**Astronomers generally believe that the universe was born with a big bang. Was it? A re-examination of available data suggests that, after all, it could be in a steady state. And, in the 25th year since it was proposed, it is premature to think that the Steady State Theory is dead**

# WAS THE UNIVERSE BORN WITH A BIG BANG?

J. V. NARLIKAR

MORE than 40 years ago, the American astronomer, Edwin Hubble, made a remarkable discovery. He found that light from distant galaxies undergoes a systematic increase in wavelength. Or, that distant galaxies appear red, red having a higher wavelength than the other colours in the visible spectrum. He also found that the more distant the galaxy, the redder it looked. The fractional increase in wavelength, known as the redshift, increased with distance.

In simple terms, we can interpret this result as Doppler effect. The galaxies are all receding from us. The Doppler effect states that any source of light or sound moving towards or away from an observer changes in wavelength with reference to the observer. A nearby source may thus look blue, which has the shortest wavelength, but as it recedes, it will appear red. A typical example is the sound of a train which increases or decreases in shrillness (or frequency) as it moves towards or away from an observer.

Hubble's observations supported the concept that the universe is expanding. To get this idea clear, just imagine a spherical balloon with dots all over it. As the balloon expands, the dots move away from one another. No dot has any special position. You can now compare the universe or space to the balloon, with galaxies embedded in it, undergoing expansion. A typical observer on any galaxy will then see the others receding from him.

These ideas can be expressed mathematically in an elegant form with Einstein's General Theory of Relativity. Various models of the universe so constructed from this theory have one common feature. They all indicate that at some time in the remote past, all the matter in the universe burst out of a small volume, ideally a point, the Primordial Egg. That is how the universe is supposed to have been born, according to these models. This event is often called the big bang. However, Einstein's equations do not explain where the original matter came from.

To the religiously oriented, the big bang has its own attractions ; it signifies the act of creation by God. But the scientist, used to probing nature's mysteries, finds this state of affairs unsatisfactory. To him, the origin of matter is perhaps the deepest mystery. Yet, the big bang denies him the opportunity to investigate this ! All his mathematical equations break down at this stage and several questions keep nagging. Why did the big bang occur at all ? What was there before it ? What was the process by which the matter was created ?

Many scientists think that these questions cannot be answered, and go on working with the big bang models. Their primary concern is the investigation of the universe *after* the big bang. Some, on the other hand, do not accept this point of view, and are willing to look for alternatives to the big bang models.

THUS in 1948, three British astronomers, Hermann Bondi, Thomas Gold and Fred Hoyle, proposed a model of the universe which has

## Olbers paradox

**About 150 years ago, Olbers raised the following question: Why is the sky dark at night ? He gave a simple calculation to show that in a universe with Euclidean geometry and a uniform distribution of equally bright sources of light, the sky should be infinitely bright! A more sophisticated calculation shows that the sky brightness should be as much as that of a typical source. So if a typical source were as bright as the Sun, we should be living in a background temperature of nearly 6000°C. This problem was satisfactorily resolved by using the concept of the expanding universe. In an expanding universe, because of redshift, the light from distant sources is considerably weaker than what would be expected from the Inverse Square Law, and the brightness of the sky is negligible.**

neither a beginning nor an end. The universe, according to them, is in a steady state. That is, if we observe it over sufficiently long periods of time, it appears to be unchanging. This theory, known as the Steady State Theory, strongly challenges the big bang theories. But any theory, big bang or steady state, must pass the test of astronomical observations. How does the Steady State Theory stand up to these tests? Before going into this question, let us discuss the salient features of this theory.

