$P(\rho)^{\frac{1}{2}}$ relation (if β could be near unity), give a density in the range 10^{-10} cgs and a fundamental period near 10 years, where indeed much of the power in the frequency spectrum of 3C 273 is concentrated. But Fowler and others have pointed out that β is not likely to be greater than 10^{-3}, in which case the problem for this hypothesis becomes one of finding any set of parameters for which pulsation of such a massive object is possible.

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DISCUSSION

J. Greenstein. Interpretation of the quasi-stellar sources requires a considerable sophistication. First, note that variations (flashes) in 10 days do require motions at the speed of light if the scale is too near 10^{16} cm; these will be difficult on any theory. Similarly, the difficulties to be noted in an over-simple treatment of pulsation in massive objects are very real. Even in main-sequence stars the correction to the density caused by radiation pressure is large since the latter is dominant. Also, if the mass is as high as required, the relativistic corrections are large. In other words, a large change in the $P(\rho)^{\frac{1}{2}}$ law is required.

Returning to the observational interpretation, the radius is deduced from the luminosity by means of the black-body law and the assumed temperature, taken by Smith as a normal stellar temperature. If the continuum observed is not a black body—if it is largely hydrogen recombination—the black-body law should not be used.

H. J. Smith. While there are difficulties with any theory of quasars, Greenstein's remarks are of course correct. The pulsation suggestion may prove entirely unfounded, and even if partly true would leave much to be interpreted. But it does offer several predictions, especially that of the future behavior of the light curve as an extrapolation from the quasi-periodic behavior observed particularly after 1929, also that a substantial part of the continuum should fluctuate in brightness against a relatively constant set of emission-line intensities.

6. SOME REMARKS ON THE NATURE OF THE NUCLEI OF GALAXIES

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There is no doubt now that the phenomenon of radio-galaxies is closely connected with the processes going on in the nuclei of galaxies. Therefore it seems appropriate to make here some general remarks on the nuclei of galaxies.

In our Solvay report of 1958 and Invited Discourse in Berkeley (1961) we have tried to show that we can reduce many phenomena we observe now in galaxies to the *activity of nuclei.* It was supposed that owing to this activity the nuclei play an essential role in the formation and evolution of corresponding galaxies. At that time the general impression was that we overestimate strongly the part played by nuclei in the evolution of galaxies. But in the light of recent developments it seems to me that we were rather cautious in this respect.

Our information about the processes in radio-galaxies is still very restricted. Nevertheless we can say definitely that the phenomenon of a radio-galaxy is to be considered as one of the forms of the activity of a nucleus.

There are also several other forms of the activity of nuclei of galaxies. For the description of them I refer to my Berkeley Discourse.

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Since the nuclei of distant galaxies usually have very small angular dimensions, mostly below the resolution limit of our photographs, and since in many cases we cannot even distinguish them on the background of the general field of the given galaxy, it is extremely difficult to judge about the nature of nuclei.

Of course the spectral data are very important and in many cases they give a large amount of information. Therefore we should not consider the situation as hopeless, remembering that in the case of stars (excluding our Sun) we are essentially in the same situation.

The first problem which arises is the problem of the population of nuclei. Are the nuclei simple stellar systems like globular clusters, with some degree of dynamical autonomy or do they contain something else? If they are not simple stellar systems, what other kinds of bodies do they contain?

In the light of evidences now present we can assume that there are three possible constituents in each nucleus: stars, gas and *non-stellar hypermassive bodies*, which are responsible for unusually energetic forms of activity of nuclei and also for the origin of gaseous masses.

Depending on the state of the activity of nucleus one of these components may become more prominent than others. For example, in the nuclei which are in a state of low activity (passive nuclei) the stellar component is most prominent in optical region. I am not entering into details, but it seems to me that a classification of nuclei can be worked out based on these concepts.

One of the advantages we have by the study of nuclei of galaxies is the fact that we can always compare the state of the nucleus with the state of surrounding galaxy. And this may bring us to some valuable conclusions. If the state of a galaxy determines the state of its nucleus we may expect one type of correlation between the parameters describing those states. However, if the activity of nucleus itself is of primary importance and influences the whole story of development of surrounding galaxy, we shall have correlations of a different type.

