

A DIFFERENT APPROACH TO COSMOLOGY

Modern cosmology began with the solutions to Einstein's theory of gravity discovered by Aleksandr Friedmann and Georges Lemaitre in the 1920s. When combined with the Hubble redshift-distance relation, these solutions could be interpreted as showing that we live in an expanding universe. By 1930, the scientific establishment and much of the lay public believed in this expanding cosmos. It then requires only time reversal and elementary logic to conclude that the universe must originally have been so compact that we can talk of a beginning. Lemaitre tried to describe this state as the "primeval atom."

For a decade or so after World War II, George Gamow, Ralph Alpher, Robert Herman and others explored this supposed dense primordial state, trying to make all the chemical elements from protons and neutrons. They soon learned that this could not be done, because of the absence of stable nuclei at mass numbers 5 and 8. But they also realized that, if there had been such an early ultradense stage, the universe might well contain an expanding cloud of primordial radiation that would preserve its blackbody form as the universe evolved.

In the mid-1960s, Robert Dicke and his Princeton colleagues rediscovered this idea and decided to look for the microwave background radiation. Of course Arno Penzias and Robert Wilson at nearby Bell Laboratories beat them to the discovery and, 25 years later, the COBE (Cosmic Background Explorer) satellite demonstrated that the microwave background has a perfect blackbody spectrum out to radio wavelengths.

The discovery of the microwave background, together with the fact that the abundances of the helium isotopes and deuterium turn out to be about right for nucleosynthesis in a hot, superdense primordial state has led to the wide acceptance of the standard "hot Big Bang" cosmology.

The standard cosmological model

In 1967, Robert Wagoner, William Fowler and Fred Hoyle¹ repeated a calculation originally reported by Alpher and Herman.² They calculated that a synthesis of the light elements in the early hot universe yielded abundances of deuterium, ³He, ⁴He and ⁷Li that were satisfactorily in agreement with astrophysical observations if the average

In this unorthodox assault on mainstream cosmology, three venerable stalwarts argue for a quasi-steady-state universe, with some quasars quite nearby and no Big Bang.

Geoffrey Burbidge, Fred Hoyle
and Jayant V. Narlikar

cosmological density ρ (in g/cm³) of baryonic matter was related to the radiation temperature T (in kelvin) by $\rho \approx 10^{-32} T^3$.

Cosmological theory requires this relationship between density and temperature to be maintained throughout the expansion of the universe from its early hot state. So, putting in COBE's measured value of

the present background temperature, $T = 2.73$ K, yields about 2×10^{-31} g/cm³ for the present-day average density of the cosmos. Although this result was almost two orders of magnitude less than the standard model's so-called closure density, it agreed with Jan Oort's estimate for the cosmic average density of observable material. The higher "closure" value of about 10^{-29} g/cm³, given by standard cosmological theory, is explained in terms of nonbaryonic matter that has changed its identity over the years from neutrinos to esoteric "cold-dark matter" particles, perhaps with some remaining admixture of neutrinos. For us, it is not reassuring that this line of reasoning from the 1960s is still the best available in favor of Big Bang cosmology, despite the continuing failure of attempts to identify the required nonbaryonic matter.

This standard-cosmology argument can be countered by a still more precise calculation with a very different implication. We know that ⁴He is synthesized from hydrogen in stars with an energy yield of about about 6×10^{18} ergs for each gram of helium, the energy being radiated by the stars to produce a radiation background. If all of the ⁴He in the universe has been produced in this way (the observed abundance is about one ⁴He for every 12 hydrogen atoms), then the accompanying radiation background should have an energy density of 4.37×10^{-13} erg/cm³. That is quite close to the observed energy density of the microwave background, namely 4.18×10^{-13} erg/cm³.

Either this agreement is coincidental, or we must conclude that the ⁴He was created, not by Big Bang nucleosynthesis, but rather by hydrogen burning inside stars (a process that we *know* to exist), and that the radiation background from stars has become subsequently thermalized into the far infrared (as discussed in detail below).

It has often been argued that the microwave background and the abundances of ⁴He and the other light isotopes are the two major pieces of observational evidence on which the whole edifice of the hot Big Bang cosmology rests. This argument is powerful only if no other way has been found to explain the helium abundance and the microwave background. We have just provided such an alternative explanation.

We turn now to further problems associated with the so-called standard model. If negative values of the energy

GEOFFREY BURBIDGE is a professor of physics at the University of California, San Diego. FRED HOYLE was the Plumian Professor of Astronomy at the University of Cambridge and the founding director of the university's Institute for Theoretical Astronomy. JAYANT V. NARLIKAR is director of the Inter-University Centre for Astronomy and Astrophysics in Pune, India.

