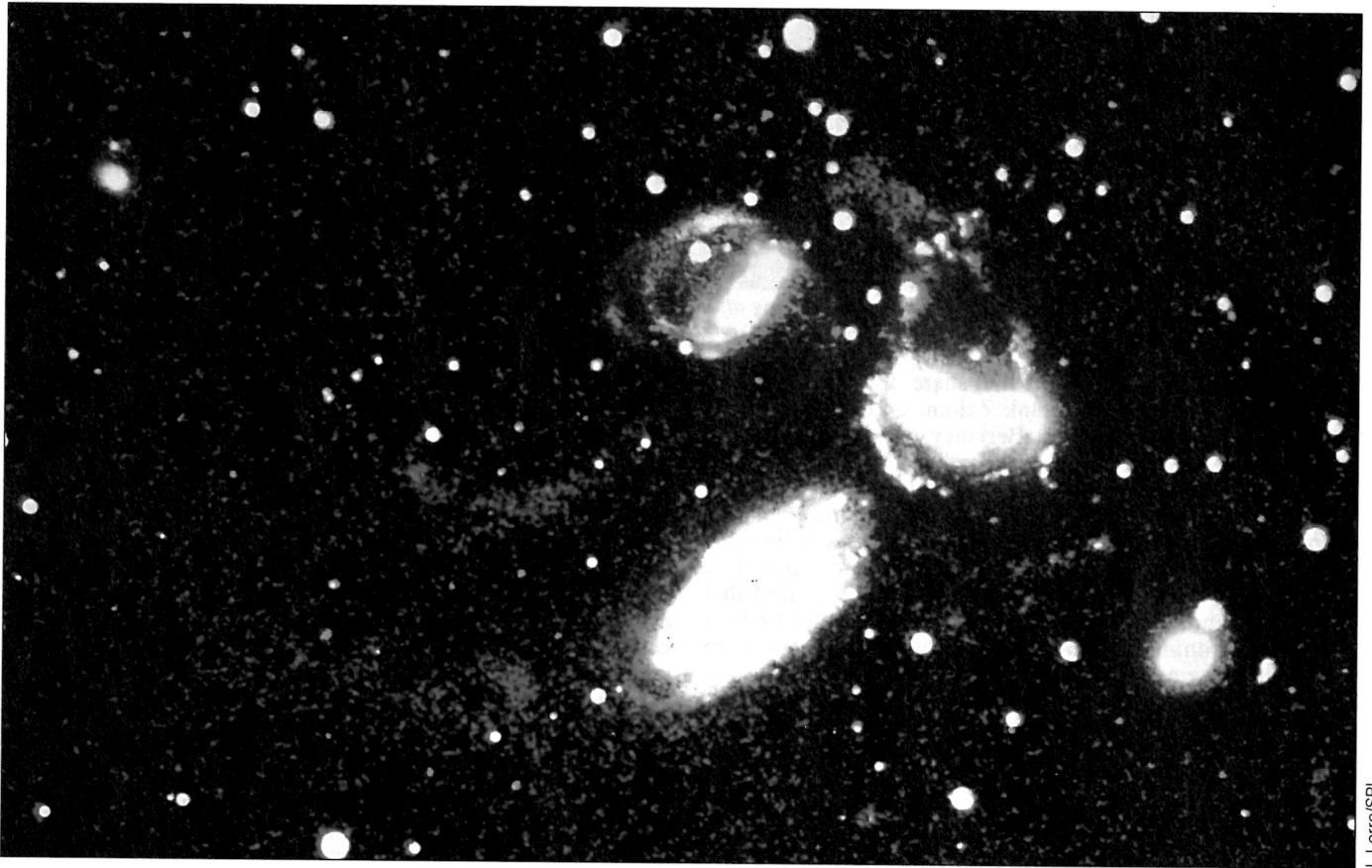


What if the big bang didn't happen?

