was soon realised that this had a very natural explanation in terms of Einstein's recently discovered General Theory of Relativity: our Universe is expanding!

In fact, Einstein might have predicted that the Universe is expanding after he first proposed his theory in 1915. Matter tends to fall together under gravity so it was impossible to have a static universe. However, Einstein realised he could introduce a arbitrary constant into his mathematical equations, which could balance the gravitational force and keep the galaxies apart. This became known as the cosmological constant. After it was discovered that the Universe was actually expanding, Einstein declared that introducing the cosmological constant was the greatest blunder of his life!

The Russian mathematician and meteorologist Friedmann had realised in 1917 that Einstein equations could describe an expanding universe. This solution implied that the Universe had been born at one moment, about ten thousand million years ago in the past and the galaxies were still travelling away from us after that initial burst. All the matter, indeed the Universe itself, was created at just one instant. The British astronomer Fred Hoyle dismissively called it the "Big Bang", and the name stuck.

There was a rival model, called the Steady State theory - advocated by Bondi, Gold and Hoyle - developed to explain the expansion of the Universe. This required the continuous creation of matter to produce new galaxies as the universe expanded, ensuring that the Universe could be expanding, but still unchanging in time.

For many years it seemed a purely academic point, whether the universe was eternal and unchanging, or had only existed for a finite length of time. But a decisive blow was dealt to the Steady State model when in 1965 Penzias and Wilson discovered a cosmic microwave background radiation. This was interpreted as the faint afterglow of the intense radiation of a Hot Big Bang, which had been predicted by Alpher and Hermann back in 1949.

Following on from earlier work by Gamow, Alpher and Herman in the 1940's, theorists calculated the relative abundances of the elements hydrogen and helium that might be produced in a Hot Big Bang and found it was in good agreement with the observations. When the abundance of other light elements was calculated these too were consistent with the values observed.

Since the 1970's almost all cosmologists have come to accept the Hot Big Bang model and have begun asking more specific, but still fundamental, questions about our Universe. How did the galaxies and clusters of galaxies that we observe today form out of the primordial expansion. What is most of the matter in the Universe made of? How do we know that there are not black holes or some kind of dark matter out there which does not shine like stars? General relativity tells us that matter curves space-time, so what shape is the Universe? Is there a cosmological constant after all?

We are only beginning to find answers to some of these questions. The cosmic microwave background radiation plays a key role as it gives us a picture of the universe as it was only a hundred thousand years after the Big Bang. It turns out to be so remarkably uniform, that it was only in 1992 that NASA's Cosmic Background Explorer satellite detected the first anisotropies in this background radiation. There are slight fluctuations in the temperature of the radiation, about one part in a hundred thousand, which may be the seeds from which galaxies formed.

Since the early 1980's there has been an explosion of interest in the physics of the early universe. New technology and satellite experiments, such as the Hubble Space Telescope, have brought us an ever improving picture of our Universe, inspiring theorists to produce ever more daring models, drawing upon the latest ideas in relativity and particle physics.

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