A specific prediction of the model is that sufficiently close to the galactic nucleus the magnetic field should be in one direction along the spiral arm *above* the plane of the galaxy and in the opposite direction *below* the plane. Some evidence for this effect has been found for our local spiral arm by Morris and Berge (6).

In our opinion the double character of many large extra-galactic radio sources can be understood in terms of an enormous dipole magnetic field centered at the optical object with its axis along the line of centers of the inner pair of sources. A reasonable mechanism for generating such a dipole magnetic field in astrophysical objects has been devised by Greyber (7). The identical mechanism was proposed much earlier by D. H. Menzel for the generation of a loop current during star formation.

After the gravitational contraction and explosion which generated the dipole magnetic field (many times the size of the optical galaxy or 'quasar'), two huge clouds of hot gas and relativistic electrons are expelled mainly along the minor axis (i.e. dipole magnetic field axis). A quadruple source such as Centaurus A would be interpreted as two successive contractions and explosions.

It is important to note that the line of centers of the inner radio sources in Centaurus A lies along the rotation axis of the optical object. It is also significant to note that up to now, only in two optical objects which are also strong radio sources, has the rotation axis been carefully measured—Centaurus A and 3C 33—and in both cases the rotation axis is also the line of centers of the radio sources. In M82, the dipole field axis is also found to be the rotation axis. The 'core-halo' radio sources are interpreted in this model as the case when we observe roughly along the dipole field axis.

The model is obviously crude and the evidence available so far is fragmentary and inconclusive. However, the idea that (on the galactic dipole magnetic field model) the creation of spiral structure in galaxies and the evolutionary dynamics of strong radio galaxies and 'quasars' are similar phenomena on very different scales is appealing on theoretical grounds.

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2. PROPERTIES OF QUASI-STELLAR RADIO SOURCES

M. Schmidt

The discovery of a large redshift in the star-like object associated with the radio source 3C 273 changed our concept of this class of object completely. Until that time, four similar star-like objects had been identified with radio sources (3C 48, 147, 196, and 286). They had been considered to be stars in our own Galaxy, but we now are quite certain that they are extra-galactic, as I will discuss presently.

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The quasi-stellar objects identified with radio sources differ from radio galaxies such as Cygnus A in the following respects:

1. Their appearance is stellar, i.e. the optical diameter is less than one second of arc.

2. The redshift-visual magnitude relation for these objects is displaced from that of the radio galaxies, the quasi-stellar objects being on the average 4 magnitudes brighter than radio galaxies of equal redshift.

3. The optical light is variable over a factor of about 2 with a characteristic time of several years.

4. The spectrum shows very broad emission lines and probably no absorption lines. The total half width of the emission lines corresponds to around 4000 km/sec. The emission lines in radio galaxies are at least five times narrower, except in Seyfert-type galaxies.

5. The optical energy distribution shows a considerable excess in the ultra-violet (relative to stars). Whether radio galaxies have less ultra-violet energy is not known because no accurate photometry is available as yet.

The table summarizes the observations for each of nine quasi-stellar objects. The gaps in the table are all caused by lack of relevant observations.

	3C 9	47	48	147	196	216	245	273	286
1.	+	+	+	+	+	+	+	+	+
2.		+	+	+				+	
3.			+		+			+	
4.		+	+	+	−		+	+	+
5.	+	+	+	+	+	+	+	+	+

The negative entry for 3C 196 accounts for the absence of any certain emission lines in its spectrum; because the redshift is unknown, this absence does not necessarily imply an exception.

