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The role of the Sardinia Radio Telescope in Very Long Baseline Interferometry

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Abstract. The role of the Sardinia Radio Telescope in Very Long Baseline Interferometry (VLBI) and in particular its contribution to VLBI observations at high frequency will be examined. The planned Italian VLBI array will also be mentioned.

1. Introduction

The history of radio astronomy can be understood as a continuous development of techniques aimed to improve the angular resolution and the sensitivity of the observations. A lot of efforts have also been devoted in developing data analysis techniques which allowed obtaining radio images of high quality.

In this contribution I will examine the role that the Sardinia Radio Telescope (SRT) can play in Very Long Baseline Interferometry (VLBI) observations in terms of gain in sensitivity and angular resolution when it will join the existing and/or planned arrays of radio telescopes.

2. Angular resolution

Among people working on the physical evolution of radio sources, there is a great interest to better understand the physical processes generating the enormous amount of energy produced in a small volume (a few parsecs or less) at the very centre of the objects. This requires one to be able to observe the radio-loud objects at milli-arcsecond scale resolution. The synthesized beam (or angular resolution) of a radio telescope of diameter D observing at a wavelength λ is given by the solid-angle $\Omega \approx (\lambda/D)^2$, expressed in radians^2. For a two-element (connected) interferometer, D is the separation between the two antennas. If D is hundreds of kilometres, the connection with coaxial cables of the two antennas becomes impractical. The only solution to get angular resolutions of the order of milli-arcseconds, is then to make use of VLBI techniques. Observations in the optical band, which might in principal allow a very high resolution, are in fact limited to the range 0.3 – 0.5 arcseconds by the effect of the atmosphere.

The infrastructure which supports the astronomers for an easy access to VLBI observations is the European VLBI Network (EVN). The EVN is an interferometric array of radio telescopes spread throughout Europe, with the participation of radio telescopes in China, South Africa, Puerto Rico. The EVN Consortium can provide the users with support for the observations' planning and the data analysis via the Join Institute for VLBI in Europe (JIVE). Through the Trans National Access to the European infrastructures of RadioNet, funded by the European Commission under the 6th Framework Programme, users of the EVN can

Fig. 1. The distribution of antenna sites in the European VLBI Network. (*Courtesy M. Garrett)*

also obtain financial support for their approved VLBI observations.

The distribution of the EVN antenna sites is shown in Fig. 1. As one can easily realize from Fig. 1, the addition of a telescope with the location of the Sardinia Radio Telescope (SRT) to the EVN, produces a negligible improvement in terms of angular resolution of the full array.

This is true, however, only when the array observes at centimetre wavelengths. The situation becomes much more interesting in terms of angular resolution if the SRT and the other two Italian antennas are used in the mm-range, e.g. at 7 mm and 3 mm (43 GHz and 90 GHz, respectively), since, at present, not many of the EVN antennas are able to observe at mm-wavelengths. The telescopes in Europe equipped with a 43 GHz receiver are those of Onsala (Sweden), Effelsberg (Germany), Metsähovi (Finland) and Pico Veleta (Spain). A new 40-m radio telescope in Spain at Yebes is under construction.

The two receivers needed for observing at 43 GHz and 90 GHz are planned for the SRT telescope. At 43 GHz, the SRT is expected to have an antenna efficiency of ≈ 50%. A second Italian antenna, the Noto 32-m dish also shows very good performance at 43 GHz. The Noto dish has a very high efficiency (≈ 50%), which is constant with elevation thanks to the active surface system implemented for the main mirror. If we consider to upgrade also the Medicina 32-m dish with an active surface, as done for the Noto dish, we can create a very powerful European array of 8 telescopes able to observe at 43 GHz, achieving an angular resolution of ≈ 0.2 milli-arcseconds (i.e. ≈ 2 parsec in linear size for $z = 1$, $q_o = 0$, $H_o = 100$ km s^{-1} Mpc^{-1}).

The $u - v$ plane coverage for the above European array at 43 GHz with and without the 3 Italian antennas is shown in Fig. 2.

Global VLBI observations at 43 GHz, with the European and USA antennas operating together via the the Coordinated Millimeter VLBI Array (CMVA) are also possible. The members of the CMVA Consortium are the antennas belonging to the Haystack Observatory, Onsala Space Observatory, Millimeter Radio Astronomy Institute, Metsähovi Radio Observatory, Berkeley Illinois Maryland Association, Very Long Baseline Array, Max

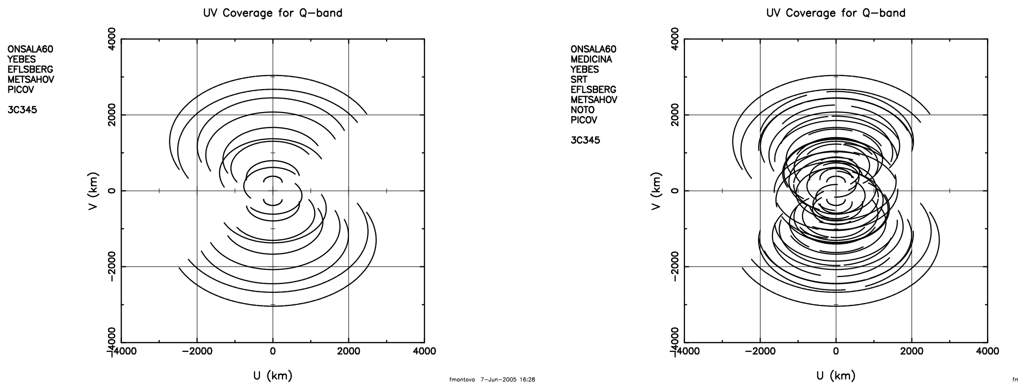

Fig. 2. The u–v plane coverage for the source 3C 345 tracked by the existing European antennas able to observe at 43 GHz *(left)*, and by adding to that array the Italian antennas of SRT, Noto and Medicina *(right)*.

