TWO LUMINOSITY CLASSES OF QUASARS

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Abstract. Observations of quasars suggest that compact quasars with flat radio spectra belong to the class of dwarf galaxies and extended quasars with steep spectra to the one of bright galaxies. This can be seen also in the associations of quasars with clusters of galaxies, compact quasars occurring in nearby clusters and extended quasars in distant clusters.

1. Introduction

When considering the relation of quasars and other peculiar galaxies to normal galaxies, the wide range of mass (luminosity) of the latter should be taken into account. Both giant galaxies and the companions may have counterparts in peculiar classes.

Different observations lead to different estimates of the absolute luminosity of quasars: (A) The cosmological interpretation of redshifts gives values which can even be several hundred times larger than those of the brightest cluster galaxies; (B) Quasars being in the sky in the direction of clusters of galaxies are on the average of the same brightness as the other galaxies belonging to the cluster; (C) In the suggested associations of quasars with bright galaxies the former usually appear about a hundred times fainter than the latter.

We make a working hypothesis that the luminosities of quasars correspond to the estimates B and C. Arguments for rejecting class A are: firstly, the inner metagalaxy lacks such objects; secondly, the energy production difficulties are thereby avoided; thirdly, there is no direct evidence, excepting the redshift – which is controversial – in favour of ultraluminous quasars.

We first bring together the evidence pointing to the existence of two luminosity classes of quasars, and then consider in particular the associations of quasars with clusters of galaxies and their implications for the luminosities of quasars.

2. Evidence for Two Luminosity Classes of Quasars

It is well-known that, according to the radio properties, quasars can be divided into two classes: extended sources with steep radio spectra and compact sources with predominantly flat spectra. (We use the abbreviations e for extended, s for steep, c for compact, f for flat.) The majority of identified radio galaxies have the properties e and s (Kellermann, 1972). So, if quasars are of the luminosity classes B and C, and this is

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reflected in the radio properties, the (e, s)-quasars would be of the brighter class B, and the (c, f)-quasars of the companion galaxy class C.

The question discussed in the following is whether such quasars are (c, f)-sources, for which various observations have been suggested to show a local distance and thereby luminosity class C, and whether those showing indications of a cosmological distance are (e, s)-sources. The answer is illustrated in tabular form (Table I). The radio data have been taken mainly from Miley (1971). The reasons for prediction are evident, taking into account the hypothesis made above. The tests used are partly interrelated, but each one contains some evidence not included in the others.

TABLE I

Quasar observations considered in respect to the radio properties. The quasar class to which the observation cited in column 1 should apply (column 2) is given using the abbreviations: f – flat, c – compact, s – steep, e – extended. The class observed is given using these appreviations or numerically, the denominator giving the number of quasars with the data needed and the nominator the number of those with the predicted radio properties (columns 3 and 4). N_G is the number of quasars

Observation	Radio spectrum and structure				Notes	References
	Predicted	Observed sp.	Observed struct.	N_Q		
Association with peculiar gal.	f, c	5/7	7/7		1, 2	1
Close association with gal. ($\theta \leqslant 6\overset{'}{.}2$, $m_Q > m_G$)	f, c	5/8	3/6		2, 3	2
Association with Virgo cluster	f, c	5/6	3/6		2	Table II
Association with other nearby cluster or group	f, c	7/12	5/9		2, 4	Table II
Association with distant cluster or group	s, e	9/11	10/11		2	Table II
Concentration along the Local Supergalaxy	f, c	f	c	7	1	3
$z_Q = z_G$ of nearby galaxy	s, e	3/3	3/3			4, Table II
Brighter member of double quasar, smaller z	s, e	1/1	1/1		5	5
Optically violent variables	f, c	6/6	6/6		6	6
Radio variables	f, c	16/16			6	7
'Relativistic expansion'	f, c	4/4	3/4		7	2, 8
$z_{em} - z_{abs} > 0.05$	f, c	2/3	2/3		8	9
(m, z)-relation	s, e	s	e	81		10
No (m, z)-relation	f, c	f		82		10
No (S_{2700}, z)-relation	f, c	f		17		11
(angular diameter, z)-relation	s, e	s	e	47	9	12
Continuity in radio diameter with radiogal.	s, e	s	e	47		12
Near the Hubble line of bright gal.	s, e	6/9	7/9		10	6
Largest redshifts ($z > 2.0$)	f, c	9/12	8/9			13
(depolarization, z)-relation	s, e	s		28	2, 11	14, 15
No (depolarization, z)-relation	f, c		c	11	1, 2	15
Peaks in z-distribution	f, c		c	53	12	16
Smooth z-distribution	s, e		e	74	13	16
Low slope for ($\log N$, $\log S$)-relation	f, c	f		81	14	11, 15

