

The Expanding Horizons of Cosmology

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'The history of astronomy is a history of receding horizons'. Nowhere are these words of Edwin Hubble more apt than in *cosmology*, the branch of astronomy which is concerned with the profound questions of the origin, structure and evolution of the universe in the large. Indeed, as we shall see later, Hubble himself played a very crucial role in pushing back the horizons of knowledge in cosmology.

In the present age of science, astronomy like any other branch of science, has registered tremendous achievements in the comparatively brief span of five decades. Yet, to appreciate this march of progress it is necessary to take cognizance of the preceding five millennia. For, the foundations of modern cosmology rest on the painstaking work of hundreds of generations of astronomers and physicists. Not all of what they thought or conjectured was right; indeed most of it turned out to be wrong. But in this long drawn out process of trial and error, man was led along the track of progress in understanding the universe; the track which brought him where he is today.

Man has always been curious about himself and his environment. Written records of ancient civilizations show how man has tried to satisfy his curiosity, how he tried to reason out the cause of his existence or of the existence of the universe around him. Ancient cultures which prospered in Egypt, Babylon, China and the Indus Valley must have wondered where the stars in the clear night sky came from or how far they were spread. The brilliance of the Sun in the daytime and the soothing light of the moon not only inspired

religious and/or romantic feelings, they also kindled the torch of curiosity.

Ancient mythologies contain many different types of speculations about the origin and evolution of the universe. Even Hindu mythology has not one but several concepts of the world's creation, structure and evolution. It would be difficult to do justice to them all here. We will, however, refer to one particular concept later in this article.

The most systematic account of cosmology which has some sort of link with modern ideas, is found in the writings of the Greek scholars more than two thousand years ago. The philosophical ideas of Aristotle (a mentor of Alexander the Great) played a very vital role in influencing the development of science in Europe right up to the Middle Ages and even beyond.

Aristotle attached a prime importance to the Earth. To him the Earth occupied a central place round which the whole cosmos revolved. The rising and setting stars (including the Sun) bore testimony to the fact that the Earth was fixed and the celestial sphere revolved round it. Indeed, this circular motion, according to Aristotle, was the natural motion for all objects in the universe. The circle as well as the straightline, has the property of *self similarity*: any portion of a self similar curve can be moved and placed over any other portion congruently, that is, in a way that would cover it exactly. Any departure from the natural motion in a circle or a straight line, meant according to Aristotle, that a force was in action. The role of the force was to change motion from *natural* to *violent* form.

Astronomers suveying the sky over centuries were, however, worried that some heavenly bodies did not follow these natural circular tracks. These bodies were called the planets (meaning *wanderers*). The planets showed many irregularities in their motion. The planet Venus showed a retrograde motion part of the time: that is, relative to the Sun it reversed its tracks part of the time and went the opposite way. To fit the planets within the Aristotelean system of natural motions it was necessary to show that their tracks were made of circles.

This demonstration was finally given by Hipparchus and Ptolemy with their theory of epicycles. These two Greek astronomers evolved elaborate geometrical constructions in which the planets were shown to move on circles whose centres moved on other circles whose centres moved on other circles...and so on. The object of the whole exercise was to reproduce the apparently irregular planetary motion as seen from the Earth.

The epicyclic theory looks, from today's hindsight, like an intricate exercise in geometry. There is also the indication as pointed out recently by R R Newton (*Crime of Claudius Ptolemy*, Johns Hopkins University Press, Baltimore, 1977) that Ptolemy had fudged the data in order to fit his theory. The theory certainly was artificial in the sense that it insisted on describing everything within the 'fixed Earth' framework of Aristotle. Nevertheless the work of Ptolemy as contained in his classic volume *Almagest* did have one merit: it could predict with reasonable accuracy the location of a planet at a given instant of time.

The 'fixed Earth' or the *geocentric* theory gained considerable credence in medieval Europe partly because of its predictive power, but more because of the backing it received from the Roman Church. It seems to have spread even beyond Europe, through Arabia to India.

There is an interesting episode in Indian astronomy, involving Aryabhata, the leading astronomer who flourished in India in the 4th century A D. There is a verse in the *Aryabhatiya*, the scientific work of Aryabhata, which clearly states that because the Earth revolves about an axis, the stars (which are really fixed) appear to move from East to West. Aryabhata even compares this scenario with the backward motion of objects on the bank of a river as seen by a man in a boat. Yet so firmly rooted was the geocentric theory that Aryabhata's pupils or successors either denied that he ever said such a (stupid?) thing or tried to reinterpret his verse in a totally different way.