Bondi and Gold had a different approach to the theory from that of Hoyle. They adopted a deductive argument. To study the structure of the universe, we look at distant galaxies. But since light travels with a finite speed, where astronomical distances are involved, the distant galaxies that we see now appear to us as they were at earlier epochs. To compare them with our neighbouring galaxies, we use the same laws of physics. If the universe itself were changing with time, how can we be sure that the same laws of physics operated in the past ? The only alternative, therefore, is to assume that the universe as a whole is unchanging. And to put this argument on a formal footing, Bondi and Gold formulated the so-called " Perfect Cosmological Principle " (PCP). It states that for a class of observers, known as the fundamental observers, the universe in the large does not change in space or time. The PCP is the logical step from the ordinary cosmological principle used by the big bang theorists, which regards the universe as uniform over space (but not necessarily over time).

The PCP is a powerful deductive principle. Using this, Bondi and Gold were able to deduce many characteristics of the steady state universe. For example, they could prove that the universe must expand. For, if it did not, it would either contract or remain static ; in either case, we would be landed with the Olbers paradox (see box). And a consequence of this expansion is the continuous creation of matter. New matter must be created in order to fill up the gaps left by existing matter in the process of expansion. Thus, in contrast to the big bang models where matter is created only once, here matter is being created at all epochs.

Though the Bondi-Gold approach is based on nice deductive reasoning, it suffers from lack of mathematical equations which a physicist would like to have. Hoyle sought to modify Einstein's equations so as to admit the possibility of creation of matter. His simplest model was the steady state model.

**HOW** is matter created ? In Hoyle's formulation, matter appears from a reservoir of negative energy, called the C-field (see box). The process of expansion of the universe is related directly to that of creation of matter. If there is too much matter-creation, the universe expands rapidly ; if there is too little matter-creation, it expands slowly. In the steady state, these two processes are in exact balance. The rate of creation of matter, on an average, is very small — about $10^{-46}$ gm per cubic centimetre. This corresponds to the creation of one gramme of matter in a volume equal to that of the Earth in about 10,000 crore years!

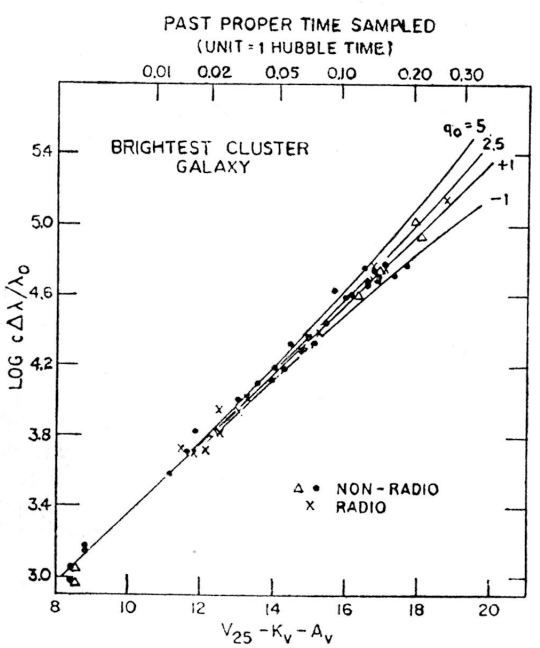
A major difference between the two steady state models is that in Hoyle's approach temporary departures from the steady state are permitted, and can be studied quantitatively. In the Bondi-Gold approach, the universe is in a strict steady state because of the PCP.

**WITH** all its radical aspects, the Steady State Theory stirred quite a storm in the placid world of the astrophysicists. Cosmology until then had been a relatively quiet field. Almost everyone, either by inclination or with resignation, had accepted the Big Bang Theory. The controversy now stimulated observational astronomy as well as related branches of astrophysics. We shall now review the numerous challenges the Steady State Theory has had to face.

The first major challenge came from the theory of origin of elements. It relates to the explanation of how elements could have been formed. Early work by George Gamow and others had shown that the big bang provided suitable conditions of high temperature and density necessary for synthesising elements like helium from the simplest element hydrogen. Starting with hydrogen, the possibility therefore existed that heavier elements could be formed in the early moments after the big bang. According to the Steady State Theory, there was no such period of high temperature and density. How, then, could it account for the observed abundance of various elements ?

