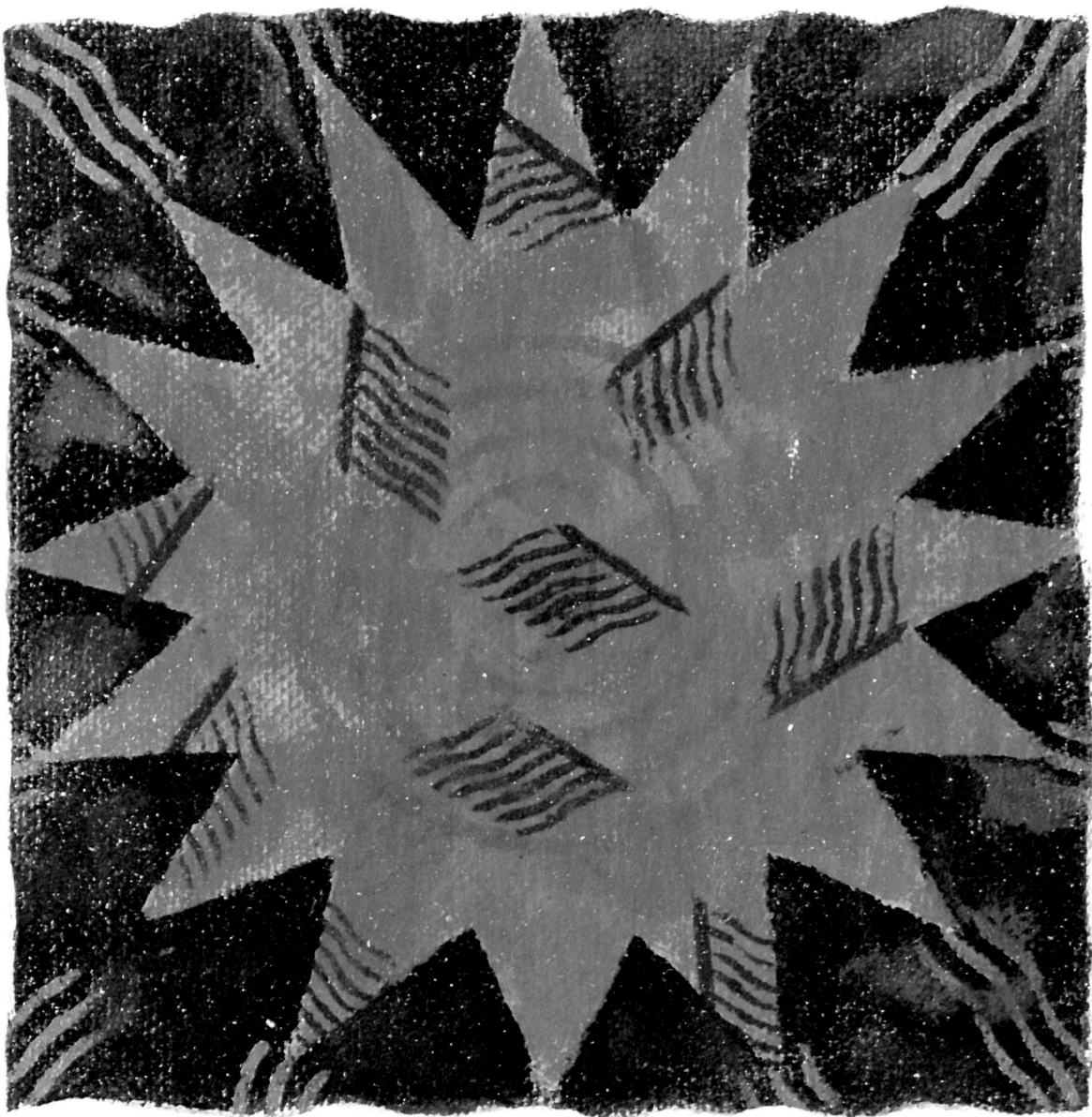




Jayant Narlikar

QUESTIONS of origin have always been the most difficult ones to answer. But perhaps the most fundamental of all questions concerns the origin of the Universe. Many astronomers and physicists today feel they have found the answer. They believe that the Universe was created at one instant in a hot explosion, called the big bang, and that the basic structure of matter was decided in the first billion-billion-billion-billionth part of a second (10^{-36} seconds). But this hypothesis has serious deficiencies, which the results from the satellite COBE have only served to highlight.