Thirty years ago, two rival cosmologies, the big bang theory and the steady state theory, fought for supremacy. The big bang won. But recent observations suggest that we should take another look at the alternatives

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J. Lorre/SPL

A group of apparently neighbouring galaxies called Stefan's Quintet poses a cosmological conundrum. The big bang theory suggests that the red shift of an object depends on its distance from us. The bluish galaxy, however, has a quite different red shift from the other four

MOST astronomers believe that the Universe is expanding, and that it was created at one instant in a hot big bang. Indeed, much of the framework of modern physics is built around the concept that all the fundamental particles and forces that we are familiar with today came into being in the first few seconds after the big bang.

But what evidence do we have that the big bang ever happened? In fact, the big bang hypothesis is based on only three observations. The first is the red shift, whereby the lines in the spectrum of a galaxy moving away from us are shifted towards the red due to the Doppler effect. The degree of shift depends on the velocity of the galaxy relative to us. Edwin Hubble, working in the 1920s, noticed that the shift increased with the distance to the galaxy.

Distances to relatively nearby galaxies can be estimated fairly accurately from the behaviour of stars known as Cepheid variables, and from the apparent brightness of globular clusters—groups of stars that have a uniform intrinsic brightness. If all globular clusters are equally bright, then the fainter such a cluster seems to us, the further away must be the galaxy in which that cluster resides. Hubble extended his measurements farther into the Universe by interpreting the faintness of whole galaxies as a distance effect. He concluded that the red shift of a galaxy is directly proportional to its distance—a galaxy

twice as far from us as another has twice the red shift of the other galaxy. This is now known as Hubble's law.

Before Hubble had made this discovery, the theoretician Alexander Friedman had used Einstein's equations of general relativity to propose that the Universe was expanding. In this model, galaxies embedded in space recede from one another with those furthest away moving the fastest, not because the galaxies move through space but because the space between them expands. Hubble's observations, therefore, provided dramatic confirmation of this surprising prediction based on the general theory of relativity. The notion of the big bang is based on Friedman's model of the Universe. By going backwards in time, we arrive at a moment when all the matter (and all space) was concentrated into a single point which then exploded outwards in a single catastrophic event.

The second observation supporting the big bang is that the Universe appears to be bathed in a uniform wash of microwave radiation. In the mid-1940s, George Gamow with his colleagues, Ralph Alpher and Robert Herman, suggested that if the big bang hypothesis was right, then today there should be radiation left over from the early hot epoch (with a temperature of 10 billion K) when the Universe was barely a second old. This relic radiation would have a typical black body spectrum at temperatures which the researchers estimated in

the range of 5 to 7 K. In 1965, Arno Penzias and Robert Wilson came across this microwave background radiation at the slightly lower temperature of around 3 K. Again, observations had confirmed something predicted by the theorists. This greatly strengthened the appeal of the big bang model to cosmologists. In the 25 years since, astronomers have studied this background extensively—the most recent studies being made by the Cosmic Background Explorer Satellite (COBE) launched in 1989.

The final observation which supports the big bang hypothesis is that the amount of helium and deuterium as well as the light elements lithium, beryllium and boron that we see in the Universe is exactly what theorists predict should have formed at the high temperatures during the big bang. By working backwards from the state of the expanding Universe today, using the appropriate relativistic equations, it is possible to work out the conditions of pressure and density during the big bang, and how long they lasted. Such studies were pioneered by Gamow in the 1940s; the definitive calculations, by Robert Wagoner, Willy Fowler and Fred Hoyle, were carried out in the mid-1960s. They show, for example, that during the big bang, just under 25 per cent of the matter initially in the form of hydrogen should have been processed into helium-4. And, indeed, the spectra of old stars reveal that they do contain that amount of helium.

You might think, therefore, that it would be foolhardy to question the validity of the big bang. Yet, about a year ago, five of us, Chip Arp from the Max Planck Institute for Astrophysics in Munich, Geoffrey Burbidge from the University of California at San Diego, Fred Hoyle recently retired from the University of Cambridge, Chandra Wickramasinghe at University College, Cardiff and I, met in Cardiff to review the current status of the big bang hypothesis. An account of our discussions and conclusion (which we like to call the “Cardiff Manifesto”) was published in the research journal *Nature* in August last year.

We first examined Hubble’s law, which relates red shift to distance, and its implications for cosmology. At small red shifts, the law is linear, as Hubble discovered. At larger red shifts where we are dealing with very large distances, we must, according to Einstein’s theory, take account of the possible curvature of the geometry of space and time. This relation depends on which particular cosmological expanding model we use. So, if we wish to verify the validity of Hubble’s law, we need to know the distance of a galaxy along with its red shift.