This problem was eventually solved by the pioneering work of four astrophysicists, Geoffrey and Margaret Burbidge, William Fowler and Fred Hoyle. They demonstrated that all the elements can be synthesised from hydrogen inside stars in their various stages of evolution. For example, stars like the Sun act as fusion or thermonuclear reactors, converting hydrogen to helium. Since this process could work very well within the steady state universe, there was no longer any necessity to invoke the big bang. Further, it also became clear that not all elements can be synthesised in the early stages of a big bang universe. Stars are required to do the job anyway.

**Fig. 1. Redshift-magnitude relation for brightest cluster galaxies, denoted by dots. The continuous curves represent the theoretical predictions of different cosmological models. The parameter $q_0$ is a measure of deceleration of the expansion of the universe. At one stage Sandage himself favoured the value $q_0 = +1$ on the basis of his data. This represents a universe whose expansion is slowing down, leading eventually to contraction. The curve on the extreme right corresponds to the steady state model. Sandage minimised the variation in the intrinsic brightness of galaxies by choosing the brightest members of clusters of galaxies. [Diagram based on Sandage, Halley Lecture, Observatory *88*, 91 (1968)]**




## What is C-Field?

**Einstein's Special Theory of Relativity established the equivalence of energy and matter through the famous relation $E = mc^2$. So if matter is created from a positive energy reservoir, the latter is depleted. But what happens when the reservoir has negative energy ? Suppose we have — 10 units of energy per unit volume to start with and we create one unit of matter from it. We are left with — 11 units of energy ! In an expanding steady state universe, space expands at such a rate that the — 11 units have to be distributed over a larger volume, leading to — 10 units per unit volume as before. This process cannot work with a positive energy reservoir.**

Another threat to the Steady State Theory came in the early fifties. Stebbins and Whitford found that distant galaxies are redder than the nearer ones (this reddening was over and above that induced by the redshift effect). Since distance relates to the past epochs, this implied that the composition of the galaxies was different in the past than it is now ; the excess redness possibly comes from their intrinsic composition. This contradiction, however, did not last very long and soon it was found that the Stebbins-Whitford effect was essentially due to wrong calibration of instruments.

The debate, and possibly a definite answer, now seems to rest on three crucial issues — the redshifts of far remote galaxies, the distribution of extra-galactic radio sources in the universe and the measurement of black body radiation (see SCIENCE TODAY, p. 14, November 1972). Of these, some observational tests relating to the first two have, on several occasions in the past, been claimed to have disproved the Steady State Theory. But the present status of these observations remains uncertain.

Let us now examine the first one—redshifts from distant galaxies. From Hubble's studies of redshifts mentioned in the beginning of the article, we could imply that the universe is

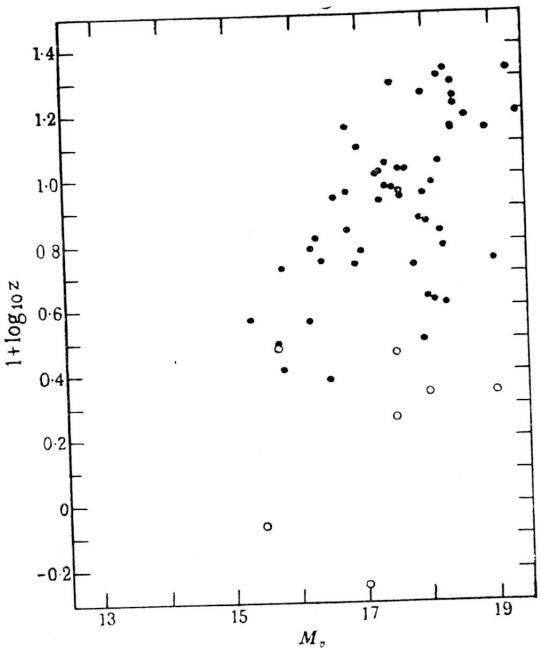



**Fig. 2. Redshift-magnitude relation for QSOs and N-type galaxies. [Diagram based on Burbidge and Burbidge, ' Quasi-Stellar Objects ', London & San Francisco, Freeman (1967)]**

