RELATIONS BETWEEN RADIO AND OPTICAL PROPERTIES OF RADIO SOURCES - RADIO ASTRONOMER'S POINT OF VIEW

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One particular aspect of the relations between the radio and optical properties of radio sources has been examined for a complete sample of 3CR sources, namely the relation between the radio structure of a source and its optical identification. Possible differences between the radio structures of quasars and radio galaxies are investigated, and the data provide clues as to the optical nature of the unidentified sources.

1. THE DATA

A complete sample of 166 3CR sources has been observed in total intensity with the Cambridge 5-km telescope at 5 GHz with a resolution of 2" arc in RA and 2" cosec δ in Dec.(Jenkins et al 1977, and references therein). This sample was selected as follows : (a) the flux density of each individual source at 178 MHz is greater than or equal to 10 Jy according to the compilation given by Kellermann et al (1969), (b) $\delta \geqslant 10^{\circ}$ and (c) $|b| \geqslant 10^{\circ}$. Spinrad's most recent compilation of the identification status of each 3CR source was used. The sources in the 166 sample have been divided into 3 classes according to their identification (i) galaxies, including N galaxies, (ii) quasars and (iii) unidentified, including those for which the identification is uncertain.

2. THE RESULTS

2.1. LAS Distribution

The distributions of the largest angular size of the radio structures (LAS) for the 3 optical classes are shown in Fig.1. The distribution for the unidentified sources is similar to that for the galaxies shifted to a slightly smaller angular size. The distribution for quasars differs from both in having more very compact sources ($<1''$ arc) but even for the resolved sources the LAS for the quasars are smaller on average than for the unidentified sources. These results indicate the likelihood that the majority of the unidentified sources are asso-

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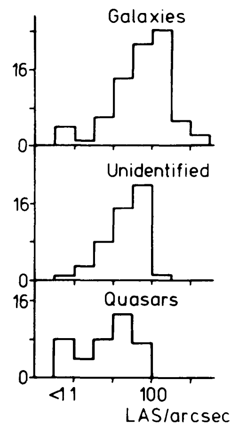

Fig.1. The distributions of the LAS of the radio structures of sources in the 166 sample.

ciated with galaxies and are slightly more distant on average than the sources already identified with galaxies.

2.2. Radio Structural Types

The sources in the sample have been divided into 4 classes according to their radio structure; compact components coincident with the optical objects are not taken account of in this scheme except where there is no other radio structure. The classification is as follows : (i) compact, unresolved by the 5-km telescope e.g. 3C 147, (ii) double, with components on either side of the associated optical object e.g. Cygnus A, (iii) asymmetric double, with one compact component coincident with the associated object and only one component displaced from it, e.g. 3C 273 and (iv) other, which includes any source which does not fall into one of the other 3 classes e.g. 3C 83.1B, and any source for which there is uncertainty as to which of the three classes it belongs. The distribution of these radio structural types within the 3 optical classes

Table 1

		Compact	Double	Asymmetric Double	Others
Galaxies	All	4%	70%	1%	25%
	$\log(P_{178}) > 26$	7%	78%	0%	15%
Quasars		25%	50%	13%	12%
Unidentified		4%	45%	-	51%

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is shown in Table 1 as the percentage of those sources with a given optical class which have a given structure. Any unidentified source with two components has been classified as double when both components are resolved, and as other when at least one component is unresolved as in this case the source could be a double or an asymmetric double; nearly all the unidentified sources classified as other are of the latter type. It is difficult to compare the distributions for radio galaxies and quasars meaningfully as the quasars are nearly all much more powerful than the radio galaxies. However comparison of the quasar distribution with that for radio galaxies with luminosities $P_{178} > 10^{26}$ W Hz^{-1} sr^{-1} indicates a very much higher proportion of compact and asymmetric double sources amongst the quasars.