The trouble starts right here. There is no unambiguous way of estimating the distance of a galaxy. The best we can do is estimate it in the way Hubble did back in the 1920s, using the inverse square law of illumination. The fainter an object appears, the farther away it is. This method is reliable provided we assume that all the objects have the same brightness. In the 1960s, Allan Sandage at the Mount Wilson and Las Campanas observatories found that this can be achieved by choosing the brightest member of a cluster of galaxies as a “standard candle”. Figure 1 shows the plot of red shift against faintness for

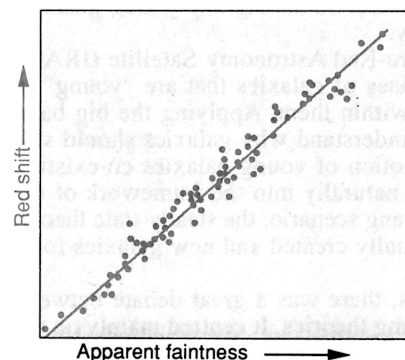
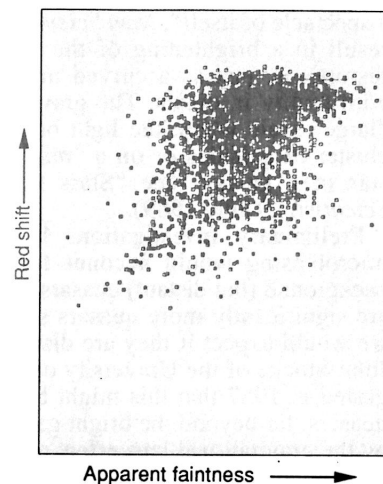


Figure 1 A plot of the red shift of galaxies against faintness gives a straight line. This seems to indicate that Hubble’s law relating red shift to distance works well for galaxies

Figure 2 Plotting the red shift of quasars against their apparent brightness produces a random scatter of dots. Hubble’s law does not seem to apply. Perhaps, quasars give out widely differing amounts of energy, or maybe the red shift has nothing to do with distance



a sample of such “standard candle” galaxies. The Hubble relationship is fairly tight. More recently, Sandage has shown that the surface brightness of a sample of nearby galaxies related to the red shift confirms Hubble’s law

The discovery of quasi-stellar objects, or quasars, by Maarten Schmidt of the California Institute of Technology in 1963, however, raised new questions. Most of these strange objects have much higher red shifts than galaxies. So, according to Hubble’s law, quasars must be very distant. They must, therefore, emit huge amounts of energy in order to be visible at such vast distances.

But does Hubble’s law apply to quasars? Because there is no independent way of measuring their distances, we again rely on the plot of red shift against faintness as in Figure 2. We do not need a statistician to tell us that this is a scatter diagram. There is no linear correlation, let alone a tight relationship between red shift and distance. It might be that the scatter is due to a variation in the intrinsic power of quasars, and that the Hubble relationship still holds.

There is a way of measuring the distance to quasars directly, however. Some quasars appear to be physically attached to a galaxy, perhaps by a “bridge” of stars. If a galaxy obeys Hubble’s law, then we would expect its companion quasar to do so as well. Indeed, some quasars seem to lie at the centres of galaxies and, according to conventional theory all quasars are the active nuclei of galaxies. But it is very difficult to measure the red shift of the galaxy surrounding a quasar because the instruments are swamped by the light from the quasar itself. It is easier to compare the two red shifts if quasar and galaxy lie side by side in the sky.

Alan Stockton demonstrated this approach in 1979. He chose a sample of 25 nearby quasars, and looked for galaxies that were very close to them. He then measured the red shift of the galaxy (if found) and called it a “success” if its red shift was similar to that of its neighbouring quasar. Stockton recorded 13 successes. The probability that the quasars and galaxies were chance juxtapositions was less than three parts in two million. Stockton concluded, therefore, that the pairs of quasars and galaxies were close neighbours.

