New observations of cosmic relic radiation

JAYANT NARLIKAR

I.U.C.A.A., Pune University Campus, Pune 411007

The year 1990 began with some exciting findings on the cosmological front. The findings were made by a satellite launched by NASA, the National Aeronautic and Space Administration of the United States. The satellite is called the Cosmic Background Explorer or COBE in short. To understand the COBE results in their proper context, it is necessary to take a brief look at how the subject of cosmology has developed over the last six decades.

Cosmology deals with the ideas and facts on the origin of the universe, its large scale structure and its evolution. Although in the previous centuries this subject was mainly speculatious, the twentieth century has treated it with the discipline of science. That is, cosmological theories are expected to be founded on facts and developed in a quantitative mathematical fashion. They have to make predictions that can be tested, confirmed or disproved. Indeed, modern technology has provided the cosmologist with numerous ways of checking upon his theories.

The first major finding of great relevance to cosmology came in 1929 when Edwin Hubble working in the Mount Wilson Observatory near Los Angeles in Southern California found the remarkable fact that the spectrum of light from galaxies shows a systematic shift towards the red end of its seven colour band of rainbow colours. Physics tells us that the red end of the spectrum has light waves of longer wavelength than the opposite violet end. Thus the *prima facie* conclusion of Hubble was that light from these galaxies is undergoing an increase of wavelength in its passage to us. This phenomenon is known as 'redshift'. Moreover, Hubble found that the quantitative extent of the redshift was larger for fainter galaxies than nearly ones.

Hubble interpreted this result in the following way. He assumed that the fainter galaxies were farther away than nearly ones and used the then available techniques of distance measurement based on the inverse square law of illumination to estimate their distances. He then concluded that the redshift is proportional to distance. That is, if one galaxy is ten times farther away from us, compared to another then its redshift will be ten times larger compared to the redshift of the other galaxy. This is now known as Hubble's law.

The next step was to interpret the result in physical terms. What does it mean? The physicist had one simple explanation for redshift. whenever, a source of light moves away from the observer, its spectrum exhibits redshift. Thus Hubble was able to argue that all galaxies are moving away from our galaxy, the so called Milky Way, and that the farther they are the faster they are receding from us.

As it happened, some seven years earlier a Russian physicist of the name Alexander Friedman had constructed mathematical models of the large scale structure of the universe which anticipated Hubble's result. Friedman's models were based on Einstien's general theory of relativity—a theory that links the gravitational property of matter with the geometrical properties of space and time. They described a universe that is expanding so that all galaxies embedded in it are found to be moving away from one another.

Ironically, Friedman's paper did not evoke a positive response either from Einstein or from the observers. This was because Einstein believed that the universe is static; that is, there is no large scale motion of galaxies relative to one another. Observationally too, there was no evidence of this kind until Hubble's law appeared on the scene.

Thus it was after 1929 that the Friedman models really became accepted. These models describe a universe that is supposed to have originated in a big explosion and which has been expanding from that initial state. The models differ in their future scenarios. Thus one class of models describes the universe as expanding for ever, with all galaxies continuing to recede from one another until each one is infinitely far away from its neighbours. The other alternative is that the galaxies continue to move away from one another with decreasing speeds until they all come to a momentary halt and then begin to fall back towards one another.

Thus the universe, according to these models, had a beginning in a big bang and it would either continue to expand for ever and disappear into infinity or it would later contract back to a point and end there. Fred Hoyle, who is one of the opponents of these models termed the initial instant somewhat derisively as 'big bang'. This name, however, struck as the models gained popularity.

What was the reason for their popularity? As I said before, speculations alone are not enough: their acceptance in science comes from factual corroboration. Something like this happened in 1965. But before coming to 1965, let me describe the remarkable work of George Gamow that preceded it by about fifteen years.

Gamow had calculated that the universe must have been extremely hot in the first few moments after the big bang. For example, just one second after creation, its temperature would have been around ten billion degrees. For Gamow temperatures ranging from ten billion to a few hundred million were just right for the synthesis of atomic nuclei by the fusion process. Gamow had theorized that starting from the nuclear particles protons and neutrons, the thermonuclear fusion would build up the nuclei of progressively heavier atoms: hydrogen to helium, to begin with.

Gamow and his colleagues Alpher and Herman were partially right in their theory. Later work corroborated their conclusion so far as light nuclei were concerned, like deuterium, helium, lithium and berrylium. It was not, however possible to make up heavier nuclei. In fact astrophysicists Geoffrey and Margaret Burbidge, William Fowler and Fred Hoyle showed in 1957 that most nuclei can be made in the fusion processes taking place inside stars.

However, Gamow and Alpher and Hermann, independently made another prediction arising out of their work, namely that the hot era would have left behind considerable radiation which should be detectable today albeit at a much lower temperature. They estimated the temperature of the relic radiation to be around 5 to 7 degrees on the absolute scale of temperature—that is about 266 to 268 degrees below zero on the Celsius scale.

