AN UNSTEADY UNIVERSE?

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The discovery of the "quasi-stellar galaxies" announced this week gives a new picture of distant regions of the universe which may disagree with the simple "steady state" theory. The possibility remains, however, that we live in a rarified "bubble" within a much denser, more rapidly expanding universe

Recent advances in observational astronomy have focused great scientific interest on cosmology, the branch of astronomy that deals with the nature of the universe as a whole. Only a few years ago cosmology was looked upon as a somewhat speculative subject where very few observational results were available and where the theorist could let his imagination run riot. The situation has now changed in a remarkable manner. During the last few weeks several new results have come forth which may lead to a serious revision of our ideas on what the universe is like.

Last month Professor Maarten Schmidt at the California Institute of Technology discovered five new quasi-stellar radio sources, or "quasars", with large red shifts in their emitted light, indicating that they were very distant objects. At about the same time scientists at the Bell Telephone Laboratories observed significant radio background noise. The origin of such noise cannot be attributed to isolated sources, but must be traced to the universe as a whole.

This week Dr Allan Sandage at the Mt Wilson and Palomar Observatories has announced the discovery of a new class of objects which he calls "quasi-stellar galaxies" or QSGs (see page 759). Originally they were thought of as blue stars in our own Galaxy. However, their occurrence in directions remote from the plane of the Galaxy, and their optical similarities to the quasi-stellar radio sources, made him suspect that they were not ordinary stars. An examination of the spectra of the blue objects by Sandage and Schmidt led to the discovery that while some of the objects were like ordinary stars, there were others which showed large red shifts. The red shifts could be best accounted for by assuming that the objects in question are far beyond our own Galaxy and moving away from us at high speeds in the general expansion of the universe. Since the quasi-stellar galaxies are very distant, they must be very bright—about 100 times brighter than ordinary galaxies.

Moreover, because they are so bright and so plentiful, and range out to such great distances, the new objects should very soon enable us to distinguish between possible models of the universe. Because light takes many billions of years to reach us from the most distant objects now observable, we can see the universe as it was long ago. If the universe has been changing, it should look different at greater distances. In particular, if the universe originated in a big bang, and what we observe is the debris flying away in all directions, when we look back in time to an epoch soon after the explosion the objects should be more densely packed than in our immediate vicinity. If, on the other hand, the universe is essentially unchanging, such variations should not occur. Corrections have to be applied to take account of the fact that the universe does not conform to Euclidean geometry.

Sandage says that the recent data for the quasi-stellar radio sources fit a model of a closed oscillating universe—that is to say, one of limited size which alternately expands or contracts—with a period of about 82 billion years. However, more careful examination and further exploration of the data on both kinds of quasi-stellar sources are necessary before a definite conclusion can be drawn. The present knowledge of the occurrence of the quasi-stellar galaxies is indicated in Figure 1.

The quasi-stellar galaxies are about 500 times more numerous than the quasi-stellar radio sources. The life-time of a radio source is estimated to be about a million years. From this Sandage concludes that the quasi-stellar galaxies probably last about 500 million years. Does this mean we are actually witnessing the birth of galaxies? The data seem to indicate that galaxies were not born just after the creation of a "big bang" universe, but are being born continuously.

What are the implications of the recent observations for the steady state model, according to which the universe, while expanding is essentially unchanging and infinite in extent? This seems to be an appropriate occasion to reassess the steady state cosmology and the recent theoretical developments in the ideas of creation of matter.

