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Intrinsic Properties of High and Low Power Radio Sources and Unified Scheme Models

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Abstract. We present VLBI data on 46 objects of a new sample of radio sources selected from the B2 and 3CR catalogues, with $z < 0.1$. Using these data we investigate the parsec scale morphology of radio sources with different radio power and kpc scale morphology. We stress the evidence for high velocity pc scale jets in all sources and conclude that the properties of parsec scale jets are similar regardless of the source total power and large scale morphology.

1. Introduction

The study of the parsec scale properties of radio galaxies is crucial to obtain information on the nature of their central engine, and provides the basis of the current *unified theories* (see e.g. Urry & Padovani 1995), which suggest that the appearance of active galactic nuclei strongly depends on orientation. In the *high-luminosity unified scheme*, quasars and powerful FR II radio galaxies are suggested to be the same class of objects but seen at different viewing angles. Similarly, the *low-luminosity unified scheme* assumes BL-Lacs to be the beamed population of radio galaxies of low-intermediate luminosity (FR I).

To get new insight in the study of radio galaxies at pc resolution, it is important to select source samples from low frequency catalogues, where the source properties are dominated by the unbeamed extended emission and are not affected by observational biases related to orientation effects.

To this aim, we undertook a project of observations of a complete sample of radio galaxies selected from the B2 and 3CR catalogs (Giovannini et al. 1990; Giovannini et al. 2001). However, because of obvious observational reasons at the time of the sample selection, we selected radio sources with a relatively high core flux density limit (> 100 mJy at 6 cm). This results in a selection effect in favor of objects with a beamed core i.e. oriented at a small angle with respect to the line of sight. We will refer to it as the *Bologna Strong Core Sample* (BSCS).

For this reason we recently selected a **second sample** with all the B2 and 3CR radio sources present in the same sky region of the first sample (see Giovannini et al. 1990), with z < 0.1 (i.e. no constrain on the core flux density): the *Complete Bologna Sample* (CBS). This sample consists of 95 sources and includes all the sources of the BSCS except 3C109, 3C 303, and 3C 346 because of the redshift limit. At present 46 on 95 sources have been studied with VLBI observations. Here we will discuss preliminary results using data from these sources.

We use a Hubble constant $H_0 = 50$ km sec^{-1} Mpc^{-1} and a deceleration parameter $q_0 = 0.5$

2. Observations and source morphology

We obtained VLBI observing time to image sources with no information on their pc scale properties. Observations were made with the full VLBA and one VLA telescope[1] at 5 GHz on April 4, 1997 (12 hours of observing time) and on January 22, 2000 (24 hours of observing time). Each source was observed for about 1 hour with short scans at different hour angles to ensure a good uv-coverage. The observing data have been correlated in Socorro, NM. Postcorrelation processing used the NRAO AIPS package. All data were globally fringe fitted and then self-calibrated. Final images were obtained using the AIPS and DIFMAP. Adding to these new observations, data available in the literature, we have 46 sources with a good VLBI image to study their pc scale properties.

In Fig. 1 we show a plot of the observed core radio power versus total radio power for the BCS sources with available VLBI data. The line represents the correlation found by Giovannini et al. (1988), revised according to Giovannini et al. (2001). Sources show the well known dispersion around the straight line since the observed core radio power is affected by the source orientation angle. Most points are on the upper side with respect to the correlation line since observations are available only for ~ half of the BCS sources and sources with a higher core flux density are usually preferred in observing schedules.

Among the observed sources we have:

- 28 FR I radio galaxies
- 8 extended, steep spectrum FR II radio galaxies
- 7 Low Power Compact sources with a flat spectrum

[1]VLBA and VLA are operated by NRAO as a facility of the NSF, operated under cooperative agreement by Assoc. Universities, Inc.

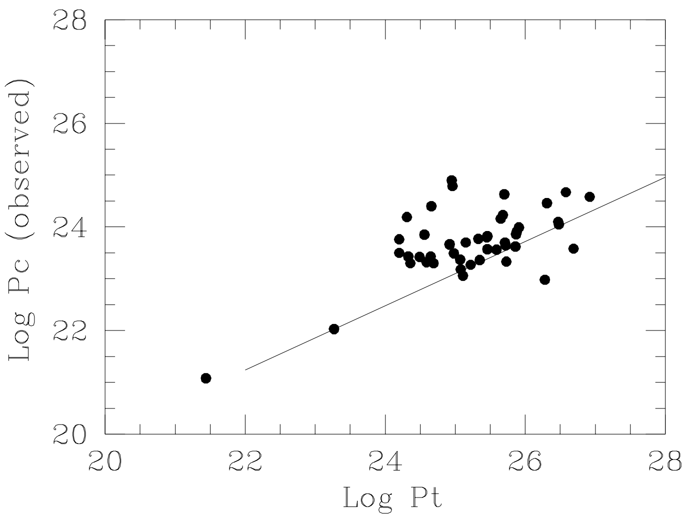

Figure 1. Total radio power at 408 MHz versus the measured arcsecond core radio power at 5 GHz for VLBI observed sources of the BCS. The straight line represents the correlation between the core and total radio power found by Giovannini et al. (1988).