2.3. Symmetries in Double Sources

For the sources classified as double it is possible to investigate the symmetry of the two components with regard to their flux densities and separation from the associated object. The distributions of the ratio of the total flux density of the brighter component to the total flux density of the fainter are shown in Fig.2(a) for all double sources

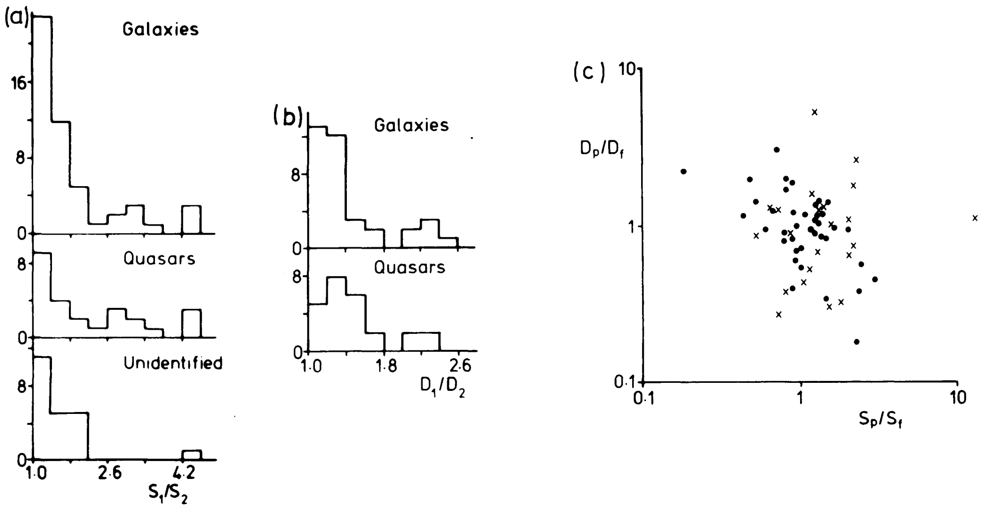

Fig.2. (a) The distributions of the ratio of the total flux density of the brighter component to that of the fainter component for all double sources in the sample. (b) The distributions of the ratio of the distance of the peak of the component further from the optical object to that of the component near to it for identified double sources in the sample. (c) The ratio of the distance of the peak of the preceding component from the optical object to that of the following one plotted against the ratio of the total flux density of the preceding component to that of the following one for double sources identified with galaxies (●) and quasars (×).

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in the sample. The galaxies and quasars both show tails towards large flux density ratios, though the galaxies are more peaked towards 1; the distribution for the unidentified sources is similar to that for the galaxies. The distributions of the ratio of the distance of the peak of the component further from the optical object to that of the component nearer to it are shown in Fig.2(b) for all identified sources. Again the galaxies show a tendency to be more peaked towards 1. A plot of the ratio of the distance of the peak of the preceding component from the optical object to the distance of the peak of the following one against the ratio of the total flux density of the preceding component to that of the following one for double sources identified with galaxies and quasars is shown in Fig.2(c). It can be seen that there is a correlation for the galaxies in the sense that the nearer component is brighter, whilst no such effect exists for the quasars which also show a much broader spread. It is difficult to say whether any of these effects reflect a genuine difference between the structures of the double sources associated with galaxies and quasars or whether it is just a question of the power of the radio source, as the quasars are nearly all much more powerful than the galaxies.

2.4. Compact Central Radio Components

Compact central radio components (ccrc), taken as being unresolved radio components associated with the optical objects in extended sources, have been detected in many of the sources in the sample. The distributions in total luminosity at 5 GHz for all identified sources and those with ccrc are shown in Fig.3(a); redshifts estimated from the apparent magnitudes have been used where no measured redshifts exist. It can be seen from Fig.3(a) that the majority of the galaxies with $P_{5000} < 10^{25}$ W Hz^{-1} sr^{-1} possess ccrc whilst there is an apparent lack of ccrc in the galaxies of higher power. This absence of ccrc in the higher power sources is not a result of inadequate resolution as it was shown in section 2.1 that the majority of the sources associated with galaxies are well resolved with the 2" arc beam; it therefore seems likely that the sensitivity is insufficient to detect ccrc in the more distant powerful sources. That this is indeed the case is indicated in Fig.3(b) which is a plot of the ratio of the flux in the ccrc to the total flux at 5 GHz against total power at 5 GHz for radio galaxies with total flux densities at 5 GHz greater than 1 Jy; as only the brightest sources have been used any ccrc with more than 1 percent of the total flux could in principal be detected and there is no observational selection against populating any part of Fig.3(b). From this diagram it can be seen that the fraction of flux in the ccrc increases with decreasing power, in agreement with the results of Perola & Fanti (this volume), and there are no ccrc with luminosities at 5 GHz greater than 10^{24} W Hz^{-1} sr^{-1}; these results are suggestive of a narrow luminosity function for ccrc. The luminosity distribution for the ccrc associated with galaxies in the sample is shown in Fig.3(c) from which the sharp cut-off at 10^{24} W Hz^{-1} sr^{-1} is obvious. It is possible to construct the luminosity function for central components in galaxies and it is found that this fits well to an extrapolation of the luminosity function for nearby bright