The steady state theory—The steady state theory was put forward by Fred Hoyle and by Hermann Bondi and Thomas Gold in 1948. Bondi and Gold arrived at the concept of steady state via their "perfect cosmological principle". The principle states that the large-scale properties of the universe are independent of the position of the observer and also of the time of making the observation. The theory is deductive and does not rely on additional postulates besides the perfect cosmological principle. Although the principle is a powerful one, and in many respects aesthetically pleasing, it does not give *quantitative* information about the universe. For example, it tells us that in an expanding universe the density of matter must be constant and this requires con-

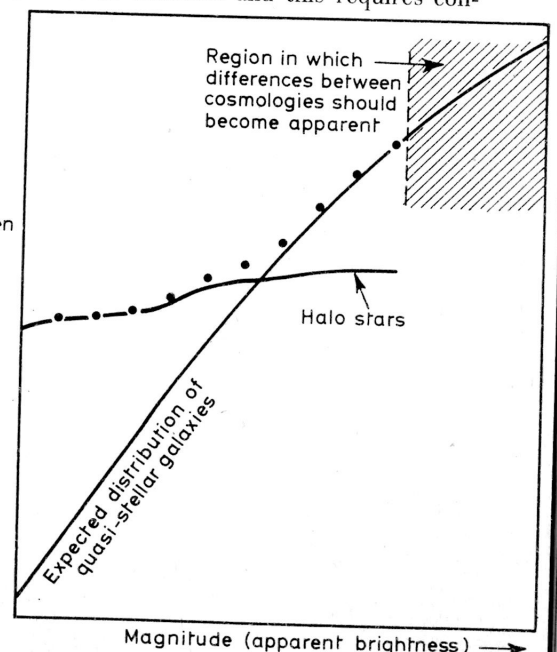

Figure 1 *This diagram, adapted from Dr Allan Sandage's paper in* Astrophysical Journal, *shows how the fainter of the blue stars, previously thought to be ordinary stars in our own Galaxy, correspond instead with very distant extra-galactic objects and approach the region in which cosmological issues may be resolved. Fainter objects to the right of the diagram (higher "magnitude" numbers)*

AN UNSTEADY UNIVERSE? *continued*

tinuous creation of matter. However, it does not tell us what that density should be, nor does it throw any light on the actual mechanism of creation of matter.

Hoyle adopted a different approach to the steady state theory. Instead of deducing creation of matter from a general cosmological principle, he preferred to treat it as any other normal physical process which can be described by definite physical laws. The question of origin of matter is present, in some form or other, in any cosmological theory. However, in a big bang universe all matter appeared at an initial moment of explosion; the question of creation is excluded because the theory is concerned with what happened *subsequent* to the explosion.

Now Einstein's equations, which provide a good framework for cosmology, have the interesting feature that they imply conservation of energy and momentum. Therefore, if matter is to be created, it can only be created at the expense of another energy reservoir—*it cannot be created out of nothing*. It was therefore necessary to modify Einstein's equations to include the effect of this additional cosmological reservoir of energy, now known as the *C*-field. A simple and elegant mathematical formulation of the *C*-field has been given by Professor M. H. L. Pryce.

The *C*-field differs from an ordinary reservoir of energy such as electromagnetism, in one important respect. It has negative energy. This ensures that the *C*-field reservoir is not depleted to zero as a result of matter creation and the expansion of the universe.

With the help of these additional features it is possible to give a simple mathematical description of the steady state universe. In this description the universe is homogeneous and isotropic—that is to say, there is no preferred position nor a preferred direction anywhere in the universe. The overall picture is therefore the same as that arrived at by Bondi and Gold with the help of the perfect cosmological principle. However, this approach, being a quantitative one, yields some more information about the universe. For example, it expresses the rate of expansion of the universe (measured generally by Hubble's constant H), the mean density of matter in the universe and the rate of creation of matter, all in terms of a single constant, f. Just as the strength of electromagnetic field depends on the electric charges, the strength of the *C*-field depends on f. Theory alone does not specify f, but if we use the observed value for H ($1/H$ is about 3.10^{17} seconds) f is fixed. We then get numbers for the density of matter, 3.10^{-29} g per cu. cm, and for the creation rate 3.10^{-46} g per cu. cm per second. The latter figure can be translated as meaning around ten new hydrogen atoms per litre every million years!

