RADIO EMISSION FROM OPTICALLY SELECTED QUASARS

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I. INTRODUCTION

Shortly after their discovery, it was realized that most quasars are not found in radio source catalogues, and a number of searches were initiated to try to detect weak radio emission from "optically selected quasars." See Table 1.

The earliest observations, all made using single-dish radio telescopes, were unsuccessful due to inadequate sensitivity. By the early 1970's much greater sensitivities were available with the use of interferometer systems and large single dishes operating at shorter wavelengths to reduce the effects of confusion. Flux densities of the order of 10 mJy could be reached. At this level, some 10% to 20% of optically selected quasars could be detected as radio sources. It was noticed by several investigators that about half of the quasars detected were already catalogued radio sources, and that the number of radio detections increased only slowly as the flux density limit was decreased. (Fanti et al. 1977, Sramek and Weedman 1980, Strittmatter et al. 1980, Shaffer et al. 1982. Several authors also commented that among quasars brighter than 17th magnitude, the fraction of radio detections was apparently higher than for the fainter quasars (e.g., Smith and Wright 1980, Condon, et al. 1980).

Since quasars are generally thought of as active objects, the apparent absence of radio emission from most quasars has been a subject of much discussion. The simplest and most trivial interpretation, of course, is that the radio luminosity function of quasars is broad, and because of their generally large distance, only the most luminous appear as radio sources. It is also possible that there may be two fundamentally different types of quasars; those which are radio loud and those which are radio quiet. Variability may also explain the lack of observed strong radio emission from most quasars. But known variable radio sources generally do not vary by more than a factor of two or three; so it seems unlikely that variability alone can account

G. Swarup and V. K. Kapahi (eds.), Quasars, 95–102.

https://doi.org/10.1017/S0074180900152374 Published online by Cambridge University Press

TABLE 1

λ	$B_{\ell im}$	S_{min}	n_{obs}	n_{det}	%	Reference
70	18	500	15	0	0	Bracessi et al. 1967, Nuovo Cimento 49B, 151
2,4	18	1000	2	0	0	Weinreb and Shapiro 1966, Ap. J. 143, 598
6	18	5	12	0	0	Pauliny-Toth and Kellermann 1966, Nature 212, 781
75	18	100	15	0	0	Mills and Little 1970, Ap. L. 6, 197
4,11	18	10	54	0	0	Wardle and Miley 1971, Ap. J. (Lett.) 164, L119
21	19	7	95	4	4	Katgert et al. 1973, A & A 23, 171
73	18.5	100	36	2	6	Murdoch and Crawford MNRAS 1977, 180, 41P
21	18	10	62	8	13	Fanti et al. 1977, A & A 61, 487
4,11	16,2	20	6	1	16	Shaffer and Green 1978, PASP 90, 22
2,6	19	25	240	18	8	Savage and Bolton 1979, MNRAS 188, 599
13	20	14	247	18	7	Sramek and Weedman 1980, A. J. 238, 435
2,6	19	10	122	10	8	Smith and Wright 1980, MNRAS 191, 871
3,6	19	10	70	10	14	Strittmatter et al. 1980, A & A 88, L12
6	17	0.5	22	9	41	Condon et al. 1981, Ap. J. 246, 624
6	16	2	94	27	29	Shaffer et al. 1982 IAU Symp. 97, p. 367
20	18.5	10	30	2	6.5	Mitchell 1983 thesis,
	19.5	10	26	2	8.5	Pennsylvania State University
6	17	0.5	41	7	17	Hutchings and Gower 1985, A. J. 90, 405

Notes to Table I. λ, observing wavelength in cm; $B_{\ell im}$, approximate limiting magnitude of optical sample; S_{min}, approximate limiting flux density in mJy for radio detection; n_{obs}, number of QSO's observed; n_{det}, number of quasars detected above S_{min}; %, percent of QSO's with detected radio emission.

for the wide spread in the observed ratio of radio to optical flux density. It has also been suggested that quasars may be surrounded by a cold cloud of absorbing gas, and that only in those cases where the radio source "breaks through" the absorbing cloud, is there observable radio emission (Bolton, 1977, Strittmatter et al. 1980). Finally, there has been the suggestion of Scheuer and Readhead (1980), that due to relativistic beaming, only the small fraction which have their beams oriented toward the observer appear radio loud.

The relativistic beaming model has enjoyed great popularity, because it appears to explain a number of observed phenomena including superluminal motion, rapid flux density variations, and the absence of Compton scattered X-rays (e.g., Porcas, 1986). However, the relativistic beaming model predicts that the number of detected radio quasars per flux density interval should increase roughly as $S^{-5/2}$. Although the specific value of the exponent is somewhat model dependent, the relatively few quasars which are weak radio sources appear to be inconsistent with simple beaming models (e.g., Strittmatter et al. 1980, Smith and Wright 1980).