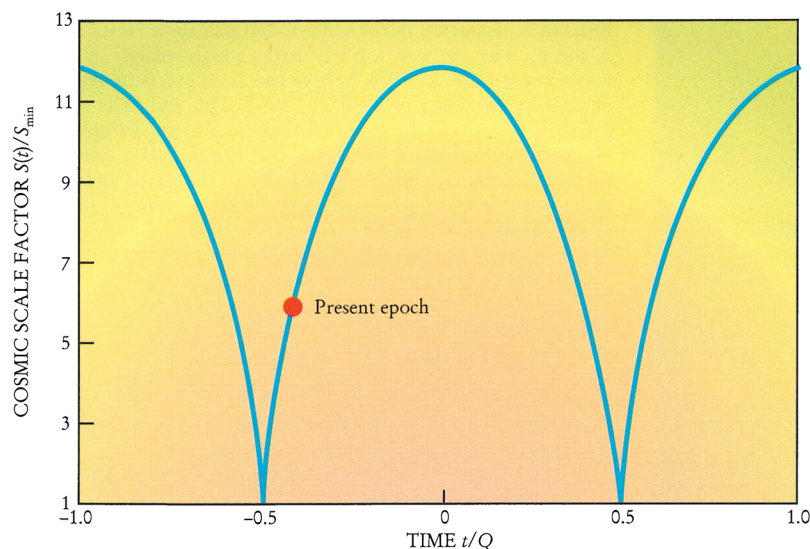


FIGURE 1. OSCILLATION OF THE COSMIC scale factor $S(t)$ in our quasi-steady-state cosmology, for the case in which the matter creation rate is assumed to be small. The ratio of S to its minimum is plotted against time normalized to the characteristic oscillation time $Q \approx 10^{11}$ years. The red dot marks our present epoch.

density are prohibited, one can argue that the observed expansion of the universe requires not only that the universe was more compressed in the past, but additionally that it was also expanding in the past. If we denote the time dependence of the linear scale factor of the universe as $S(t)$, general relativity always yields a positive time derivative for S^2 . So the scale factor is always increasing and, as we look back in time, we see the universe become more and more compressed at earlier and earlier times. Ultimately to what?

In attempts to answer this question, it is accepted that particle energies increase up to values in the TeV range, and then, by speculation, all the way to the Big Bang. Up to 10^{15} GeV, symmetry arguments are invoked and the theory departs increasingly from known physics, until ultimately the energy source of the universe is put in as an initial condition, the energy supposedly coming from somewhere else. Because that "somewhere else" can have any properties that suit the theoretician, supporters of Big Bang cosmology gain for themselves a large bag of free parameters that can subsequently be tuned as the occasion may require.

We do not think science should be done that way. In science as we understand it, one works from an initial situation, known from observation or experiment, to a later situation that is also known. That is the way physical laws are tested. In the currently popular form of cosmology, by contrast, the physical laws are regarded as already known and an explanation of the later situation is sought by guessing at parameters appropriate to the initial state. We think this approach does not merit the high esteem that cosmologists commonly accord it.

Quasi-steady-state cosmology

Since 1993, we have been developing an alternative cosmology,³ beginning from an action principle by which we seek to explain how matter and radiation appeared in the universe. That is to say, the action principle includes the possibility that a typical world-line of a particle can have a beginning. The details involve a scalar field analogous to that which appears in popular inflationary models. As it does in the inflationary models, the scalar field exerts a negative pressure that explains the universal expansion. In our theory, the field also acts negatively in the creation process, balancing the positive energy of matter production. That permits new matter to appear in an already existing universe, instead of requiring the creation of the

entire universe *de novo*, in a Big Bang.

We regard the creation process as being triggered locally in what we call minicreation events, with the negative field component subsequently escaping from the region of creation, which has experienced an accumulation of positive energy. It is in this way, we argue, that black holes are formed—not through the infall of matter. The reason for this further divergence from what is popularly assumed is the following: Matter moving at velocity c transverse to the radius vector from the center of a spherical black hole of mass $M = 10^{10}$ solar masses ($M_\odot$), at the critical distance $2GM/c^2$, has angular momentum of order 10^{26} cm²/s per gram. But matter rotating about a galactic center typically has ten thousand times more angular momentum than that. Therefore it is difficult for us to see how a large quantity of matter in a galaxy could come to be packed into the small scale of a black hole, even when the black hole has a mass as large as 10^{10} solar masses.

Conventional cosmology has, as yet, found no satisfactory way around this difficulty. But if, at the centers of galaxies, there are black holes that act as minicreation events, the escape of the negative energy field generated in the creation process provides a ready explanation for the accumulation of the positive material component, leading to an easily understood development of the central black hole.

