THEORIES PROPOSED TO EXPLAIN QUASI-STELLAR OBJECTS AND RADIO GALAXIES

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In this paper I shall consider briefly two major questions. The first is concerned with whether the QSO's are at cosmological distances or not. The second is concerned with the theoretical models proposed to explain the observed properties of radio galaxies and quasi-stellar objects.

In the Invited Discourses Dr. Sandage and Sir Martin Ryle gave arguments which lead them to believe that the QSO's lie at cosmological distances. They both have strong convictions in this matter. However, Dr. Sandage did remark that he was only giving one side of a 'great debate'. It is presumably up to me to give the other side of this argument. I have no strong beliefs in this matter but it appears that on the basis of the evidence as it is today we cannot reasonably assert that the QSO's are at cosmological distances. If at all I think that the evidence argues against the QSO's being at cosmological distances. The arguments run as follows:

Plots of the red-shift against apparent radio or optical magnitudes show that there is no correlation which can be interpreted as due to a red-shift-distance effect. The diagrams can be interpreted as being due to evolutionary effects if it is assumed that the objects lie at cosmological distances, but in no sense can they be used in evidence for this hypothesis.

The variability of the sources shows us that they are excessively small, and the very high radiation densities which must then be present if the QSO's are at cosmological distances lead to apparent difficulties in the construction of theoretical models. However, models can be constructed, and thus one cannot make a conclusive argument based on apparent contradictions here.

Sandage and Ryle have made much of the continuity arguments but continuity can also be invoked if the QSO's are comparatively nearby. In this case their optical properties are practically identical (apart from the red-shifts) with the nuclei of Seyfert galaxies, and they are weak radio sources similar to those found in the centres of galaxies such as M 82. As a physicist I can make little of the continuity argument one way or the other.

Attempts to detect the presence of intergalactic matter from absorption or scattering of the optical flux from QSO's have failed. This means either that the matter is in a form such that it cannot be detected, or else the objects are not at cosmological distances.

Perek (ed.), Highlights of Astronomy, 376–378. © *I.A.U.*

Arp has suggested that the QSO's and radio galaxies are in some cases associated with comparatively nearby peculiar galaxies. No one is happy about his analysis but it has not been conclusively ruled out.

Strittmatter, Faulkner and Walmsley have found that QSO's with large red-shifts are concentrated in two comparatively small areas in the sky. In my opinion no one has been able to show that this effect is not real. Many people simply hope that it will go away. The discovery that all of the QSO's with enough absorption lines present so that an absorption red-shift can be unambiguously obtained, give the same value of 1·95, with a very small dispersion, is a strong argument in favor of the local hypothesis for QSO's. Šklovskij and Kardashev have attempted to explain this by going back to a Lemaître model, but this is highly improbable. Moreover, if any of the objects with only one line and an emission red-shift very much less then 1·95 are shown conclusively to have an absorption-line red-shift of 1·95, and there are several possible cases, all cosmological interpretations will be ruled out.

The strongest argument in favor of the cosmological hypothesis for the QSO's is the presence of the large red-shifts. However, the recent work of Hoyle and Fowler has shown that the red-shifts may be gravitational in origin. The arguments just made by Woltjer are not strong.

I now turn to the second topic – the present status of theories explaining the outbursts in radio galaxies and quasi-stellar objects.

Before the discovery of the QSO's it had been realized that large-scale violent events take place in the nuclei of galaxies. These give rise to large fluxes of relativistic particles, to highly excited gas, and to large-scale motions of gas and dust. The total amount of energy released is not well known, but minimum estimates reach values as large as $10^7 \, M_\odot \, c^2$ in the strongest radio sources. In the QSO's the minimum total energies required to explain the observations are often less than this but it seems clear that the outbursts in these cases must have a similar origin. The mass energy released is so large that it is clear that very large condensed masses must be present in the nuclear regions of galaxies and in QSO's.

The mechanism by which the energy is converted largely into relativistic particles is not understood. It has usually been assumed that two large clouds of particles are ejected to give rise to a double source. However, the discovery that the sources have fine structure, and that in many cases very small sources are present far from the explosion centre, lead to the conclusion that small fairly massive coherent objects are thrown out in the explosion and that each of these is a secondary source of relativistic particles.

If extremely high mass densities are assumed to be present in the nucleus – at least $10^8 \, M_\odot$ per cubic parsec – then a variety of catastrophic processes will occur. These include multiple supernova explosions, star collisions, and gravitational collapse of a single coherent mass. All of these ideas and others are being explored with a view to understanding the mechanism by which the very large energies are released, largely in the form of relativistic particles. At present we do not have any satisfactory theory which will explain the observed phenomena. Probably the most promising idea is that the energy is released by a large coherent mass in gravitational collapse. If large numbers of small objects are thrown out the large mass must fragment in the collapse. Classical relativity theory shows that it is exceedingly difficult to get out a large fraction of the rest mass in such a process. Some have therefore suggested that, under extreme conditions, modifications of the general theory of relativity are required. Others have concluded that much larger masses are involved and that the energy release takes place at very low efficiency – perhaps 1% to 0·1%.

There is also no real understanding of the way in which very large masses are condensed into very small volumes in the first place. Some have argued that such large mass concentrations are themselves cosmological in origin. Thus, in the framework of an evolving universe it has been suggested that QSO's are parts of the expanding universe which were 'left behind' and are just now expanding from a high-density state. In the framework of the steady state cosmology it has been argued that matter is created in places where the matter density is highest so that in the nuclei of galaxies very high-density configurations are being continuously formed. Others have attempted to show that large mass concentrations will form through the natural processes of dynamical evolution in the nuclear regions where the star density is high. If one assumes a high enough star density to begin with, then the required conditions can be reached, but these models are also rather *ad hoc* in character.

The discovery of the radio galaxies and then the quasi-stellar objects has led to a revolution in our thinking concerning the evolutionary processes on the scale of galaxies. We know that we are on the verge of major discoveries which relate back to fundamental physics. However, we have as yet no real understanding of many of the fundamental physical processes which are operating in the nuclei of galaxies and in QSO's. Most attention has been paid in recent years to determining the distance scale of the QSO's. When this problem is solved it may be possible to decide unambiguously which models of QSO's are compatible with the observations and proceed to further observational programs which get us closer to an understanding of the physics of explosions on the galactic scale.

DISCUSSION

Oort: What do you think of 3C 371?

G. Burbidge: Because this object has a very small red-shift the apparent difficulties which are present for the QSO's – associated with the high radiation densities – are not present to the same extent. While there is some sort of continuity between QSO's and N-type galaxies, this is not evidence for the cosmological nature of QSO's. The continuity argument also holds if they are close by.

https://doi.org/10.1017/S1539299600001477 Published online by Cambridge University Press