Was there really a BIG BANG?

by Jayant V. Narlikar

WHAT do we know about the origin of the Universe? If today an opinion poll were to be conducted on this question, a great majority of astronomers would agree with the view that the Universe came into existence in a gigantic explosion that took place some 10 to 15 thousand million years ago.

This conventional view, commonly known as the "Big Bang" theory, has it that at the moment of origin the Universe was infinitely dense and infinitely hot but as it expanded in all directions, it cooled and became less dense. Soon after the Big Bang, there formed from its debris the basic building blocks of matter which later developed into large astronomical units that we recognize today as stars, galaxies, clusters of galaxies and so on.

Although the Universe is still expanding as a result of that initial Big Bang and all the galaxies are moving away from one another, the ferocity of the initial explosion is no longer present now, nor is the universe very hot or very dense. Its overall temperature is estimated at about 270 degrees Celsius (Centigrade) below zero, while an average cubic volume of a million kilometre size is believed to contain no more than about one kilogram of visible matter.

Cosmology is the branch of science concerned with the study of the large scale structure of the Universe, its origin and its evolution. Like other parts of astronomy (and of science in general) cosmology has its share of controversies and, if history is any guide, the majority view has not always prevailed. For, in the last analysis speculations, however popular, have to give way before hard facts.

The Big Bang scenario described above has grown over the years out of a series of plausible speculations based on a comparatively few hard facts. But do we have the guarantee that in this scenario we have at last found the answer to the ultimate question that man has been attempting to grapple with since time immemorial? Have we reached the level of sophistication needed to understand the origin of the Universe?

Opinions differ amongst scientists on this question. There are those who feel that with the unification of all the basic forces of nature in sight, the "end of physics" is not too far away. For them the cosmological problem is also near its solution. I share the more pessimistic (and more realistic?) assessment of English astronomer Sir Fred Hoyle who said in 1970:

"I think it is very unlikely that a creature evolving on this planet, the human being, is likely to possess a brain that is fully capable of understanding physics in its totality. I think this is inherently improbable in the first place, but, even if it should be so, it is surely wildly improbable that this situation should just have been reached in the year 1970".

With these reservations in mind one can ask if the presently popular Big Bang scenario is the only plausible one for the origin and evolution of the Universe.

The discovery that the Universe is expanding was made by the American astronomer Edwin Hubble (1889-1953) in 1929. Hubble's original observations have since been repeated with greater accuracy and out to greater distances, and these have confirmed the view that the space in which the galaxies are embedded is expanding. The rate of expansion of the Universe at any given epoch is measured by a constant H, commonly known as Hubble's constant.

Given the fact that the Universe is presently expanding we need a dynamic theory to tell us what it did in the past and what it will do in the future. Einstein's General Theory of Relativity is the simplest and most suitable theory available today for this purpose. Models of the Universe based on this theory lead us to the concept of the Big Bang origin. According to these models the density of the Universe and the Hubble rate of expansion would be found to be higher and higher as we probe the history of the Universe further back in time, so much so that at an epoch a finite time ago both these quantities were infinite. This is the Big Bang epoch. ▶