II. THE VLA OBSERVATIONS OF THE BRIGHT QUASAR SURVEY

In an attempt to understand better the radio emission from quasars, we have observed all 114 objects in the Schmidt and Green (1983) Bright Quasar Survey (BQS), using the VLA in the D configuration with 18 arcsec resolution at 6 cm wavelength. The radio observations are complete for all BQS quasars down to a flux density limit of 0.25 mJy, and for some objects to 0.15 mJy. All objects detected as radio sources were reobserved in the A-configuration with 0.5 arcsec resolution to isolate the flux density contained in the compact core. A preliminary account of these results has already been reported (Kellermann et al., 1983) and a more detailed description will be discussed elsewhere.

The new observations differ from previous studies of optically selected quasars in several ways.

(1) It is based on a sample which is optically complete to a average limiting B magnitude of 16.16.
(2) The sample consists of the optically brightest quasars.
(3) The typical redshift is small, with a median value of only $z = 0.19$.
(4) The limiting radio flux density is well below that of other surveys of optically selected quasars.

Thus, for the two-thirds of the objects with $z < 0.3$ the limiting flux density of 0.25 mJy corresponds to a monochromatic luminosity about 10^{22} WHz/Hz, whereas most previous radio observations were less sensitive by several orders of magnitude. Moreover, since the BQS objects are among the brightest quasars in the sky at optical wavelengths, the low limiting radio flux density corresponds to a ratio, R, of radio to optical flux density, S_r/S_o of 0.2 even for

B = 16. The new radio data, together with the previous radio searches listed in Table 1, help to determine the distribution, Ψ(R), and its dependence ón optical luminosity and cosmological epoch.

We have been able to detect 73 (79%) of the 92 BQS quasars with M < -23; 32 (97%) out of the 33 of objects with z < 0.5, but only 13 (59%) of 22 of those with z > 0.8. As suggested by previous observers, the detection rate apparently depends on optical magnitude. For the 44 quasars with B < 15.5, we detected 39 (89%); whereas for the 48 quasars, faint quasars with B > 15.5, we detected only 28 (63%) above 0.25 mJy.

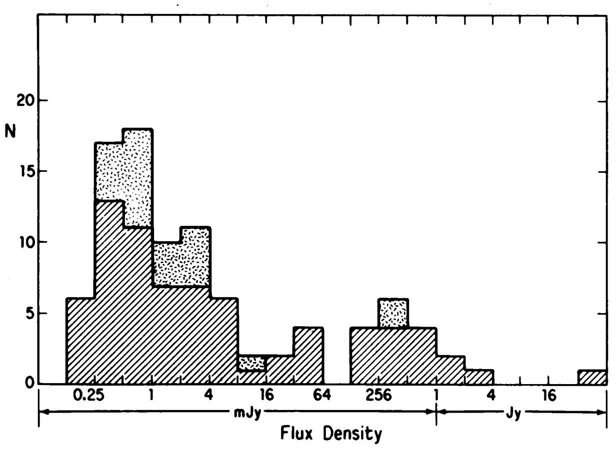

Figure 1. The distribution of radio flux density of the 94 detected BQS objects. The 73 quasars with M < -23 are shown with diagonal shading, while the 21 objects with M > -23 are shown with stippled shading.

In Figure 1 we show the distribution of observed flux density for the detected quasars. The distribution is unusual, in that there is a small fraction (17%) which are relatively strong with observed flux density greater than 100 mJy. These are the "radio loud" population which has been observed in previous radio observations of optically selected quasars, and which are normally found in radio surveys. In the range 10 < S < 100 mJy the number of radio detections increases only slightly, in agreement with previous surveys. But for S < 10 mJy, the numbers increase rapidly, and 67 (72%) of the 92 quasars have a total flux density greater than 0.25 mJy. The distribution of radio flux density is clearly bimodal. The presence of a separate radio loud population is shown clearly in the distribution of S_r/S_o illustrated in Figure 2. For the radio loud population the radio flux density is 1000 times greater than at optical wavelengths, but for the "radio quiet" population the radio and optical flux density is equal to within a factor of 10. Even for the non-detections, the observed radio limits are not extreme and do not require that the radio flux density be less than 10% of the optical flux density.