- 2 Bl-Lac objects and 1 Compact Symmetric object (CSO)

2.1. Parsec – kiloparsec scale comparison

In all sources but 1316+29, we find a good agreement between the pc and kpc scale: the jet position angle and the sidness of the main jet with respect to the core, are the same. In the source 1316+29 we found a symmetric two-sided structure on the parsec scale misaligned of about 90° with respect to the kpc scale jet (which show a complex structure). More data will be necessary to properly study this source.

Parsec scale structures are mostly one-sided because of relativistic Doppler boosting effects. However, some sources within the CBS have faint cores because of Doppler–deboosting implying that are observed at sufficiently large angles to the line of sight that counterjets are also visible (see e.g. 3C 33 in Fig. 2).

A few complex sources have been found. An example is NGC 4278 (Fig. 3), a low power compact source where all the radio emission originates in a source $\sim$ 1 pc in size well resolved in our VLBA image.

3. Parsec scale jet velocity

There are several strong and widely accepted lines of evidences for the existence of relativistic bulk velocities in the parsec scale jets of radio sources: the observed super-luminal motions, the rapid variabilities, the observed high brightness temperatures, the absence of strong inverse-Compton emission in the X-ray and the

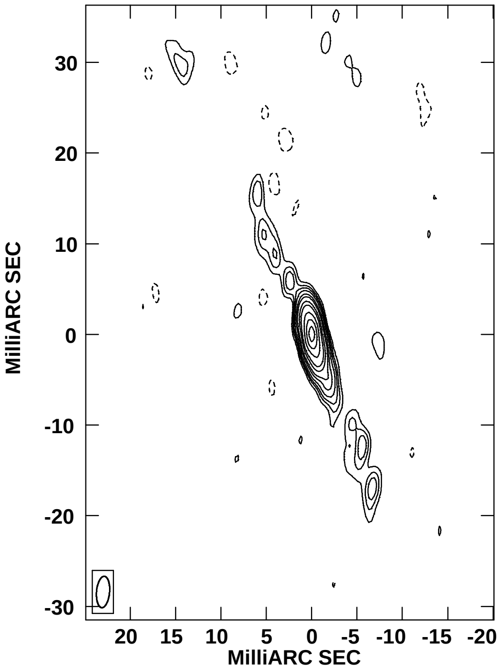

Figure 2. VLBA image of the narrow line FR II galaxy 3C33, at 5 GHz. Parsec scale jets are oriented as the extended kpc scale structure.

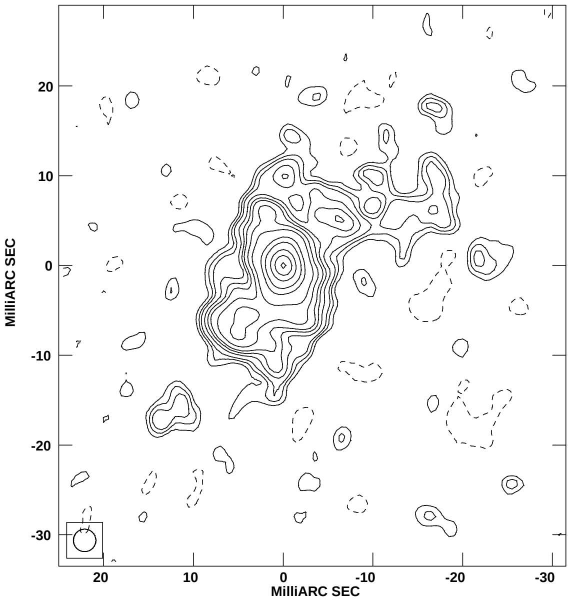

Figure 3. VLBA image at 5 GHz of NGC 4278. For this source 1 mas corresponds to 0.06 pc.