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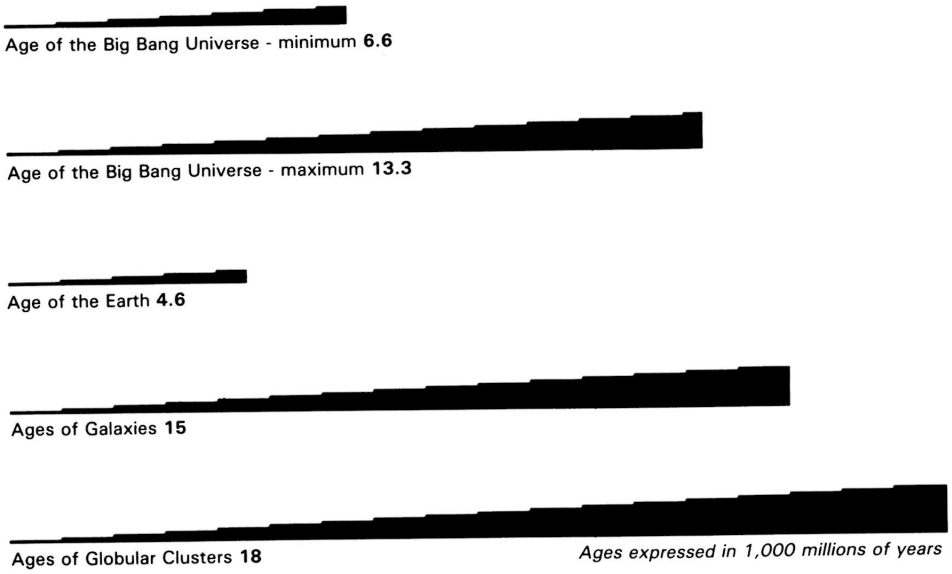
The !Kung Bushmen of the Kalahari Desert in Botswana call the Milky Way, which is often overhead at their latitude, "the backbone of night". They believe that the Galaxy holds up the night, as if the sky were a great beast within which we live. Jon Lomberg's painting* The Backbone of Night *is inspired by this metaphor about the Milky Way.



Because of the present uncertainties in the value of Hubble's constant, the age of the Big Bang universe is believed to lie between 6,600 million and 13,300 million years. This age range can accommodate the age of the earth but not of the older galaxies or globular clusters.

▶ Physicists normally become suspicious of the validity of their theoretical framework if it leads them to infinities like this. Einstein's theory makes the situation even worse because it links the density and the motion of matter with the geometrical properties of space and time. At the Big Bang epoch, therefore, it is impossible to define these properties. This total breakdown of physical and mathematical descriptions has led to the Big Bang epoch being called a "singular" epoch.

The appearance of this singularity is more a reflection on the incompleteness of our understanding than a description of physical reality.

The singular epoch is identified with the origin of the Universe. The law of conservation of matter and energy breaks down at this epoch since all the matter (and radiation) present in the Universe would have to be created at this time.

Cosmologists define the age of the Universe as the time elapsed since this epoch and this has been worked out by using the reciprocal of Hubble's constant (in other words by "working the sums out backwards") to calculate how long it would take for the Universe as it is now to *contract* back to the time of the Big Bang.

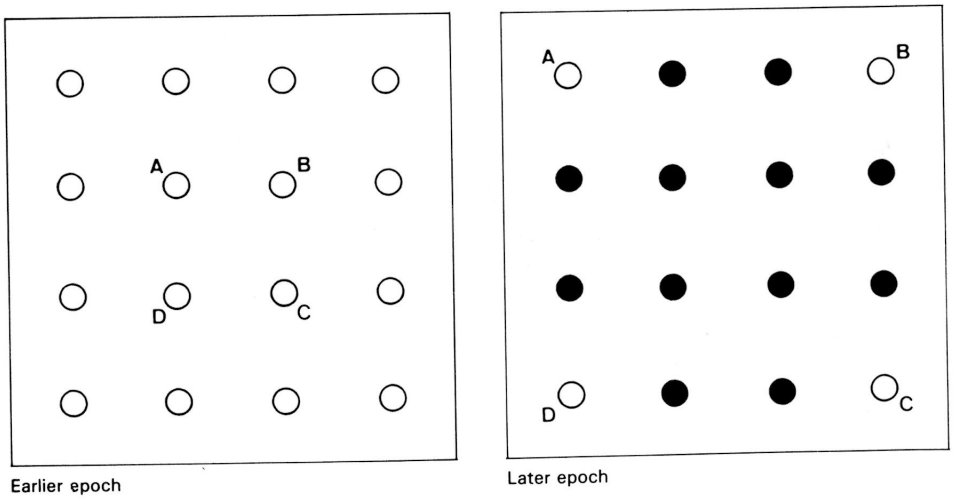
Although astronomical observations today cannot give the value of Hubble's constant accurately, the model universe currently most favoured by cosmologists and particle physicists working together gives an *upper limit* for the time elapsed since the Big Bang of between twenty thousand million and ten thousand million years.

