MILLIARCSECOND SCALE COMPACTNESS OF EXTRAGALACTIC RADIO SOURCES AT COSMOLOGICAL DISTANCES

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ABSTRACT

A combination of VSOP pre–launch survey data and our own observations of extremely high redshift quasars provides a data base for studying structural properties of radio–loud quasars as a class of objects. We concentrate our attention on analyzing the compactness of the sources as a function of their redshift (and therefore the emitting frequency) as a precursor to the use of milliarcsecond scale structures of AGN as a cosmological standard rod. Data from the VSOP Survey program, as well as additional VSOP observations of the most distant quasars will enable us to conduct a similar study on sub–milliarcsecond angular scale in the near future.

INTRODUCTION

Radio–loud active galactic nuclei (AGN) populate the widest redshift range available for the present–day astronomical techniques. The increasing number of compact AGN observed with ground–based VLBI in the past few years led to promising attempts to use milliarcsecond scale structures as "standard" objects for constraining cosmological parameters (see Gurvits *et al.* 1998b, and references therein). An interesting question in these studies is whether these AGN can indeed be considered as more or less "standard" objects over the observed wide range of redshifts. Recently we studied VLBI images of 151 quasars in the redshift range $0.2 < z < 4.5$. We concluded that the observed average increase in the source compactness with increasing redshift is not in contradiction with the assumption of objects with intrinsically "similar" spectral properties (Frey *et al.* 1997, Frey & Gurvits 1997). Here we analyze another, somewhat larger sample of 191 quasars using a similar method, and come to a numerical estimate of jet and core spectral index difference which is in agreement with earlier results. We also emphasize that the VSOP Survey program data, combined with data from VSOP imaging experiments at 5 GHz will constitute a unique data base for studying quasar structural properties on sub–milliarcsecond scale.

THE SAMPLE

We used 5 GHz VLBI imaging observations of 175 sources classified as quasars with known redshifts from the VSOP pre–launch continuum survey (Edwards & Fomalont 1998). The pre–launch survey was conducted on 5-6 June 1996 with the NRAO Very Long Baseline Array (VLBA), correlated at Socorro, edited and calibrated with the AIPS package and imaged with the Difmap program. The typical dynamic ranges achieved with the 150 s snapshot observations were 500:1 to 100:1 (Fomalont *et al.* 1998b). The redshift distribution of the sources in the sample is shown in Figure 1. Most of the redshifts were taken from Véron-Cetty & Véron (1996). Since the highest redshift part of the distribution was sparsely populated we included 16 more quasars at extremely high ($z > 3$) redshifts in the sample. These sources were observed in our on–going program to image $z > 3$ quasars with ground–based VLBI at 5 GHz (Gurvits *et al.* 1992, 1994; Frey *et al.* 1997; Paragi *et al.* 1998) and are indicated with different column type in Figure 1. As a consequence, the overall redshift range in the sample is $0.16 < z < 4.72$, which allowed us to better represent the most distant quasars in the subsequent analysis.

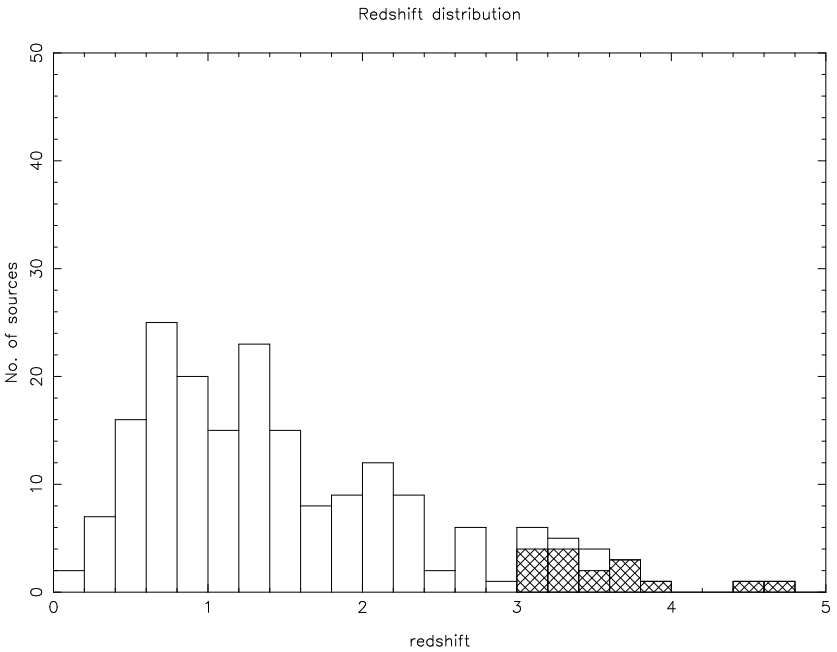

Figure 1: Redshift distribution of the 191 quasars used in the analysis. The 16 sources at $z > 3$ added to the pre–launch survey sample are indicated with cross–hatched columns at the high redshift end of the diagram.

