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Parsec Scale Properties of Radio Sources

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Abstract. We present a new complete sample of radio sources selected from the B2 and 3CR catalogues, with no bias respect to the jet velocity and orientation. Using preliminary data we investigate the parsec scale properties 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. Moreover we show two epoch images of two nearby radio galaxies: a low power compact source and a CSO. The comparison of the two epoch images suggests that in both sources the size is increasing with time. We derive a possible advance speed and estimate their dynamic age.

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.

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. After the results presented in Giovannini et al. 2001, where we studied a sample of 26 radio galaxies with strong cores, we undertook a new project to observe a complete sample of radio galaxies selected from the B2 and 3CR catalogs with z < 0.1 and no limits on the core flux density: the *Complete Bologna Sample* (CBS). This sample consists of 95 sources and includes 23 of the 26 sources studied in Giovannini et al., 2001 (3C109, 3C 303, and 3C 346 are excluded because of the redshift limit). We observed with the VLBA 31 more sources allowing us to discuss preliminary results using data from 54 on 95 sources.

Moreover we present observations at two different epochs (5 yrs apart) of two peculiar sources of this sample to study their possible expansion velocity and to derive their dynamical age.

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 observed at 5 GHz with the full VLBA and one VLA telescope[1] 31 sources from our sample to properly image the parsec scale structure. 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 packages.

In Fig. 1 we show a plot of the observed core radio power versus total radio power for BCS sources. 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 sources with VLBI data 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 have been observed so far.

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. This implies that they are oriented at sufficiently large angles to the line of sight so that counterjets are visible (see e.g. 3C 33 in Fig. 2).

3. Parsec scale jet velocity

There are several strong and widely accepted lines of evidence for the existence of relativistic bulk velocities in

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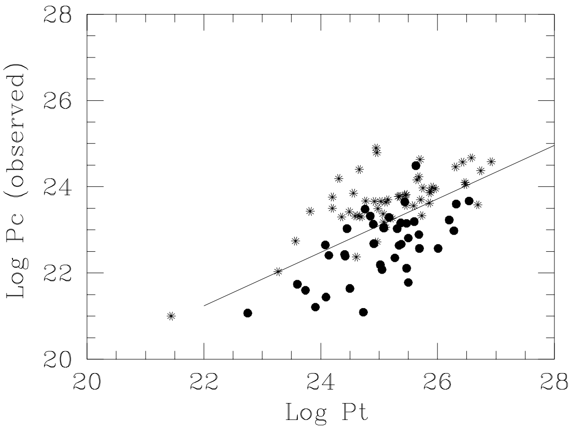

Fig. 1. Total radio power at 408 MHz versus the measured arcsecond core radio power at 5 GHz for sources of the BCS. Asterisks represent sources with VLBI data. The straight line represents the correlation between core and total radio power (Giovannini et al. 2001).

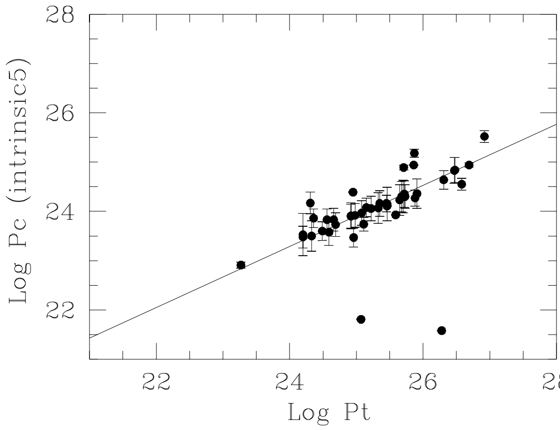

Fig. 3. Total radio power at 408 MHz versus the intrinsic core radio power at 5 GHz derived with $\gamma = 5$, for observed sources. The continuum line represents the correlation between the core and total radio power found by Giovannini et al., 2001. The two discrepant points refer to the sources M87 and 3C192 (see text).

