Richard Porcas et al.: How Compact Are Faint Radio Sources?, IVS 2006 General Meeting Proceedings, p.326–329
http://ivscc.gsfc.nasa.gov/publications/gm2006/porcas

How Compact Are Faint Radio Sources?

Richard Porcas [1], *Walter Alef* [1], *Chris Salter* [2], *Tapasi Ghosh* [2], *Simon Garrington* [3]

1) *Max-Planck-Institut für Radioastronomie*
2) *Arecibo Observatory*
3) *Jodrell Bank Observatory*

Contact author: Richard Porcas, e-mail: porcas@mpifr-bonn.mpg.de

Abstract

We present preliminary results from a statistical survey of compact structure in faint radio sources. Around 1000 sources from the VLA FIRST survey (flux densities $\geq$ 1 mJy at 1.4 GHz) have been observed with the single-baseline interferometer Effelsberg-Arecibo. We observed each source, selected from a narrow strip of sky at declination 28°, for just one minute. The baseline sensitivity at 1.4 GHz, using 512 Mb/s recording, is such that *any* FIRST source, selected at random, would be detected if most of its flux density is in compact structure. We discuss the detection-rate statistics from one epoch of these observations.

1. Introduction

We have been investigating the existence of compact structure in the faint radio source population using a single, but highly sensitive, long-baseline interferometer between the 305-m Arecibo and 100-m Effelsberg radio telescopes. Preston et al. (1985) showed the value of such observations by surveying 1398 known radio sources at 2.29 GHz between 1974 and 1983, using single baselines between the (then) 64-m DSN antennas, in order to select candidate sources for use in establishing the celestial reference frame. Sparse u,v-coverage VLBI observations were also used by Lawrence et al. (1985) at 22 GHz to investigate highly compact structure in radio sources, as a preliminary to future space-VLBI projects.

In the same spirit as these previous surveys, we decided to investigate the prevalence of compact structure in a sample of sources chosen from the 1.4 GHz FIRST survey (Becker et al., 1995). This survey, made using the VLA with a resolution of 5.4″, contains 138,665 sources down to 1 mJy in the first instalment (White et al., 1997), with a sensitivity of 0.15 mJy. Garrington et al. (1999) have made global 5-GHz observations of a small sample of 35 FIRST sources, with flux densities $\geq$ 10 mJy and preselected using MERLIN to have compact structure. They detected 27 sources, using the phase-referencing technique.

In our investigation we have used a highly sensitive long-baseline interferometer, between Arecibo and Effelsberg, using the FIRST survey frequency of 1.4 GHz and recording using 512 Mb/s. For a given integration time this baseline is 42 times more sensitive than a single VLBA baseline, 6.2 times more sensitive than the full (phase-referenced) VLBA, and 12.5 times more sensitive than the full VLBA at its sustainable recording rate of 128 Mb/s. We believe this is the most sensitive VLBI baseline ever used.

2. Observations and Source Selection

We made VLBI observations between Arecibo and Effelsberg using Mark IV recording at 512 Mb/s. We observed the 64-MHz band from 1.366-1.430 GHz in both LHC and RHC polarization, using 2-bit sampling, and subdivided into 4 upper and 4 lower sideband channels, each of 8 MHz, for each polarization. At Effelsberg the signal was recorded using a Mark 5A system. At Arecibo the data was recorded on a VLBA4 recorder using 2 heads. We configured this so that the LHC signal was recorded by one head, and RHC by the other, thus making it convenient to make a preliminary analysis of the polarizations separately from the results of the necessary 2-pass correlation (see Section 3).

Since the Arecibo telescope has a limited hour-angle range, we decided to make "single-shot" observations of FIRST sources at a fixed hour-angle. We observed sources in a 1°-wide declination strip between declinations 28° and 29° at ~30 mins before Arecibo transit, in order to minimize Arecibo drive times between sources whilst being at a reasonable elevation (~34°) at Effelsberg. The projected baseline results in a resolution of ~6 mas in PA ~20°. We planned an on-source integration time of 60 s, for which the estimated rms noise is 0.1 mJy. This permits us to detect *any* FIRST source if it is sufficiently compact. We allowed 30 s for telescope drive-time between sources, resulting in observation of 15 target sources for every 22 min tape pass. We initially planned four 6-hour observing periods, separated by a few weeks; in the end we had 4 observing epochs in October 2003, March and June 2004, providing a total of 27.5 hours of observing. At our first observing epoch we were also able to add the 76-m Jodrell Bank Lovell Telescope and the phased Westerbork Array, for the purpose of investigating short-baseline flux densities for some of the stronger FIRST sources.