According to the big bang theory, in those early epochs of high energy activity, particles of matter and radiation interacted closely, leading to the formation of light atomic nuclei by the time the Universe was barely three minutes old. Matter and radiation separated after about a hundred thousand

Challenge for the big bang

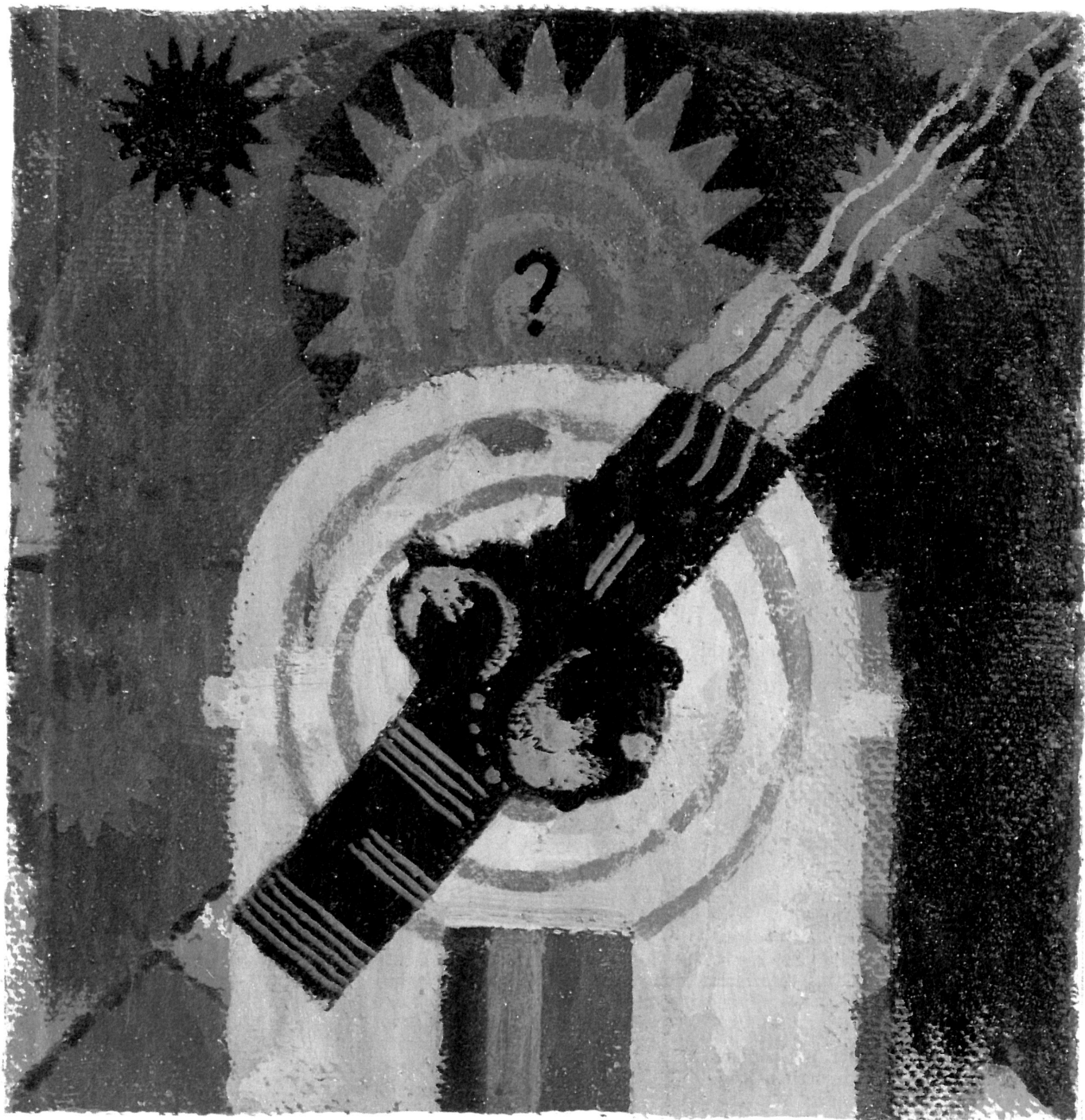
Results from the COBE probe ruled out key elements in the conventional explanation of how the Universe began. Is it time for an alternative theory?

years. These primordial "seeds" of matter grew to form the galaxies and larger structures that astronomers observe today, while the radiation cooled to give a microwave background radiation of some 2.7 kelvin.