expanding. Hubble found that the greater the distance of the galaxy, the higher is the redshift. This he formulated in a law $z = \frac{H}{c} D$, where z is the redshift, D is the distance, c the velocity of light and H a constant known as Hubble's constant. This is called Hubble's Law. Allan Sandage and his collaborators at Mt. Palomar, in the US, later extended Hubble's studies to much fainter or distant galaxies to see whether the law still holds good, and to compare the data with theoretical redshift values for the galaxies calculated according to the various cosmological models. This could possibly decide which of the models is nearer to the actual observations.

The data and the theoretical curves are shown in Figure 1. The dots indicate individual galaxies plotted on a graph with redshift on Y-axis and the apparent magnitude, a measure (on a logarithmic scale) of the faintness of the galaxy as seen from the Earth, on X-axis.

Studies showed (as noticed from the curves in Fig 1) that Hubble's Law was valid for all galaxies. And the observed values gave almost a straight line on the graph. For small redshifts (or possibly nearer galaxies), theoretical values for all the models too correspond with these observations. But they differ as we go farther and farther. Yet up to a point, the differences are not so marked as to distinguish them clearly. For the differences to show, we need to observe more distant galaxies, with redshifts in excess of 0·2. Since so far only three such galaxies have been found with $z = 0{\cdot}29, 0{\cdot}36, 0{\cdot}46$, nothing can be concluded on the basis of galaxies alone.

**THE OPPORTUNITY** to study sources with high redshifts, however, came with the discovery of quasi-stellar objects (QSO) in 1963. Quasi-stellar objects are star-like in appearance, but are much more massive and energetic. They are located outside our galaxy, the Milky Way. A large number of them were found to have redshifts close to $z = 2$; nearer and farther, the number seems to decrease. On the basis of the first few quasi-stellars observed, and his data on galaxies, Sandage concluded in 1965 that the expansion of the universe is slowing down. We see the more distant sources, as noted earlier, essentially as they were in the distant past; more distant the sources, the fainter and older they are. And if redshifts and the consequent faintness are related entirely to distance, then the presence of fewer QSOs beyond a redshift 2 and an increase in their number around 2 could be interpreted to mean that QSO formation began at an epoch corresponding to earlier than $z = 2$, increased to a peak around the epoch $z = 2$ and then slowed down to $z = 0$, the time of our making the observations.

For some time, this conclusion seemed convincing. But not any more. A redshift versus magnitude plot of quasi-stellar objects known so far does not show any definite tendency to follow Hubble's Law; that is, their redshifts do not necessarily relate to distance. This fact had become clear as early as 1966–67 as seen from Figure 2. The quasi-stellar points are rather scattered, raising doubts whether their redshifts are due to the expansion of the universe as is generally assumed. To this important point we shall return later. Meanwhile we examine the second observational test relating to the distribution of extragalactic radio sources.

Suppose we live in a universe obeying the laws of Euclid's geometry. And also that it contains a uniform distribution of radio sources, all of equal strength. If we count such sources out to a distance $R$, the number $N$ will vary as $R^3$. The faintest of these sources will have a flux density (the rate of radiation received from the source by a terrestrial observer in a unit area in a unit frequency range about a specific frequency) $S$ proportional