But to return to the Europe of the 15th century! Nicolaus Copernicus, born in 1473, did firmly repudiate the geocentric theory. Copernicus encountered severe opposition to his alternative theory, the so called *heliocentric* theory which put the Sun firmly fixed in space. All planets, including the Earth are supposed to go round the fixed Sun in the Copernican theory. To the Church-dominated intelligentsia of Europe the Copernican theory was heretical and considerable pressure was brought on Copernicus not to publish or propagate his ideas. But Copernicus persisted although he saw his published book *de revolutionibus orbium caelestium libri VI*, for the first (and the last) time on his deathbed.

Was Copernicus right and Ptolemy wrong? Einstein's relativity theory has taught us that we can describe physical events from any frame of reference. Thus one is equally well entitled to describe the planetary system from the fixed Earth frame as Ptolemy did or from a fixed Sun frame as Copernicus did. So neither of them could be considered wrong!

The merit of the Copernican theory lies in the fact that it shows clearly the special status of the Sun *vis-a-vis* the planetary system. It was the first step in trying to answer the question: Why do the planets move in the way they do? The heliocentric theory hinted that the Sun must play a key role in planetary motion. Later the work of Johannes Kepler identified the Sun as a focus of the ellipse along which the planet moves. Kepler also gave basic laws which seemed to govern the apparently irregular motion of planets. And from Kepler's laws Newton was able to construct a theory which explained *why* the planets move according to these laws.

The Copernican theory not only initiated the revolution against the geocentric theory, it further led to an assault on the basic principles of motion as given by Aristotle. The assault was led by Galileo Galilei whose book, *Dialogue concerning the Two Chief World Systems—Ptolemaic and Copernican* laid the foundations of the laws of motion which Newton later enunciated.

In his book *Philosophiae Naturalis Principia Mathematica*, published in 1687, Isaac Newton laid the foundations of modern physics. His laws of motion and universal gravitation not only described the motion of planets, comets and satellites of the solar system, they also inspired developments in laboratory physics such as in the area of electricity and magnetism.

Newton in the 1690s did attempt to describe the largescale structure of the universe in terms of his laws of gravity and dynamics. Newton made the simplest assumptions, that the universe is *static*, *homogeneous* and *isotropic*. This meant that the universe has no large-scale motions in it, that it looks the same from everywhere and that it looks the same in all directions. Newton soon discovered, however, that such a universe is unstable : that it would not stay that way under the slightest disturbance. The tendency of the universe would be to shrink in small lumps rather than stay homogeneous. Newton was unable to offer any explanation as to why and how the universe is able to maintain a stable situation in spite of this unsettling tendency.

In the year 1826 Heinrich Olbers, a Viennese physician mentioned another difficulty with regard to the Newtonian system of the universe as enunciated above. By a simple calculation Olbers demonstrated that an infinitely old universe with a uniform distribution of shining objects like stars would have an infinitely bright sky. There will be so much radiation from the distant stars that it would be immaterial whether we are facing the Sun or away from it. Starting with an innocent looking question like 'Why is the sky dark at night?' Olbers concluded that in the static uniform universe the sky

would be so bright as to burn the Earth to a crisp!

The difficulties of Newton and Olbers were resolved at a stroke by the modern theories of the structure of the universe. The modern cosmology is based on two important developments. In 1915 Albert Einstein came up with the general theory of relativity. As a theory of gravity and motion general relativity has certain conceptual advantages over the Newtonian system. It resolves the lacunae which arose in Newtonian gravity when, in 1905 Einstein himself had revolutionized the physicist's concepts of space and time. The important development in cosmology was in 1929 when Edwin Hubble discovered the phenomenon of nebular redshift a phenomenon which seemed to suggest that the universe is *not static*.

Basically, what Hubble found was the following result: when he analysed the light from a typical remote galaxy he found that its spectrum contained the familiar absorption lines but with *increased* wavelength. In other words, Hubble's observations seemed to imply that the light coming from the remote galaxy undergoes an increase in wavelength. In the visible part of the spectrum the red colour is seen at the maximum wavelength end. Hence an increase in wavelength shifts the spectrum of any galaxy towards the red colour end, which accounts for the term 'redshift'.