Cosmological solutions

The spacetime geometry of our quasi-steady-state cosmology is described, just as in standard cosmology, by the Robertson–Walker line element, with the expansion of the universe determined by the scale factor $S(t)$. The difference in our theory is that the equation for the time derivative of S^2 now carries a negative term that decreases like S^{-6} . Thus, in a time-reversed picture, in which the scale factor S grows smaller, a stage will eventually be reached in which this new term will dominate over the *positive* term, due to the material content of the universe, that goes like S^{-3} .

The effect, as one goes backward in time, is to produce a zero of dS^2/dt and an *oscillation*

$$S(t) = F_Q(t) \cdot \exp(t/P)$$

in the time-dependent scale factor. The parameter Q is the temporal period of the periodic function $F_Q(t)$, which turns out to be barely an order of magnitude longer than

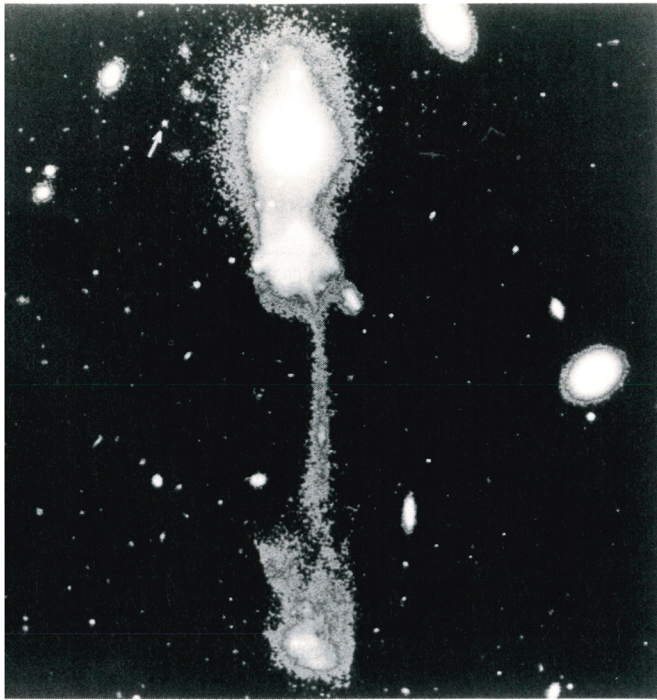


FIGURE 2. FAMOUS INTERACTING GALAXY PAIR NGC 3561 A and B. The arrow at top left marks a high-redshift quasar very close on the sky. We believe this is an excellent example of a galaxy ejecting a new galaxy. But L. Duc and Felix Mirabel, who made the exposure, believe it is the disruptive merger of two galaxies. We argue that the abundant star formation seen here and the proximity of the quasar indicate that matter creation is at work in this system. (Image courtesy of L. Duc and F. Mirabel.)

the “age of the universe” arrived at in the Big Bang scenario. The other characteristic-time parameter, $P \gg Q$, describes an exponential growth that is very slow on the time scale of the periodic function. P is determined by the rate of matter creation averaged over a large number of minicreation events.

The quasi-steady-state model also has two dimensionless parameters: the ratio $S_{\max}/S_{\min}$ between the amplitudes of $S(t)$ at its maxima and minima, and the ratio $S(t_0)/S_{\min}$ of the present scale factor to its periodic minimum.

The approximate values of these four parameters that

best fit the observational data are

$$Q = 9.6 \times 10^{10} \text{ years}, \quad P = 20Q, \\ S_{\max}/S_{\min} = 12 \quad \text{and} \quad S(t_0)/S_{\min} = 6.$$

For these parameter values, the form of the oscillation of the cosmic scale factor is shown in figure 1.

Among the broad observational data that these parameters must reproduce are (1) the relationship between the redshifts of galaxies and their visual magnitudes and angular sizes, (2) the population counts of galaxies and radio sources, (3) the largest observed redshifts, (4) the microwave background and (5) the cosmic abundances of the lightest nuclear isotopes.

Reproducing the microwave background

Our quasi-steady-state model must account for the near blackbody nature of the microwave background spectrum. We have already explained its energy density in terms of helium production in stars. It used to be argued that thermalization of starlight was not possible because the thermalizing particles in intergalactic space would produce too much extinction of distant galaxies. But we argue that this argument fails, because the thermalization in the quasi-steady-state cosmology occurs near the oscillatory minimum, when the density of intergalactic absorbing particles would be greater than at the present epoch by the factor $(S(t_0)/S_{\min})^3 \approx 200$. Thus, one can have the requisite intergalactic opacity of order unity at oscillatory minimum without having significant opacity in the present epoch.

