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VLBI observations of faint radio galaxies with the inclusion of the SRT

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Abstract. We present a sample of faint radio galaxies associated with bright ellipticals ($\log P_{325MHz} \leq 23.5$ W/Hz, $m_r \leq 16$), which is suitable for VLBI follow-up observations with the European VLBI Network with the inclusion of the SRT. The aim of this project is to shed light on the nature of the radio emission associated with low power radio galaxies. The sample is selected at the low frequency of the WENSS minisurvey (325 MHz). It is expected that the whole WENSS will host about 70 suitable targets. VLA–B array observations of some sources in the sample show that their arcsecond-scale peak flux ranges from few mJy to few tens of mJy. Therefore high-resolution and high-sensitivity imaging is possible with the performance expected for the EVN+SRT array.

1. Faint extragalactic radio sources

The radio sky is dominated by extragalactic radio sources at metre to centimetre wavelengths. At flux densities going from tens of mJy to Jy or more, most of them are active galactic nuclei (AGN). At lower flux densities radio sources associated with star-burst galaxies are the dominant population in the source count statistics (Condon et al. 2002), however a fraction of faint radio sources associated with elliptical galaxies is also found. Most of these faint sources have radio luminosities $P_{1.4} < 10^{23}$ W/Hz, steep spectra and angular size comparable to, or smaller than, their parent galaxies. Therefore the study of this population of radio sources requires high angular resolution and high sensitivity.

It is well-known that radio galaxies associated with ellipticals with total radio power $23.0 \lesssim \log P_{1.4\,GHz}$ (W/Hz) $\lesssim 24.5$ are usually characterized by a central compact *core,* coincident with the nucleus of the parent galaxy, and *twin jets*, emerging from the core and propagating through the interstellar medium, out to distances which often exceed the extent of the optical galaxy. These jets diffuse out to form the *radio lobes*. Such radio morphology is usually referred to as FRI (Faranoff & Riley 1974). Arcsecond-resolution radio images for this class of radio sources can be found in Parma et al. (1987).

When observed at the high resolution of VLBI, the nuclear regions of low/intermediate power radio galaxies typically show a one–sided jet structure, signature of relativistic flows. A summary of the nuclear properties in a sample of low/intermediate power radio galaxies can be found in Giovannini et al. (2001).

On the other hand, the nature of the faint population of radio sources associated with elliptical galaxies, i.e. total radio powers in the range $21.5 \lesssim \log P_{1.4\,GHz}$ (W/Hz) $\lesssim 23$, with compact components whose flux density on the arcsecond-scale is $S_{1.4\,GHz} \lesssim 20$ mJy, is still

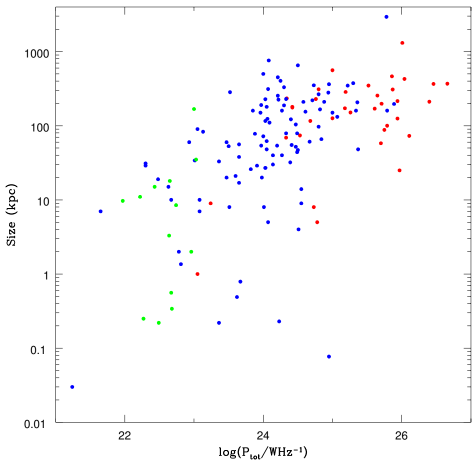

Fig. 1. Power – diameter correlation for low power radio galaxies with redshift z<0.2. Green dots are faint radio galaxies from the WENSS minisurvey, resolved with the VLA–B at 1.4 GHz; blue dots are B2 radio galaxies and red dots are 3C radio galaxies.

unexplored, due to the sensitivity limitations of the VLBI recording systems over the past two decades. The most relevant questions still waiting for an answer can be summarized as follows:

(i) Is the AGN the dominant mechanism responsible for the radio emission?

