

Was there a big bang?

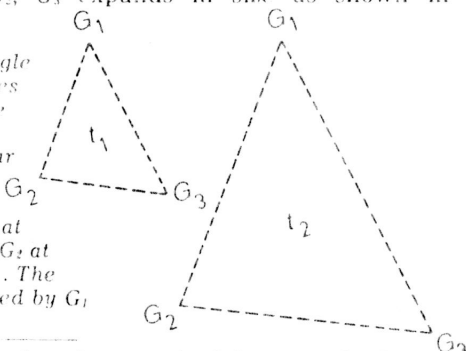
It is widely held that the Universe started several thousand million years ago in a gigantic explosion, the "big bang". How firm is the evidence? Objective assessment of the data raises many doubts

Dr Jayant Narlikar Ten years ago Geoffrey Burbidge wrote an article in *Nature* entitled "Was there really a big bang?" I cannot improve upon his remarks on cosmology in the early-1970s. "To the outsider and even to many inside, it looks, at first sight, as though considerable progress has been made in recent years, so that the outline of the way in which the Universe has evolved is understood and only the details need to be explained . . . Those who have read widely in the earlier and more recent cosmological literature . . . are aware that views of cosmology at any epoch are largely determined by the ideas of a few strong individuals, rather than by an objective appraisal of the information available . . ."

These remarks apply even more forcefully to the state of cosmological research today. If popular and to a large extent serious scientific literature is anything to go by, the big-bang model of the Universe is as firmly established in cosmology as the periodic table is in chemistry and DNA is in molecular biology. Yet, some cosmologists, albeit a minority, do sometimes wonder whether the confidence so often claimed in the big bang picture is justified by our observational knowledge of the Universe. In this article I will air a few of these misgivings.

First, what is the big bang model? In its simplest form the model is based on the theoretical work of A. Friedmann in 1922. Friedmann solved the equations of general relativity and came up with models of an expanding universe. In an expanding universe the basic constituent units, the galaxies, move apart from one another. Thus a typical cosmic triangle obtained by joining the positions of any three galaxies G_1 , G_2 , G_3 expands in size as shown in Figure 1.

Figure 1 A cosmic triangle connecting three galaxies expands as the Universe expands. Here, the triangle doubles in linear dimensions between epochs t_1 and t_2 . Light emitted from galaxy G_1 at time t_1 and received by G_2 at t_2 shows a red shift $z=1$. The same red shift is observed by G_1 looking at G_2



The expansion may be characterised by a scale factor which we may denote by S . Thus in Figure 1, the triangle on the right is twice the linear size of the triangle on the left, indicating that S has increased by a factor two from the epoch t_1 (on the left) to the epoch t_2 (on the right). A mathematical equation tells us how S changes with time. There is not just one Friedmann model; there are many. But all of them share one common feature. In every model there was an epoch in the past when the scale factor S was zero. This is the epoch now commonly identified with the epoch of the "big bang".

Towards the end of the 1920s, the expanding-universe models received observational support from the data compiled by Edwin Hubble and Milton Humason working with the 254-cm (100-inch) telescope at Mount Wilson in southern California. The data showed systematic increases in the wavelengths of spectra of nearby galaxies. The fractional increase in wavelength is called "red shift" and it is usually denoted by the letter z . A naive interpretation

of red shift is through the doppler effect. If the galaxies are all moving away from us we should see just such an increase in wavelengths in their spectra.

Hubble and Humason also found that the red shifts of galaxies increased with faintness; that is, the fainter the galaxy seemed on the photographic plate the larger was its red shift. Assuming that the galaxies look increasingly faint as their distances (D) from us increase, Hubble was able to deduce a linear law of the following type: $cz=HD$, where c =speed of light and H =a constant, now known as Hubble's constant.

In the expanding-universe picture, the red shift can be explained quite simply. Suppose in the situation depicted in Figure 1, light left galaxy G_1 at the epoch t_1 and reached the galaxy G_2 at the later epoch t_2 . Then to G_2 the light from G_1 appears red-shifted by the fraction by which the scale factor increased between the two epochs. In this example, the red shift will therefore be $z=1$. Notice that light leaving G_2 at the epoch t_1 will arrive at G_1 at the epoch t_2 with the same red shift. Thus there is nothing special about us observing red shifts from all other galaxies: observations made from any other galaxy would lead to the same Hubble law. This is one of the symmetries of an expanding universe.

Weaknesses of big bang cosmology

Symmetries like the one described above are among the many attractive features of the Friedmann models. The models are simple solutions of the otherwise very complicated equations of general relativity. Moreover, they provided a ready interpretation of Hubble's law. It was not surprising, therefore, that cosmologists took these models as the starting point of their investigations. What is surprising is that they are now being considered as the last word in cosmology. As papers are regularly published which take the above fact for granted, I will play here the role of a devil's advocate and look at the weaknesses of the big-bang cosmology.