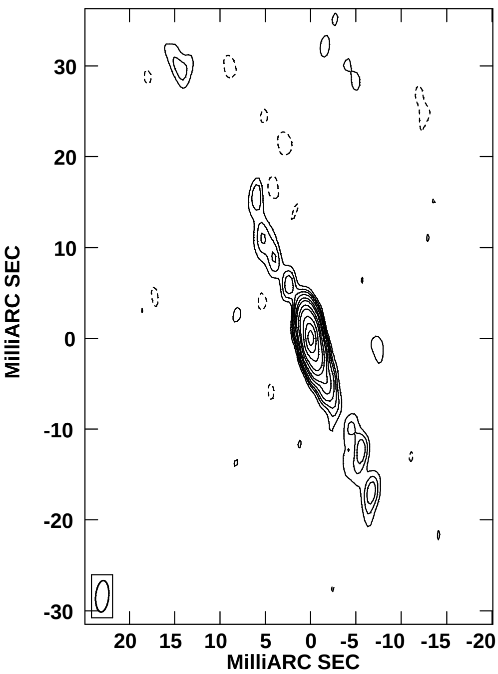

Fig. 2. VLBA image of the narrow line FR II galaxy 3C33, at 5 GHz. Parsec scale jets are oriented as the extended kpc scale structure. Noise level is 0.1 mJy/beam. Levels are: -0.3 0.3 0.5 0.7 1 1.5 2 3 4 6 8 10 mJy/beam.

the parsec scale jets of radio sources: the observed superluminal motions, the rapid variabilities, the observed high brightness temperatures, the absence of strong inverse-Compton emission in the X-ray and the 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 $\gamma > 3$.

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).

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: $P_{c-\mathrm{observed}} = P_{c-\mathrm{intrinsic}} \times \delta^2$ (assuming $\alpha = 0$). Since there is a range of possible jet orientations, we have a possible range of values for δ and therefore of $P_{c-\mathrm{intrinsic}}$.

We found that γ cannot be larger than 10, or we would see a dispersion in the plot of the observed core versus total radio power larger than reported in Giovannini et al., 1988 (see also Fig. 1).

Moreover observational data rule out values of γ lower than 3. Such low values imply too small Doppler factor corrections, and we still see the effect of different orientation angles in the distribution of core radio power. This is in agreement with the evidence of high velocity jets discussed at the beginning of this Section.

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. 3) and have a small dispersion around it, as expected since the spread due to the different orientation angles is removed. This result implies similar jet velocities ($\gamma = 5$ in Fig. 3) for all sources despite the variety of their large scale morphology and different total radio power. We remind that a correlation between the