It is a matter of convenience and of observational possibilities to select the parameters describing the galaxies and nuclei in order to study the correlation between them. For example, we can try to find the correlation between the total absolute magnitudes of galaxies and their nuclei.

Much simpler is to investigate the correlation between two following parameters: (*a*) The morphological type of the galaxy and (*b*) some number estimating the prominence of its nucleus on the background, when observed with a given resolution and within a certain range of distances from the observer. Naturally it is better to take rather narrow range of such distances.

Some work in this direction is now being done at our Observatory with plates of rather small scale taken with our medium Schmidt telescope (21-inch).

The numbers estimating the degree of the prominence of the nucleus seen on the background of a galaxy are explained in Table 1.

Table 1

Prominence of Nuclei on the Images of Galaxies

Mark	*Pattern*	*Interpretation*
1.	No appreciable condensation at the centre	No nucleus present
2.	Weak condensation at the centre	Probably a nucleus exists
3.	Strong concentration at the centre, but no starlike image	A nucleus definitely exists but cannot be distinguished from the background
4.	Starlike nuclear image at short exposures, but nebulous at long exposures	A nucleus is seen surrounded by the dense part of the bulge
5.	Starlike nuclear image even when the exposures differ from the limiting	A bright nucleus which stands out on the background

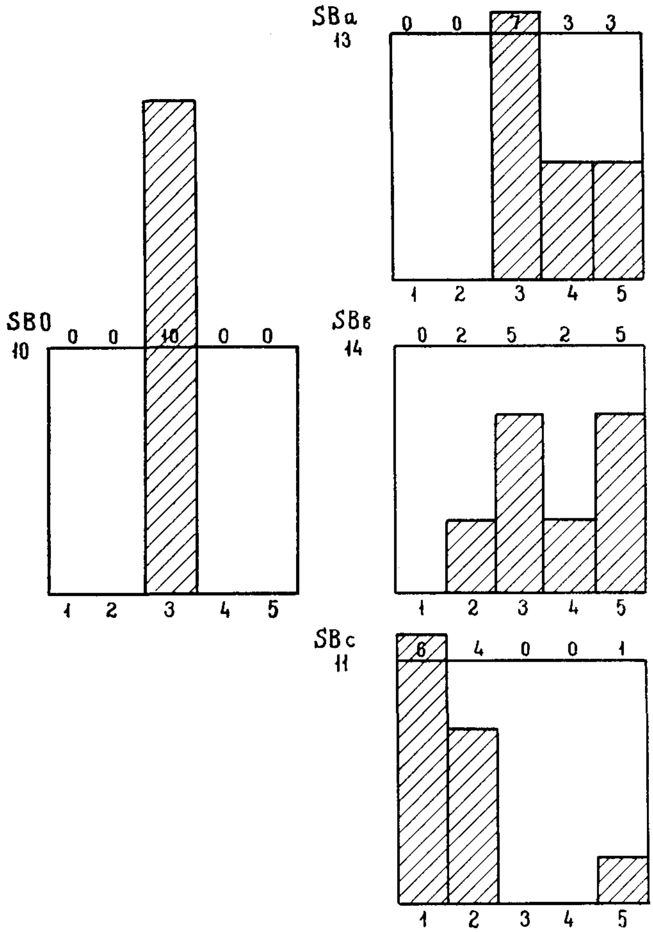

Fig. 1. Histograms showing the distribution of the estimates of the prominence of nuclei for different subtypes of barred galaxies. The numbers under each diagram are the estimates, and at the top are the numbers of corresponding galaxies. Under the letters designating the subtype the total numbers of galaxies of that subtype are given.

