

# The extragalactic Universe: an alternative view

H. C. Arp, G. Burbidge, F. Hoyle, J. V. Narlikar & N. C. Wickramasinghe

We discuss evidence to show that the generally accepted view of the Big Bang model for the origin of the Universe is unsatisfactory. We suggest an alternative model that satisfies the constraints better.

OVER the past twenty years, studies of the extragalactic Universe have been carried out by many astrophysicists — this is one of the most popular and spectacular branches of observational and theoretical astrophysics. In this period, a framework of belief has grown up in such a way that the observational phenomena have been fitted into a picture whose basic structure we now describe.

It is generally supposed that we live in an expanding Universe that originated in a hot Big Bang and that has an age between  $10$  and  $20 \times 10^9$  yr. The basis for belief in this cosmological model is the existence of the Hubble law for galaxies, which is well established for normal galaxies up to a redshift of about  $z \approx 0.5$ , the discovery of the microwave background radiation by Penzias and Wilson in 1965, together with the evidence that it was of black-body form, and the demonstration that the observed abundances of the light nuclei D,  $^3\text{He}$ ,  $^4\text{He}$  and  $^7\text{Li}$  could be explained in terms of early (Big Bang) nucleosynthesis. More recently, the popularity of the inflationary model and the conviction of many that the Universe has a density equal to the closure density have been amplified, not by observational evidence, but by the speculations of particle physicists eager to lead in the studies of the early Universe.

Parallel with these developments (and even earlier), studies of discrete extragalactic sources of non-thermal emission have contributed to the overall cosmological picture. First came the identification of the powerful radiogalaxies and the general phenomenon of radioemission. This was followed in the early 1960s by the discovery through radio techniques of the quasi-stellar objects (QSOs). It soon became clear that these phenomena were related to similar effects in the nuclei of galaxies — Seyfert nuclei — and in recent years there has been an irresistible urge to lump all these phenomena together under the heading of active galactic nuclei (AGN).

The characteristics of all of these discrete objects are the nonthermal character of their continuum spectra, the very strong and broad emission lines in the spectra, their variability in flux in many wavelengths ranges and, most important for their impact on extragalactic astronomy, the wide range in redshifts up to values of  $z > 4$ .

From the earliest days of the studies of radiogalaxies and, separately, of QSOs, it has been claimed that, provided their red-

shifts arise from the expansion of the Universe, these discrete sources show evidence for strong evolution in time, in their density and other physical characteristics. Thus the idea has developed that not only is the Universe as a whole evolving as it expands, but that populations of the discrete objects out of which the Universe is made are also evolving.

In what follows we shall argue that:

- The currently popular cosmological model is subject to many doubts based on observational data which suggest that, perhaps, there never was a Big Bang.

- The observational evidence concerning non-thermal objects with large redshifts leads inescapably to the conclusion that these redshifts are largely intrinsic in origin. This means that these objects do not lie at large cosmological distances, but in general that they lie much closer with  $z \leq 0.1$ . This in turn means that there is no evidence for evolution in the discrete objects and, as predicted by Ambartsumian<sup>1</sup> about 30 years ago, in these objects we are witnessing creation events involving the ejection of new matter from the nuclei of galaxies.

We discuss these two topics in reverse order.

## Nonthermal sources

For some years after Hubble demonstrated the law of the redshifts and tied it to the expanding Universe, attempts were made to reinterpret the redshifts as resulting from other causes — for example, the tired light phenomenon — but gradually these ideas died away.

Alternative explanations of the redshifts were not seriously attempted again until the discovery of large redshifts of the QSOs. Terrell<sup>2</sup> proposed that all these objects were ejected from the galactic centre and had passed us. By 1966, two arguments were going on. On the one hand, there was apparently no correlation between redshifts and apparent magnitudes for the QSOs. By various types of binning, the enormous scatter in the Hubble diagram could be reduced, but in no case did the correct slope of 5 naturally emerge<sup>3,4</sup>. Thus there was no real evidence for cosmological redshifts. On the other hand, we had discovered the severe problems imposed by the rapid variability of the QSOs; for we had to understand how the very high luminosity of a source can come from a very compact region whose size is set by the timescale of variability. F.H., G.B. and Sargent<sup>5</sup> discussed this

so-called Compton paradox and pointed out that it could be avoided if the objects were closer than was indicated by their redshifts, thus reducing the luminosities and hence their photon fluxes. F.H. and G.B.<sup>7</sup> then argued that a case could be made for bringing all the QSOs much closer than was indicated by their redshifts. Later, the discovery of apparent superluminal separation of compact radio components in a few QSOs demanded special geometrical assumptions with highly relativistic bulk motions to explain the observations as illusions<sup>8</sup>. Such contrived assumptions are not needed if the QSOs are much closer than their redshift distances.

Yet there was still no direct evidence for the distances. This began to be collected only when H.C.A. started to look at the associations between peculiar galaxies and radio sources<sup>9</sup>, and when G.B. *et al.*<sup>10</sup> studied a well-defined sample — the 3CR QSOs and their proximity to bright galaxies in the Shapley-Ames catalogue. Over the next 15 years, more data have accumulated, and several samples have been analysed in detail. It soon became clear from statistical arguments alone that there are more QSOs close to bright galaxies than there should be by accident, thus implying that QSOs with high redshifts are physically associated with galaxies of low redshifts. But it was often argued, by those who were not prepared to believe in physical associations, that proper statistical methods were not being used.