Notes to Table I

1. The observation referred to is for 3C objects.
2. See the text.
3. For 3C objects, for which Burbidge found the linear (angular separation, z_G)-relation, the distribution is only 2/5.
4. In 4 out of 5 and 3 out of 4 cases with unpredicted spectrum and structure, respectively, the cluster is unusually extended. If associations with $D_{Cl} > 30$ cm are excluded as probable chance events, the frequencies in question will be 6/7 and 4/5.
5. 4C 11.50a. The extended component radiates one-third of the flux (Murdoch, 1974).
6. The argument for the prediction is that a smaller amount of energy is needed in dwarf objects than in larger ones to be released during active phases. For radio sources the feature (f, c) follows also from the physical theory of the radio emission.
7. 3C273, 3C279, 3C454.3 and 3C287. The expansion is relativistic if the redshift is cosmological.
8. Table 5 of Burbidge (1971). PKS 1116+12, 0237-23 and 4C5.34. For the latter the spectrum is steep, but only slightly ($\alpha = -0.65$; Lynds and Wills, 1972).
9. The test should be read in the form: 'Is there an (angular diameter, z)-relation for (s, e)-quasars?'
10. The quasars are those of Table 7 from the paper by Sandage (1971). For 3C sources the distributions are 6/6 and 5/6, respectively. Two out of three flat spectrum sources are extended.
11. 12 extended 3CR sources show a significant correlation (Morris and Tabara, 1973).
12. Uncertain peak distribution for 16 3C sources.
13. Smooth distribution for 32 3C sources.
14. Parkes 2700-MHz survey. Most of the identified flat spectrum sources are QSO's (Condon and Jauncey, 1974).

References to Table I

1. Arp (1967, 1968, 1970a); Rowan-Robinson (1972); Plagemann (1973); van der Kruit (1973). 2. Burbidge (1973). 3. Plagemann (1973). 4. Gunn (1971); Oemler *et al.* (1972); Stockton (1973). 5. Wampler *et al.* (1973); Murdoch (1974). 6. Sandage (1971). 7. Harris (1972). 8. Matthews (1968). 9. Burbidge (1971); Lynds and Wills (1972). 10. Setti and Woltjer (1973). 11. Condon and Jauncey (1974). 12. Miley (1971). 13. Murdoch (1974); Lynds and Wills (1972); De Veny *et al.* (1971). 14. Morris and Tabara (1973). 15. Rowan-Robinson (1973). 16. Karlsson (1973).

We do not make any quantitative statistical analysis which is not in place here due to the heterogeneity of the observations considered. It can still be said that the consistency of the ideas presented with the observations is remarkably good, the trend in every one of the 24 kinds of observations being the same as predicted. Of course, the individual items in Table I can have alternative explanations, including selection.

Some of the arguments used appear the same as those used in the articles of Rowan-Robinson (1972, 1973). The conclusions, however, are different. Rowan-Robinson assumes that compact quasars have luminosities similar to those of the Seyfert nuclei, with a mass of the order of $5 \times 10^{11}\ M_\odot$, thus approximately corresponding to our class B. The extended sources would correspond to our class A. On the basis of several arguments presented above (those under items B and C, and the radio structure) this seems not to be the case. Further, if compact quasars are related to objects like NGC 1275 which is the brightest galaxy in a cluster, and if extended quasars form a basically different class, the latter objects fall out of the mass range of galaxies.

Also the depolarization properties of quasars throw light on the question of luminosity of the two quasar classes. According to Morris and Tabara (1973), the (s, e)-quasars together with the radio galaxies show a relationship between radio luminosity and depolarization (and a weaker relation between redshift and depolarization). The (f, c)-quasars do not partake in this trend. The masses of thermal plasma in quasars, calculated assuming Faraday depolarization within the sources, are for (s, e)-quasars seven orders of magnitude larger than for (f, c)-quasars (De Veny *et al.*, 1971). This probably reflects a difference also in the total masses and luminosities, and suggests a basic physical dissimilarity between the two classes, not explainable as caused by different stages of evolution. The small value of the mass of thermal plasma in the (f, c)-class, only $\sim 1\ M_{\odot}$, favours the dwarf nature of these objects, as assumed above. The small depolarization of the (f, c)-quasars is also consistent with the alternative hypothesis that the Faraday depolarization occurs in the intergalactic medium, presuming that the objects are at local distances and thereby of the class C.