Experimental work⁴ on the cooling of carbon and metallic vapors has shown that there is a strong tendency for condensates to appear as long thread-like particles, often called whiskers. Carbon and metal whiskers are particularly effective at converting optical radiation into the far infrared. Calculations show that a pre-

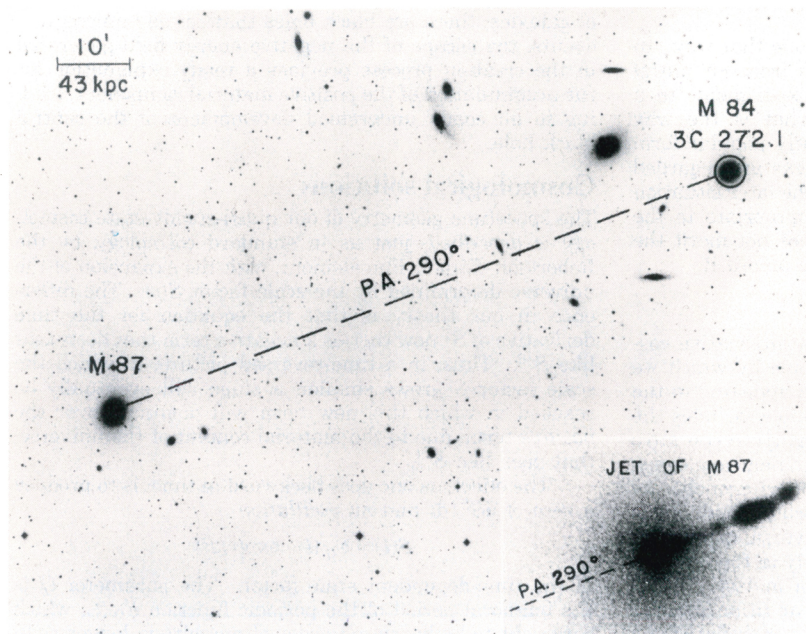


FIGURE 3. ELLIPTICAL GALAXIES M 87 and M 84 in the Virgo Cluster are connected here by a dashed line figure to make a point. Both are powerful radio galaxies. The inset is a short exposure of M 87 that shows its synchrotron-radiation jet. It was pointed out in 1960 that the jet points precisely along the line joining the two galaxies. Halton Arp has shown that there are many high-redshift quasars lying in this general direction. This suggests to us that creation processes in the nucleus of M 87 continue to give rise to the ejection of compact objects that can evolve into galaxies.

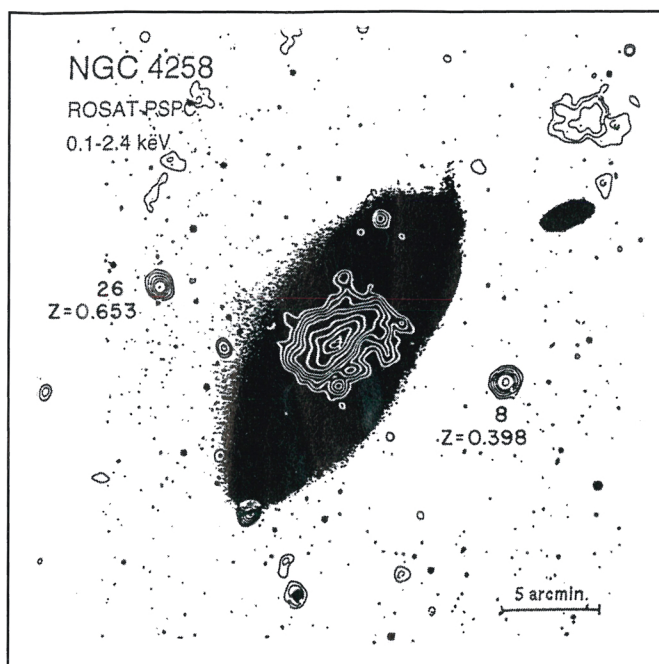


FIGURE 4. X-RAY IMAGING of the nearby galaxy NGC 4258 by the ROSAT satellite suggests that the two high-redshift x-ray quasars labeled on either side were ejected from the low-redshift galaxy. (See W. Pietsch *et al.* and E. M. Burbidge *et al.* in ref. 18.)

sent-day intergalactic density of 10^{-35} g/cm³ for such whiskers would suffice to thermalize the accumulated starlight at an oscillatory minimum. Such a whisker density could readily be accounted for by the ejecta of supernovae.

But near an oscillatory maximum, the universe is sufficiently diffuse that such intergalactic particulates have a negligible effect on starlight. Light propagation is then essentially free and, because of the long time scale of the maximum phase of each cycle, there is a general mixing of starlight from widely separated galaxies. Because of this mixing and the large-scale cosmic homogeneity and isotropy, the energy density of the radiation also acquires a high degree of homogeneity. That homogeneity persists, because the absorption and reemission of the starlight at the next minimum does not change the energy density. Thus we have an explanation of the remarkable uniformity of the cosmic microwave background.