In 1971, H.C.A.<sup>11</sup> found the remarkable optical bridge between Mk 205 ( $z = 0.07$ ) and NGC 4319 ( $z = 0.0057$ ), about  $40''$  away. Controversy continued about the reality of this feature until the definitive study by Sulentic and H.C.A.<sup>12,13</sup>. In 1979, G.B.<sup>14</sup> analysed all QSOs found near bright galaxies and showed that, within separations of  $3''$ , the results were highly significant. Other landmarks along the way included the discovery of three QSOs within  $2''$  of the centre of NGC 1073 (ref. 15), three QSOs within  $2''$  of NGC 3842 (ref. 16) and other multiple systems investigated by H.C.A. The strong evidence up to 1987 is contained in H.C.A.'s book<sup>17</sup>.

Most recently, G.B. *et al.*<sup>18</sup> have compiled nearly 500 QSO-galaxy pairs mostly lying within  $10''$  of each other. This includes both QSOs near bright galaxies found by a computer search and QSOs near faint galaxies reported in the literature. Detailed statistical analyses of these large samples leads to the conclusion

that the QSOs with large redshifts are physically associated with galaxies with lesser redshifts, both for faint and bright galaxies.

In the past few years, work by other groups (see refs 19–21) has produced further samples of QSO galaxy associations far above the level expected if these were chance configurations. In fact, it is often the case that when a QSO is identified, one or more galaxies are found to lie nearby. So far, nearly 4,500 QSOs with redshifts have been catalogued<sup>22</sup>. From the counts of galaxies, the sky-surface density of galaxies brighter than 15<sup>m</sup> is about 0.25 per square degree. Thus, on a random distribution, the probability of finding such a galaxy within 2' of a QSO is  $\approx 4 \times 10^{-4}$ . Thus, out of all the catalogued QSOs, we would expect about two pairs with separation 2'. This is at least an order of magnitude less than the number found. We therefore consider that the evidence for the physical association of QSOs of high redshift with galaxies having much smaller redshifts is by now overwhelming.

The only way of understanding the observational evidence that would allow galaxies and QSOs to lie at different distances is the proposal<sup>23</sup> that the QSO is gravitationally microlensed by a star in the halo of the foreground galaxy. For some years, this was considered to be a possible solution, and it is enlightening to note that Stocke *et al.*<sup>19</sup> were prepared to believe in their own result only because they thought that it could be explained by gravitational microlensing. We quote from their paper:

For several years now there has been some evidence for a slight statistical excess of QSOs projected on the sky near bright galaxies. Over most of the history of these observations, the sole interpretation has been that these QSOs were physically associated with the bright galaxies near them and that the QSO redshifts were, therefore, "non-cosmological". Because this interpre-

tation was contrary to the well-accepted cosmological redshift hypothesis, this evidence was largely dismissed on the grounds that the data were either statistical fluctuations or were due to an improper statistical analysis. More recently, another interpretation has arisen following the discovery of multi-image QSOs in which QSOs near foreground galaxies are brightened by the gravitational effects of individual stars in these galaxies near to our line of sight, so-called minilensing or microlensing. This new interpretation is consistent with the cosmological redshift hypothesis and has revitalized interest in the observational data on QSO-galaxy associations.

In fact, this explanation will not work<sup>24–26</sup>. Essentially, the reasons are that the observed luminosity function for QSOs shows that there are not enough faint ones to be amplified by microlensing, and in halos there are not enough mass points. The following argument by F.H. demonstrates this:

(1) A galaxy with its mass distributed over a radius  $\sim 10$  kpc does not produce QSO amplification unless the mass exceeds about  $5 \times 10^{11}$  solar masses ( $M_{\odot}$ ). Divided into many smaller masses of stellar order, however, amplification by microlensing can occur, even though the total mass is less than  $5 \times 10^{11} M_{\odot}$ .

(2) When a QSO assumed to be cosmologically distant is known to be projected against a nearby galaxy, the possibility of the received radiation being magnified by a factor  $Q$  above what it would otherwise have been is  $\sim 2 \times 10^{-2} Q^{-2}$ . For example, the chance of a twenty-second magnitude QSO being magnified so as to appear to the observer as a seventeenth magnitude QSO is  $\sim 2 \times 10^{-6}$ . There would need to be  $5 \times 10^5$  times more QSOs at the twenty-second magnitude than at the seventeenth for the number observed at the seventeenth to be significantly increased by microlensing. This is a vast excess, several hundred times at least, over the number of QSOs observed at the twenty-second

magnitude.

(3) Quite apart from the small coefficient of  $\sim 2 \times 10^{-2}$ , the number of faint QSOs would need to increase more rapidly than  $2.5 \log_{10} Q$  for magnification by microlensing to be significant. Although such an increase with magnitude holds between the fifteenth and seventeenth magnitudes, the increase at still fainter magnitudes is much less than  $2.5 \log_{10} Q$ .

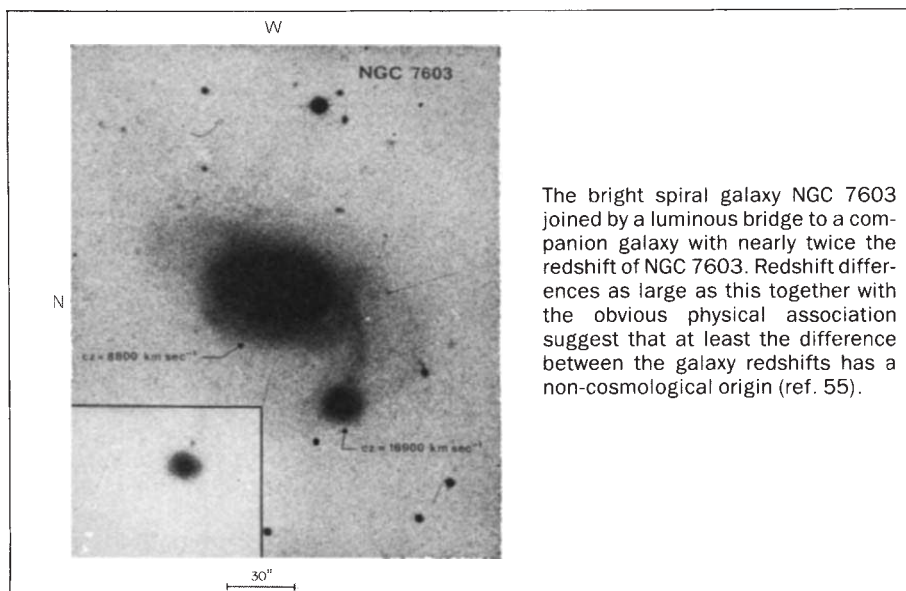
(4) Changing nearby galaxies to distant galaxies does not increase the small normalizing coefficient  $2 \times 10^{-2}$  at all appreciably. Microlensing by faint galaxies is just as unimportant as microlensing by bright galaxies.