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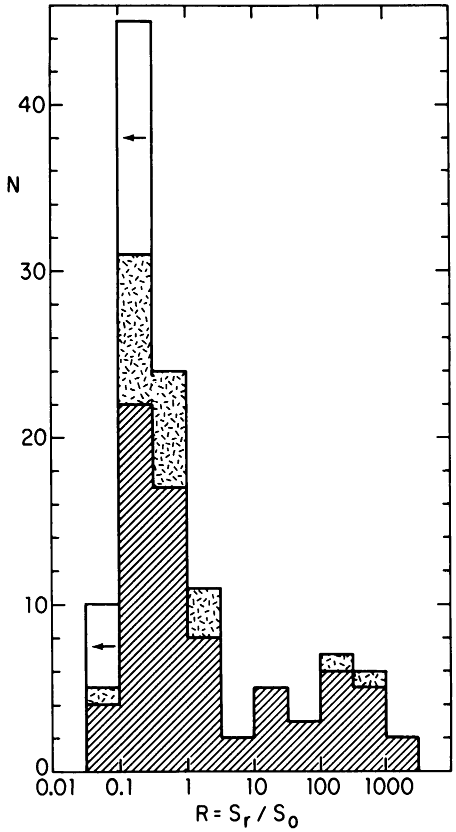

Figure 2. Distribution of S_r/S_o. Shading as in Figure 1.

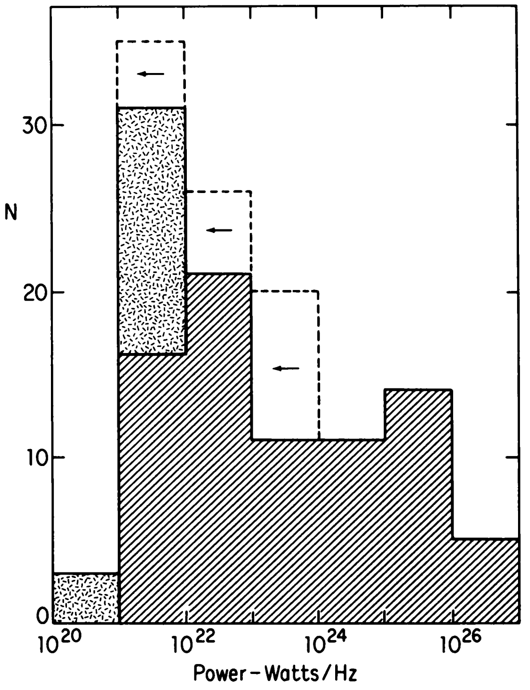

Figure 3. The distribution of 6 cm absolute monochromatic luminosity and upper limits for the BQS objects. Shading as in Figure 1.

The distribution of absolute radio luminosity for all objects in the BQS is illustrated in Figure 3, which shows that the detected quasars have radio luminosities in the range 10^{20} to 10^{27} WHz, essentially the same range covered by radio galaxies. The non-detections correspond to a typical upper limit between 10^{21} and 10^{24} WHz^{-1}, a value equivalent to weak radio galaxies or Seyfert galaxies. The objects with $M > -23$, all have radio luminosities at the low end of the distribution between 10^{20} and 10^{22} WHz^{-1}.

III. SUMMARY AND CONCLUSIONS

The fraction of BQS quasars detected as radio sources depends on apparent magnitude and redshift, but apparently not on absolute magnitude. The observed radio luminosity has a range roughly equivalent to that of radio galaxies. A small fraction, between 15 and 20 percent are anomalously strong radio sources, with most of their radio emission coming from extended regions well removed from the quasar, and with radio flux density up to 1000 times greater than the optical flux density.

The bimodal distribution of radio luminosity is clearly not consistent with the simple interpretation of radio loud quasars being those with relativistic beams oriented toward the observer. For the weak source population, however, the numbers do increase in a manner roughly consistent with the beaming model. If the detection rate were to continue to increase below 0.25 mJy, in the way calculated from beaming, then essentially all of the quasars should be detected above 0.15 mJy. However, for the 20 quasars we have not detected, we measure an average flux density of only 8 ± 17 micro Jy. These may be truly "radio silent" quasars.

The beam model predicts that the stronger sources, (i.e., those with beams oriented along the line of sight) should contain a relatively larger fraction of their flux density in the Doppler boosted core, whereas the weaker sources with beams oriented more in the plane of the sky, should be dominated by the extended component. Our high resolution observations, however, show no dependence of the core fraction on total flux density for the sample with $S < 100$ mJy.

Relativistic effects may be important in quasars, and indeed the preponderence of superluminal motion in nearly all well-studied quasars suggests that this is indeed true (e.g., Porcas, 1986). However, the distinction between radio loud and radio quiet or radio silent quasars apparently depends primarily on intrinsic effects as well as possibly geometry.

