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HOMOGENEITY OF BRIGHT RADIO SOURCES AT 15 GHz ON THE SKY AND IN SPACE

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Abstract. A revised sample of the 2 cm Very Long Baseline Array (VLBA) survey is studied to test the isotropic distribution of radio sources on the sky and their uniform distribution in space. The sample is complete to flux-density limits of 1.5 Jy for positive declinations and 2 Jy for $0° > \delta > -20°$. At present the sample contains 122 flat-spectrum AGNs (99 confirmed members and 23 candidates). The application of the two-dimensional Kolmogorov-Smirnov (K-S) test shows that there is no significant deviation from a uniform distribution in the sky, while the $V/V_{\rm max}$ test shows that the space distribution of active nuclei is not uniform at high confidence level (99.9 %). There is a significant positive evolution of flat-spectrum quasars at low-redshifts ($z<0.5$) and negative evolution at redshifts $z>1.7$ with space density decline up to $z\sim2.5$. This implies that the powerful jets were more populous at redshifts between 0.5 and 1.7.

Key words: surveys – quasars: general – galaxies: active, nuclei, jets – BL Lacertae objects: general

1. INTRODUCTION AND THE SAMPLE

The original 2 cm survey sample (Kellermann et al. 1998 and Zensus et al. 2002) was selected from the Stickel catalog (Stickel et al. 1994) with the aim of including flat-spectrum, core-dominated active galactic nuclei with spectral indices > -0.5. This sample was enlarged by adding some sources of special interest, such as steep spectrum sources, a few lobe-dominated sources and GHz-peaked spectrum sources. The 2 cm sample is being used to study the morphology of compact radio sources, their variability and jet kinematics. To investigate statistically significant correlations between the jet parameters, to compare theoretical predictions of relativistic beaming model, it has been necessary to define a complete flux-density limited sample. The revised sample consists of 122 AGNs (see, e.g., Zensus et al. 2003). The main selection criterion is the flux-density limit at 15 GHz: all variable sources with galactic latitude $|b| > 2.5°$ and with measured VLBA flux densities exceeding 1.5 Jy (2 Jy for southern sources) at any epoch since 1994 are included in the sample. All 122 AGNs are radio-loud and core-dominated. Most of them have superluminal radio jets on parsec-scales. At present there are 99 members and 23 candidates. Among members there are 73 quasars, 14 BL Lacs, 7 radio galaxies and 5 sources with no optical counterparts. All AGNs except 0642+449 ($z = 3.41$) have redshifts less than 2.43.

Since this sample is a subsample selected from the Stickel catalog, it is important to understand what selection effects it might contain. Here we describe preliminary study of the sample of 99 AGNs to test their distribution on the sky and in space.

2. SKY DISTRIBUTION

If the sample of radio sources is free from selection effects, then we should expect that radio sources are distributed uniformly in the sky. The distribution of the 99 member AGNs on the celestial sphere is shown in Figure 1.

The distribution of radio sources looks patchy with a few clusters and voids in the sky. We also generated 99 points randomly distributed in the same region of the sky and saw that for small number of random points there are modest clusterings and voids as seen in the real data. To confirm this result we performed two dimensional K-S test to test the consistency of the coordinates of sources with the coordinates of uniformly distributed points on the sphere. No significant deviation between data and model is found for any redshift bin.

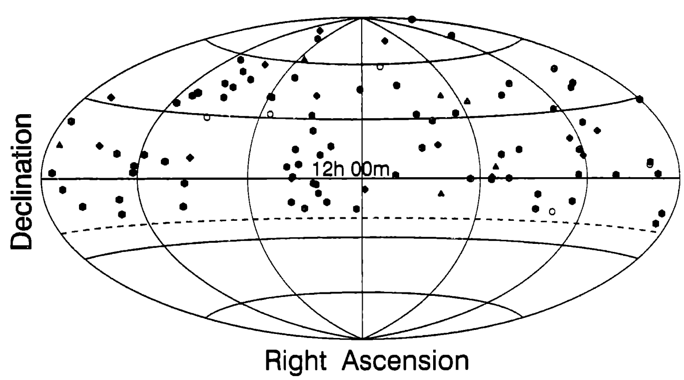

Fig. 1. The filled circles, diamonds and triangles are quasars, BL Lacs and galaxies, and open circles are sources with no optical counterparts.