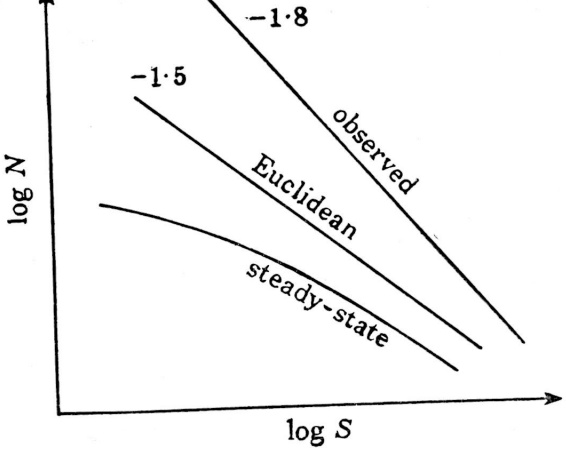



**Fig. 3. Log $N$-log $S$ curves for radio sources. The steady state and the Euclidean curves have a slope of — 1·5 at high flux levels. At lower values of $S$, the former curve becomes flatter compared to the latter. Both curves are less steep than the observed one, thus presenting a problem to the theoretician**

to $1/R^2$, according to the Inverse Square Law. Combining these two relations ($N \propto R^3$ and $S \propto 1/R^2$) for the number of sources and the flux density (or brightness), we get $N \propto S^{-3/2}$, ie, $\log N = -1{\cdot}5 \log S +$ constant. This is the Euclidean equation for the number of extra-galactic sources in the universe. It says the number of sources ($N$), brighter than a specified flux density ($S$), will vary with $S$. And a $\log N - \log S$ curve drawn relating these two on the basis of theoretical calculations should have a slope of $-1{\cdot}5$.

That is as far as theoretical calculations go. In actual situation, this is likely to be affected by other factors. The main ones are: (*i*) the non-Euclidean geometry of the expanding cosmological models; (*ii*) the variation in the intrinsic strength of the sources; and (*iii*) the variation in the density of such sources with space and epoch. Therefore, the number of sources with a specified brightness actually observed may vary from the number predicted by the Euclidean equation, and the slope of the curve for the observed number may not be $-1{\cdot}5$ throughout.

We can now compare such curves for different models — Euclidean, steady state and actual observations (Fig. 3). Calculations made according to the steady state model give a curve of $-1{\cdot}5$ for high flux densities (or higher brightness) but this falls lower (about — 1 at the lower flux density) for fainter sources around redshift 2. Against this, the curve based on a number of observations made by the Cambridge radio astronomers working under Sir Martin Ryle gave a slope of $-1{\cdot}8$.

THIS result is often quoted to disprove the Steady State Theory, and to imply that there were more sources per unit volume in the past than there are now. For, the observations show that there are more fainter or distant sources than would be expected in the steady state model. If the observational position were clear-cut enough, such a conclusion would indeed be justified. But this is not the case. The earlier Cambridge surveys had quoted much steeper slopes. The first one in the fifties gave a slope of — 3. The second brought it down to $-2{\cdot}2$. And eventually it was lowered to $-1{\cdot}8$, all after many observational errors were detected and corrected. Can we be sure that this slope is free from all instrumental errors?

Even if we are, further complications arise from quasi-stellar sources. The radio sources covered by the survey can be divided into three categories. First, those which can be identified with galaxies observed with the help of an optical telescope. Second, those which can be identified with quasi-stellars. The third category is not yet identified. The slope of the observed $\log N - \log S$ curve for the first category is not steeper than $-1{\cdot}5$. The observed slope for quasi-stellars too is of the same order. Sources in the third category, however, have a steep slope of $-2{\cdot}5$ or so.

Now this raises two questions. And the conclusion hinges on these. First, are the quasi-stellars really distant objects and their redshifts of cosmological origin? If they are, then the slope $-1{\cdot}5$ is really steep and disproves the Steady State Theory. For, the Steady State Theory gives a slope — 1 (or even flatter) for objects with cosmological redshifts as high as $z = 2$ around which the quasi-stellars are concentrated. The nature of quasi-stellar redshifts, therefore, becomes very much an open question. In recent works, Harlton Arp, Geoffrey and Margaret Burbidge, Peter Stritmatter and Phil Soloman show that quasi-stellars with large redshifts may be close to, and are also physically associated with, nearer galaxies with low redshifts. This throws doubt on the once widely held view that quasi-stellar redshifts are of cosmological origin.