This picture received considerable support in the mid-1960s when Arno Penzias and Robert Wilson first detected the microwave background and astronomical surveys began to reveal abundances of light nuclei close to those predicted by the hot big bang theory. Over the years belief in the big bang has strengthened. Last year, COBE reported temperature fluctuations in the background, the imprint of seeds of what have now become large-scale structures of matter. Surely, this should have convinced any doubting Thomases.

Far from it. The COBE results have ruled out a large number of contending theories of galaxy formation, some of which had enjoyed wide popularity—for example, those based on pure hot dark matter and on pure cold

Illustrations: Nigel Owen



dark matter (see "Beyond cosmic ripples", *New Scientist*, 1 May). The surviving theories must not only explain the COBE results but also relate them to other data on large-scale structure, such as the motion of galaxies on the largest scale. COBE has made life for big bang cosmology more difficult than anyone expected.

There are three major problems with the big bang model. First, as a theory of physics, it breaks a cardinal rule by violating the law of conservation of matter and energy. At the instant of the big bang the entire Universe is created in what is known as a singular event, or "singularity". Physics is believed to apply only after this instant. Secondly, the microwave background is believed to be the strongest evidence for the big bang. Yet such a fundamental feature of the radiation as its temperature cannot be deduced from any calculations of the early Universe. Its value is assumed.

The third problem is that big bang cosmology is supposed to explain the origin of most light nuclei. But although it can with some success explain the formation of helium and deuterium, it runs into problems with other nuclei such as lithium, beryllium and boron. Even with deuterium it places such stringent upper limits on how much baryonic matter ("ordinary" matter, in the form of neutrons and protons) is allowed in the Universe that it forces astronomers to suggest that the "dark" matter thought to make up most of the mass is in some exotic form.

Furthermore, the most popular version of the big bang model, that involving inflation, implies a total age for the Universe that is uncomfortably small compared with the ages of our Galaxy, of globular clusters and of other galaxies.

The knots into which big bang theorists have tied themselves in the post-COBE era convinced Fred Hoyle, Geoffrey Burbidge

and myself that we should seriously explore an alternative theoretical framework for cosmology. In this framework, which we call “quasi-steady state cosmology” (QSSC), matter and energy are created by routine methods of theoretical physics. Using the model, we can estimate correctly the present temperature of the microwave background, explain the formation of light nuclei in the right quantities without requiring non-baryonic dark matter, and avoid the “age difficulty”. Our theory attempts to link the large-scale features of the Universe with the phenomena of high-energy astrophysics. Before coming to cosmology, let us look at these astronomical events.

Driving force of the Sun

By 1960, it was becoming clear that the process of nuclear fusion that works well in explaining stellar energy, from Sun-like stars to red giants and supernovae, proves either inadequate for or inapplicable to a wide variety of more violent phenomena. Today, these include binary X-ray sources, the nucleus of our Galaxy, extragalactic radio sources, quasi-stellar objects (QSOs) and active galactic nuclei (AGNs). By 1964, the team of astrophysicists that had earlier carried out seminal work on the synthesis of nuclei in stars—Hoyle, Geoffrey and Margaret Burbidge and William Fowler—had come to the conclusion that the clue to the energy of many of these objects lay in gravity rather than in nuclear physics, as the energy in such sources is being generated in compact regions where gravity is very large and dominates all other known forces.

Today the popular version of that scenario envisages a massive spinning black hole at the centre of the object, which pulls in matter to form a thick, hot “accretion disc” around it. Much of the observed radiation from these objects is believed to come from this hot disc. Over the years this basic idea has been expanded to accommodate more recent observations—but in a way that is reminiscent of the ancient Greeks’ practice of grafting extra epicycles to their model of planetary motion.

In a typical double-lobed radio source, for example, the two lobes, several hundred thousand light years apart, are “activated” by the bombardment of jets from the central region, which is believed to contain a massive black hole. The black hole pulls in surrounding matter into an accretion disc which somehow makes long, narrow jets. These jets, which emerge in opposite directions, are thought to contain plasma travelling at near the speed of light. But neither the black hole, nor the accretion disc, has been directly observed. It is not clear how accretion is possible, despite the strong outward pressure of radiation from the object. In a typical astrophysical process energy is converted to a more useful form (radiation or dynamical motion) very inefficiently, usually with an efficiency of below 1 per cent. In the Sun, for example, only 0.7 per cent of the matter is converted into radiation. But the black hole accretion process requires between 10 and 30 per cent of the gravitational energy to be converted to X-rays and other radiation. Finally, the circumstantial evidence claimed for the existence of a black hole stops far short of explaining its theoretical radius.