But what about the 12 “failures” that Stockton ignored? Here the red shifts of the quasar and galaxy were quite different. This illustrates the weakness in this line of approach both for and against Hubble’s law. Over the years, several astronomers have reported many such discrepant cases. These were brushed aside as “freaks” for some time, until astronomers discovered a new phenomenon called gravitational lensing which seemed to offer a plausible explanation without disturbing the facade of Hubble’s law. In gravitational lensing, the gravity of a foreground object can bend and focus rays from a background source of light (see “Gravity makes

a spectacle of itself", *New Scientist*, 19 March 1987). This can result in a brightening of the source, multiple images and distortions, just as a curved mirror or lens can play havoc with reality in optics. The gravitational lensing can be on a "large" scale where the light bending agent is a galaxy or a cluster of galaxies or on a "micro" scale where it may be a star in a galaxy (see "Stars that magnify quasars", *New Scientist*, 29 July 1989).

Preliminary investigations in the 1980s indicated that microlensing would account for the apparent nearness of background (but distant) quasars to foreground galaxies. There are significantly more quasars seen near bright galaxies than we would expect if they are distributed at random in the sky. John Stocke of the University of Arizona and colleagues suggested in 1987 that this might be because the images of dim quasars, far beyond the bright galaxies, were being brightened by the gravitational lens effect of individual stars in the intervening galaxy. The astronomical community felt relieved that the framework of Hubble's law was no longer threatened.

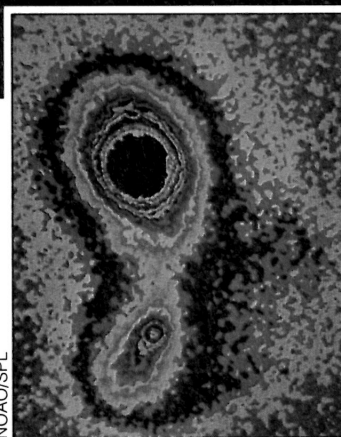
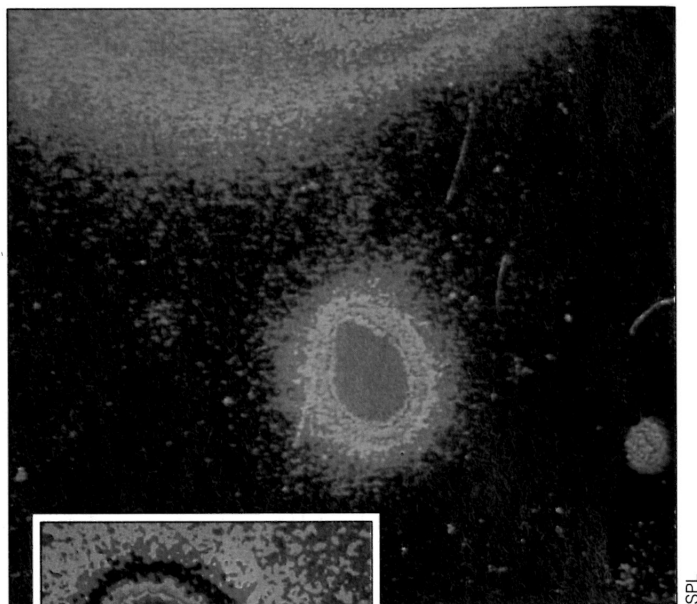
Unfortunately, it is now becoming difficult to believe that gravitational microlensing can explain why so many quasars seem to be near galaxies. And, recently, we have discovered many more pairs of neighbouring galaxies and quasars where the red shifts do not match up.

How are these pairs linked up? The most well-known couple are the bright galaxy NGC 4319 and the quasar Markarian 205. These objects have very different red shifts, and according to Hubble's law, M 205 is more than 12 times farther away from us than the galaxy. In 1971, Arp reported that the two objects were linked by a filament. Was the filament real? The issue remained controversial until 1984 when Jack Sulentic at the University of Alabama established that the connection was real by sophisticated image processing techniques.

Arp has found several skeletons in the cosmological cupboard where filaments connect bright galaxies with smaller companions. Such links by themselves are not always disturbing—indeed, we know of many cases in which the companion pulls out material from the bigger neighbour in a tidal interaction. What makes Arp's findings so worrying is the large difference in the red shifts of these linked objects. Either the links are spurious, or Hubble's law needs a rethink, at least in its application to quasars.