Hubble found the redshift to increase with the faintness of the galaxy, implying that: If two galaxies have equal radiating power, the galaxy which is further away would appear fainter. So the redshift seemed to increase with distance. But what did redshift owe its origin to? According to a well known effect discovered by the Austrian physicist Christian Johann Doppler in 1842, if a source of light (or sound) moves away from an observer, the wavelength of the light (or sound) waves from the source appear to the observer to have increased. Thus, the Doppler effect interpretation of Hubble's observations implied that the remote galaxies are all moving away from us.

Does this interpretation take us back to the pre-Copernican scenario which had the Earth fixed in space and the rest of the universe moving? Instead of the Earth our Galaxy appears to be fixed and the other galaxies seem to be moving from it. No! We are not back to the days of Aristotle. In fact Hubble's observations imply that the universe as a whole is expanding. If we were to view the universe from *any* other galaxy we would again see the rest of the universe receding from our new location. There is nothing special about our Galaxy; all galaxies have equal status in the universe.

Even before Hubble's observation became known, the models of the expanding universe had been obtained as mathematical solutions of Einstein's equations. These models were first discussed by

A Friedmann in 1924 and are named after him. The Friedmann models not only describe the present state of the expanding universe, but they also tell us what the universe was like in the past and what it would be like in the future.

The Friedmann models tell us that the universe originated in a *big bang* : an enormous explosion which took place some ten billion year (10 thousand million years) ago. The present expansion is the slowed down version of the explosion in the past. The slowing down of expansion will continue : it may either go on for ever or it may stop and give way to contraction. It is here that we encounter a striking similarity of time-scales of modern cosmology and the ancient Hindu mythology. The latter has the day of Brahma (the creator of the Universe), which corresponds to the life span of creation, as equal to 4.32 billion years!

These models would have remained mere speculative exercises like the ancient cosmologies had there been no observational tests of their predictions. Thanks to the recent technological developments, many attempts have been made and are being made to probe the largescale structure of the universe and to test the predictions of cosmological theories.

The centuries old optical astronomy is of course continuing to provide valuable evidence, with its modern telescopes. After World War II, radio astronomy added another dimension to these investigations. Cosmic radio sources located billions of light years away are being picked up by radio telescopes all over the world. The very long baseline interferometry is one of the ways in which radio telescopes thousands of miles apart act in a concerted fashion to provide detailed maps of the structure of radio sources.

An attempt to study the structure of the universe through measurements of the angular sizes of distant radio sources was made in the mid-1970s by Govind Swarup and Vijay Kapahi with the help of the radio telescope. The telescope is situated on a hill slope near Ootacamund in South India and its array of antennae extends to over half a kilometre. From their observations Swarup and Kapahi concluded that the sizes of radio sources were smaller in the past than they are now. Although this conclusion does not directly prove that the universe originated in a big bang, it lends support to the belief held by many cosmologists today that the universe is evolving, i.e., changing with time.

The recent developments in space technology have added new inputs to cosmology. X-rays, gamma rays, microwaves, infrared, ultraviolet—these different 'windows' of the electromagnetic radiation are now open for observation. Already it is becoming clear that our

concept of the universe is going to be considerably enriched by these new branches of astronomy. Towards the end of 1983, the space telescope is expected to be in orbit. This orbiting optical telescope is expected to see *seven* times further away than the best ground based instruments of today.

Is the big bang picture supported by these observations? To date there is one evidence which is considered decisively favourable to the big bang theory. One of the predictions of this theory was that the universe was very hot and radiation dominated in the early stages, and that at present we should be able to see the cooled down relic of this radiation. Such a radiation background was first seen in 1965 by Arno Penzias and Robert Wilson at a wavelength of around 7 cm. Subsequent observations have confirmed the existence of this radiation at several different wavelengths. It is predominantly in the microwaves and appears to have the spectrum expected of the relic radiation. Most astronomers therefore regard the microwave background as conclusive evidence for the big bang origin of the universe.

Personally, I would advocate a more cautious appraisal of the present cosmological observations. Remarkable though the advances of science have been in the recent years, I think it premature to conclude that astronomers have *solved* the age-old problem of the structure of the universe. As we push back the horizons of knowledge, new problems and questions are bound to appear : for that is the way science makes progress.