Whatever its ultimate fate, the steady state theory in this simple form has served two useful purposes. Its very vulnerability to observation has prompted several attempts by observers to disprove it and this had led to important work in observational astronomy. Secondly, it has initiated fruitful lines of investigation in astrophysics such as the work on the synthesis of elements in the stars. In one important respect, however, the theory has failed to come up to expectations. This is the problem of galaxy formation. At one stage it was believed that galaxies could form as a result of the growth of small perturbations in the diffuse medium of hydrogen. Calculations show, however, that small perturbations have a tendency to die out rather than grow. The universe, in other words, is stable against small disturbances. Other ingenious attempts to condense galaxies from a homogeneous material—such as the "hot universe" of Gold and Hoyle—have met with difficulties.

Pockets of creation—Last year Professor Hoyle and I made fresh attempts to come to grips with the problem of galaxy formation. We abandoned the above simplified picture of a homogeneous universe in which gentle creation goes on everywhere. Rather, we considered the universe to be inhomogeneous, made up of galaxies and clusters of galaxies, and with a non-uniform creation rate. In such a model the creation of matter takes place, not all over the universe, but in certain isolated pockets. A suggestion of a similar nature was made by Professor W. H. McCrea last year. In view of their relevance to the recent observations, I shall describe the general features of this model.

As was mentioned earlier, matter can be created from the *C*-field only provided the law of conservation of energy and momentum is not violated. Thus, if a particle of certain mass M is created at a point in space, the balance of energy and momentum must come from the *C*-field at that point. The requirement on the *C*-field strength will be more severe, the larger M is. Since we observe baryons (heavy particles) in nature, the *C*-field must be able to create such particles. This places a minimum requirement on the strength of the *C*-field, which we shall call the "threshold". No creation occurs if the *C*-field falls below the threshold. More massive (or energetic) particles may be created the higher the *C*-field strength above the threshold.

Consider now a massive object with a strong gravitational field. Just as a material particle falling freely into the object gains kinetic energy, so does the *C*-field become stronger in the neighbourhood of the massive object. Thus it is possible to imagine a situation where the *C*-field is below the threshold far away from the object, and above it near the object. In such a case creation will take place only within a limited region surrounding the object. Massive objects with strong gravitational fields therefore act as pockets of creation (see Figure 2).

The expansion of the universe depends critically on the distribution of inhomogeneities. Creation in the pockets generates *C*-field (just as electric charges generate electromagnetic field) which, because of its negative energy, produces a force of repulsion. As a result the pockets recede from one another. In steady state, creation and expansion are in exact balance. The constant f mentioned above determines the creation rate in a pocket and hence the rate of expansion of the universe.

This picture has many interesting implications for high-energy astrophysics. It is tempting to suggest that massive galaxies and quasi-stellar objects act as pockets of creation and that the origin of cosmic rays and the electrons in radio sources can be traced to creation in strong gravitational fields. The similarity between the theoretically computed energy spectrum and the observed one, in the case of cosmic rays and the electrons in radio sources, lends support to this hope.

However, the theory receives a serious blow when one calculates the total energy output from a typical radio source and compares it with predictions of the theory. The prediction is too small by a factor 10^{-20}.

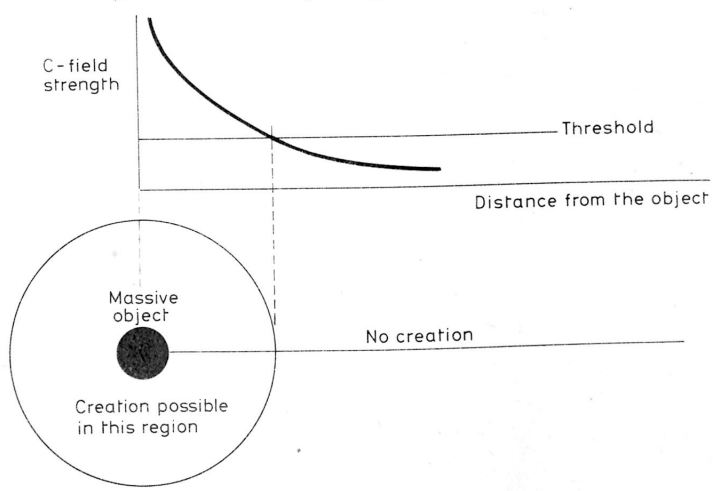

Figure 2 *According to Hoyle and Narlikar's new theory of the creation of matter, the creation field,* C*-field, may become too weak for creation to occur. With such a threshold, the possibility arises that relatively rarified regions in a dense expanding universe may become even more rarified because there is no creation of matter*