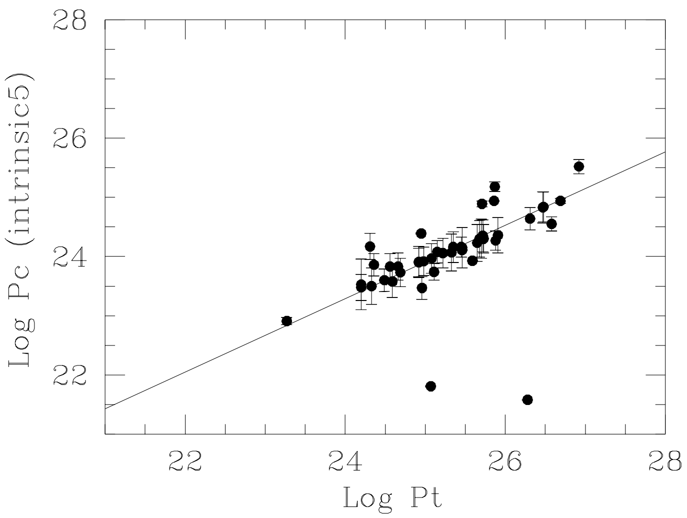

Figure 4. Total radio power at 408 MHz versus the intrinsic core radio power at 5 GHz derived with $\gamma = 5$, for observed sources of the second sample. The continuum line represents the correlation between the core and total radio power found by Giovannini et al. (1988).

detection of a high frequency emission (gamma ray) for the two BL-Lacs Mkn 421 and 501 all seem to require relativistic bulk speeds with Lorentz factor (γ) > 3.

We used the observational data to constrain the jet velocity and orientation. The methods used were the jet sidedness and the core dominance (see Giovannini et al., 2001 for a more detailed discussion), while for a few sources where a proper motion was reported in the literature, we assumed that the bulk and pattern jet velocity have comparable values.

The derived constraints confirm that in all sources radio jets move at high velocities on the mas scale. Since in many cases we can only give a lower limit to γ, we used the following approach: we assumed different γ values and we tested if the derived source properties are in agreement with the observational data. Once a jet velocity is assumed, the jet orientation is constrained by the observational data and it is possible to compute the corresponding Doppler factor $\delta = (\gamma(1 - \beta cos\theta))^{-1}$ for each source. Then, from the value of δ and of the measured radio power, we can derive the intrinsic core radio power for each source: $P_{c-observed} = P_{c-intrinsic} \times \delta^2$ (assuming $\alpha = 0$). Since there is a range of possible jet orientations, we have a possible range of values for δ and therefore of $P_{c-intrinsic}$.

We found that γ cannot be larger of 10, otherwise we should see a larger dispersion in the plot of the observed core radio power versus the total radio power with respect to the dispersion observed in Giovannini et al. (1988).

Moreover observational data exclude that γ could be smaller than 3. A too low value for gamma implies a too small Doppler factor correction and we still see the effect of different orientation angles in the distribution of core radio power. This is in agreement with the evidences of high velocity jets discussed at the beginning of Sect. 3.

Assuming $3 < \gamma < 10$ and plotting the intrinsic core radio power versus the total radio power, we find that all sources but two (M87 and 3C192), are in good agreement with the correlation line (see Fig. 4) and have a small dispersion around it, as expected since we removed the spread due to the different orientation angles. This result implies similar jet velocities ($\gamma = 5$ in Fig. 4) for all sources despite the variety of their large scale morphology and different total radio power. We remember that as shown in Giovannini et al. (2001) a correlation between the core and total radio power is expected if sources are in energy equipartition conditions.

The two discrepant points in Fig. 4 are the sources M87 and 3C192. Both radio galaxies have a too faint core radio emission with respect to the total radio power at 408 MHz. To have M87 in agreement with the other sources we need parsec scale jets moving at a much higher velocity than the other sources and/or an orientation angle larger than the angle derived from its high proper motion (see Giovannini et al. 2001). For 3C 192, even assuming that this source is on the plane of the sky, we need very high velocity parsec scale jets, alternatively we are observing a core in a low activity phase: if it is turning off, this source could be in a pre-relic phase

In conclusion preliminary observations of $\sim 50\%$ of sources belonging to the Bologna Complete Sample confirm the results obtained by Giovannini et al. (2001) studying the 26 radio sources of the BSCS. In particular we confirm that observational data imply similar jet velocities with γ in the range $3 - 10$ for all sources, despite of the variety of their large scale morphology and different total radio power. The observational differences on the large scale could be due to a different ISM on the pc scale. A denser ISM in low power radio sources could produce a stronger interaction with pc scale jets (two velocity structure) and a decrease in the jet velocity: FRI jets will become mildly relativistic after a few hundreds of parsecs and sub-relativistic within a few kpc. Conversely, jets in FR II sources suffering a smaller interaction with the ISM are mildly relativistic up to the hot spot region.

References

Giovannini, G., Feretti, L., Gregorini, L., Parma, P. 1988, A&A, 199. 73

Giovannini, G., Feretti, L., Comoretto, G. 1990, ApJ, 358, 159

Giovannini, G., Cotton, W.D., Feretti, L., Lara, L., Venturi, T. 2001, ApJ, 552, 508

Urry, C.M., & Padovani, P. 1995 PASP, 107, 803