For extended quasars the total energy in the form of relativistic particles and magnetic field is about three orders of magnitude larger than for compact quasars (Kellermann, 1972), even if the latter were at cosmological distances. If compact sources are local, the difference is much larger. Also from this consideration one can reach a conclusion, similar to that based on the mass of depolarizing plasma, that there is no evolutional relationship between compact and extended quasars, but that they are basically different objects. Nevertheless, intermediate forms between the two classes of quasars are quite possible.

Van der Kruit (1973) has criticized the results of Rowan-Robinson (1972). The following comments are on those arguments of van der Kruit which might be applied also to the present paper: (1) Dividing the quasars into two classes on the basis of their radio spectra, we have found a similar trend as for the division on the basis of radio diameter; (2) van der Kruit used the radio diameter 70 kpc (at cosmological distance) as the dividing value between compact and non-compact sources. Compact sources being here identified as dwarf objects, this is too large a value to be applied to the present results. The large non-cosmological part in the redshifts, assumed here for compact galaxies, would increase their apparent linear diameter, and might remove some intrinsically compact quasars into the class with the larger apparent linear diameter; (3) Although van der Kruit did not find clustering of small diameter quasars with Zwicky clusters above that of ones with large apparent linear diameter, this is no evidence against compact quasars as local objects. For the distant clusters just the (s, e)-quasars are those expected to be found in the associations.

3. Associations of Quasars with Galaxies and Systems of Galaxies

According to the working hypothesis, in associations between quasars and bright galaxies compact quasars with flat spectra should predominate. According to Rowan-Robinson (1972), all 7 3CR quasars belonging to Arp's (1967) associations of radio-sources with peculiar galaxies are compact sources. Plagemann (1973) points out that 5 out of 7 3C (f, c)-quasars belong to Arp's (1967, 1970a) associations, while only 2 out of 20 (s, e)-objects do. Examining Arp's (1968) study of radio sources paired across galaxies, and excluding quasars fainter than 9 flux units at 178 MHz, van der Kruit (1973) found that there are as many (8) quasars with steep as those with flat spectra in the associations. The excess of small diameter sources was found also by van der Kruit. Out of the 5 3C QSO's in close associations with galaxies, forming a linear relation between angular separation and galaxy redshift (Burbidge, 1973), only two have the expected flat spectra. Using data also from the other catalogues (quasars in Table 2 of Burbidge (1973) and PKS 1953-325, described in his text), expected radio properties are found in 5 out of 8 cases. So the evidence is not clear-cut but a trend in the right direction is found in the quasar-galaxy associations.

Table II lists the quasars in the directions of clusters or groups of galaxies, the radio spectrum or diameter of the quasar being known. In the upper part those cases are given where the magnitudes of the brightest cluster galaxies (m_G) are given in the literature or can be seen from photographs. The middle part gives the associations between quasars and Zwicky's clusters, listed by Bahcall *et al.* (1969) and Bahcall (1969). The m_G-values for these clusters are quite uncertain, calculated from the estimates of distance (redshift) ($H = 50$ km s^{-1} Mpc^{-1} and $M = -21^{\mathrm{m}}.5$ were used). Because the boundaries of the Virgo cluster are not given in the *Catalogue of Galaxies and of Clusters of Galaxies* (Zwicky *et al.*, 1961–68), the lists (Bahcall *et al.*, 1969; Bahcall, 1969) referred to above lack several quasars in association with a cluster. They are given in the lower part of Table II. Also the Southern Extension of the cluster is taken into account.