There are even more serious difficulties concerning the cosmic microwave background. The problem is that it is much too smooth. Observations have shown that matter in the Universe is in the form of galaxies grouped into clusters and superclusters with long filamentary stretches and giant voids in between. When these structures formed in the early Universe, they should have left an imprint on the microwave background, in the same way holiday-makers leave behind footprints on a beach. So far, COBE, the satellite currently investigating the microwave background, has found no evidence for any unevenness in the radiation. These latest observations pose a serious problem for cosmologists dedicated to the big bang. Indeed, a considerable amount of theoretical ingenuity is being devoted towards scenarios that would leave imprints below the observable threshold. Avoiding confrontation with observations is scarcely the hallmark of a good theory.

Another aspect is that in order to explain how structure developed in the early Universe, big bang cosmologists have had to conclude that the stars and galaxies we actually see are not all that make up the Universe. They have invoked an exotic type of matter called dark matter to provide the necessary gravitational force that would cause matter to coalesce into galaxies and clusters of galaxies. What is this dark matter made of? Theoretical particle physics has provided a rich menu of dark matter candidates such as photinos, gravitinos, axions and so on. So far no one has detected any of these particles in accelerators on Earth.



Quasars often appear to be connected to galaxies. The inset shows a quasar and a galaxy with similar red shifts, indicating that they are neighbours. The top photo, however, shows the quasar Markarian 205 linked by a faint bridge of stars to galaxy NGC 4319. It has a very different red shift from the quasar

Current versions of the big bang hypothesis also require the Universe to have undergone a transient "inflationary" phase when it was barely 10^{-36} seconds old. Inflation, in this case, means a rapid expansion when the scale factor grows exponentially with time. The inflationary phase sets the initial conditions for the subsequent development of the Universe. In particular, it tells us that the present age of the Universe has to be between 6.5 billion and 13 billion years. This may be compared with the ages of the oldest stars, which are in the range of 13 to 17 billion years, and the ages of elements in the range 12 to 16 billion years. It seems that the Universe is just not "old enough" to accommodate its constituents.

There is also a problem at the "young" end of the galactic age range. As we saw earlier, in discussing dark matter, the big bang hypothesis is still grappling with the problem of how galaxies and galaxy clusters formed. Most theories predict that they formed within a relatively short period, making all galaxies roughly of the same age between 10 and 15 billion years. In other words, we should not be seeing any young galaxies in our neighbourhood now.

The surveys by the Infra-Red Astronomy Satellite (IRAS), however, show several cases of galaxies that are "young" in terms of the stars found within them. Applying the big bang hypothesis, it is hard to understand why galaxies should still be forming. Rather, the notion of young galaxies co-existing with older ones fits more naturally into the framework of the one-time rival of the big bang scenario, the steady state theory, in which matter is continually created and new galaxies form all the time.

In the 1950s and 1960s, there was a great debate between the steady state and big bang theories. It centred mainly on the concept of evolution. Is the Universe evolving with time,

following the big bang, or does it remain the same over cosmic time scales—in a steady state? We might consider using the red shift to decide the issue, provided it is an indicator of cosmological time. As we look out farther into the Universe, we are also looking back in time (because of the time light takes to travel), so the red shift of an object not only measures its velocity and distance but also its age. The red shifts of the quasar population do appear to show evidence of evolution. But if the red shift of a quasar is not entirely due to the expansion of the Universe, it cannot be used as the basis for asserting evolution. So it is significant that recent analysis by Patrick DasGupta, of the Inter-University Centre for Astronomy and Astrophysics at Pune, shows the “no evolution” hypothesis (the steady state theory) to be consistent with the results obtained from counting bright radio galaxies. DasGupta has shown that the number of bright radio galaxies detected in any chosen volume of space is constant, whether the sample is taken nearby or far away. Because light (or radio waves) take a finite time to cross space, this means that the density of bright radio galaxies was the same long ago as it is now—in other words, the Universe is not evolving.