(5) Even if the microlensing had worked, it would not apply to the observed QSO-galaxy pairs where the separation is of the order of two to three times a typical galaxy radius.

It is widely believed that the blobby structure of the QSO image near the centre of 2237+305 is evidence of a gravitational lens<sup>27–29</sup>, but the chance of this is  $\sim 2 \times 10^{-6}$ , which is appreciably less than the chance,  $\sim 5 \times 10^{-5}$ , of the QSO being accidentally projected against the associated galaxy; the lens suggestion is highly unlikely. The blobby structure of the QSO image can rather be interpreted as evidence of emission from the central regions of a strong gravitational well. Light emitted at angles to the radial direction is curved by  $\pi/2$  or more, so that to an external observer the QSO light appears as a halo encompassing the entire well. The halo has a blobby structure simply because the sources within the well happen to be irregularly distributed.

Thus it seems that in some way the QSOs are physically connected to the normal galaxies both for  $z_Q \gg z_G$  and where  $z_G \approx z_Q$ . Physically, this means that QSOs often appear and are formed in comparatively dense regions of galaxies. This result can be extended to explain the high frequency of the presence of absorption in the spectra of QSOs, usually interpreted as meaning that there is much absorbing matter ejected from the QSO and/or there are many absorbing clouds along the line of sight. Since the discovery of this effect, it has been realized that the amount of absorption requires a cross-section of absorbing matter greater than expected from normal galaxy halos by a factor of five or more<sup>30</sup>. This has been attributed to the presence of more absorbing matter of high redshift than is present locally<sup>31</sup>. But it is easily seen that it is better interpreted in terms of our newly found rule: it is due to abnormal amounts of matter with very different redshifts all lying near the QSO. It has also been reported that there are more normal galaxies than expected by chance near to powerful 3CR radiogalaxies<sup>32</sup>. This suggests that the rule can also be extended to such objects.

Our conclusion, therefore, is that the



The bright spiral galaxy NGC 7603 joined by a luminous bridge to a companion galaxy with nearly twice the redshift of NGC 7603. Redshift differences as large as this together with the obvious physical association suggest that at least the difference between the galaxy redshifts has a non-cosmological origin (ref. 55).



evidence for the effect is overwhelming and a general rule can be stated. More galaxies than expected by chance are found very close to QSOs and other active nuclei. This conclusion applies to associations both between QSOs and bright galaxies and between QSOs and faint galaxies; it also applies both in situations in which  $z_Q \approx z_G$  (refs 33,34) and when  $z_Q \gg z_G$ .

### Cosmic microwave background

The strongest evidence cited in favour of the hot origin of the Universe is the observed radiation background<sup>35</sup>. The recent announcement by COBE<sup>36</sup> that the spectrum of the radiation is planckian to a high degree of approximation will be interpreted by many as a confirmation of their belief in the correctness of the Big Bang model. But there is bad news for the Big Bang as well as good. The effective temperature of the radiation is remarkably constant with respect to direction, both on small and large angular scales. Thus, on a scale of a few arcminutes there is constancy in the temperature to within about 1 part in 50,000 (ref. 37).

But, in the Big Bang model, an early planckian spectrum will be distorted by subsequent events of a non-thermodynamic character, of which the condensation of galaxies, of clusters of galaxies and, perhaps, of a still larger cellular structure on a present-day distance of about 100 Mpc, are the most frequently discussed examples. The microwave background has no imprints to mark the occurrence of such events, contradicting the theoretical expectations of a decade ago and causing theoreticians in recent years to search for variants of the Big Bang that avoid a confrontation with observation on this point. Our opinion is that avoiding confrontation with observation is not the hallmark of a good theory.

The Big Bang model offers a Universe created in a smooth featureless condition, out of which a highly structured Universe is nevertheless supposed to have evolved. Numerous attempts have been made to explain how this miracle is supposed to have happened. They have two features in common, one a retreat into the highest flights of physics and the other an unsatisfactory absence of the immense detail that would be required to support them in a proper manner, from which we suspect the attempts to be little more than ingenious handwaving. Perhaps this is why they are called 'scenarios'.

The root of the matter, it seems to us, is one of time-ordering. In the Big Bang model, the microwave background came first and the galaxies second, whereas the observations suggest (almost to the point of compelling) the opposite. For the microwave background to come second, it is necessary that some form of particle should be widespread extragalactically,

either at present or in the relatively recent past, with the property of being strongly absorptive of microwaves, yet of being almost translucent in both the visible and longer radio wave regions of the spectrum. We can ask three questions:

- Do such particles exist as a theoretical possibility?
- Is there laboratory evidence for their existence?
- Is there astronomical evidence of their presence?