Far from matter falling into a black hole, the evidence shows matter and radiation pouring out of compact regions, as emphasised by the Armenian astrophysicist Viktor Amazaspovich Ambartsumian in the early 1960s and conjectured even earlier

by James Jeans, back in 1929. But these ideas have found little support among theoreticians, mainly because they are perceived to violate the law of conservation of matter and energy. The idea of a single, ancient explosion as found in the big bang cosmology did not look too bad until the discovery of QSOs, AGNs, radio sources and so on, which are phenomena indicative of ongoing explosive activity. Today it looks inadequate to explain the continuing occurrence of such violent events. Somehow, cosmology has to come to terms with these without sacrificing the conservation law.

Our attempt to do this is based on a model in which a series of “minibangs” replaces the single big bang. These “minibangs” begin with a physical process that resembles the way matter falls into a classical black hole. But instead of everything being gobbled up indefinitely, at some critical point defined by the size of a repulsive “field”, the material is pushed out with tremendous force, rather like an explosion. Unlike the big bang, which is spontaneous and causeless, these smaller creation events are part of an ongoing process. The idea that matter is being created continuously—the so-called steady state model—was put forward by Hermann Bondi and Thomas Gold in 1948, and by Hoyle, who also tried to reconcile the creation of matter with the theory of relativity.

Creation great and small

We now propose a model in which the Universe passes through alternate phases of “large” and “small” creation. In large creation more matter is created by means of more frequent or larger explosions than in small creation. Large creation therefore accelerates the expansion of the Universe as the matter flies apart. But this acceleration simultaneously reduces the strength of the repulsive field responsible for creating matter. The expansion process slows down until, at some point, more and more explosions occur and the whole process repeats itself. The overall picture is one in which slow and steady exponential expansion over the order of a thousand billion years is combined with short-term “wiggles” of between 20 and 40 billion years.

Today’s measurements give a range of values between 50 and 100 kilometres per second per megaparsec for the Hubble constant, H , which relates the speed of recession of a galaxy to its distance from us. That is, a galaxy at a distance of 1 megaparsec is typically moving away from us at a speed of between 50 and 100 kilometres per second. The constant has the dimensions of the reciprocal of time, with $1/H$ between 10 and 20 billion years. We suggest that the Hubble constant is a measure of the short-term “wiggles” in our model.

Large-scale surveys of the Universe, using radio and optical astronomy, should eventually show whether the idea of these two timescales is correct. Meanwhile, the QSSC model will be judged largely by its ability to explain the origin of light nuclei and the microwave background radiation.

In big bang cosmology the process of nucleosynthesis in the early Universe is able to account for the quantities of deuterium observed in the Universe—provided there is a strict upper limit (about 10^{-30} grams per cubic centimetre) on the density of baryonic matter in the Universe. This leaves the problem of deciding what the dark matter in the Universe is made of. For if we add in dark matter to the matter density, we exceed this

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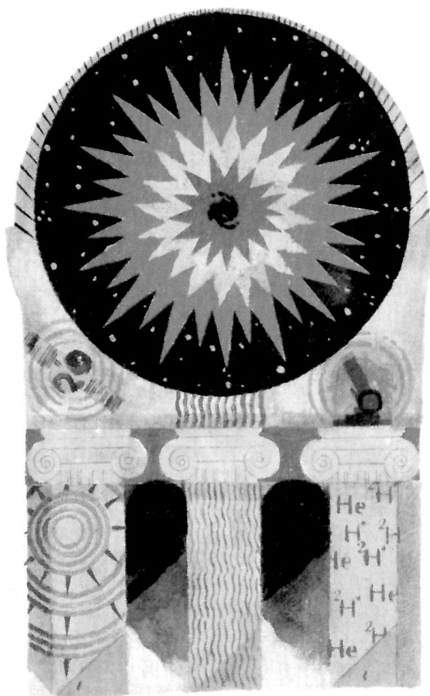
upper limit. This has led big bang cosmologists to suggest that dark matter must be in an exotic, non-baryonic form which does not take part in the synthesis of deuterium.

In the QSSC model the entire process of synthesis of nuclei is different, so in the production of deuterium there is no upper limit on the density of ordinary matter. In the QSSC the first particle to be created is the so-called Planck particle, whose mass is determined by the three fundamental constants of physics, the speed of light, Planck's constant and the constant of gravitation. This mass is a few tens of micrograms, but its lifetime is extremely short, about 10^{-43} seconds. So the particle decays into less massive but more stable particles: the neutron and the proton and six other, less stable baryons. Since the creation process is continuous, it works in favour of the existing mass—one generation of masses are made of matter, so the next one continues to be made of matter.

