VLBI observations of nearby radio loud
Active Galactic Nuclei

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Abstract. We present an update of the parsec scale properties of the Bologna Complete Sample consisting of 95 radio sources from the B2 Catalog of Radio Sources and the Third Cambridge Revised Catalog (3CR), with \( z < 0.1 \). Thanks to recent new data we have now parsec scale images for 76 sources of the sample. Most of them show a one-sided jet structure but we find a higher fraction of two-sided sources in comparison with previous flux-limited VLBI surveys. A few peculiar sources are presented and discussed in more detail.

1. Introduction

The study of the parsec scale properties of radio galaxies is crucial to obtain information on the nature of their central engine.

In order to study statistical properties of different classes of sources, it is necessary to define and observe a sample that is free from selection effects. To this aim, it is important to define the sample using a low radio frequency, to avoid observational biases related to orientation effects, thanks to the dominance at low radio frequency of the unbeamed extended emission. With this purpose, we started a project to observe a complete sample of radio galaxies (the Bologna Complete Sample (BCS)) selected within the B2 Catalog of Radio Sources and the Third Cambridge Revised Catalog (3CR) \([7, 8]\), with no selection constrain on the nuclear properties.

The sample consists of 95 radio sources. We selected the sources above a homogeneous flux density limit of 0.25 Jy at 408 MHz for the B2 sources and those above 10 Jy at 178 MHz for the 3CR sources \([5]\) and applied the following criteria:

1) declination >10\(^\circ\)
2) Galactic latitude | b | > 15 \(^\circ\)
3) redshift \( z < 0.1 \)

At present VLBI observations are available for 76 sources. The missing 19 sources will require very sensitive observations (phase reference technique and large bandwidth) because of the very low activity of the radio core.
2. Source morphology

Among sources with VLBI data, we have the following kiloparsec-scale structure:

- 50 FR I radio galaxies;
- 13 FR II radio galaxies;
- 8 compact sources with a flat spectrum;
- 2 BL Lac objects;
- 1 compact symmetric object (CSO);
- 1 compact steep-spectrum source (CSS).

Moreover, 1 source is identified with a peculiar Spiral galaxy and was not included in the present discussion.

The observed sample is representative of a sample of sources oriented at random angles with respect to the line of sight. In fact, in a randomly oriented sample of radio galaxies, the probability that a source is at an angle between $\theta_1$ and $\theta_2$ with respect to the line of sight is $P(\theta_1, \theta_2) = \cos \theta_1 - \cos \theta_2$. We find that the percentage of FR I plus FR II radio sources is $\sim 80\%$, corresponding to sources oriented at angles greater than $\sim 35^\circ - 40^\circ$, in agreement with unified models.

At parsec scale most of the sources (24 FR I and 7 FR II) show as expected a one-sided jet structure because of relativistic effects, however we have also a high number of sources with a symmetric jet structure. We note, however, that the detection of a counter-jet may be related to the sensitivity of the map, whereas the dynamic range is not a problem in our images, as the sources are generally weak. We classify as two sided all sources showing both a jet and counter-jet, regardless of the value of the jet to the counter-jet ratio or the length of the counter-jet.

The total number of sources with a two-sided morphology is 17, corresponding to $\sim 25\%$. This percentage is significantly higher than that found in previous samples in the literature: there are 11% symmetric sources in the PR (Pearson-Readhead) sample [12] and 4.6% (19/411) in the combined PR and Caltech-Jodrell (CJ) samples [14, 13].

For two-sided sources, the brightness ratio between the two jets is in the range 1–5, while most of the brightness lower limit in one-sided sources is higher than 5 confirming that the sensitivity in our maps is generally good enough to detect two sided sources.

The main difference between the percentage of symmetric sources in the present sample and in previous samples is naturally explained in the framework of unified scheme models since our sources have been selected at low frequency and should not be affected by an orientation bias.

The comparison between the VLA and VLBA jet position angles (P.A.) shows that most of the sources do not show a large misalignment and that the one-sided parsec scale (or the brighter jet in double-sided parsec jets) is oriented with respect to the nuclear emission, on the same side of the brighter kiloparsec-scale.

We compared the total flux at VLBA scale with the core arc second flux density. We find that 70 % have a correlated flux density larger than 70% of the arc second core flux density. This means that in these sources we mapped most of the milli arc second (mas) scale structure and so we can properly connect the parsec to the kiloparsec structures.

For 19 (30%) sources, a significant fraction of the arc second core flux density is missing in the VLBA images. This suggest variability or the presence of significant structures between $\sim 30$ mas and 2'' that the VLBA can miss because of the lack of short baselines. To properly study these structures, future observations with EVLA or the e-MERLIN array will be necessary.
3. Individual sources

**0802+24 – 3C 192.** This source has an X symmetric double-lobe structure which extends 212″ at 8.35 GHz (see Fig. 1), showing bright hotspots at the end of the lobes [1, 11]. Extended and highly ionized emission lines were detected in this galaxy [2]. In our VLBA image (Fig. 2), the source appears two-sided oriented as the kiloparsec jet (P.A. ∼80°), with a core flux density ~2.1 mJy and a jet flux density ~1.45 mJy.