The answer to the first question is certainly yes. The optical constants of metals are such that the absorptivity of thin metallic needles, determined by a Mie-type calculation<sup>38</sup>, is 100 times greater at a wavelength of 1 mm than it is at 5,000 Å. This is at room temperature. At cryogenic temperatures, because of the lowering of metallic resistivity with temperature, the factor is increased from 100 to 1,000. Thus extragalactic space could be exceedingly opaque to microwaves and still exceedingly translucent in the visible. Depending on their diameters and lengths, metallic whiskers ultimately lose their high absorptivity at sufficiently long wavelengths. A whisker of length 1 mm would, for example, lose its high absorptivity at a radio wavelength of about 10 cm.

The answer to the second question is also yes. Laboratory experiments (ref. 39, D.V. Gal'tsov, personal communication) show that slowly cooled metallic vapours condense into whiskers typically with radii of  $\sim 10^{-6}$  cm and lengths of about 1 mm. The experiments are explained in a scheme where the first nucleation occurs into liquid droplets containing a few thousand atoms. When sudden crystallization eventually occurs to the solid state, the considerable energy released causes the resulting crystal to possess dislocations. One particular dislocation, the screw dislocation, has the property of causing subsequent growth to occur linearly, whereas other dislocations lead to more or less spherically growing particles. Now it can easily be shown that, whereas the radius of a spherically growing particle increases proportionally to the time, the length of a linearly growing particle increases exponentially. Thus those nucleations that happen to develop the linearly growing property soon come to dominate. Because of their exponential growth they largely consume the available supply of vapour.

There are two lines of astronomical evidence pointing to an affirmative answer also to the third question, both connected with supernovae. First, because of their synthesis of metals, one would expect metallic whiskers — iron whiskers especially — to condense in expanding ejecta from supernovae, just as they do in the laboratory. Radiation from the pulsar in the Crab Nebula has been found<sup>40</sup> to be drastically weakened over the wavelength

range from about 30  $\mu$ m to about 10 cm, just the range in which the absorptivity of iron whiskers would be strong. Apart from the unlikely possibility that the absence of this band of radiation is an intrinsic property of the pulsar itself, the natural explanation is that whiskers in the supernova ejecta, still surrounding the pulsar (but not surrounding the outer regions of the Crab) are absorbing the missing radiation.

Second, there is a remarkable correlation between the radio luminosities of galaxies and their luminosities in the far infrared ( $\sim 100 \mu$ m), a correlation maintained over some four orders of magnitude in the intrinsic emissions<sup>41</sup>. The radio emissions come via the synchrotron process from high-energy electrons derived from pulsars. The supernovae that provide the pulsars would also provide quantities of iron whiskers. The greater the frequency of supernovae the larger the number of pulsars and the greater the quantity of whiskers, thereby establishing the required correlation in what otherwise would seem to be an inexplicable situation.

The absorptivity of iron whiskers is so large in the far infrared that whiskers in a local infrared radiation field experience strong outward radiation pressure. Using known energy densities for such fields it can be calculated that whiskers could attain speeds of emission into extragalactic space as high as 10,000 km s<sup>-1</sup>, sufficient to carry them from their parent galaxies to a distance of  $\sim 100$  Mpc in a time  $H^{-1}$ . Viewed cosmologically, therefore, the distribution of whiskers in extragalactic space could be much more uniform than the galaxies producing them. In effect, the whisker production of  $10^6$  galaxies becomes averaged together in a Hubble time.

In relation to this, note that once a radiation field has been thermalized, the distribution of the thermalizing agent is irrelevant. The thermalizing agents are not required to be smooth. It is the energy density of the radiation that is required to be smooth. In this regard, suppose a microwave quantum to have a mean free path  $\lambda$  before being absorbed and re-emitted. In a time  $H^{-1}$ , radiation then has a diffusion distance  $(\lambda c H^{-1})^{1/2}$  which is  $\approx 0.1 c H^{-1}$  for  $\lambda = 10^{-2} c H^{-1}$ , implying that in a time  $H^{-1}$ , fluctuations in the radiation field would be greatly smoothed, even for a cosmological optical depth for microwaves as large as 100.

Consequently, there is a double tendency towards smoothness, a tendency in the thermalizing agent and a strong tendency in the radiation field. If the cosmological model were also steady-state, one could expect this double tendency, combined with an ongoing cosmological situation, to have produced the high degree of smoothness that observations show the micro-

wave background to possess.

Fast-moving whiskers are exposed to sputtering effects, which are at a maximum for speeds of a few hundred  $\text{km s}^{-1}$  — the effects become less important at higher speeds because impacting micro-particles have less time to impart momentum to the material of a whisker. A critic, anxious to find a flaw in the above argument, could therefore argue that sputtering would destroy whiskers as fast as they were produced. As well as overlooking the astronomical evidence cited above, such a criticism also misses the important point that, because of their high emissivity in the far infrared, whiskers tend to stay very cool. For the most part their temperatures cannot much exceed that of the microwave background itself, even for whiskers in the vicinity of a galaxy. Foreign molecules therefore condense readily on their surfaces, and it would largely be such foreign molecules that would suffer evaporation by sputtering. All solid substances except  $\text{H}_2$  condense at a temperature of 2.7 K.

The commonsense inference from the planckian nature of the spectrum of the microwave background and from the smoothness of the background is that, so far as microwaves are concerned, we are living in a fog and that the fog is relatively local. A man who falls asleep on the top of a mountain and who wakes in a fog does not think he is looking at the origin of the Universe. He thinks he is in a fog.

### Expectations of the steady state

**Young Galaxies.** In the days when both Big Bang and steady-state cosmologies were being widely debated it was often pointed out that if the steady-state theory was correct, we would expect to see at all redshifts a small fraction of galaxies that were genuinely young in evolutionary terms. For example, in 1963 it was pointed out that NGC 2444-45 might be such a system<sup>42</sup> as it appeared to contain nothing but gas and hot O and B stars. It was immediately argued that the continuum of this remarkable hot spot galaxy had colours suggesting an intermediate age stellar population<sup>43</sup>.