In big bang cosmology, there was no initial distinction between matter and antimatter; both were treated on a par. Physicists therefore have a puzzle on their hands as to how the Universe today seems to be made predominantly of matter. Moreover, big bang cosmology has not explained why the particles of light (photons) in the radiation background outnumber particles of matter, baryons, by about a billion to one.

In the QSSC model, baryons and radiation are both end products of the decay of the Planck particle. The two baryons familiar to us, the neutron and the proton, form part of an octet that makes up the baryon family. Of these, the remaining six particles are very short-lived and decay into protons which form the nuclei of hydrogen atoms we see today. The original neutron and proton pairs, on the other hand, combine to form the nuclei of helium atoms. So we would expect about 25 per cent of the mass in the Universe to be helium and the rest hydrogen. More detailed calculations lower the helium fraction to about 23 per cent, while calculations for light nuclei like deuterium, tritium, lithium-6, lithium-7, beryllium-8 and boron-11 all agree well with estimates of primordial abundances based on their observed abundances today. The model also allows small quantities of elements such as carbon, oxygen and iron to be formed.

Now for the microwave background radiation. In big bang cosmology the background radiation is seen as the relic of an early hot beginning. In the QSSC there is no beginning, so we have to show how the existing steady background is continually replenished as the Universe expands. We suggest that it works mainly by starlight being absorbed by matter and re-radiated as energy, a process called thermalisation. In this picture, the source of the microwave background radiation is starlight left over from previous wiggles. By calculating the amount of starlight produced in the present wiggle so far—that is, since the last minimum phase of the oscillation—we can infer the amount of starlight being carried over from one cycle to the next, and thereby estimate the temperature of the background radiation. We find that this thermalised



The microwave background radiation... works mainly by starlight being absorbed by matter and re-radiated as energy'

starlight should indeed have a temperature of about 2.7 kelvin.

Having got the temperature right (an achievement as yet denied to the big bang scenario) we next have to explain how the background radiation produces a spectrum of the perfect "black body" shape that is observed. A black body spectrum arises whenever the radiation has passed through a series of absorption/re-emission sequences. In the QSSC model, we suggest that the radiation from previous wiggles is continually absorbed and re-emitted by needle-shaped dust, mainly at the minima of oscillations (thermalisation is a continuous process but acts more strongly at the minima because of their high densities). Iron needles about a millimetre long and about 0.01 micrometres across are needed to bring this about. Laboratory experiments show that metallic vapours do tend to condense into whisker-like shapes. Such iron vapour would have been produced in supernovae, as well as in the nucleosynthesis process of a minibang, and only a tiny fraction of the estimated cosmic abundance of iron would be needed for thermalisation to work. This process would have gone on long enough to produce a perfect black body spectrum, and a near perfect isotropy (sameness in all directions). The

tiny fluctuations detected by COBE in its isotropy are then simply the marks of imperfect processing since the last wiggle.

The QSSC model also has implications for astrophysics. In the QSSC, the dark matter believed to be present in large quantities in spiral galaxies (including our own) would simply be remnants of burnt out stars. The estimated mass of the Galaxy could be built up to its present value through several cycles of matter creation, some as long as 200 billion years, and this would be long enough for some star clusters to be too faint to be seen. A similar argument applies to dark matter in clusters of galaxies. In the QSSC, the timescales are also sufficiently long to allow clusters to merge into superclusters.

Several types of future observation might support the model. For example, the search for gravity waves now being planned might be one way of detecting minibangs if they exist, since such minibangs would generate gravity waves. For this to happen, the explosions would have to be irregular in shape and their intensity and duration would be such that they can be distinguished from other gravity wave sources like exploding stars and shrinking binary neutron stars. The gravity wave background may also be detectable through its effect on the precise timing mechanism of millisecond pulsars; pulsar measurements are not yet sensitive enough to detect such a background.

The framework described here serves only as a starting point. Unlike the big bang model, it is not presented as the definitive theory of cosmology, but as one theory. We hope it will at least provoke some debate. □

Jayant Narlikar is director of the Inter-University Centre for Astronomy and Astrophysics at Pune, India. **Further reading:** "A quasi-steady state cosmological model with creation of matter", *Astrophysical Journal*, 20 June 1993.