If sources are randomly distributed in the sky, then the right ascensions will be uniformly distributed and declinations will be $\sin(\pi/2 - \delta)$ distributed. The one-dimensional K-S test does not show significant deviation of the declinations from the expected distribution. One interesting result comes for the distribution of right ascensions of 15 sources between $1.3 < z < 2$: there is a clustering of 14 sources between $03^{\rm h} < \alpha < 15^{\rm h}$, so, the uniform distribution can be rejected at high, 99.92 %, confidence level. The non-uniform distribution is still significant for 24 sources with $z > 1.3$, but since this result is based on small number statistics, it can only be taken as a provisional conclusion.

3. SPACE DISTRIBUTION

We use the generalized and banded versions (Avni & Bachcall 1980; Avni & Schiller 1983) of $V/V_{\rm max}$ statistics (Schmidt 1969) to test the null hypothesis of a uniform distribution of AGNs in the space and to trace their evolutionary behavior with cosmic epoch.

The distribution of $V/V_{\max}$ (Avni & Bahcall 1980) for 88 AGNs with redshifts is presented in Figure 2. For quasars, the distribution is not uniform at high confidence levels (see Table 1), and it is biased towards large $V/V_{\max}$ which indicates that quasars, and hence the jet activity phenomena, were more populous at high redshifts. The BL Lacs show a similar trend but this is not statistically significant because of the small number of sources. The distribution seems to be uniform for nearby radio galaxies, i.e., with no luminosity/density evolution. The plausible explanation is that all seven radio galaxies occupy the low redshift region where the density/luminosity evolution is negligible, but better statistics would be needed to confirm this result.

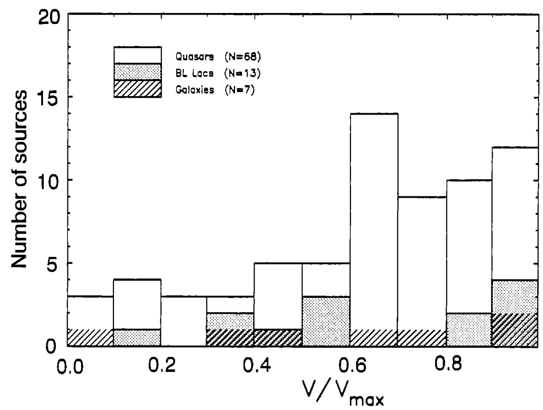

Fig. 2. The distribution of $V/V_{\max}$ for quasars, BL Lacs and galaxies.

Table 1. $V/V_{\max}$ test for 88 AGNs ($H_0 = 70$ km s^{-1} Mpc^{-1}, $q_0 = 0.1$).

ID	Number	$\langle V/V_{\max}\rangle$	K-S (%)
QSO	68	0.64 ± 0.03	99.9
BL Lacs	13	0.64 ± 0.07	75
Galaxies	7	0.57 ± 0.12	16

The results are in agreement with the value of $\langle V/V_{\max}\rangle = 0.68 \pm 0.04$ for steep-spectrum quasars and radio galaxies (Longair & Scheuer 1970) having extended double structure from the complete 3CRR sample. Dunlop & Peacock (1990) studied the evolution of the radio luminosity function for extragalactic radio sources combining different flux-density limited, complete samples at 2.7 GHz from the literature. They conclude that both the steep- and flat-spectrum radio sources show the same form of evolutionary behavior: radio luminosity function of quasars and radio galaxies displays positive luminosity evolution out to $z \sim 2$, and it declines at high redshifts.

To investigate the evolutionary behavior of quasars at high redshifts, we used the banded version of the $V/V_{\max}$ test (Avni & Schiller 1983) which allows us to mask out evolutionary effects at high redshifts. For quasars, a weak positive evolution is seen at low redshifts, $z<0.5$, while a negative evolution becomes significant for quasars with $z>1.7$, and it remains significant out to $z\sim2.5$ at which only a few sources can be found. This result is in agreement with the high-redshift cut-off of flat-spectrum quasars found by Dunlop & Peacock (1990) for the combined sample of quasars at 2.7 GHz.

The main results of this analysis are: (a) the distribution of 99 AGNs is uniform on the sky; (b) the strong positive evolution of flat-spectrum quasars is significant at low-redshifts, $z<0.5$, no-evolution is seen between $z\sim0.5$ and $z\sim1.7$, and a statistically significant redshift cut-off is present at $z\geq1.7$ with space density decline up to high redshifts, $z\sim2.5$.

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