Given these problems, it is not a sound strategy to put all our cosmic eggs in one big-bang basket. Rather, we should explore other possibilities. Thirty years ago, there was a more open debate on alternative theories, which made valuable contributions to our understanding of cosmology. For a healthy growth of the subject, the big bang hypothesis needs competition from other ideas. Let us consider some alternatives.

First, the cosmic background: could this be of more recent astrophysical origin? The answer is “yes”. What it requires is a population of particles that absorb microwaves but are nearly transparent to optical as well as radio waves. These particles, distributed through intergalactic space, serve to absorb and redistribute any radiation as a microwave background. In fact, back in 1968 Hoyle, Wickramasinghe and V. C. Reddish had shown that if all observed helium were produced in thermonuclear processes in stars, then the resulting starlight would, after being absorbed and re-emitted by intergalactic particles, generate a microwave background at the observed temperature. The main difficulty was to identify a suitable particle.

Alternatives to the big bang

Recent work on cosmic grains—small particles of iron, carbon and the like found in interstellar space—has turned up a promising candidate: an iron whisker about 1 millimetre long and 1 micrometre wide. Laboratory experiments show that slowly cooled metallic vapours do condense into such whiskers. Because metals are expected to be ejected in supernova explosions, such whiskers could very well form in the expanding envelopes of supernovae. Significantly, the spectrum of the Crab Nebula pulsar (which is the relic of a supernova) shows a dip in the range of wavelengths from 30 micrometres to 10 centimetres, which are just the wavelengths where we would expect iron whiskers to absorb radiation. Once produced in supernovae in galaxies, these whiskers would (in a reasonably short time compared with cosmological time scales of 10 billion years) ultimately be pushed out into the intergalactic space by radiation pressure. Calculations show that such particles could very efficiently wipe out any underlying unevenness in radiation from stars and galaxies.

In short, the microwave background would have been generated after the stars and galaxies had formed instead of before, with the whiskers playing the role of a tide washing away the footprints on the beach.

What explains the anomalous red shifts of quasars? One solution uses a theory of gravity that Hoyle and I developed. This theory depends on Mach’s principle, whereby the inertia of matter arises from its interaction with other matter in the Universe, and may increase with the age of matter.



The bending of light by gravity may explain why distant quasars can appear close to galaxies. The strange arc in the photo above could be the image of a distant quasar whose light has been “smeared out” by the gravity of the cluster of galaxies in the foreground

According to this idea, any particle just created starts with zero inertial mass. It picks up mass as it grows older by interacting with more and more particles in the Universe. Because the effect is universal, a hydrogen atom of young matter will have a smaller inertial mass and so its spectral lines will have longer wavelengths. Therefore, its lines will be shifted to the red compared with those of an old hydrogen atom measured in the laboratory.

This approach would explain why some quasars have much larger red shifts than their galactic partners. The quasar could have been ejected from an older galaxy in a process of “minicreation”. As the quasar grows old, the discrepancy in red shift gradually diminishes.

On a larger scale, clusters and superclusters of galaxies form through “local” creation events, which may be likened to “white holes” or “mini bangs”. Thus, we might have as many as about a 1000 creation events happening at different epochs. Judging by the ages of the oldest stars in our Milky Way galaxy, it was created in a very early epoch.

This scenario forms a bridge between the big bang and the steady state hypotheses, incorporating the explosive creation of the former with the continuity of creation events from the latter. It has the advantage of a natural link between the local explosions observed in quasars, galaxies where stars are actively forming, and cosmology.

Perhaps the strongest point in favour of this alternative is that it brings cosmology within the scope of the physics and astrophysics of the Universe as it is today. By contrast, the big bang hypothesis relegates most observable features of the Universe such as the cosmic background and formation of galaxies to the remote past, to a transient era when the physical state of the Universe was supposed to be vastly different from what we can now test in the laboratory. The big bang hypothesis relies upon esoteric forms of matter not found in the laboratory to explain how the Universe got to be the way it is. What is most disturbing is that the scenarios proposed are supposed to have happened only once, not being repeatable as required by the norms of science.

Our alternative cosmological scenario does not claim to be the last word but it deserves further critical appraisal as an alternative to the big bang. □

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Further reading: “The extragalactic Universe: an alternative view”, *Nature*, 30 August 1990, p 807.