Because O and B stars have ages of at most a few tens of millions of years, such attempts to identify young galaxies were, from the point of view of the steady-state theory, unnecessarily rigorous, as galaxies with ages  $\sim 3 \times 10^9$  yr would still be 'young' according to the theory. It is widely assumed by cosmologists that essentially all galaxies have closely the same age. But there is no proof of this, as the integrated colours of distant stellar populations are insensitive to age once the age increases above  $\sim 10^9$  years. It is perhaps conceivable that with the great improvements of observational technique now in the offing, subtle differences of integrated colours may yield information on the ages of

galaxies. Significant variations might well prove to be one of the shocks that cosmologists will experience in the future.

Despite the over-rigorousness of the young-star criterion from the point of view of the steady-state theory, it is worth noting that there are now many known examples of 'star burst' galaxies dominated by recently formed stars. Recent infrared surveys with the IRAS satellite reveal considerable numbers of galaxies which are indicated to be young in evolutionary terms<sup>44</sup> as they appear to contain little else but atomic and molecular gas and high-mass young stars. The number of such galaxies that may be very young — objects such as Arp 220, NGC 6240 are some of the most luminous<sup>45</sup> — is small but they are nearby and fit well with predictions of the steady-state model. In the framework of the Big Bang cosmology they are not understood at all and would have to be protogalaxies long delayed in their collapse. But protogalaxy clouds of gas in the process of collapsing are not observed even after extensive search and therefore the presence of young galaxies furnishes yet another objection to the Big Bang theory.

**The age of the Universe.** At the time the steady-state theory was proposed (1948) the age of the Universe appeared to be less than the ages of objects in it and this was very much an argument in its favour. Depending on the value chosen for the Hubble constant and other factors, the age discrepancy problem may be back with us. For  $H = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ , the lowest value currently favoured, the typical age would be  $2/3 H = 13 \times 10^9$  yr. For a value as large as  $80 \text{ km s}^{-1}$ ,  $2/3 H = 8 \times 10^9$  yr. Values for the ages of the oldest stars are currently about  $13\text{--}17 \times 10^9$  yr (ref. 46), and the age of the elements  $\sim 12\text{--}16 \times 10^9$  yr (ref. 47). Thus, for most of the range of allowed values the age of the oldest stars is greater than the age of the Universe. For some reason it is not being discussed, but in terms of numerical factors the problem for the Big Bang is back again.

The resolution of the age problem within the conventional framework lies only in abandoning the inflationary model or in robbing the model of its only important good point by finely tuning a cosmological constant. This constant has been in and out of cosmology ever since Einstein introduced it in 1917. It is brought in whenever it is felt that observations warrant it, only to be abandoned when theoreticians find that they can do without it.

**Evolution of discrete objects.** One of the arguments that has continually been used to attack the steady-state cosmology is that counts of discrete sources show strong evolutionary effects. It is obvious from what we have discussed above that if these discrete sources are not at great distances

this argument disappears.

It is also important to point out that a detailed study of the  $\log N\text{--}\log S$  relation was recently carried out for the 3CR radiogalaxies, a sample in which practically all the redshifts are now measured. It was shown that, even on the assumption that these redshifts are cosmological in origin, this most important sample of radio sources shows a  $\log N\text{--}\log S$  distribution entirely compatible with the steady-state model<sup>48,49</sup>.

Moreover, the discovery of the highest redshift quasar at  $z = 4.7$  was recently announced (ref. 50). Even though it must be far back near the age of formation of galaxies on the Big Bang hypothesis, it shows no spectroscopic differences from lower redshift, presumably much nearer quasars. This is direct evidence against evolution of properties of the universe over a major portion of its lifetime.

We conclude this section by emphasizing that each of these arguments which was used in the debate some twenty years ago concerning the viability of the steady-state cosmology is still with us and on balance the steady-state model is favoured.

### Alternative theories

The above discussion clearly indicates that the present evidence does not warrant an implicit belief in the standard hot Big Bang picture. What are the alternative ideas? We do not claim to present here 'the' alternative to the standard picture. Rather we draw the attention of the reader (and the prospective research worker in the field) to some ideas that have already addressed these questions at least partly.

It is important to decide whether the issue of non-cosmological redshifts discussed in the earlier sections are of chief importance to cosmology itself. But that there is a serious problem (as opposed to a cosmological problem) we are not in doubt. There is simply too much evidence to be dismissed as coincidental. Even in the short time since we wrote this article, evidence has appeared<sup>51</sup> to show that the prototype quasar 3C 273 is situated in the Virgo cloud of galaxies at a cosmological redshift of only  $1,170 \text{ km s}^{-1}$ , far less than the redshift of 3C 273 0.16 ( $0.16c \approx 48,000 \text{ km s}^{-1}$ ).

Adherents of the popular cosmological interpretation of QSO redshifts dismiss such situations as coincidental, even though the probability of coincidence is very low. For the situation concerning 3C 273, the probability is  $\sim 10^{-3}$ . Small but not as small as in some other cases. The psychology that permits such situations to be dismissed is that of mental compartmentalization. Stop thinking about the million-to-one chance of three QSOs lying within  $2'$  of NGC 3842, or about the 100,000 to 1 chance of a system like 2237 + 0305 being found, or the many other



examples we could mention, when thinking about 3C 273. And of course omit 3C 273 when thinking about any one of the others. And so on in turn down the list.