(ii) Are radio jets still present at these low power levels? If so, how do they compare with those in the more powerful radio galaxies (i.e. morphology, plasma speed)?

(iii) Do these objects fit the faint end of the P_{core} – P_{tot} and power – diameter correlations found for the more powerful radio galaxies? For reference, the power–diameter correlation obtained using the B2, 3C and the radio galaxies from the WENSS minisurvey (de Ruiter et al. 1998) is reported in Fig. 1.

In order to tackle these issues it is necessary to look into the very inner region of these radio galaxies, and this implies the need of the angular resolution provided by the Very Long Baseline Interferometry (VLBI) technique. Imaging at parsec-scale resolution will enable us to distinguish between AGN radio activity (if compact cores and radio jets are detected) and star-burst activity (usually characterized by extended and diffuse emission). Furthermore it will allow one to study the properties of both classes of radio sources.

2. The relevance of the SRT in the European VLBI Network

The European VLBI Network (EVN) consists of a large number of telescopes distributed over Europe, China and South Africa, and includes some of the largest telescopes in the world. The recent recording upgrade based on PC disks (MK5A) has greatly improved the sensitivity and the reliability of the EVN array, making it the current most sensitive VLBI array at the standard frequencies of 1.6 GHz and 5 GHz (see the most updated information at `http://www.evlbi.org`). The inclusion of the 64-m SRT in the EVN strengthens and consolidates this high level of performance, especially in the light of the upcoming e–VLBI.

The two key parameters which will most benefit from the presence of the SRT in the EVN are the *sensitivity* and the *uv–coverage*. These will strongly improve the image fidelity, thanks to the much better uv–coverage over the whole baseline range, and will allow imaging of very faint sources. An example of the EVN uv–coverage, with and without SRT, is given by Mantovani (these Proceedings). Figure 2 shows the change in sensitivity of the EVN array at 5 GHz (filled red triangles) and 1.6 GHz (empty blue triangles) going from the early 1980s to the present days. The inclusion of the SRT, given for epoch 2007 (see figure caption), follows the trend of improving sensitivity of the whole EVN. VLBI image sensitivities of the order of few μJy/beam are a realistic expectation, and this implies imaging the population of faint radio sources, i.e. arcsecond-scale peak flux densities of the order of a few mJy/beam.

3. Selection of a sample of faint radio sources

The most promising database for the selection of a sample of faint extragalactic radio sources are the low frequency ($\nu \lesssim$ 1.4 GHz) radio surveys covering large parts of the sky,

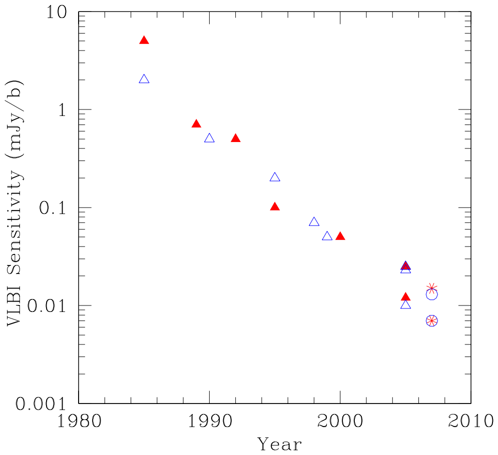

Fig. 2. Sensitivity of the EVN versus time. Filled red triangles: 5 GHz data. Empty blue triangles: 1.4 GHz data. Red stars: 5 GHz data with the inclusion of SRT, at 256 Mbps (upper) and at 1 Gbps (lower). Empty blue circles: 1.6 GHz data with the inclusion of SRT, at 256 Mbps (upper) and at 1 Gbps (lower).