The following conclusions can be made from Table II: (1) In accordance with our hypothesis, most (12 out of 14) (f, c)-quasars appear to be associated with nearby systems ($z_G \leqslant 0.05$ or $m_G \leqslant 16^{\mathrm{m}}$). (2) The (f, c)-quasars are in 13 cases out of 14 fainter than the brightest cluster galaxies. The mean $\Delta m = m_Q - m_G$ for the associations with the Virgo cluster equals $+5^{\mathrm{m}}.6$, and Δm decreases for the more distant clusters, probably due to the observational limit. (3) Contrary to the class (f, c), the (s, e)-quasars tend to be associated with distant clusters ($z_G > 0.05$ or $m > 16^{\mathrm{m}}$); this frequency is 10 out of 16. The diameters given in *CGCG* (Zwicky *et al.*, 1961–68) for the nearby clusters associated with (s, e)-quasars are in four cases out of five larger than 30 cm. They are much larger than for the nearby Zwicky clusters associated with (f, c)-quasars, with Zw 1916.8+4855 as the only exception. Also the diameters of the clusters associated with radio quiet quasars, not included in Table II, are small compared with diameters over 30 cm. Hence, the (s, e)-quasars in directions of nearby clusters are more probably chance associations than the other associations considered. This makes the trend of (s, e)-quasars to be physically associated with distant clusters clearer. (4) In the associations with distant clusters, the (s, e)-quasars are brighter or at most one magnitude fainter than the brightest galaxies. (5) The brightest quasar in Table II, PKS 2251+11, has, on the basis of the redshifts of QSO and two associated galaxies, an absolute magnitude $-24^{\mathrm{m}}.7$[10] ($\Delta m = -3^{\mathrm{m}}.5$). Hence, the quasar is clearly brighter than the brightest cluster galaxies but still much fainter than many quasars if assumed to be at a cosmological distance. The Δm-values in the rest of the associa-

TABLE II

Quasars with known radio spectrum or diameter in the direction of clusters of galaxies. m_G means the apparent magnitude of the brightest cluster galaxies, α the radio spectral index, LAS the largest angular scale of the quasar, and D_{Cl} the diameter of the cluster in the Sky Survey plates in cm, taken from *CGCG*. A flat spectrum is denoted by f. In Table I and in the text the quasars with LAS < 7″ are considered as compact and those with LAS ≥ 7 as extended

QSO	Cluster or group	z_Q	z_G	m_Q	m_G	α	LAS	D_{Cl}	Notes	Ref.
0159+034	A 293			17	16	f			1	1
4C 11.45	faint cluster	2.17	< 0.3	19	fainter	0.7				2
4C 37.43	faint galaxy, cluster?	0.371	0.372	15.5	20?	0.9	56″		2	3
3C 323.1	1545.1+2104	0.264	0.270	16.6	18.2	0.8	68.1	0.8		4
1953−325	group or small cluster			17.5	15	f				1
2020−370	group or small cluster			17.5	brighter	f				5
2251+11	small compact cluster	0.323	0.324	15.8	19.3	0.7	8			6
PHL 658	0004.2+1516	0.450	0.1–0.15	16.5	18	0.6	6	7.2		7
0122−00	0121.5+0113 0123.6−0133	1.070	≤0.05 0.02	16	16 14	f	< 7	12.8 20.2		7
PHL1093	0136.7+0053	0.260	0.15–0.2	17	19	f	11	5.3		7
0214+10	0214.2+1106	0.408	≥0.2	17	20	0.8	58	3.5		7
0736+01	0737.5+0108	0.191	0.05–0.1	18	17	f	7	5.4		8
4C 17.46	0909.7+1814	1.449	0.01	17	12.5	1.0	10	31.7		7
3C 215	0909.7+1814	0.411	0.01	18.5	12.5	1.0	25	31.7		7
0957+00	0958.9+0038	0.906	≤0.05	17.5	16	0.7	34	9.3		7
1055+20	1054.6+2017	1.11	0.05–0.1	18	17	0.6	21	11.2		7
3C 249.1	1021.0+7728	0.311	≤0.05	15.5	16	0.8	18.8	32.2		7
3C 254	1111.3+4051	0.734	0.05–0.1	18	17	1.0	13.5	10.3		7
3C 261	1132.4+3010	0.614	0.1–0.15	18	18	0.9	10.8	4.0		7
4C 49.22	1150.6+4920	0.334	0.05–0.1	16	17		7	7.7		7
4C 31.38	1155.0+3127	1.557	≤0.05	19.5	16	0.8	< 5	8.6	3	7
3C 288.1	1341.0+5930	0.961	≤0.05	18	16	1.0	6.4	35.3		7
3C 380	1916.8+4855	0.692	0.01	17	12.5	f	< 4	73.7		7
2344+09	2343.4+0845	0.677	0.04	16	15.5	f	< 5	11.1		7
1217+02	Virgo cluster	0.240	0.004	16.5	10.5	f	150			
3C 273	Virgo cluster	0.158	0.004	12.8	10.5	f	20			
1229−02	Virgo cluster	0.388	0.004	16.8	10.5	f	< 4			
3C 275.1	Virgo cluster	0.557	0.004	19.0	10.5	0.8	13.2			
1252+11	Virgo cluster	0.870	0.004	16.6	10.5	f	< 5			
3C 279	Virgo cluster	0.536	0.004	17.8	10.5	f	< 3			