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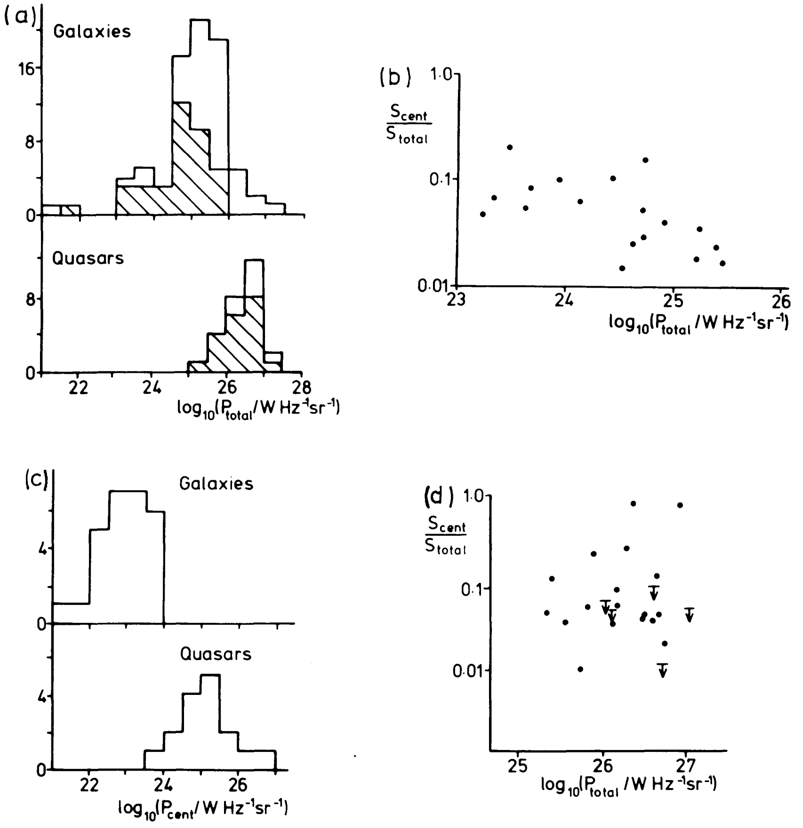

Fig.3. (a) The distributions in total luminosity at 5 GHz for all sources identified with galaxies and quasars; the hatched boxes are sources with ccrc. (b) The ratio of the flux density of the ccrc to the total flux density at 5 GHz plotted against total power at 5 GHz for galaxies with total flux densities at 5 GHz greater than 1 Jy. (c) The distributions in the luminosity of the ccrc at 5 GHz for galaxies and quasars. (d) As in (b) for all the quasars in the sample.

ellipticals.

From Fig.3(a) it is apparent that nearly all the quasars in the sample have ccrc indicating a difference from the powerful radio galaxies. A plot of the ratio of the flux in the central component to the total flux at 5 GHz against total luminosity at 5 GHz for the quasars is shown in Fig.3(d) from which it is clear that there are no trends similar to those seen for the radio galaxies and there is a very broad spread in the luminosity of the ccrc, shown in the luminosity distribution in Fig.3(c). The luminosities of the quasar ccrc are all much higher than those of the galaxy ccrc. These differences reflect a genuine difference between galaxies and quasars.