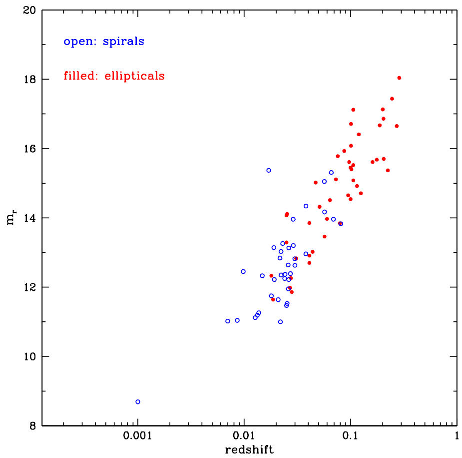

Fig. 3. Redshift distribution of the WENSS minisurvey radio galaxies with optical counterpart with $m_r \leq 16$.

such as for instance (a) the NRAO VLA Sky Survey (NVSS) and Faint Images of the Radio Sky (FIRST), both carried out at 1.4 GHz, but with different resolutions (Condon et al. 1998; Becker et al. 1995); and (b) the Westerbork Northern Sky Survey (WENSS), similar to the NVSS in terms of sky coverage and resolution (Rengelink et al. 1997) but carried out at 610 and 325 MHz. These surveys have image rms (1σ) in the range 0.2 mJy/b (FIRST) – 5 mJy/b (WENSS at 325 MHz). Furthermore in the optical band the Sloan Digitized Sky Survey is providing a wealth of information, which is an invaluable support to the radio surveys.

Based on the WENSS minisurvey (a restricted region of the WENSS of $\sim$ 500 deg^2 selected for radio/optical investigations, de Ruiter et al. 1998), a radio and optically complete source sample was selected for our scientific goal. This sample includes 119 radio sources with an optical counterpart brighter than m = 16. Among them 13 (i.e. $\sim$ 11% of the total) are identified with elliptical galaxies and have $\log P_{325\ \mathrm{MHz}}$ (W/Hz) < 23.5. They are therefore suitable targets for our investigation. Given the sky coverage of the minisurvey compared to the complete WENSS, a total of about 70 faint radio galaxies are expected on the whole WENSS. The redshift distribution of the whole sample of radio sources is given in Fig. 3, where spiral and elliptical counterparts are plotted with different symbols.

In order to select the most suitable targets for VLBI follow-up observations, all 13 faint elliptical radio galaxies are under investigation on the arcescond-scale at 1.4 GHz with the VLA–B at the resolution of 5″ (FIRST or pointed observations). A variety of radio morphologies has been found at this resolution, going from point–like sources to downscaled versions (in size and flux density) of two–sided sources. The peak flux densities range from a few mJy/b up to 40 mJy/b, and are therefore very good cases for the proposed study. Some examples are given in Fig. 4.

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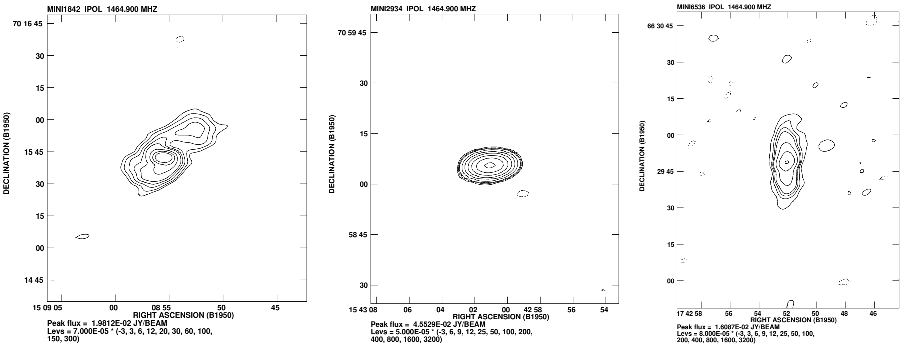

Fig. 4. VLA–B 1.4 GHz radio contours of the radio sources B1508+70 (left), B1543+70 (centre) and B1742+66 (right). Peak flux densities are respectively 20 mJy/b, 40 mJy/b and 16 mJy/b.

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