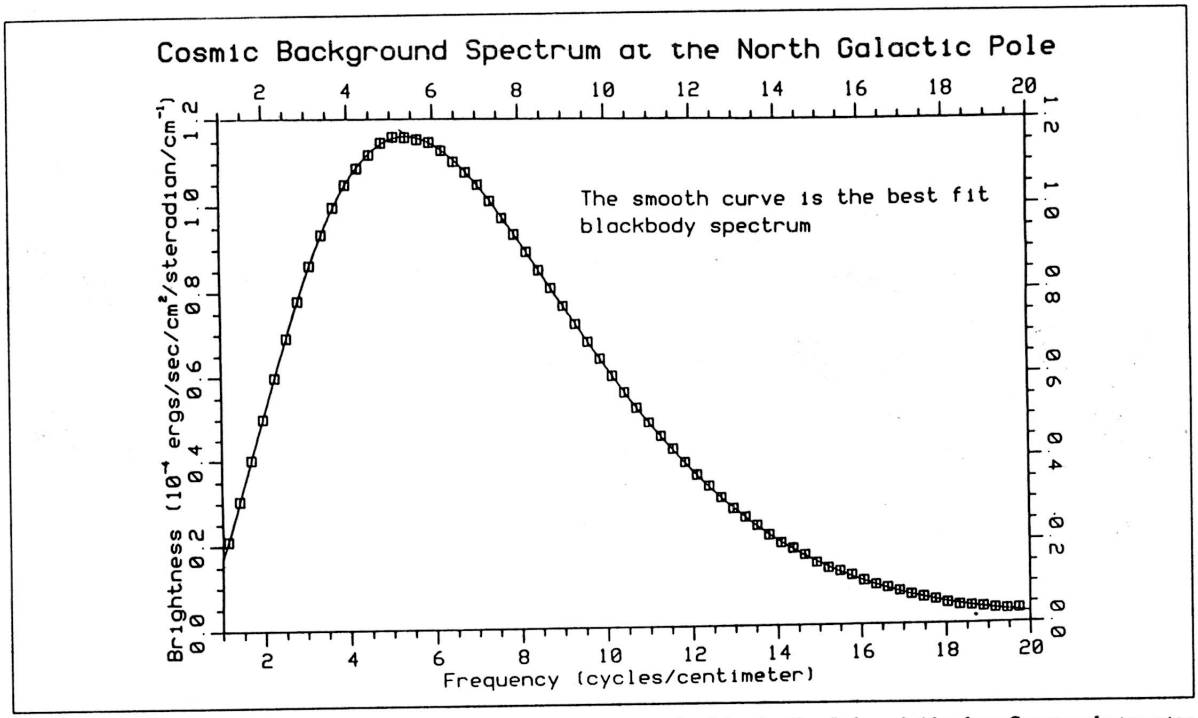
These predictions were, however forgotten or ignored as being too speculative. Thus when in 1965 two physicists Arno Penzias and Robert Wilson from the Bell Telephone Labs in New Jersey found a radiation background in the microwaves with a temperature of about 3 degrees absolute, the result came to them as a complete surprise. This radiation could not be associated with any sources in the sky.

However, cosmologists were not slow in recognizing the significance of this result. Gamow and his colleagues may have guessed the temperature a little on the higher side, but they had predicted relic radiation in the microwaves. To make the interpretation stronger it was necessary to demonstrate that the spectrum was Planckian as required in a black body.

What is a black body? Ideally, it is a perfectly sealed enclosure that does not allow any radiation from inside to escape. Physics tells us that inside a black body the radiation goes back and forth, knocking at the walls and getting scattered until it settles down to a definite spectral form which was first explained by the physicist Max Planck at the turn of the century.

The relic radiation from the big bang should have such a form it inherited from the early epochs when it was frequently scattered and knocked around. Was the microwave background found by Penzias and Wilson of this Planckian form?

Over the years observers have been busy measuring the spectrum of the microwave



The preliminary spectrum of the cosmic microwave background obtained by the Far Infrared Absolute Spectrophotometer on the COBE satellite. The continuous curve is the best fit black body spectral curve for $T = 2.735$ K.

background at different wavelengths. As the wavelength is reduced from the value of around 7 cm by Penzias and Wilson, the intensity of the radiation should rise until it peaks at around 1 mm after which it should drop. This rise and fall must conform with the formula given by Planck.

Observations have indeed confirmed this expectation. There was, however, a flurry of anxiety when a joint Japanese-American rocket experiment a couple of years ago revealed significant differences from the predicted Planckian curve on the short wavelength side of the peak. Observations at these wavelengths have to be performed above the atmosphere to avoid the attenuation due to absorption.

This is where the COBE results come in. The first analysis of the COBE data taken well above the atmosphere shows the spectrum of the microwave background to be strictly Planckian, thus providing relief to the relic interpretation. It is still to be found out whether the discrepancy between the Japanese-US experiment and the COBE results is attributable to experimental errors. Meanwhile the Japanese are expecting to repeat the earlier experiment with greater sensitivity.

Another finding of COBE has however proved somewhat disappointing to the relic interpretation. If the radiation background is indeed of primordial origin then it should carry imprints of the processes of structure formation in the universe. The structures are the galaxies, clusters of galaxies and even very large superclusters of galaxies, found in the universe today. How did they come about? Evidently some turmoil should have taken place in the cosmological medium, churning it up in order to condense these structures. And that turmoil would not have left the radiation undisturbed. So theorists have been expecting to find inhomogeneities—lumps and knots—in the radiation background.

All attempts to date to detect these imprints have failed. Even the COBE data reveal the

background to be extremely smooth! What does this mean?

Is nature playing a subtle trick, hiding all the evidence of the galaxy formation process? Or, are we on the wrong track, in believing the radiation background to be primordial? The majority of astrophysicists believe in the first possibility and theorists are busy trying to wriggle out of the implications of the embarrassingly smooth microwave background.

I belong to the small minority who would like to keep an open mind and look for alternative scenarios for the microwave background.

Only time and more observations will tell which point of view is right.