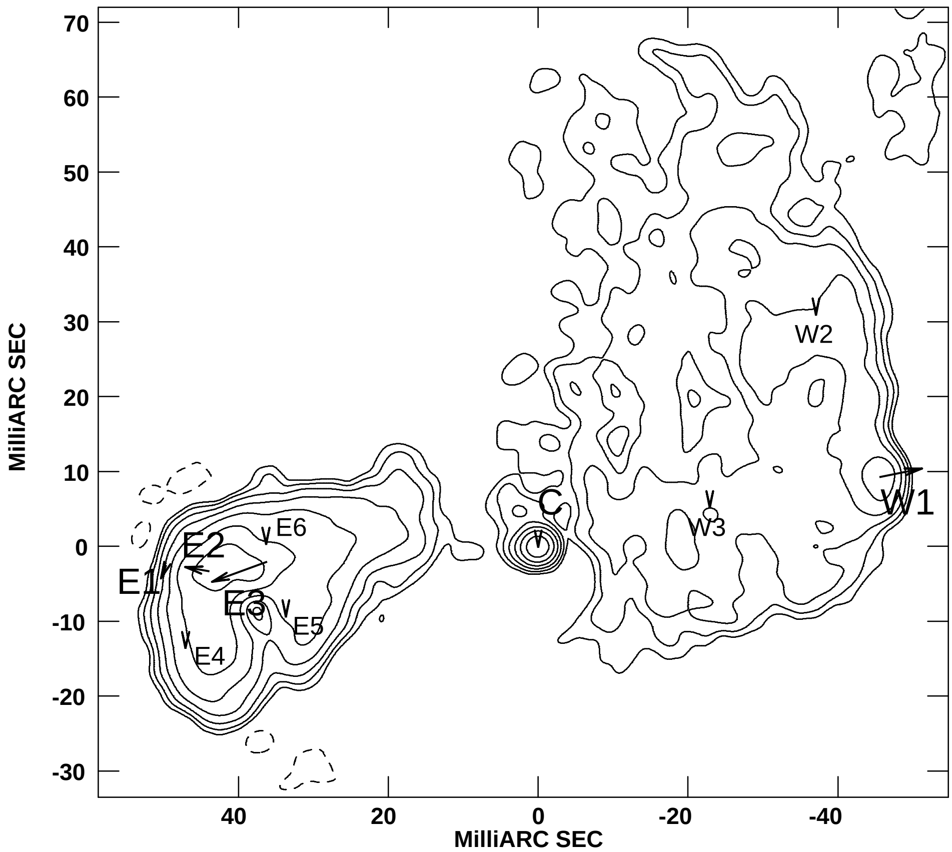

Fig. 4. VLBI image of 4C31.04 at 5 GHz, July 2000 epoch. The HPBW is 3 mas, the noise level is 0.1 mJy/beam. Levels are: -0.4 0.4 0.8 1.6 3.2 6.4 12.8 25.6 mJy/beam. The peak flux is 40 mJy/beam. Arrows indicate the positions and motions of components derived from modelfitting, magnified by a factor 5. At the source distance 1 mas = 1.56 pc

core and total radio power is expected if sources are in energy equipartition conditions, as discussed in Giovannini et al. (2001).

The radio core of the two discrepant sources (M87 and 3C 192) is too faint with respect to their total radio power at 408 MHz. In order to shift M87 on the correlation 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.

Present data from 54 BCS sources confirm the results obtained by Giovannini et al. (2001) on the basis of a subsample of 26 radio sources. In particular we confirm that the observational data imply similar jet velocities, with γ in the range $3-10$ for all sources, in spite of the variety of their large scale morphology and different total radio power.

4. 4C31.04

The radio galaxy 4C31.04 (0116+31) was tentatively classified as a low redshift (z = 0.0592) Compact Symmetric Object (CSO) by Cotton et al., 1995. Conway (1996) showed the presence of a complex HI absorption across the lobes. A detailed optical study is given by Perlman et al. (2001). Giovannini et al. (2001) confirmed the CSO structure and the core identification with the faint flat spectrum component in between the two extended lobes. Here we present a second epoch observation of this source with the VLBA and one VLA telescope obtained on July 03, 2000, five years after the first epoch image at the same frequency.

The images at the two epochs were calibrated and reduced in the same way and were compared to look for proper motion. The two images are in very good agreement, and the same radio features are visible in both of them. We measured the position of several structures visible in the images with respect to the core using different methods, e.g. by model-fitting (DIFMAP), by fitting gaussian components with JMFIT (in AIPS) and by subtracting the second epoch image from the first one. In fig. 4 we show the final image at 5 GHz, July 2000 epoch, with superposed arrows, whose length is proportional to the apparent motion, derived from the comparison of the two epochs. Despite the low brightness complex structure of the two lobes, their expansion is well defined in the peaks and confirmed by the shift of the whole sharp edges (well visible in the *difference* image).