Turning now to cosmology, the Big Bang is a necessary consequence of Einstein's theory of relativity. Unlike all other parts of physics, the Einstein theory is not scale-invariant. But a gravitational theory can indeed be constructed possessing scale invariance<sup>32</sup>, and if one thinks that the whole of physics should be scale-invariant this formulation should be followed rather than Einstein's. The latter then appears as a special case of the more general theory. The general theory is wider than Einstein's in that it admits of two other cases. The other cases can be written mathematically in a form like Einstein's but with extra terms appearing in the field equations. One case is equivalent to introducing the so-called cosmological constant into the equations, which of course was done empirically by Einstein himself and used by later workers, notably by Lemaitre. It is this case that is used in modern inflationary cosmology.

The wider second possibility admits the creation of matter, which is to say it permits the trajectories of particles to be segments rather than paths extending to infinity in both the past and the future. Is this not just what the Big Bang model does, one can ask? Are the paths of particles not half-lines with a beginning at the origin of the Universe, and then extending infinitely into the future? The answer to these questions is that it is precisely because the Big Bang model seeks to bring segmented paths into a theory that does not admit them that the theory breaks down. In other words, the 'origin of the Universe' is not what is usually supposed, a true origin of the Universe. It is rather a breakdown of the theory itself.

The theory permitting segmented paths has no such breakdown. The full range of

mathematical solutions permitted by the wider theory has not yet been explored. In a first approximation there are two forms of solution, one the old steady-state solution, which had a high closure density analogous to that of the Einstein-de Sitter ( $q_0 = +0.5$ ) case among the Friedman models, and the other at a significantly lower density comparable to the mean density of baryonic matter that is normally observed. This second possibility is much harder to investigate because in a second approximation it is necessarily inhomogeneous, according very well with the observed distribution of galaxies on inhomogeneous scales up to at least 100 mpc. The difficulty for theoretical analysis is that the cosmological equations are necessarily of a partial character. Although the gravitational equations in their most general form are of course of a partial character, it is a feature of orthodox cosmology that approximations are used to simplify them into ordinary differential equations. It is the assumption of orthodox cosmology that nothing of major importance is lost in this simplification. It is a critical mathematical feature of the second possibility outlined above that it challenges this conventional assumption.

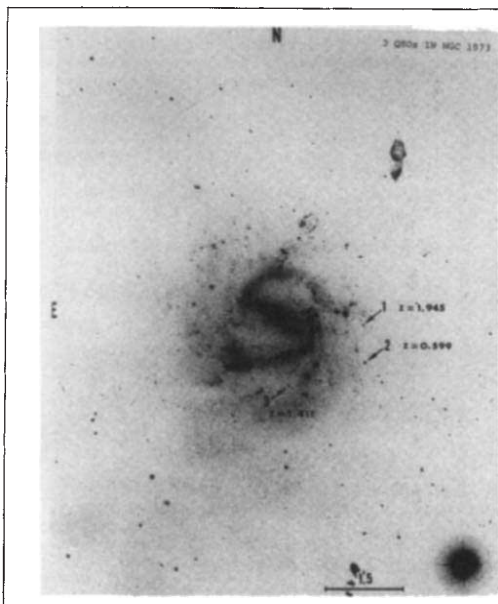
In a scale invariant gravitational theory it is possible to choose a particular conformal frame in which particle masses are everywhere the same, as they are normally supposed to be. Inhomogeneities then appear as gravitational potential wells, producing locally generated redshifts. Alternatively, a conformed frame can be chosen to remove the potential wells, at least to the extent of removing the Riemann scalar curvature. When this is done, the redshifts appear again as variations of particle masses. Thinking of such redshifts as 'anomalous', the anomalous values required by the second possibility of the previous paragraph appear to be about one-third of those arising from the

usual Hubble flow. This is on the average, and on the scale of the larger inhomogeneities, say 100 mpc. On smaller scales of the order of 1 mpc, and still more on the scale of QSOs, the anomalous redshifts required by theory could be appreciably larger than one-third of the Hubble flow. We think that it is in such terms that the facts concerning anomalous redshifts, discussed earlier in this article, are to be explained. This has been the mathematical basis underlying our position concerning those data. There are two ways to extend the existing position, one to continue to seek further connections with observation, the other to introduce real particles into the theory in place of classical particles.

Considering relations with observation further, and noting that the cosmological equations always have local solutions essentially identical to the main cosmological model, it is tempting to incorporate the Big Bang concept in the form of local events. Such local events could vary in scale from masses that have been associated with events in galactic nuclei, say  $10^8 M_\odot$ , up to the masses of whole galaxies, and thence to the masses of clusters and superclusters, the former being relatively common and the latter of a cosmological degree of rarity — that is, happening in any particular locality only once in a timescale of about  $H^{-1}$ .

It is important that, as the theory admits the creation of matter within its mathematical structure, creation events of this kind would be causal. They would be related to the Universe as a whole, mathematically through boundary conditions of the partial differential equations governing their internal properties and moments of occurrence. Otherwise the physics involved would be no different in principle, and for larger masses of the order of superclusters no different in detail from the situation in the supposed universal Big Bang. Associations between particle physics and the Big Bang translate, so far as physics is concerned, into similar associations at the large-scale end of creation when treated as a non Big Bang phenomenon.