The observed core radio power is very low with respect to the total radio power (see also Fig. 1) suggesting the presence of very fast jets at a large angle with respect to the line of sight and therefore a Doppler factor << 1. This result is in agreement with the presence of faint symmetric jets in our VLBA image.

![Figure 1. VLA image of 3C 192 at 1.4 GHz. The HPBW is 3.9″](image1)

![Figure 2. VLBA image at 5 GHz of 3C 192. The HPBW is 3.5 mas.](image2)

**0836+29-I – 4C 29.30.** This source named also B2 0836+29A, was studied in detail by [4], and recently by [10].

On the large scale the source shows a clear evidence of intermittent activity. There is a large scale structure about 9′ in size, with an estimate age of about 200 Myr; a more compact structure shows a central core and two bright spots and an extended emission about 1′ in size with an age lower than 100 Myr. The inferred spectral age for the inner double is 33 Myr [10]. At higher resolution [4] is visible the core source (component C2) and a one-sided bright jet about 3″ in size, which terminates with a bright spot (C1).

The high resolution (mas scale) is shown in Fig.3 and Fig.4. It looks very similar to the arc second scale by [4]. At mas resolution we do not have spectral information, however, we identify the nuclear source with the North component because it is the only unresolved structure, and because of homogeneity with the arc second scale. From the jet to counter-jet ratio (> 50) we estimate that the orientation angle has to be smaller than 50° and the jet velocity larger than 0.65 c. Assuming a high jet velocity [8] with a Lorentz factor in the range 3 to 10 and an orientation angle ∼ 40°, we can derive the intrinsic jet length and age of single components. In this scenario the first knot after the core is ∼ 15 yrs old and the Southern knot is ∼ 70 yr old.

The parsec scale structure is in agreement with a periodic non constant activity of this source in the small as well as on the large time scale.

1. [http://www.jb.man.ac.uk/atlas/](http://www.jb.man.ac.uk/atlas/)
Figure 3. VLBA image of 0836+29 at 5 GHz. The HPBW is $3.5 \times 2.1$ mas in PA = 8°.

Figure 4. The same as Fig. 3 but with a HPBW = 1.4 mas.

We note that [10] discuss on the evidence of a strong outburst in the time range from 1990 to 2005, which could be related to the presence of the new component with an estimated age of 15 yrs.

**B2 1350+31 – 3C 293.** This peculiar source has been studied in detail in the radio and optical bands. Recent results are discussed in [3], and [6], where the source structure is presented from the sub-arc second to the arc minute scale. In [9], we presented a VLBI image at 5 GHz where a possible symmetric two-sided jet structure is present at mas resolution. Because of the complex structure of the inner structure we observed again this source with the VLBA at 1.7 GHz in phase reference mode to properly map the inner structure. Moreover we reduced VLA data obtained including also the VLBA-Pt telescope to increase the VLA angular resolution and to study the connection between the sub-arc second and the arc second structure. In Fig.5 we show the VLBA image at 1.6 GHz where the nuclear source and a two-sided symmetric emission is seen.

In Fig. 6 we show the VLA and VLBA-Pt image: we have a symmetric structure with two symmetric jets. The East jet is slightly brighter, in agreement with the indication discussed in [3] that the East jet is pointing toward us. However, the high symmetry of the VLBA jet
suggests that this source is oriented at a large angle ($\sim 75^\circ$) with respect to the line of sight. Therefore, the change in the jet PA from the sub-arc second to the large scale structure (see Figs. 6 and 7) is real and not enhanced by projection effects.

The source brightness between these two structures suggest a two phase activity: the source emission after some time re-started with a higher activity with respect to before. However the jet direction appears to be constant in between the two activity epochs. In Fig. 6 is already visible the bending of the jets in the direction of the kiloparsec scale structure shown in Fig. 7. This large change is not due to a different direction in the restarting nuclear activity but it looks constant in time and it is likely produced by the jet interaction with a rotating disk as discussed in [4].

4. Conclusions
Detailed VLBI images of 76 sources of the BCS, a complete sample selected at low frequency, show the presence of a large number of two-sided jet structures ($\sim 22\%$) in agreement with a random orientation of radio galaxies and a high jet velocity ($\sim 0.9c$).

Sources with a two-sided jet structure show a faint nuclear emission (e.g., 3C192) and are identified with galaxies with no broad emission line, in agreement with prevision of unified models.

In most case the parsec and kiloparsec scale jet structure are aligned with the main jet on the same side with respect to the nuclear emission, in agreement with a continuity of jet properties from the parsec- to the kiloparsec-scale and no large intrinsic change in the jet position angles.

A few sources show evidence of a restarted activity (e.g. 0836+29-I). The recent activity is at the same PA of the older structure.

In 3C 293 we find a Z-shaped structure probably due to the strong interaction of jets with a rotating disk.
Figure 6. VLA and VLBA-Pt image of 3C 293 at 5 GHz. The HPBW is $0.2 \times 0.3''$ in PA 30°.

Figure 7. VLA image at 1.4 GHz of 3C 293. The HPBW is 6''.

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