All five properties of the quasi-stellar objects listed above refer to the *optical* objects. The associated radio sources do not uniformly stand out by any one radio property. The angular diameter of the quasi-stellar radio sources ranges from less than 1 second of arc for 3C 48 to as much as a minute of arc for 3C 47. Interpreting the known redshifts as cosmological ones, this corresponds to a range in radio size from less than 5 kpc to 250 kpc. Of course, it cannot be excluded that the quasi-stellar radio sources contain components or nuclei of very small diameter, as is the case for 3C 273. The radio luminosity of the four quasi-stellar radio sources with known redshifts is very high, about as large as that of the most intense radio galaxies. The range of radio luminosity of the quasi-stellar sources is only over a factor of 10, whereas that of radio galaxies is very much larger. However, this narrow range depends on only four samples as yet. The radio spectra of the quasi-stellar sources often show curvature at low frequencies; however, as many as four of the nine sources tabulated have essentially straight radio spectra. Finally, the radio output of the quasi-stellar sources has not yet been shown to be variable.

We shall now inquire into the nature of these quasi-stellar objects. Of primary importance is, of course, the nature of the redshift. There are three possibilities for its explanation. First, these quasi-stellar objects might be stars that in some way had acquired the high velocities corresponding to the observed redshifts, up to 40 per cent of the velocity of light. The fact that only redshifts have been found, and no blueshifts, is rather against this interpretation. A more serious objection to this hypothesis is that the undetectably low proper motion would imply space motions that all point away from us, if these hypothetical stars were in our Galaxy. We believe that this hypothesis can be excluded.

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The second possible interpretation of the redshifts is that we are concerned with gravitational redshifts. If the object involved has a mass like that of the Sun, we would have a neutron star with a radius of about 10 km. At this stage, we note that the spectra show forbidden lines of strengths comparable to those of the Balmer lines. This can only occur in a gas with an electron density of less than 10^9 per cm^3. If we fill a volume with a radius of 10 km with ionized gas of electron density 10^9 cm^{-3}, we get an object that is intrinsically very faint. So faint in fact, that if we were to explain the observed strengths of the emission lines in this fashion, we would have to put 3C 273 at a distance about the Earth's radius. The presence of a solar mass at a distance of 5000 km would, of course, not have passed unnoticed.

We might consider the possibility that the mass of the star is not one solar mass as for a neutron star, but much larger. It turns out that the objects then can be placed at a larger distance. However, it also turns out that the gravitational attraction of the object dominates in our neighborhood over the galactic attraction. This can only be avoided by placing the objects at a a still larger distance, and finally leads to

$$r > 25 \text{ kpc}$$
$$\mathfrak{M} > 10^{11}\mathfrak{M}_\odot$$

for 3C 48, on the assumption of gravitational redshift. Thus, it is impossible to have the quasi-stellar objects within our Galaxy. On the basis of the above arguments, it cannot be excluded that the quasi-stellars are intergalactic objects of, say, 10^{12} solar masses, condensed to less than a parsec. However, we have no assurance that such an object would be stable for any length of time. Also, on the basis of gravitational redshifts, we could not understand the redshift-apparent magnitude relation, although it must be admitted that this relation is rather weakly established by only four quasi-stellars as yet. Altogether, we believe that it is quite unlikely that the redshifts are gravitational, and we have adopted the hypothesis that they are cosmological. This establishes the distances at once through Hubble's constant.

For a detailed discussion of the above and also the following considerations, see Greenstein and Schmidt (**1**). The electron temperature and electron density were estimated from line ratios in the emission spectra, and, for instance, for 3C 273 we adopted an electron density of 3×10^6 cm^{-3}. This fixes the emissivity in, say, $H\beta$ per cm^3, and with the total emission we find a required volume of 10^{56} cm^3 or a sphere with a radius of 1·2 pc or 4 light years. In a similar fashion we find about 11 pc for 3C 48. With the adopted electron temperature of about 17000°K most of the observed continuum cannot be explained on the basis of the free-free and bound-free continua. Since, moreover, both 3C 48 and 3C 273 show light variations that seem to require radii for the main part of the optical light of 1 light year or less, a segregation between the optical continuum and the ionized gas region is indicated. We then have an optical continuum source with $R \leqslant 1$ light year and a larger H II region around it.