Notes to Table II

1. m_G estimated from $m = 17^m.3$ for the 10th brightest galaxy in the cluster (Abell, 1958).
2. m_G refers to the faint galaxy; the galaxies of the nearby cluster would be brighter (Stockton, 1973).
3. Low frequency cut-off in radio spectrum. Such quasars are all compact (Miley, 1971). This kind of spectrum belongs to the same class as flat spectra (Kellermann and Pauliny-Toth, 1973). Thus 4C 31.38 and the other quasars with low-frequency cut-off found in compiling Table I are included in the class (f, c).

References to Table II

1. Peterson and Bolton (1973). 2. Lynds and Wills (1972); Hazard *et al.* (1973). 3. Stockton (1973). 4. Oemler *et al.* (1972). 5. Hazard *et al.* (1973). 6. Gunn (1971); Robinson and Wampler (1972). 7. Bahcall (1969). 8. Bahcall *et al.* (1969).

tions in Table II, as well as in those of the radio-quiet quasars, are not much below zero (excepting 0214+10; $\Delta m = -4\overset{\mathrm{m}}{.}5$ of 4C 37.43 does not refer to galaxies of the nearby cluster (Stockton, 1973)). From this it can be inferred that the value $M = -24\overset{\mathrm{m}}{.}7$ is probably near to the upper limit of the luminosity of quasars. (6) There are six quasars within the boundaries of the nearest cluster, the Virgo cluster. In spite of the large area of the sky covered by Virgo, this is more than expected by chance. Five of the six quasars have flat spectra, this uneven distribution favouring them as real members of the cluster.

All these results conform with the hypothesis given at the beginning of the present paper. The comparison of the brightnesses of the quasars and the galaxies in associations made above is the most direct means of determining the actual luminosities of quasars.

In Arp's (1973) list of close quasar-galaxy associations the galaxies are on the average $3\overset{\mathrm{m}}{.}7 \pm 0\overset{\mathrm{m}}{.}6$ brighter than the quasars. This is of the same order of magnitude as the difference between bright galaxies in the Local Supergalaxy and the 3C QSO's with flat spectra which have anisotropic distribution along the axis of the Supergalaxy (Plagemann, 1973) ($\overline{\Delta m} \sim 4\overset{\mathrm{m}}{.}5$). Also $\overline{\Delta m} = 5\overset{\mathrm{m}}{.}6$ obtained for the quasars in association with the Virgo cluster (Table II), as well as the difference ($\sim 5\overset{\mathrm{m}}{.}0$) between M31 and its companions can be considered in this connection.

4. Discussion

One consequence of the preceding results is that these diminish the extremity of the properties often attached to quasars, and removes other anomalies connected with them. The energy production problem is reduced, variable quasars and those with the largest redshifts being dwarf objects. Also the most violent motions within the quasars, their curious distribution in the sky and in distance, as well as difficulties connected with depolarization, can be avoided.

Even after exclusion of class (f, c)-objects, quasars do not lie around the Hubble line for the brightest cluster galaxies. In addition to the large absolute luminosity of (s, e)-quasars, this is probably due to a non-cosmological component of the redshift, at least in some members of this class. This is suggested by the existence of high redshift quasars in association with lower redshift clusters (Hazard *et al.*, 1973; Bahcall *et al.*, 1969; Bahcall, 1969), many of them being (s, e)-objects.

If the two quasar populations evolve to more common forms of galaxies and the conclusion made on the absolute luminosities is right, the dwarf and giant classes of peculiar and normal galaxies may have properties reflecting those of the corresponding quasars. Checking this would be of importance for the problem of evolution of galaxies. In this connection, it is worthwhile to mention the small excess redshift of companion galaxies (Arp, 1970b; Bottinelli and Gouguenheim, 1973).

As a summary, the quasar observations show a regularity pointing to the existence of two populations of radio emitting quasars. One of them, i.e. compact sources with flat spectra, probably at local distances, having mostly non-cosmological redshifts, would belong to the class of dwarf galaxies. The other, i.e. extended sources, at more cosmological distances, would belong to the class of giant galaxies.

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