These calculations are based on an idealized model of an empty universe. The presence of matter, however, tends to slow down the expansion of the model universe and to reduce its age. If there is enough matter in the real Universe to slow down its expansion to a momentary standstill followed by contraction (as the most widely accepted version of the Big Bang theory predicts), then its present age cannot be more than two-thirds of the theoretical calculation of the time elapsed since the Big Bang. In other words, the age of the Universe must be somewhere within the range of 13.3 to 6.6 thousand million years.

Large though this age is by human standards, it is not so large in the astronomical context. The age of the Earth is 4.6 thousand million years. The age of our Milky Way Galaxy is variously estimated at 10 to 15 thousand million years. The ages of certain large clusters of stars, called the globular clusters, are even higher, at 17 to 18 thousand million years. It therefore seems that if all matter were created in the Big Bang it is simply impossible to accommodate most of these astronomical systems within the time span available.

It is clear that these problems arise because of the so called "origin" of the Universe. Are there models of the Universe *without* an origin, models in which the Universe is infinitely old? For such models one has to go beyond the more conservative framework of Einstein's general relativity.

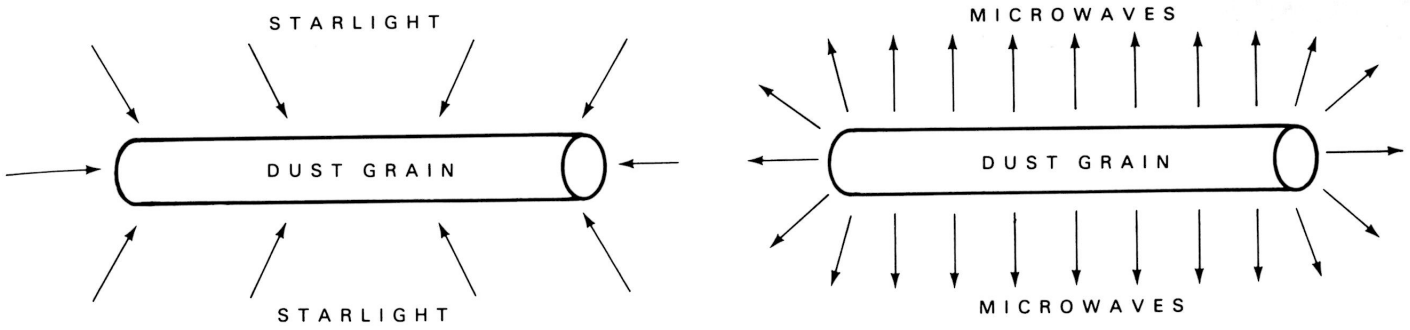
In 1948 Hermann Bondi, Thomas Gold and Fred Hoyle proposed a new model of this kind. Known as the "Steady State" model, it described a universe which is ever-expanding, without a beginning and without an end. As its name implies, the density of matter in this model is held at a *steady* value. How can a system expand and yet retain the same density? This result is achieved in the Steady State model by the injection of new matter continuous-



Earlier epoch

Later epoch

In the expanding steady state universe galaxies like A, B, C, D, move apart when observed from an earlier to a later epoch. New galaxies (filled circles) are created to fill the space generated by expansion so that the universe as a whole does not change from the earlier to the later epoch.



Narrow grains of graphite, about a millimetre long, can form in the intergalactic space. These grains can absorb starlight and radiate it again as microwaves. The microwave background could very well be such a recycled form of radiation.

ly. It is possible to give a mathematical formulation of the creation process *without* violating the law of conservation of matter and energy.