Small deviations from this uniformity, on the order of a part in 10^5 , are expected for regions near rich clusters of distant galaxies. This implies that the microwave background should exhibit temperature fluctuations on the sky of a few tens of microkelvin on an angular scale determined by the clustering of distant galaxies. For a distant cluster of diameter 10 megaparsecs observed at a redshift $z \equiv \Delta\lambda/\lambda$ of 5 (about the highest redshift that's been seen), that angular scale is about 0.7° , in good agreement with the largest observed fluctuations in the microwave background.

The ease with which the complexities of the microwave background can be understood in the quasi-steady-state cosmology is, in our opinion, a strong indication that the theory is on the right track. Rather than being put in by parametric choices, the observed fluctuations of the microwave background arise naturally from the clustering of galaxies.

Origin of the light nuclei

There are more than 320 known isotopes of the elements. Together with Fowler and Margaret Burbidge, two of us⁵ showed in 1957 that, with the possible exceptions of deuterium, ³He, ⁴He, ⁶Li, ⁷Li, ⁹Be, ¹⁰B and ¹¹B, all the isotopes were synthesized by nuclear processes in stellar

interiors. We have recently surveyed what has been learned about the origins of these light nuclear species in recent decades.⁶

The list of eight problematic cases was soon reduced to five, as ⁶Li, ¹⁰B and ¹¹B were found to be produced in the spallation reactions of cosmic rays. More recently, it has been found that the depletion of Fe in old stars correlates closely with the abundance of ⁹Be, strongly suggesting that ⁹Be was produced in association with the iron in supernovae.⁶ Thus the original list of eight light nuclear species that at one time were candidates for association with a hot Big Bang cosmology was, in our view, reduced to four.

Next, we point out that Andrew McKellar long ago discovered a class of lithium-rich supergiant stars, of which WZ Cas is the prototype.⁷ That told us that the synthesis of lithium, probably with ⁷Li dominant over ⁶Li, was an astrophysical possibility. A scenario for lithium production was indeed proposed in 1971 by Fowler and Alastair Cameron.⁸

Then we have the striking fact that the energy density of the microwave background is very close to what we calculate for the production of the observed ⁴He abundance solely by hydrogen burning in stars. When all this is put together, we are left with only two of the eight special cases, as they seemed in 1957—namely deuterium and helium-3.

What is the likelihood, we now ask, that even these last two will turn out to have purely astrophysical origins? Helium-3 is accumulated in large quantities in dwarf stars whose masses are too small for the isotope to be destroyed by the reaction ³He + ³He → ⁴He + 2p. There is also a class of earlier-type, more massive stars (including 3 Cen A),⁹ in which *most* of the helium is ³He. On the $Q \approx 10^{11}$ -year time scale of the quasi-steady-state cosmology, it seems likely that the cosmic abundance of He³ (Big Bang nucleosynthesis predicts about one for every ten thousand ⁴He nuclei) is to be explained by an escape from stars of these types in stellar winds.

Deuterium, the last survivor from our original list of problematic light nuclei, is a particularly difficult case. It is both produced *and* destroyed by astrophysical processes. Deuterons are made in high-energy processes, such as solar flares,¹⁰ that generate free neutrons, and destroyed by burning in stellar interiors. Arguments over whether astrophysical production suffices, with no need to invoke cosmological deuteron production, therefore turn on measurements of the cosmic D/H abundance ratio, which are difficult to accomplish with precision. (See PHYSICS TODAY, August 1996, page 17.) In these circumstances, we think that the deuterium case can reasonably be regarded as uncertain. With all other nuclides (except, of course, ¹H) produced in adequate abundance by astrophysical means, it would seem best to extend this generalization to the deuterium and presume that any nucleus heavier than the proton has been synthesized by processes associated with stars.

Clusters of galaxies

In 1994, toward the end of his life, the eminent Armenian astronomer Victor Ambartsumian wrote:

It is natural to try to uncover the secrets of

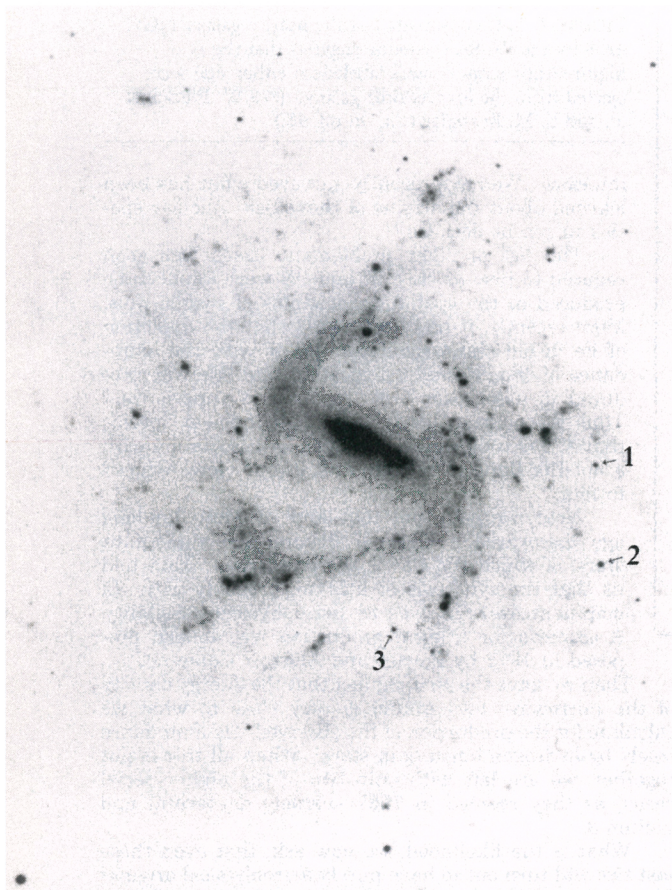


FIGURE 5. THE LOW-REDSHIFT SPIRAL GALAXY NGC 1073 has three high-redshift quasars (marked) lying within 2 arcminutes of its nucleus. They were first identified by Halton Arp.¹⁷ There being fewer than 20 quasars of this magnitude per square degree of sky, we think it very unlikely that this is a chance superposition of a foreground galaxy and three distant quasars.

nature by observing the key points where they are hidden. We can hardly achieve this aim only by theorizing. Observations produce almost innumerable evidences in favor of ejections and explosions [of galaxies], and are rather scant regarding the processes of condensation and collapse. The facts are pronouncing an indictment against the ideas connected with the condensation process; in the observable universe, the opposite phenomena, *i.e.* expansion and diffusion, are responsible for the majority of changes now taking place.¹¹

In the period 1958–74, Ambartsumian¹² first developed the idea that many groups and clusters of galaxies are systems of positive total energy—that is to say, expanding systems not gravitationally bound—and that many small galaxies were formed in and ejected from the nuclei of larger systems. He also accepted the evidence of explosive events in radio sources and Seyfert galaxies.¹³ In the 1960s, when quasi-stellar objects with large redshifts were being identified in increasing numbers, it was realized that they are also highly energetic objects closely related to explosive events in galaxies.

How are we to understand such great outpourings of matter and energy? As far as the associations and clusters of galaxies are concerned, most theorists, unlike Ambartsumian, have simply not been prepared to accept the observations at face value. For many years, they have clung to the belief that the protogalaxies and galaxies were formed early in the history of the universe. From that point of view, it is impossible to believe that many

galaxies are less than a billion years old, which must be the case if galaxies are, even now, being formed and ejected in expanding associations. It is generally agreed that, in such groups and clusters, the kinetic energy of the visible objects is much greater than their potential energy. The conventional way out nowadays is to assume that such groupings are indeed gravitationally bound—by large quantities of unseen “dark matter.” This conjecture was already put forward for some of the great clusters of galaxies by Fritz Zwicky in the 1930s. In the 1970s, the view that the masses of systems of galaxies on all scales are proportional to their sizes became widely believed, but it was not stressed that this result is only obtained by assuming that they are bound and therefore obey the virial condition.¹⁴

At the same time, we do have considerable evidence—from the flat rotation curves of spiral galaxies—for the existence of dark matter in them. We also know that, in some rich clusters, the galaxies are virially relaxed, indicating that these clusters are gravitationally bound with the help of some dark matter. But the use of the virial theorem to calculate unseen mass indiscriminately in all circumstances is totally unreasonable. Many highly irregular and small clusters are clearly unstable; they are either forming or coming apart. As Ambartsumian put it, they are systems with positive total energy.

In practice, there has been a continuous emphasis on the gravitational merger hypothesis, and none on the alternative ejection scenario. Figure 2 shows a remarkable system originally placed in the ejection category by Ambartsumian. Figure 3 shows another such system, strongly suggestive of ejection. We believe that these are images of galaxies in the process of ejecting new galaxies. For 40 years, there has been observational evidence in the literature that some galaxies are comparatively young, having been ejected from the nuclei of previously existing massive galaxies. That is precisely what one would expect from the quasi-steady-state cosmology.