DATA ANALYSIS

In order to quantitatively characterize the "compactness" of the sources, we determined the flux density ratio of the brightest "jet" component and the "core" (S_j/S_c) for each source. Component flux densities were the result of a model fitting procedure in Difmap. We adopted a 15 pc linear size threshold to distinguish between core and jet. A linear size of 15 pc corresponds to ~ 2.4 mas angular size at redshifts higher than ~ 1 and thus represents an average angular resolution of the VLBA images (values of $H_0 = 80$ km s^{-1} Mpc^{-1} and $q_0 = 0.2$ were used to convert linear size to angular size). The brightest component inside this central region was attributed to be the core. Extended components further away than 15 pc from the field center were considered to be part of the "jet". In the cases where no jet component was detected, an upper limit of S_j was determined, based on the image noise and the restoring beam size.

Assuming that the radio spectrum of the source components follows a power law with $S \propto \nu^{\alpha}$, and the spectral properties of quasar cores and jets are similar over the observed redshift range, one can estimate the average spectral index difference between jets and cores using

$$S_j/S_c \propto \nu_{em}^{\alpha_j - \alpha_c} \tag{1}$$

where α_j and α_c are the spectral indices of the jet and core respectively. The emitting frequency ν_{em} is related to the observed frequency ν_{obs} by $\nu_{em} = \nu_{obs}(1+z)$. In our sample 5.8 GHz$\leq \nu_{em} \leq$28.6 GHz.

RESULTS AND DISCUSSION

The best least squares fit using Eq. 1 and the measured jet to core flux density ratios for the 191 sources gives $\alpha_j - \alpha_c = -0.38 \pm 0.36$. This value is close to -0.55 ± 0.43 obtained by Frey et al. (1997), and consistent with an overall picture of having generally less prominent jets at higher redshifts. The best fit curve and the data grouped into 10 bins are displayed in Figure 2. Note that if we do not supplement the pre–launch survey sample with our extremely high redshift sub–sample the trend seems to be less pronounced, leading to an estimate of $\alpha_j - \alpha_c = -0.16 \pm 0.43$. This indicates that, on average, quasars with extremely high redshifts ($z > 3$) do indeed appear to be very compact in VLBI images made at $\nu_{obs} = 5$ GHz. The apparent "compactness" of the closest quasars in the sample may be connected with the fact that the sample is essentially flux density limited. This leads to a luminosity selection effect. Sources at very low ($z < 0.5$) redshifts have 2 to 3 orders of magnitude lower luminosity than those at high redshifts.

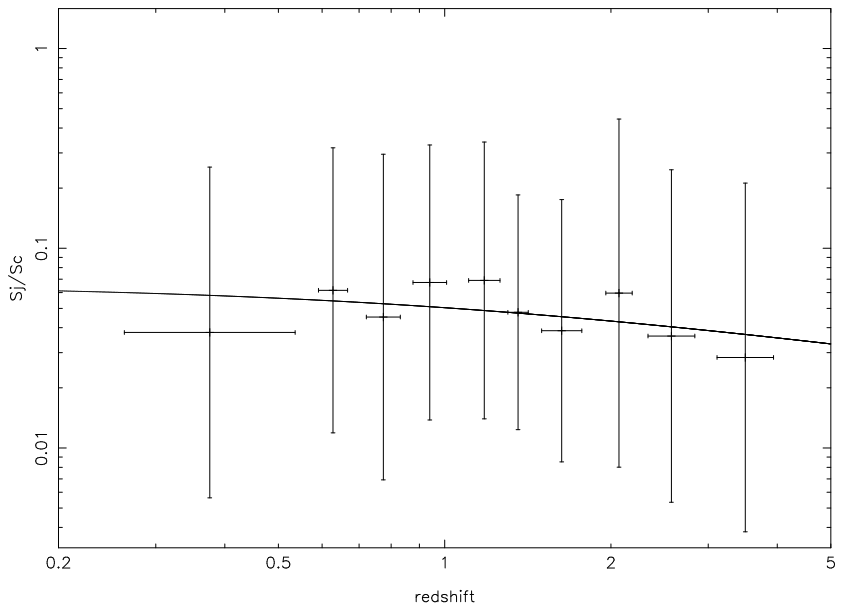

Figure 2: Median jet to core flux density ratio versus redshift. Data for 191 quasars are grouped into 10 bins containing 19 (in one case 20) sources. Error bars indicate standard deviation within each bin. The solid curve represents the best fit, calculated using unaveraged data.

CONCLUSIONS

We used the VSOP pre–launch continuum VLBA survey data at 5 GHz, supplemented with our VLBI data on extremely high redshift sources, to study the milliarcsecond scale structures of quasars at different redshifts. We conclude that quasars generally appear to be more compact at higher

redshifts, especially at $z > 3$, at a fixed observed frequency. This may be explained by a simple fact that jet spectra tend to be steeper than core spectra in quasars. This results in fainter jet components with respect to cores as the redshift, and thus the emitting frequency, increases at a constant observing frequency.

VSOP Survey program (Fomalont *et al.* 1998a) includes 5 GHz observations of many of the strongest sources detected in the pre–launch VLBA survey. Together with 5 GHz imaging experiments of the most distant quasars (e.g. Gurvits *et al.* 1998a), this will eventually constitute a unique sample for similar and more sophisticated statistical studies. With the inclusion of the Earth–space baselines to the HALCA satellite the achieved angular resolution will allow us to study sub–milliarcsecond scale structures at 5 GHz, and compare the results with those obtained using ground VLBI.

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