Despite its many attractive features the Steady State model came under a cloud in 1965 with the discovery of a radiation background in microwaves, by Arno Penzias and Robert Wilson. The challenge to the model posed by this observation does not appear so formidable today as it did in the late 1960s, however. In fact, as I propose to show below, the interpretation of this radiation as the relic of the Big Bang has come up with some unexpected difficulties.

The Penzias-Wilson discovery of microwave radiation was hailed as the strongest proof that the Universe has come out of a *hot* Big Bang. The reasons for this belief were: (i) the observed radiation is extremely smoothly distributed and hence does not show any patchiness which would be expected had it come from a large number of isolated sources; (ii) the radiation appeared to have a spectrum very similar to that of the idealized black body. [A black body is an enclosure containing objects which emit and absorb radiation continually, with no radiation escaping from the enclosure or entering it from outside. Theory tells us that such a system settles down to a definite pattern with prescribed intensity of radiation at prescribed wavelengths.]

Both these features were expected from the Big Bang models of the universe. The radiation therefore came to be recognized as the relic of the early hot era in the history of the Universe. There are, however, some difficulties with this interpretation.

One difficulty is that the observed spectrum is not *exactly* that expected from a black body. There are small departures from the black body spectrum which cannot be ignored. This result was pointed out by D.P. Woody and P.L. Richards in 1980, and has remained an awkward point for the Big Bang model ever since.

The second difficulty lies in the extraordinary smoothness of the background itself, and it shows up in two ways. The first problem is concerned with smoothness on a small scale. If, as is advocated, the radiation is the relic of an early hot phase, then it should show some imprint of the changes that the Universe went through *after* that phase. As we mentioned right in the beginning, an important change that took place in the composition of the universe was the formation of galaxies. Thus the matter distribution developed clumpiness and some of it should have been reflected in the background radiation. That no such clumpiness is seen after repeated searches is a worrying matter for Big Bang cosmologists.

The second way in which smoothness poses a problem is known as the *horizon effect*. When we survey the universe out to large distances we see it as it was in the past: because light, by which we see distant objects, travels with a finite velocity. Thus if the universe is ten thousand million years old, we can see objects out to distances of ten thousand million light years (1 light year is the distance travelled by light in one year). However, the radiation background formed when the universe was hardly 300,000 years old. At that time regions separated by more than 300,000 light years would not have been in contact with one another since their fastest means of communication, (the light ray) would not have been able to bridge the gap between them. The present large scale smoothness of the radiation background on the other hand implies that such remotely separated regions were very similar in structure and behaviour. Without physical contact how was this similarity achieved?

While the Big Bang cosmologists engage in theoretical speculations about the early history of the Universe to figure out these mysterious properties of the microwave background, I cannot help feeling that the solution may lie in an entirely different direction and that the microwave background may not, after all, be of relic nature.

The Universe is indeed full of radiation backgrounds at all wavelengths, ranging from radio waves right up to X-rays and gamma rays. With the exception of the microwave background, all are known to be of relatively recent origin, with no possible connexion with the hot post-Big Bang era. Why single out the microwaves?

Fred Hoyle, Chandra Wickramasinghe, V.C. Reddish, and others (including this author) had argued in the late 1960s and the early 1970s that the microwave radiation could be a recycled form of other radiation mainly coming from stars. Dust grains in the intergalactic space, if present in very modest proportions, would be able to do the recycling. N.C. Rana has recently worked out the details of how such a process would operate. Indeed, if a plausible explanation of the microwave background can be found along these lines, the case for a Big Bang cosmology is considerably weakened and the Steady State theory can be revived.

This is *one* of the possible unconventional alternatives to the Big Bang scenario, and I mention it here to emphasize the fact that the cosmological problem is far from being settled yet. Just as better telescopes early in this century expanded man's view and conception of the Universe in an unexpected direction, so I hope, the observing techniques of future years will further widen the cosmologist's vista dramatically.

■ **Jayant V. Narlikar**