It is commonly supposed that the so-called primordial abundances of D,  $^3\text{He}$ ,  $^4\text{He}$  and  $^7\text{Li}$  provide strong evidence for Big Bang cosmology<sup>33</sup>. But a particular value for the baryon-to-photon ratio needs to be assumed *ad hoc* to obtain the required abundances. A theory in which results are obtained only through *ad hoc* assumptions can hardly be considered to acquire much merit thereby. According to our point of view, on the other hand, the required abundances follow inescapably from the density-temperature relation that holds in all bodies with masses large compared with that of the Sun. Note that in the steady-state theory the Universe expands because of the creation of matter



Three QSOs lying within  $2''$  of the centre of the nearby spiral galaxy NGC 1073. The redshift of NGC 1073 is 0.004, or  $cz = 1,200 \text{ km s}^{-1}$ . However the QSOs have redshifts of 1.95, 0.60 and 1.41. Since the density of such objects over the whole sky is very small, no more than about 20 per square degree, the chance of finding three objects this close to the galaxy is exceedingly small, perhaps one in a million (ref. 16).

within it. The space-time structure of each new creation unit makes room for itself by shouldering aside the products of previously existing units, a process that requires each creation unit to expand with just sufficient energy to fit itself into the general Hubble flow of the Universe. This condition sets up the relation mentioned above between density and temperature, in which the density of matter is proportional to the cube of the temperature of the internal radiation field, the same relation as in Big Bang cosmology. But instead of the constant of proportionality being chosen arbitrarily to fit the required primordial abundances of D,  $^3\text{He}$ ,  $^4\text{He}$  and  $^7\text{Li}$ , the constant in the steady-state case is determined by the scale of the creation unit.

The scale of the creation unit so determined matches very well the size of superclusters of galaxies. The picture is of a Universe out to  $z = 1$  composed of about 1,000 major creation events, with creation occurring at cosmologically different epochs. Some among the 1,000 events will be relatively young, say  $0.3H^{-1}$ , others will be older, say  $4/3 H^{-1}$ , which is the age that seems necessary for 'our event' to accommodate comfortably the ages of the oldest stars in local galaxies ( $17 \times 10^9$  yr) to what seems to be the best determined value of  $H^{-1}$ . The need for us to live in the now-scattered residues from such an old event, rather than in the probably more numerous younger events, could well be anthropic. The need for human evolution to have taken place sets a lower limit to the age of our 'local' event. This lower limit may well be as large as  $4/3 H^{-1}$ .

There are several points of superiority of our view compared with the Big Bang hypothesis. One is that the baryon-to-photon ratio is set by the above considerations. Once the scale at the upper level of creation events has been set at  $0.1 H^{-1}$ , the baryon-to-photon ratio comes out necessarily as about  $3 \times 10^{10}$ , the best value for the synthesis of the light elements. In the Big Bang theory, on the other hand, this ratio has to be assumed *ad hoc*.

By having a wide spectrum in the scale of creation events (with those of smaller scale much more frequent than the larger scale of  $\sim 0.1H^{-1}$ ) there is a natural continuity between cosmology on the one hand, and the events associated with non-thermal emission — radio and X-ray sources — discrepant redshifts, and violent events on the scale of whole galaxies, which the observations clearly show to be intimately connected with one another.

The advantages of such a point of view can be measured both in details and in general principles. There has up to now been no really good stellar suggestion for the nature of the  $r$ -process in nucleosynthesis. Creation events for masses of  $\sim 10^8 M_{\odot}$ , however, provide a well-nigh perfect

process, both for the production of quantities of metals, but also for their driving by rapid neutron addition to the upper regions of the periodic table.

The conventional critic may argue that from the standpoint of economy of postulates the idea of 'many' creation events is a lot worse than the notion of the single creation event (the Big Bang). We disagree. The 'many' events in our alternative theory are potentially observable and satisfy the repeatability criterion of physical theories. The Big Bang satisfies neither of these requirements, and hence as a scientific hypothesis fails to compete with the alternative proposed here.

Cosmology is unique in science in that it is a very large intellectual edifice based on very few facts. The strong tendency is to replace a need for more facts by conformity, which is accorded the dubious role of supplying the element of certainty in people's minds that properly should only belong to science with far more extensive observational support. When new facts do come along, as we believe to be the case with anomalous redshifts, it is a serious misprision to ignore what is new on the grounds that the data do not fit established conformity. Certainty in science cannot be forthcoming from minimal positions such as those which currently exist in cosmology. It is true that when we come to astrophysics many more facts become available, and if the efforts of the past

quarter-century had succeeded in matching astrophysics to cosmology, the case would be much stronger. But this is precisely what has not happened. Astrophysics remains apart from cosmology, just as much as it was in 1965 when the microwave background was discovered. On this ground alone we think suspicions must be entertained that something in conformist cosmology is very wrong indeed.

As a general scientific principle, it is undesirable to depend crucially on what is unobservable to explain what is observable, as happens frequently in Big Bang cosmology. Geology progressed favourably from the time Hutton's principle of uniformity was adopted<sup>41</sup>, according to which everything in geology is to be explained by observable ongoing processes. One can suspect that cosmology and cosmogony would profit similarly from the adoption of the same principle, as the view proposed here does.  $\square$

H.C. Arp is at the Max-Planck Institut für Astrophysik, 8046 Garching bei München, FRG. G. Burbidge is at the Center for Astrophysics and Space Sciences, University of California, San Diego, La Jolla, California 92093, USA and acknowledges research support from NASA. F. Hoyle and N.C. Wickramasinghe are at the School of Mathematics, University of Wales College of Cardiff, Cardiff CF2 4AG, UK. J.V. Narlikar is at the Inter-University Centre for Astronomy and Astrophysics, Ganeshkhind, Pune 411007, India.