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It is interesting that none of the unidentified sources in the sample are triples in the sense of being double sources with ccrc; this again is consistent with them being associated with more distant galaxies so that the sensitivity is not adequate to detect ccrc in them.

This work will be discussed in more detail by Jenkins (in preparation).

3. CONCLUSIONS

The main difference between galaxies and quasars from the point of view of their radio structures is the much greater luminosity of the ccrc of quasars; there are also more purely compact radio sources associated with quasars. There may be a tendency for the double sources associated with quasars to be more asymmetric both as regards the fluxes of the components and their separation from the associated object. The present observations of the unidentified sources are consistent with them being more distant galaxies as (i) they possess no ccrc, (ii) the distribution of LAS is similar to that for galaxies only somewhat smaller and (iii) the distribution of radio structural type is probably similar to that for the more powerful galaxies.

REFERENCES

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Kellermann,K.I., Pauliny-Toth,I.I.K. & Williams,P.J.S., 1969. Astrophys. J.,157,1.

DISCUSSION

Ekers: Would you clarify your statement about the consistency between your luminosity function for cores in radio galaxies with that for the cores of bright elliptical galaxies? This is quite important since we need to know whether the central object is a good indicator for the correct identification or whether all E galaxies have them. I think our data indicates that the probability of core emission does approach unity but at power levels 10 - 100 times lower than that for the 3C radio galaxies.

Riley: The luminosity function for the core in radio galaxies fits well to an extrapolation of the luminosity function for bright ellipticals of higher power.

Condon: If there is a correlation between the excess optical luminosity that makes a galaxy into a QSO, and the radio flux density in a compact core, then it might be possible to identify sources as follows: if $P_{5GHz} < 10^{24}$ W/HZ/Sr (in the core), the source is a galaxy, if $P_{5GHz} > 10^{24}$, it is a QSO. How well would this reproduce the observed identifications?

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Riley: I think it would reproduce the identifications almost perfectly (except that you need the redshifts first!)

Schilizzi: The conclusion that most radio galaxies have compact radio components in their centers has been arrived at independently by VLBI measurements at 8.1 GHz between Owens Valley and Goldstone in California, (fringe spacing ~ 0".08). 39 galaxies associated with large (minutes of arc) radio sources were observed. For only a few of the sources was there any previous evidence of a central component. 17 showed fringes, 12 of the detections are amongst the 17 nearest sources (cosmologically) in the sample and are of fairly low luminosity. This strongly suggests that, with sufficient sensitivity, one could detect compact central radio components in most, if not all, radio galaxies.

LONG TERM OPTICAL VARIABILITY OF QUASARS

N. Sanitt

The magnitudes of 45 radio and 32 optically selected quasars from the samples of Schmidt, M., Astrophys. J. 151, 393 (1968), Lynds, R. and Wills, D., Astrophys. J. 172, 531 (1972), and Braccesi, A., Formiggini, L. and Gandolfi, E., Astron. and Astrophys. 5, 264 (1970) are estimated by a method of measuring image diameters on the Palomar Sky Survey prints. These are combined with known photographic or photoelectric magnitudes measured between ten and fifteen years after the epoch of the Palomar Sky Survey, and the distribution of the differences in the two magnitudes should have a standard deviation of around 0.4 mag. The 45 radio quasars have a much larger standard deviation with 9 out of 45 (20%) lying outside two standard deviations from the mean. This result is consistent with known variability of these quasars. However, the optical sample shows no evidence for long term variability with all 32 quasars showing magnitude differences within two standard deviations. This implies a correlation between radio power and long term optical variability.

H.E. Smith: Do you have any color information on the variable radio QSO's?

Sanitt: The radio quasars are from the 3CR and 4C samples and exhibit an ultraviolet excess in common with the optically selected quasars, though not quite to the same degree. The more extreme ultraviolet excess of the optically selected quasars however, is due to strong emission lines and also results in a selection at certain preferred redshift values.

D. Wills: To what extent can your result be interpreted as a correlation between large redshift and lower incidence of variability, since the radio-quiet QSO's include many near z = 2?

Sanitt: The radio quiet quasars also include a number at low redshift around z = 0.4, and these also show less variability.

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