I begin with a philosophical point, although I will soon move on to hard facts. What is the physical implication of $S=0$? At this epoch, which is denoted by $t=0$ on the cosmic time axis, the separation between any two galaxies was zero. The entire Universe was therefore confined to zero volume. In fact it is argued that the entire Universe burst out at time zero in a tremendous explosion (hence the "big bang") and the present apparent recession of the galaxies is an indication of the early violent activity. But how did this explosion occur? Why did it occur when it did? And what preceded it? Did matter exist prior to $t=0$, or was it created in the explosion? If the latter version is correct, how was matter created in apparent violation of the law of conservation of matter and energy? Questions like these are either conveniently relegated to "domain outside physics" or dismissed as philosophical nonsense.

There might have been some justification in ignoring the $t=0$ epoch as too remote if it were indeed too far back in the past. Unfortunately, as astronomical time scales go, this is not the case. Defining the time elapsed since the big bang up to the present epoch as the "age" of the Universe it is possible to compute it in any Friedmann model. While the answer varies from model to model there is an upper limit to the age; and this is given by the reciprocal of H , the Hubble constant. I will denote this upper limit by T .

There are many uncertainties in the determination of Hubble's constant and hence in the value of T . The present

estimate of T lies in the range 9 to 18 billion (1 billion = 10^9) years. Although in the 1970s the upper end of the above range was favoured it is now believed that T may be closer to 13 billion years (*New Scientist*, vol 85, p 844). If this value is correct it spells trouble for the big-bang models. For this value is the *upper limit* given by such models, and it is attained only in the idealised model of an empty universe. The presence of matter 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 then its present age cannot exceed two-thirds of T , that is about 9 billion years. Astronomers are uncertain as to how much matter is actually present in the Universe. Although visible matter in the form of galaxies is only a few per cent of the above critical requirement, there are indications that there may also be substantial amounts of non-luminous matter. If it turns out that the Universe contains matter close to the critical value its age may be closer to 9 rather than 13 billion years (*New Scientist*, vol 88, p 582).

These time scales may appear large to a non-astronomer. Certainly the age of the Universe as estimated above is larger than the age of the Earth and the Solar System (around 4.6 billion years). However, astronomers know of older objects in the Universe; for example, some of the globular star clusters are estimated to be at least 10 to 15 billion years old. And there is no guarantee that these are the oldest objects in the Universe. So unless the age determinations are wrong or the value of T is much higher than thought likely at present we are faced with the conclusion that the big-bang Universe is simply not old enough to accommodate all the objects found in it!

Looking into the past

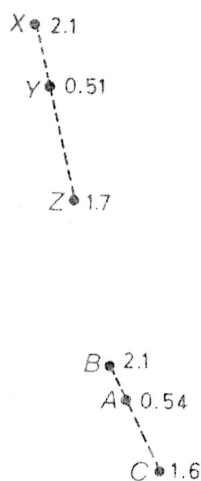
As we look at remote objects we see them as they were a long time ago. This is because our means of observation is light (electromagnetic radiation) travelling with a finite speed. A light year, the distance covered by light in one year, is approximately 10 million million kilometres. Thus if we look at a galaxy a billion light years away, we see it as it was a billion years ago. So in principle, the further we probe the Universe the further back in time we see it. How far have astronomers observed to date? How close to the big bang have they probed the Universe?

One measure of this probe is the red shift. As we saw earlier, the larger the red shift, the smaller was the scale factor at the time light left the source. The big-bang epoch has infinite red shift. What are the z -values of the most remote galaxies seen to date? These values do not exceed 1. In other words, so far as the observations of galaxies are concerned the direct evidence does not go beyond the stage described in Figure 1. The rest is extrapolation all the way to $z = \infty$. Of course extrapolation *per se* are a common feature of science and often serve to push back the frontiers of knowledge. But we must not confuse speculative extrapolations with direct evidence.

At this stage one may ask: "What about quasars?" Quasars were discovered in 1963, and are a class of astronomical objects with large red shifts ranging up to $z = 3.53$. Thus quasars do extend our domain of observation closer to the big-bang epoch, *provided* we can be certain that their red shifts do arise from the expansion of the Universe! Contrary to the impression prevalent within the astronomical community or outside it, this interpretation is open to doubts.