The second question is related to the unidentified class of objects. It is believed that

they are also radio galaxies. If they turn out to have redshifts of 0·2 or more, again their slope of — 2·5 will disprove the Steady State Theory. If, on the other hand, the redshifts are very much smaller, then they have no cosmological significance, but represent a local effect.

THUS the Steady State Theory seems to have survived all the attacks so far. But what may yet turn out to be the strongest one is a relatively recent observation. This is the discovery in 1965 by Penzias and Wilson of the Bell Telephone Laboratories, US, of background radiation in the microwave region. So far, at long wavelengths this radiation follows the pattern of black body radiation. (Black body radiation represents the equilibrium stage attained by electromagnetic radiation in a closed box from which there is no escape outside. See p. 14, SCIENCE TODAY, November 1972.) Observations are in progress to confirm whether the radiation is indeed that of a black body.

If it is, we find a ready explanation for it in terms of the big bang. All we have to say is that the radiation is the remnant of the big bang. The Steady State Theory has no such ready explanation. But if the black body character is not confirmed, the big bang explanation will be no more valid. We then have to search for some other " sources " for such radiation. At higher frequencies like optical or X-rays, the background radiation is explained in terms of other sources, and not the big bang. But in the microwave range, the case becomes difficult because of its extreme isotropy (lack of patchiness). The difficulty to account for its origin in terms of sources here exists equally in the steady state and the big bang models.

Till now, the question of the nature of the microwave background radiation has not been resolved. Theoretical calculations show that the black body radiation should begin to fall in intensity in the millimetre range as seen from the curve in Figure 4. Ground-based observations so far have been in the long wavelength region. To observe the radiation in the millimetre range, one has to go above the atmosphere. This requires the use of rockets and balloons. Early observations do not indicate this ' turn-over ' in intensity; rather they indicate an increase in radiation. However, more observations are required to confirm or disprove this result.

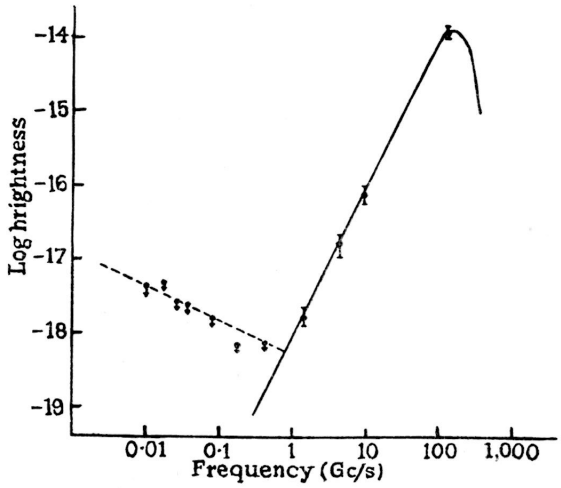



**Fig. 4. Black-body curve with the observed points. The real test will come when observed points are obtained further to the right in the millimetre range. Theoretical calculations predict that the curve should turn over. But early observations do not indicate this. [Based on Howell and Shakeshaft, Nature *210*, 1318 (1966)]**

That concludes my discussion of observational situation as it stands today. To sum up, observations with quasi-stellars, the counting of extra-galactic radio sources in the universe and the microwave background radiation seemed to go against the Steady State Theory in 1965. And at one stage Hoyle himself conceded this. But there has been a turn-around in the last two or three years which suggests that it is premature to give up the theory. Besides, there have been other developments on the theoretical front which tend to favour the steady state model (see p. 9, SCIENCE TODAY, May 1969, for this discussion). These I do not propose to discuss in this article which deals only with the observational situation. My own preference at this stage is for a model which over large regions of space and time is in a steady state, but which admits more local evolution than would be tolerated by the rigid version of Bondi and Gold.



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