It was recently realized that the optical depth for electron scattering in the H II region is large, especially for 3C 273. In that case, light variation could only be observed with characteristic times corresponding to the light time across the H II regions. This difficulty can be solved by replacing the sphere with uniform density 3×10^6 cm^{-3} in 3C 273 by a larger sphere only partially filled with gas of the same density in little blobs or filaments. An increase to a radius of at least 10 pc will make the H II region in 3C 273 effectively transparent.

The radio emission must originate from a still larger region, because the gas cloud is optically thick in radio wavelengths. Inside the optical continuum nucleus there must be a source of energy to maintain the observed rate of 10^{54} ergs each year. The total amount of energy required depends on the lifetime of the quasi-stellar stage. If it is 10^3 years, the energy might be supplied by a mass of about 10^5 to 10^6 $\mathfrak{M}_\odot$. Such a mass would not affect the dynamics of the system, and the broad emission lines would be due to expansion. On the other hand, if the

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quasi-stellar stage lasts 10^6 years, there must be some 10^8 or 10^9 solar masses present to supply this energy at reasonable efficiency, and this large mass would have a potential sufficient to bind the fast-moving gas. Also, with the longer time scale of 10^6 years, we could explain the wisps of 3C 48 and the jet of 3C 273 as part of the current quasi-stellar event, as both extend to at least 150 000 light years from the center.

It is often said that quasi-stellar radio sources are massive gravitationally collapsing objects. It should be pointed out that there is no direct observational evidence for this as yet. The current surge of interest in gravitational collapse was set off by the attempt by Hoyle and Fowler to explain the large stored energies necessary in models of particle energies and magnetic fields of radio *galaxies*. Their first publication on collapsing masses and the discovery of red-shifts in quasi-stellar objects were almost coincident in time, but were completely independent. The energy problem in quasi-stellar sources is not necessarily more severe than that in radio galaxies, and it is likely that the solution of the energy problem for both kinds of sources is similar or identical. It must be admitted, however, that the relation between the quasi-stellar sources and the radio galaxies is unclear at present.

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DISCUSSION

W. H. McCrea. I have plotted the nine sources described by Schmidt on the celestial sphere and I find that they lie on a great circle to within ± 5 degrees.

3. ETUDE SPECTRALE ET SPECTROPHOTOMETRIE DE LA RADIOSOURCE 3C 273 DE 3900 A 8700Å

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Les spectres de la radiosource 3C 273 que nous présentons ont été pris à l'Observatoire de Haute-Provence au télescope de 120 cm. Le premier a nécessité une pose de 16 heures sur plaque Kodak 1N hypersensibilisée; le spectrographe à réseau, ouvert à $f/2{\cdot}4$, couvre le domaine spectral 5600–8700 Å, avec 230 Å/mm de dispersion. Ce spectre montre principalement la raie $H\alpha$, large et très déplacée; elle est fortuitement superposée à la bande d'absorption tellurique A de O_2, comme le prévoyait J. B. Oke (**1**); elle est mesurée à 7586 Å, ce qui correspond à un décalage $\Delta\lambda/\lambda$ égal à 0·156 (vitesse de récession de 47 000 km/sec; distance de $470{\cdot}10^6$ pc). On aperçoit faiblement du côté des courtes longueurs d'onde $H\beta$, [O III] 5007 et sans doute He I 5876. Du côté des grandes longueurs d'onde, les émissions fines et nombreuses sont les bandes d'émission du ciel nocturne (OH et O_2).

Le second spectre a été pris en 7 heures avec un spectrographe à un prisme ouvert à $f/3{\cdot}5$ d'une dispersion de 77 Å/mm à $H\gamma$. Il montre nettement la série de Balmer jusqu'à $H\epsilon$. La raie $H\beta$ est assez forte ainsi que la raie [O III] 5007, mais [O III] 4959 n'est pas visible. [O II] 3727, [Ne III] 3868 et peut-être [N II] 5755 semblent présents, ainsi que quelques émissions non identifiées dont celles signalées par M. Schmidt dans son étude fondamentale de 3C 273 (**2**). Ces raies fournissent un décalage de 0·160.

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