Radio sources, AGNs and quasars

What about radio sources, active galactic nuclei and quasi-stellar objects? It is generally accepted that they all release very large amounts of energy from dense regions with dimensions no larger than our solar system. It has been clear since the early 1960s that there are only two possibilities: This energy is either gravitational in origin, or it is released in creation processes.¹⁵

Conservatively, the total energy release in powerful sources is at least $10^5 M_{\odot} c^2$. In the radio sources, much of this energy resides in GeV relativistic particles. To get such enormous energy releases in gravitational collapse it is necessary to consider processes very close to the Schwarzschild radius, where it would be very difficult to get the energy out. Even if the efficiency of the initial process is as high as a few percent, the efficiency with which the gravitational energy is then converted through several stages into relativistic particles and magnetic flux would be very small. Despite these difficulties, the standard model explaining active galactic nuclei asserts that, in all such situations, there is a massive black hole at the

FIGURE 6. THREE MORE HIGH-REDSHIFT QUASARS found within 2 arcminutes of the center of a local, low-redshift galaxy, NGC 3842. Halton Arp was involved in the discoveries of all three.¹⁷ Once again, we argue that such superposition is very unlikely to be accidental.

center of the galaxy, surrounded by an accretion disk, and that all of the observed energy, emitted in whatever form, is gravitational in origin. All of it, we are told, arises from matter falling into the disk and then into the black hole. But we have never really been convinced that this type of model could explain the many observed phenomena, largely because the efficiency with which gravitational energy can be transformed into relativistic particles and photons is so small.¹⁶

We consider it more likely that, in active galactic nuclei, we are seeing the creation of mass and energy as proposed in our quasi-steady-state cosmology. Massive near-black holes are undoubtedly present in the centers of galaxies. But when they are detected, the galaxy is typically *not* active. We argue that the important feature is probably the quasi-steady-state creation process, which can take place in the presence of a large mass concentration.

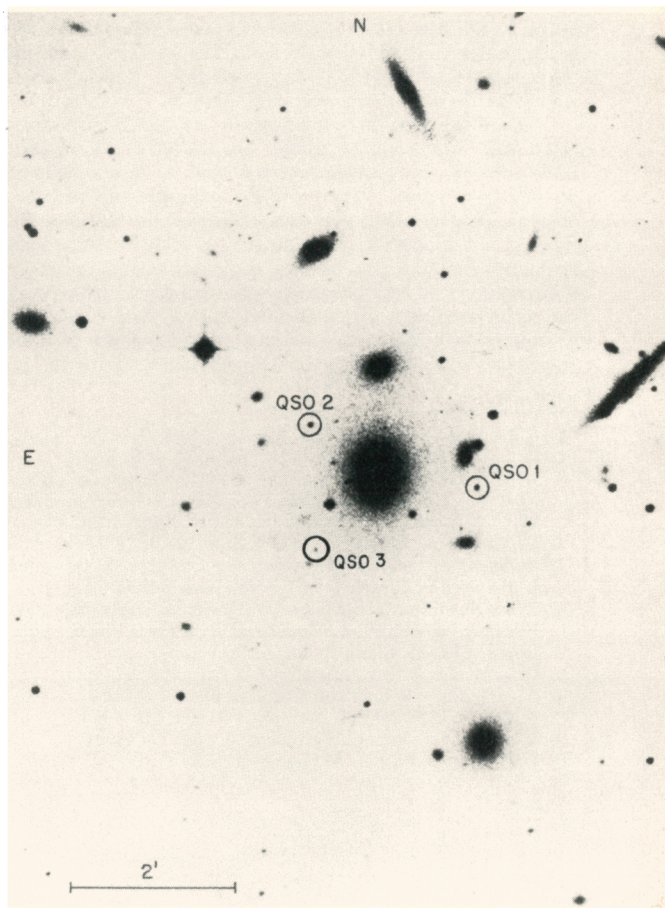
It's not just gas, relativistic particles, magnetic flux and radiation that are being ejected from active galactic nuclei. We contend that coherent systems in the form of quasi-stellar objects are also being ejected. The observational evidence for this quasar ejection is by now extensive and, in our view, overwhelming.

Soon after quasars were first discovered, it was suggested that many of them were much closer to us than their surprisingly large redshifts implied. The circumstantial and observational evidence for this unorthodox assertion was largely ignored.¹⁷ It was claimed that the statistical evidence was weak, and that there were at least some quasars apparently associated with galaxies at the same redshift. Halton Arp, the leading spokesman for the radical proposition that high quasar redshifts do not imply great distances, was eventually denied further observing time to work in this field. He was forced to take early retirement and leave the Mount Wilson and Palomar Observatories.¹⁷ This mistreatment had a chilling effect that is still being felt. The tacit message was "Don't ever find anything that conventional theory cannot explain, and if you do, stop looking immediately." On modern facilities like the Hubble Space Telescope or the Keck 10-meter telescopes, no observing time is asked for or granted for the further investigation of these issues.