1. Ambartsumian, V.A. in *La Structure de l'Univers* (ed. Stoops, R.) (Solvay Conference Reports, Bruxelles, 1958).
2. Terrell, J. *Science* **145**, 918–919 (1964).
3. McCrea, W.H. *IAU Symp.* **44**, 282–286 (1972).
4. Bahcall, J.N. & Hills, R.E. *Astrophys. J.* **179**, 699–703 (1973).
5. Burbidge, G.R. & O'Dell, S.L. *Astrophys. J.* **183**, 759–766 (1973).
6. Hoyle, F., Burbidge, G. & Sargent, W.L.W. *Nature* **209**, 751–754 (1966).
7. Hoyle, F. & Burbidge, G. *Astrophys. J.* **144**, 534–552 (1966).
8. Zensus, J.A. & Pearson, J.T. (eds) *Superluminal Radio Sources* (Cambridge University Press, 1987).
9. Arp, H.C. *Astrophys. J.* **148**, 321–365 (1967).
10. Burbidge, E.M., Burbidge, G.R., Solomon, P.M. & Strittmatter, P.A. *Astrophys. J.* **170**, 233–240 (1971).
11. Arp, H. *Astrophys. Lett.* **9**, 1–4 (1971).
12. Sulentic, J.W. *Astrophys. J.* **265**, L49–L53 (1983).
13. Sulentic, J.W. & Arp, H.C. *Astrophys. J.* **319**, 693–708 (1987).
14. Burbidge, G. *Nature* **282**, 451–455 (1979).
15. Arp, H.C. & Sulentic, J.W. *Astrophys. J.* **229**, 496–502 (1979).
16. Arp, H.C. & Gavazzi, G. *Astr. Astrophys.* **139**, 240–242 (1984).
17. Arp, H. *Quasars, Redshifts and Controversies* (Interstellar Media, Berkeley, 1987).
18. Burbidge, G., Hewitt, A., Narlikar, J.V. & Das Gupta, P. *Astrophys. J. Suppl.* **74**, (in the press, November 1990).
19. Stocke, J.T., et al. *Astrophys. J.* **315**, L11–L15 (1987).
20. Webster, R.L., Hewitt, P.C., Harding, M.E. & Wegner, G.A. *Nature* **336**, 358–359 (1988).
21. Fugmann, W. *Astr. Astrophys.* **204**, 73–80 (1988).
22. Hewitt, A. & Burbidge, G. *Astrophys. J. Suppl.* **63**, 1–246 (1987); **69**, 1–63 (1989).
23. Canizares, C.R. *Nature* **291**, 620–624 (1981).
24. Arp, H.C. *Astr. Astrophys.* **229**, 93–98 (1990).
25. Linder, E.V. & Schneider, P. *Astr. Astrophys.* **204**, L8–L10 (1988).
26. Hogan, C.J., Narayan, R. & White, S.D.M. *Nature* **339**, 106 (1989).
27. Huchra, J. et al. *Astron. J.* **90**, 691–696 (1985).
28. Yee, H.K.C. *Astron. J.* **95**, 1331–1339 (1988).
29. De Robertis, M.M. & Yee, H.K.C. *Astrophys. J.* **332**, L49–L53 (1988).
30. Roberts, D.H. et al. *Astrophys. J.* **224**, 344–367 (1978).
31. Sargent, W.L.W. *IAU Symp.* **124**, 777–793 (1987).
32. Hammer, F. reported at *Workshop on Radio Galaxies* (University of California, Berkeley, 1989).
33. Gehren, T., Fried, J., Wehinger, P.A. & Wyckoff, S. *Astrophys. J.* **278**, 11–27 (1984).
34. Yee, H.K.C. *Astron. J.* **94**, 1461–1467 (1987).
35. Penzias, A.A. & Wilson, R.W. *Astrophys. J.* **142**, 419–421 (1965).
36. Mather, J.C. et al. *Astrophys. J. Lett.* **354**, L37–L40 (1990).
37. Hogan, C.J. *Nature* **344**, 107 (1990).
38. Hoyle, F. & Wickramasinghe, N.C. *Astrophys. Space Sci.* **147**, 245–256 (1988).
39. Dittman, W. & Neumann, K. in *Growth and Perfection in Crystals* (eds Daramus, R.N., Roberts, B.W., & Turnbull, D.) (Wiley, New York, 1958).
40. Seward, F.D., Hardeon, F.R. & Elsner, R.F. in *The Crab Nebula and Related Supernova Remnants* (eds Kafatos, M.C. & Henry, R.C.B.) (Cambridge University Press, 1985).
41. Helou, G., Soifer, B.T. & Rowan-Robinson, M. *Astrophys. J. Lett.* **298**, L7 (1985).
42. Burbidge, E.M., Burbidge, G.R. & Hoyle, F. *Astrophys. J.* **138**, 873–888 (1963).
43. Sandage, A.R. *Astrophys. J.* **138**, 863–872 (1963).
44. Burbidge, G. *Pub. Astr. Soc. Pacific* **98**, 1252–1257 (1986).
45. Burbidge, G. & Hewitt, A. *Comets to Cosmology* (ed. Lawrence, A.) 320–325 (Springer, Berlin, 1988).
46. Sandage, A.R. & Cacciari, C. *Astrophys. J.* **350**, 645–661 (1990).
47. Cowan, J.J., Thielmann, F.-K. & Truran, J.W. *Astrophys. J.* **323**, 543–552 (1987).
48. Das Gupta, P., Narlikar, J.V. & Burbidge, G. *Astron. J.* **95**, 5–14 (1988).
49. Das Gupta, P. thesis, Bombay Univ., 1988.
50. Schneider, D.P., Schmidt, M. & Gunn, J.E. *Astron. J.* **98**, 1951–1958 (1989).
51. Arp, H.C. & Burbidge, G.R. *Astrophys. J.* **353**, L1–L2 (1990).
52. Hoyle, F. & Narlikar, J.V. *Action at a Distance in Physics and Cosmology* (Freeman, San Francisco, 1974).
53. Boesgaard, A.M. & Steigman, G. *A. Rev. Astron. Astrophys.* **23**, 319–379 (1985).
54. Playfair, J. *Illustrations of the Huttonian Theory of the Earth* (Edinburgh, 1802).
55. Arp, H. *Astrophys. Lett.* **7**, 221 (1971).