REFERENCES

Bolton, J. G. 1977, IAU Symposium No. 74, D. Jauncey ed., page 85.
Condon, J. J., O'Dell, S. L., Puschell, J. J., and Stein, W. A. 1981, Ap. J. 246, 624.
Fanti, C. et al. 1977, Astron. and Astrophys. 61, 487.
Kellermann, K. I., Sramek, R., Shaffer, D., Schmidt, M., and Green, R. 1983, Proceedings of 25th Liege Symposium, page 81.
Porcas, R. 1986, this volume , p.131.
Scheuer, P.A.G. and Readhead, A.C.S. 1979, Nature 277, 182.
Schmidt, M. and Green, R. F. 1983, Astrophys. J. 269, 352.
Shaffer, D. B., Green, R. F., and Schmidt, M. 1982, IAU Symp. 97, page 367.
Smith, M. G. and Wright, A. E. 1980, MNRAS, 191, 871.
Sramek, R. A. and Weedman, D. W. 1980, Astrophys. J. 238, 435.
Strittmatter, P. A. et al. 1980, Astron. and Astrophys. 88, L12.

https://doi.org/10.1017/S0074180900152374 Published online by Cambridge University Press

DISCUSSION

Wampler : Could the gap between the brighter radio sources in the BQS and the fainter radio objects be caused by the apparent insenstivity of the BQS to quasars with $z \sim 0.5$?

Kellermann : I do not think so. The radio luminosity distribution is so broad (a range of 10^5) that a gap of even a factor of two in the red-shift distribution would be washed out in the flux density distribution.

Kembhavi : If you convolve the distribution of L_R/L_{opt} with optical quasar counts, it should be possible to predict the quasar content of 6 cm source counts at very low fluxes. Has this been done ?

Kellermann : In principal what you suggest is true, but the strong radio quasars, which dominate the quasar component of the radio source counts are only weakly represented in the BQS sample, so the predictions will be subject to large statistical uncertainties. Conversely, while most BQS objects have a 6 cm flux density $\lesssim 1$ mJy, radio source surveys at this flux level contain few, if any quasars. It will be more productive, I think, to work with both the ratio of L_R/L_{opt} of the BQS sample which is dominated by quasars of relatively low radio luminosity, and the quasar radio number counts to derive the best fitting values of the local luminosity function and its spatial evolution. We plan to do this.

Swarup : What are the typical scale sizes of extended structures seen for quasars with $S_{5GHz} \lesssim 10$ mJy ?

Kellermann : There are a few sources with $1 < S_5 < 10$ mJy with angular sizes in the range $30 < \theta < 60$ arcsec, but for $S < 1$ mJy the overall sizes appear to be less than 20" in most cases.

Cohen : In the bimodal distribution, (a) The weak ones are consistent with a beamed population. What can you say about the strong ones ?
(b) The weak and strong ones have both small-scale and extended emiss-ion. Are there systematic morphological differences ?
(c) Very strong ones (3C273, 3C345, etc.) have steep spectrum outer components. Do you get a bimodal distribution if you use only cores (S within 0"5) ? Would you get a bimodal distribution with fluxes measured at $\lambda = 1$ cm ?

Kellermann : a) The strong (radio loud) quasars appear to be anomalous. They have a large ration of L_r/L_o (100 to 1000). Since they are lobe dominated, it is unlikely that they are affected by relativistic beaming.
b) Not obviously, but we really do not have enough structural infor-mation to say much. At low resolution (18") many of the sources are only barely resolved, while the high resolution (0"5) data resolves out all of the extended structure.
c) No. The core fluxes are nearly uniformly distributed in flux den-sity, with a slight excess of weak sources. There is no evidence for

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"strong" compact component such as we see for the "extended" components. The ratio L_r/L_o for the cores is about unity-within a factor of 10, so there is no evidence that the compact radio flux is dominated by beaming effects.

Kühr : Among the somewhat stronger radio sources (e.g. S > 100 mJy) we see different distributions in the differential source counts for flat and steep radio spectra objects; is this effect also found in your faint flux density (e.g. S < 100 mJy) sample ?

Kellermann : We do not have spectral information except for the "radio loud" population which is roughly equally divided between "flat" and "steep" spectra. Our structural data on the weaker radio quasars suggest that these are also roughly equally divided between lobe dominated and core dominated sources.

Segal : In the context of a temporarily homogeneous, spatially spherical, space-time model, there is a natural, simple explanation for the discontinuity between the compact flat spectrum sources and the extended steep spectrum sources. Sufficiently long-lived sources should be observable in opposite directions, providing both a primary (short-path) and a secondary (longer-path) image, - which would be expected to have a flatter spectrum (at least in the specific case of the chronometric cosmology). Can your observations invalidate this explanation ?

Kellermann : No.

H.J.Smith : Jim Douglas and Arakel Bozyan are testing for the presence of antipodal objects in Douglas 'Texas Radio Source Catalog (source positions accurate to about ±1 arcsec). So far they find, among the 52,000 sources in the 7.8 sterradians lying in the range ±35° declination, no significant increase of antipodal coincidences over chance expectations (but they also note that sufficiently large random walks in the positions, from light bending in the gravitational fields of intervening galaxies, could preclude reliable detection of antipodal sources).