Planck Institute for Radio Astronomy and Swedish-ESO Sub-millimeter Telescope.

Using that array, an angular resolution of $\approx$ 60 μarcsecs (i.e. linear resolution of $\approx$ 0.5 parsec at $z = 1$) and a baseline sensitivity of 340 mJy (7σ; value computed for the baseline BIMA–SRT, see below), can be achieved.

3. Sensitivity

The sensitivity in VLBI is defined as the ability to detect sources of high brightness temperature (or compact point sources). For a two element interferometer, the rms flux density is given by:

$$S_{rms} \approx \frac{1}{\eta_s} \times \frac{\surd(SEFD_1 \times SEFD_2)}{\surd(2\ \Delta\nu\ \Delta\tau)} \quad (1)$$

where SEFD is the System Equivalent Flux Density in Jy, $\Delta\nu$ the bandwidth in Hz, $\Delta\tau$ the integration time in seconds, $\eta_s \approx 0.5$ the correlation factor.

In Table 1 we present the SEFD computed for four telescopes at several frequencies using a 64 MHz bandwidth and an integration time of 300 sec at 5 GHz, 80 sec at 22 GHz, and 30 sec at 43 GHz and 86 GHz.

Table 1. SEFD in Jy at various frequencies.

Telescope	Frequency (GHz)			
	5	22	43	86
Effelsberg	20	90	500	2000
Medicina	330	1200	2800	
Noto	260	800	470	1825
SRT	30	120	100	370

Table 2. Baseline sensitivity (7σ) in mJy computed with the Effelsberg 100-m telescope as reference antenna

Telescope	Frequency (GHz)			
	5	22	43	86
Medicina	6.0	47.0	260	
Noto	5.2	38.2	108	431
SRT	1.8	14.7	49	196

The baseline sensitivity, computed through Eq. (1), considering Effelsberg as the reference antenna and using the SEFDs in Table 1, is reported in Table 2. Note that the values in Table 2 are $7 \times S_{rms}$ to ensure a true fringe detection.

The values given in Table 2 show a very interesting result. Assuming that the $\log N - \log S$ distribution for compact radio sources steepens as 1.5 (as found for statistically complete flux-limited samples of radio sources), we see that observing with the SRT–Effelsberg baseline allows us to detect a number of sources a factor

Fig. 3. The Map of the Italian array formed by four radio antennas: SRT, Medicina, Noto and Matera *(Courtesy Elena Cenacchi).*

of 3.2 to 12 greater than what we can now detect with the Medicina–Effelsberg and Noto–Effelsberg baselines. This is an important result since it means that we can extend our observational studies to low brightness radio-loud active galactic nuclei, moving toward the less studied (at high resolution) FRI radio sources.

Sensitivity also plays an important role in the so-called 'Image Fidelity', defined as the difference between any produced image and the correct image. Such a difference cannot be easily estimated. The data are usually corrupted and/or some of the expected visibilities might not become available. This lack of visibilities can produce a limited dynamic range of the image, i.e. a lower value of the flux density ratio between the brightest point and the rms noise of the image. An increased number of antennas in the array will produce an increasing number of points in the *u*-*v* plane. Consequently, a better dynamic range in the image will be achieved. Such an improvement is greater when the antennas added to the array have a larger (effective) collecting area (as in the case of the SRT).

The dynamic range of the image can also be increased by applying techniques like self-calibration and de-convolution in the data analysis. A greater dynamic range means smaller errors in the image, with the result of a smaller difference between the produced image and the correct image, i.e. an improved 'Image Fidelity'.

4. Science with SRT

A greater sensitivity of the VLBI array allows the observers to carry on investigations for which deeper high-resolution observations are crucial.

Among the investigations, which can be greatly improved by the use of an observing array of radio telescopes of increased sensitivity we can mention Massive Black Holes, Young Stellar Objects, circumstellar SiO Masers in late-type stars (Mira's), wide-field mapping and Supernovae remnants.

These scientific topics are extensively discussed in the contributions presented in these proceedings, so I will not treat them here.

5. Italian VLBI

Finally, it is worth to mention that with the advent of the SRT, a very sensitive array of four radio telescopes will be made available to the Italian astronomical community. A map of the Italian array formed by the SRT, Medicina, Noto and Matera (which belong to the Italian Space Agency, ASI) is presented in Fig. 3. This array, once equipped with a correlator (hardware or preferably software), will allow interesting investigations in both astronomical and geodetic VLBI fields like high-resolution spectral line surveys of masers and monitoring of baseline-length changes.