It would take too much space to give here all aspects of the controversy about quasars. I illustrate one aspect with the help of Figure 2, showing two triplets of quasars discovered by Cyril Hazard, of Cambridge University, and Chip Arp of the California Institute of Technology, in 1979. The perfect linear alignment of each trio suggests that the

Figure 2 Schematic drawing of the two triplets of quasars discovered by Chip Arp and Cyril Hazard, with red shifts marked. Are these alignments chance or is each set of three quasars physically connected?



quasars in each set are physically associated with one another. Yet, their red shifts shown in the diagram are markedly different. Thus if the quasars X, Y, Z owe their red shifts to the expansion of the Universe, then by Hubble's law they must be at different distances from us, the quasar X being the one farthest away. Their apparent alignment must therefore be attributed to pure accident. The presence of not one but two such cases on the same photographic plate makes it even more remarkable. How probable is such a situation on the basis of pure chance? If the probability comes out very low then we must suspect the cosmological interpretation of these red shifts and

argue that the quasars must indeed be physically associated (*New Scientist*, vol 88, p 157, and vol 90, p 163).

It is still too early to say what the outcome of the quasar controversy is going to be—so the quasars cannot yet be confidently considered as probes of the remote and the past Universe. Even if they are so considered, their red shifts do not take us anywhere near the big-bang epoch.

In addition we must distinguish between evidence for evolution and the evidence for the big bang. In 1948 Herman Bondi, Thomas Gold and Fred Hoyle proposed the concept of the steady-state universe. As its name implies, the large-scale properties of this model do not change with time. Such a universe is therefore without a beginning and without an end and does not have a big-bang epoch. In the first two decades following its inception considerable observational effort was spent in ascertaining whether the real Universe is changing with time or is steady. In his article in *Nature* in 1971, Burbidge reviewed such evidence as was then available and concluded that contrary to claims made for an evolving (changing) universe by the observers from time to time, an objective appraisal of the data left the issue open. A more recent study (to appear in *Astrophysics and Space Science*) comes to a similar conclusion.

But even if the evidence is that the Universe is evolving, that does not tell us whether there was a big bang. This evidence uses observations of galaxies, radio sources and quasars and is therefore limited to epochs more recent than that given by $z = 3.53$. Any conclusion with regard to the big bang depends on the *extrapolation* of this data by the theorists and therefore depends on the model he chooses.

So what direct evidence do we have that the Universe had a big bang? The strongest and the most direct evidence claimed for the big bang so far is the microwave background radiation first observed by Arno Penzias and Robert Wilson of Bell Laboratories in 1965. If the Universe originated in a *hot* big bang its temperature just after creation was very high and it began to drop as the Universe continued to expand. For example, the temperature one second after the big bang was about ten billion degrees absolute. What should the temperature be now?

According to the calculations the relic radiation from the hot era of a big bang universe of the early Universe should have the spectrum of black-body radiation first calculated by Max Planck in the early days of quantum theory. When, therefore, successive measurements of the microwave background at different wavelengths began to show similarity with the black-body spectrum, the evidence was considered conclusively in favour of the big bang. In 1979, however, measurements by D. P. Woody and P. L. Richards at the

University of California, Berkeley, showed deviations from the Planckian spectrum that are considered statistically significant. If future experiments continue to show these deviations, that should worry the supporters of the big bang.

But the actual measured temperature of 3K is itself something of a mystery. Translated into the language of particle physics it implies that there are about ten billion photons for every baryon (sub-atomic particles such as the proton and neutron) in the Universe. According to the big-bang cosmology this ratio has remained unchanged since the early epochs. Why this ratio and no other? Particle physicists are trying to see the answer to this riddle through a unified theory of basic interactions of physics (*New Scientist*, vol 87, p 869).

To astrophysicists, however, the observed energy density of the microwave background radiation suggests other coincidences. This energy density is not too different to the energy densities observed in other astrophysical phenomena in the Universe, such as starlight, cosmic rays, galactic magnetic fields and so on. Does this mean that the microwave background also is of astrophysical origin and is not a relic of the big bang? This suggestion does not now evoke a vehement negative response from the pro-big-bang cosmologists as it did in the 1960s.

What of the theoretical foundations on which the big bang is based? This cosmology is based on Albert Einstein's general theory of relativity. How far has this theory been tested? To what extent is this theory to be trusted in our extrapolations all the way to the big-bang epoch?

How universal is relativity theory?

Several experimental tests in the Solar System have confirmed the predictions of general relativity. Certainly, in comparison with Isaac Newton's law of gravitation or any other competing theories of gravity, relativity has come out triumphant. However, these tests were conducted under conditions where the effects of gravity are relatively weak. In cosmology, close to the big bang, the gravitational effects are strong and we are therefore using the theory in conditions very different from those under which it has been tested. This aspect is often forgotten when categorical statements are made about the early Universe.