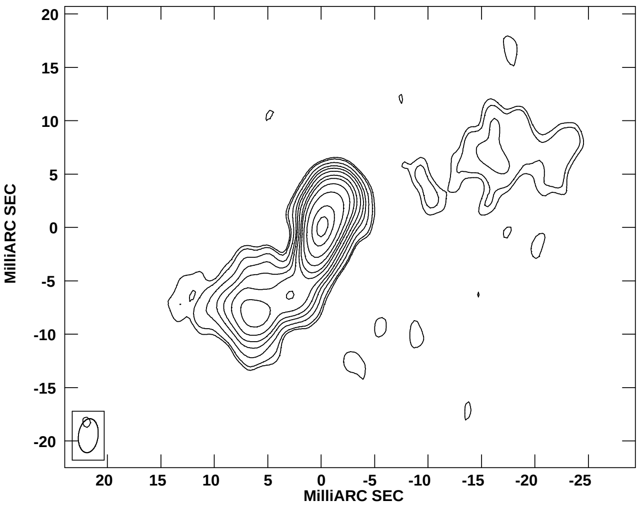

Fig. 5. VLBI image at 5 GHz of NGC 4278, July 2000 epoch. The noise level is 0.04 mJy/beam. Levels are: 0.1 0.15 0.3 0.5 0.7 1 1.5 2 3 5 10 15 mJy/beam. The HPBW is 3.2 × 1.8 mas in PA -7°. At the source distance 1 mas = 0.06 pc

The measured shift is $\sim 0.54 \pm 0.1$ mas on the West side; on the East side a region moved of $\sim 0.7 \pm 0.2$ mas while in a different region we measured an expansion of $\sim 0.3 \pm 0.07$ mas.

We are aware of the uncertainty present in our analysis, made using only two epoch data, however we note that the relative position of the core is well defined and that both lobes are increasing their distance from it. The source expansion is evident as a general increase of the distance of the whole lobes, as clearly visible in the subtraction image (Giroletti et al., in preparation), and it is confirmed by the measured shift of a few substructures. Of course new observations to be obtained in a few years are necessary to confirm this result.

If we take into account that the source is near the plane of the sky (Giovannini et al., 2001), the measured shift implies an average advance speed of ~ 0.5c in both lobes. Assuming a constant velocity we derive a source kinematic age of only ~ 400 yrs. This result strongly supports the model where the radio emission in CSO objects arises from a recently activated radio source. Even considering possible temporal variations in the lobe advance speed, the age estimate (which should be considered a lower limit) is expected to be within a factor 10 of the real source age (Owsianik and Conway, 1998). The lobe advance speeds are higher but still in agreement with previous velocities measured in CSO sources (Perlman et al., 2001 and references in).

5. NGC 4278

We observed this nearby (z = 0.0021) elliptical galaxy at two different epochs spaced by 5 years with the VLBA + Y1 at 5 GHz (as 4C31.04). This radio galaxy is a low power radio source (Log $P_{tot} = 21.44$ W/Hz at 408 MHz). The radio morphology visible in our VLBI images (see Fig. 5) is quite different from 4C31.04, as expected from the different radio power. In NGC 4278 a central flat spectrum core is visible with two elongated lobes in S-E (the main one) and N-W direction. These features are not well collimated but reseambles extended jets in low power FR I sources. We note that all the source flux density measured in arcsecond scale VLA observations at the same frequency, is present in our VLBI image excluding the existence of a larger scale emission.

We compared the two epoch images using the same technique as in 4C31.04. Also in this case the *difference* image between the two epochs and the comparison of substructure positions with model-fitting show that the blob at the end of the SE component moved between the two epochs of $\sim 0.84 \pm 0.2$ mas corresponding at the source distance to an advance speed $\sim 0.03c \pm 0.01c$. Assuming a constant expansion velocity, the dynamic age of this source is very low, of the order of only 100 yrs. We consider this value only as indicative, given that only two epochs were used in the comparison. A low expansion velocity is expected from the low radio power and the source morphology. In this case we do not have a hot spot expanding in the Interstellar Medium, but a low power jet slowly increasing its size. We expect that a low power radio source as NGC 4278 will not grow to a giant radio source, but that it will become a small size low power radio source, as e.g. NGC 5322 (Feretti et al. 1984). We suggest that NGC 4278 is a young low power radio source, slowly growing to become a low power small size radio galaxy.

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