Nonetheless, observations over many years have accumulated good statistical evidence that many high-redshift quasars are physically associated with galaxies with very much smaller redshifts. Furthermore, many high-redshift quasars have been found to have extremely small angular separations from low-redshift galaxies adjacent on the sky. In some of these cases, several quasars are associated with the same galaxy, and some appear to have a luminous bridge connecting these objects of greatly disparate redshifts.¹⁷

Originally, most of such apparent associations were between galaxies and radio-emitting quasars. But in recent years, similar connections have been made between galaxies and x-ray quasars.¹⁸ Figures 4, 5 and 6 show some of the many known cases.

All of these observations suggest to us that, in addition to any Doppler redshift, a quasar ejected from a low-redshift parent galaxy possesses an *intrinsic* redshift component z_1 not associated with any recessional motion. If z_0 is the observed redshift of the quasar, z_g is the Doppler



redshift of the parent galaxy and z_e is the quasar's Doppler shift due to its ejection velocity from the galaxy, then

$$1 + z_0 = (1 + z_g)(1 + z_e)(1 + z_1).$$

Attempts are being made to understand why there should be such intrinsic non-Doppler redshifts and why they appear to cluster about certain preferred values. In any case, we regard the data as *prima facie* evidence for galaxy formation by the ejection of condensed objects from excited galactic nuclei. Can the ejection hypothesis give rise to the large-scale structure of galaxies in the universe? Preliminary work suggests that this may be possible.

There is still much that we do not understand about ejection phenomena. But the body of observational evidence that we have outlined here fits very well into the quasi-steady-state cosmology. Like Ambartsumian, we believe that this opens up the possibility of a completely different approach to galaxy formation. The essential difference between us and the mainstream cosmologists is our conviction that nature is showing us the primary importance of ejection phenomena. Gravitational collapse does, of course, happen, but it tends to occur at a later stage than expulsion and expansion.

We have attempted to show that a good case can be made for the quasi-steady-state cosmology as an alternative to the standard Big Bang model. Our understanding of the details may be incomplete, but we believe that it is incumbent on anyone working in this field to take into account *all* of the observed phenomena, not just a selection chosen to fit a favored theory.

There is excellent observational evidence to show that some galaxies are exploding and ejecting energy in many

forms in the present epoch and at modest redshifts in the recent past. There is also good observational evidence for the presence of noncosmological redshifts. The observations fit into our theory very well.

But those who have adopted the standard cosmological model simply ignore them. On the other hand, they have to make many assumptions that have no basis in direct observation. There is, for example, no *primary* observational evidence for initial density fluctuations, for nonbaryonic matter of the kind they invoke for large-scale structure scenarios, for biasing in galaxy formation or for their assumption that clusters of galaxies must always obey the virial condition. These are all *ex post facto* theoretical postulates that allow the standard model makers to build what may well turn out to be a make-believe universe.

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REPLY TO “A DIFFERENT APPROACH TO COSMOLOGY”

As physicists confront the unknown, a crucial part of the job is choosing a set of assumptions that will guide their efforts in productive directions. The only certainty is that only a small fraction of the many conceivable outcomes of the inquiry process will remain viable as the field continues to progress—assuming it does indeed progress. Along the way, choices must be made: Which results should be taken as important hints to be used as the foundations of future work, and which results should be viewed with skepticism, needing further confirmation before being allowed to influence the field significantly? Those who wind up making good choices (either through wisdom or good luck) will eventually be recognized as pioneers.

The same body of data can produce different interpretations, depending on what prejudice the researcher starts out with. (This idea is formalized in the “priors” of Bayesian inference.) As data on a given question become more conclusive, the broader will be the range of prior prejudices that converge on a consensus. Geoffrey Burbidge, Fred Hoyle and Jayant Narlikar, the authors

Expanding surveys of galaxy redshifts and fluctuations in the microwave background continue to rein in the cosmologist’s freedom to invent.

Andreas Albrecht

of the preceeding article, “A Different Approach to Cosmology,” approach cosmology with a set of prior prejudices that take them far afield from the mainstream community of cosmologists.¹ They hold on to views that, I must say, look pretty unreasonable to most of us working in the field. Nonetheless, I believe convergence will eventually be possible.

First, let me briefly discuss some of the key points of departure:

▷ **Primordial nucleosynthesis.** One important issue is the origin of the light elements. It is commonly understood that the lightest nuclear species (in particular, deuterium, ³He, ⁴He and ⁷Li) were produced in the immediate aftermath of the Big Bang, after temperatures and densities had become low enough to allow net production to go forward.² All this was long before there were any stars around to change the nuclear abundances. The fact that this primordial nucleosynthesis can be calculated and successfully fit to the observed light-element abundances with only one free parameter (the baryon-to-photon ratio) is widely held as a great success of standard Big Bang cosmology. (See *PHYSICS TODAY*, August 1996, page 17.) Otherwise, such a good fit would have to be an extraordinary coincidence, because most conceivable sets of abundance data would fail to fit the

ANDREAS ALBRECHT is a professor of physics at the University of California, Davis.