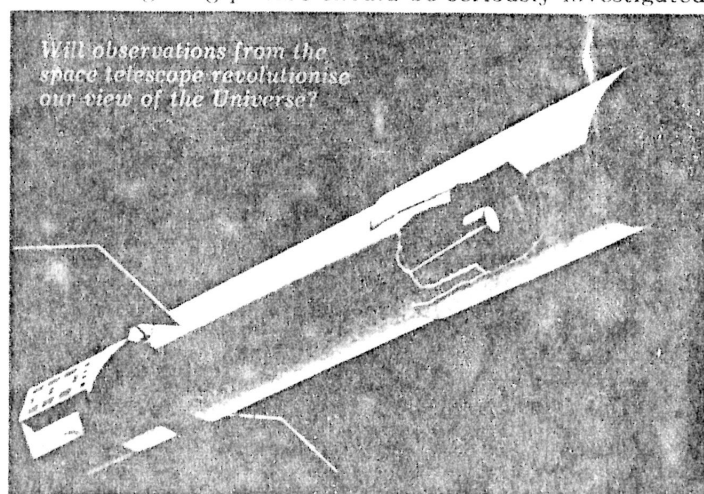
As an example of the above point I mention the hypothesis that the gravitational constant is slowly changing with time. This constant, denoted by G , was introduced by Newton to quantify the strength of gravitational attraction. According to general relativity, G is strictly a constant. Is it?

Paul Wesson has recently reviewed the observational checks that can be made on the above hypothesis (*Physics Today*, vol 33, p 32). A slow variation of G will not be seen in the experimental tests of relativity referred to above. It will, however, affect the Moon's motion round the Earth, the motion of planets round the Sun, the internal structure of the Earth, the evolution of the Sun and other stars, etc. There is some positive evidence in favour of the hypothesis, the most recent being based on an assessment Thomas Van Flandern, of the US Naval Observatory, has made of the data on the Moon's motion. G may be decreasing by a few parts in a billion per century! Small

though this rate is, if confirmed, it is sufficient to rule out general relativity in its present form (*New Scientist*, vol 81, p 856).

Another theoretical consideration relates to quantum theory. Most physicists today would agree that classical physics is at best an approximation to quantum physics. When we get down to very small scales of space and time classical physics has to give way to quantum physics. For example, the classical equations of electromagnetic theory formulated by James Maxwell tell us that an electron circling round a proton would in a short time spiral inwards and fall on the proton. Quantum electrodynamics on the other hand gives stable electron orbits with energy levels in agreement with those observed for the hydrogen atom. In the same way, what is the quantum version of general relativity? Does it also lead us to the same conclusion as the classical theory that the Universe did have a big bang? These questions have not yet been resolved.

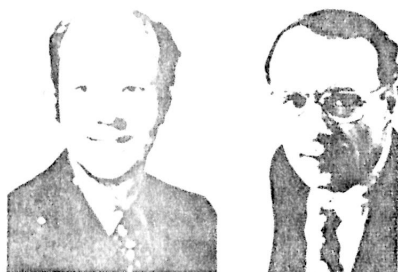
These arguments should indicate to the uncommitted that the big-bang picture is not as soundly established, either theoretically or observationally, as it is usually claimed to be. This is not to say that the picture is wrong and should be abandoned: I simply mean that the cosmological problem is still wide open and alternatives to the standard big-bang picture should be seriously investigated.



Are there are alternatives? While writing a review article with A. K. Kembhais on "Non-standard cosmologies" (*Fundamentals of Cosmic Physics*, vol 6, p 1) I came across several alternatives to standard cosmology which could serve as useful starting points. The reason that alternatives like these are not so well known or not well enough investigated is partly because of the prevalent view that the big-bang picture correctly describes the Universe. Personally I think that closing one's options at this stage is harmful to the development of the subject as a branch of science.

In the beginning of this century most astronomers believed that the Universe extended as far as our Galaxy only. This view was demolished in the 1920s by improved observational techniques. In 1948 Fred Hoyle was criticised by particle physicists for proposing baryon creation in the steady-state model. Today some of the best brains in particle physics are busy devising theories in which the number of baryons in the Universe is not conserved.

Looking towards the future I find the launching of the Space Telescope in the mid-1980s as one of the significant developments of new technology. By enabling the astronomers to observe objects up to 50 times fainter than hitherto possible with ground-based instruments this telescope is expected to improve and enlarge our understanding of the extragalactic world. Astrophysicists of today who hold the view that "the ultimate cosmological problem" has been more or less solved may well be in for a few surprises before this century runs out. □



Arno Penzias and Robert Wilson received a share in the Nobel Prize for their discovery of the cosmic background radiation, because this is interpreted as an echo of the Big Bang. But is this interpretation correct?