The only way to salvage the theory is to increase the parameter f by a factor 10^{20} to make up for this deficiency.

Such an increase in the value of f corresponds to a change in the value of Hubble's constant by a factor 10^{-10} ($1/H$ becomes 3.10^7 seconds) and an increase in the mean density of matter in the universe by a factor 10^{20}, to 3.10^{-9} g per cu.cm. Clearly we do not live in such a universe.

The difficulty is resolved when we take into consideration the inhomogeneous character of the universe. The homogeneous universe is stable against small disturbances, but it is entirely a different matter in the case of the inhomogeneous model described above. Suppose in a finite region, some pockets of creation go out of action. That may happen because of fragmentation of the big mass in the pocket. A single big mass is more effective for creation than a number of small masses. With fewer pockets in operation, the C-field strength falls. This in turn makes it more difficult for the pockets to operate. Thus a stage comes when creation is stopped in all but the very strong gravitational fields.

The region in question then expands without any significant creation and tends to become evacuated like a bubble. The bubble expands to a maximum radius and then begins to contract. During contraction the strength of the C-field rises and a stage is reached when the pockets begin to operate again. Thus although the universe as a whole expands in steady state, with a high mean density (3.10^{-9} g per cu.cm) it may occasionally develop bubbles which expand and contract *without* creation. *We live in such a bubble.*

According to this picture, our observations will be confined to the interior of the bubble. Thus the measured value of $1/H$ (3.10^7 seconds) refers not to the expansion of the outside universe, but to that of the bubble. Thus in many respects, the expansion of the bubble is similar to that of an evolving universe; but with one important difference. The bubble expands not from a stage of infinite density as the big bang and oscillating models do, but from a density of 3.10^{-9} g per cu.cm. The awkward singularity of the evolutionary cosmologies—the moment of creation—has thus been avoided.

Further, since the expansion of the steady state universe is due to pockets of creation, and the pockets in a bubble begin to die out as the bubble expands, we should be able to see more pockets (in the form of visible objects) in the past than in the present epoch. This conclusion is in agreement with the recent observations.

The very high density for the universe as a whole, 3.10^{-9} g per cu.cm, has another significance. Many years ago George Gamow pointed out that there is a unique epoch in a big bang universe when the density of radiation flowing through the universe is equal to the density of matter. The radiation is stronger before this epoch and weaker afterwards. If we identify this epoch with the galaxy formation in a big bang universe, and work from the density of about 10^{-24} g per cu.cm found inside the galaxies, we arrive at the conclusion that the present-day radiation background should be very strong (corresponding, in radio astronomers' parlance, to a temperatures of about 100°K). This is vastly greater than the estimate of most radio astronomers, including those at the Bell Telephone Laboratories who have made the recent observations. In the present picture, if we identify the epoch with the onset of the bubble, the background radiation temperature is reduced to the order of 1°K, more in conformity with observations.

Finally, the theory accounts for perhaps the most puzzling property of galaxies—the existence of a strict upper limit to their mass and luminosities. It is, in fact, the limit set by the rate of expansion in the dense regions of the universe. The value of $1/H$ (3.10^7 seconds) corresponds to a communication distance of about 10^{18} cm and to a volume of about 4.10^{54} cu.cm. The amount of matter in this volume, at density 3.10^{-9} g per cu.cm, is about 10^{13} times the mass of the Sun. This is typical of the mass of a cluster of galaxies.