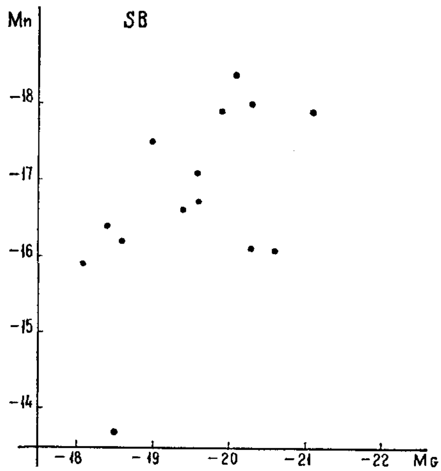

Fig. 2. The correlation between the photographic absolute magnitudes of galaxies (M_G) and their nuclei (M_n) for SB galaxies. Only the galaxies with prominences 4 and 5 are shown. The galaxies with prominence 3 would place somewhere in the lower part of the diagram, thus increasing the dispersion of points.

In Fig. 1, histograms are shown, which give the distribution of prominence estimates for each subtype of the class of barred spirals, as derived by our astronomers Tovmasian and Káloghlian from their observations.

We see that the distributions are very different for different subtypes. Therefore the morphological type of a galaxy determines the probability of having a more or less prominent nucleus.

However this does not mean that the state of the galaxy determines the state of the nucleus. To show this we have taken from the same work of Tovmasian and Káloghlian the absolute magnitudes of the nuclei having estimates 4 and 5 and compared them with absolute magnitudes of corresponding galaxies (Fig. 2). For the nuclei of lower prominence we cannot derive the absolute magnitudes, as it is seen from the explanations in Table 1. But they are certainly to be placed in the lower part of Fig. 2. Thus we may be sure that the correlation between M_{gal} and M_r is very poor indeed.

Of course it is premature to go further into interpretation of these data. But we can hope that having more data about integral properties of nuclei (magnitudes, colours, spectra), we will be in a much better position to speak about their nature. And this will perhaps help us to understand better the nuclei which are capable to produce the phenomenon of a radio-galaxy.

7. THE GENERAL RELATIVISTIC INSTABILITY OF MASSIVE STARS

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1. *Introduction*

The pioneer theoretical investigations of Burbidge (1) and of Shklovsky (2) have shown that the observations on the extended radio sources imply the generation, storage and emission of prodigious amounts of energy, in round numbers of the order of $10^7 M_\odot c^2 \sim 10^{61}$ ergs or even more. On the very general grounds that the ultimate source of energy is the conversion of mass, it is thus clear that very large condensations of matter in some form or other are, or have been, associated with the radio sources. Burbidge (3) suggested supernovae explosions in large aggregates of stars as a possible mechanism for the original generation of the energy involved.

In the summer of 1962, after conversations with Geoffrey and Margaret Burbidge, Hoyle and I (4, 5) investigated what is perhaps the simplest of many possible models, namely that a mass of the order of $10^8 M_\odot$ or greater has condensed into a single star in which the energy generation takes place. On this point of view, using the standard theory of stellar structure, one immediately obtains optical luminosities of the order of 10^{46} ergs/sec and lifetimes for nuclear energy generation of the order of 10^5 to 10^6 years so that the overall energy release is 10^{59} ergs. These figures roughly match the observational data for the so-called quasi-stellar objects subsequently discovered by Schmidt (6). Hoyle and I were seeking an explanation of the energy requirements for extended radio sources and found that our model had a large optical luminosity. Problems in the stability of massive stars arise, as will be discussed in detail below. Questions of stability aside, it is apparent that nuclear energy generation by hydrogen burning in massive stars with $M \sim 10^8 M_\odot$ is adequate to match the energy requirements in the quasi-stellar objects.

However, the energy requirements for the extended radio sources involve nuclear burning in stars with $M \sim 10^{10} M_\odot$ or even more. This assumes that hydrogen burning with 0·7 per cent conversion efficiency goes to completion in about 15 per cent of the stellar mass, giving an overall efficiency of $\sim$ 0·1 per cent and an energy output $\sim 10^7 M_\odot c^2$. The efficiency of conversion of thermal energy into that of the high energy electron and magnetic fields necessary to give the synchrotron radio emission may only be of the order of 1 per cent or even less. In this case nuclear burning in stellar masses approaching total galactic masses, $\sim 10^{12} M_\odot$, is required. Since there is no observational evidence for such wholesale nuclear conversion in the galaxies associated with the extended radio sources, Hoyle and I suggested gravitational collapse to the general relativistic limit as another possible source of energy. In principle all of the rest

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