From the outset we decided to make an un-biased selection from the FIRST catalogue, without regard to flux density, size or radio spectrum. Our motivation is not to identify "compact radio sources" but, rather, to make a *statistical* survey of the existence of compact structure in *all* source types. We thus calculated a notional right ascension for each 60 s observation and selected the first source in the FIRST catalogue with an RA greater than this within our declination strip, provided it had not been observed in a previous epoch. We also identified 11 VLBA calibrator sources within the strip. At each epoch these were substituted for the closest target sources selected.

There are 11,699 sources listed in White et al. (1997) within our declination strip. Excluding the calibrator sources, we scheduled 992 target sources (215+259+259+259) for our 4 observing epochs. However, there is often more than one FIRST source within the Arecibo beam (FWHM = 210″) and we are able to investigate a further ~400 FIRST sources using multi-pass correlation.

3. Correlation and Fringe Detection

We are correlating these observations using the Mark IV correlator at the MPIfR in Bonn. As the tape-drives are equipped with only a single playback head it is necessary to make at least 2 correlation passes, one for each head (polarization). Further passes are needed to correlate other FIRST sources which are known to be within the same Arecibo beam of the target sources. Their response is necessarily attenuated by up to 0.7; note that as the Effelsberg FWHM beam width is much larger it is the Arecibo amplitude beam which is relevent. We use a correlator mode providing a pre-average time of 1 s and 128 delay steps per 8 MHz sideband (equivalent to 62.5 kHz frequency resolution). Correlation is inhibited under control of Effelsberg and Arecibo off-source flags. For most sources, between 60 and 70 s of correlated data are recovered.

We use the Haystack HOPS package fringe-fitting program FOURFIT to search for a source response in the correlator output for each source. Source positions from the FIRST catalogue have accuracies of ∼1″ or better. The delay and fringe-rate resolution of our observations are typically 170 mas in PA 20° and 2″ in PA –50°, respectively. We can search using a range of delay and rate windows to optimise our detection threshold whilst taking into account possible instrumental and FIRST source position errors.

4. Preliminary Statistical Analysis

We present here a very preliminary analysis of results from our second epoch, observed on 22 March 2004 between UT 02h00 and 09h11. It represents only about a quarter of our sample, and uses a separate search in the LHC and RHC data, using conservative (wide) search windows and uncalibrated data. Some 7 of our 259 targets were lost due to a recording malfunction, resulting in a sub-sample of 252 sources.

A total of 71 (28%) of the 252 target sources were detected in either LHC or RHC correlations above a conservative threshold of 8-sigma, and at the expected residual fringe-rate and delay. Of these, 63 were detected in both polarizations. Note that the addition of the polarizations would result in detections above 11-sigma for these sources. For the sources detected in a single polarization the response in the other polarization was above 6.8-sigma in all cases. Analysis of the distribution of S/N-ratio for the detected sources suggests that at least a further 14 sources may be detected above 8-sigma in polarization-added data, bringing the detection rate to 33%.

We have also searched data from 86 other FIRST sources located within the target source beams. Some 11 sources were detected, in both polarizations. This lower fraction (13%) reflects signal attenuation away from the centre of the Arecibo beam.

We have investigated the detection rate as a function of the (peak) flux density listed in the FIRST catalogue. The parent distribution of flux densities in the FIRST catalogue (derived from our subsample of 1392 target or in-beam sources) has quartiles of 1.35, 2.24 and 5.42 mJy, and for the subsample of 252 sources observed here the values are similar: 1.41, 2.24 and 4.86 mJy. The numbers of sources detected in these ranges are 8, 19, 22 and 22. The median FIRST catalogue peak flux density of our detected sources is 3.37 mJy. 11 sources are in the range 1.0 to 1.5 mJy. Fringe detection plots for the 5 detections with lowest listed flux densities are presented in Figure 1.

5. Conclusions

It is, of course, premature to draw any definitive conclusions, but our preliminary analysis suggests that up to a third of all FIRST sources contain detectable compact structure at the mJy level. Note that long, thin structures—e.g. jets—may be missed in our observations if the structure is oriented along our resolution direction. Interestingly, the detection rate for sources ≥4.9 mJy is not significantly higher than that for weaker sources. Our 8-sigma single-polarization detection threshold corresponds to ∼1.1 mJy. For sources with true flux densities in the 1-2 mJy range, a detection implies that at least half of the total flux must reside in compact components. The fall-off in detection rate between 1.41 and 1.00 mJy may represent this fraction falling below our detection threshold, or may reflect source variability or increasingly large errors in the FIRST flux densities at the bottom of the survey. Once the data have been calibrated, a detailed investigation

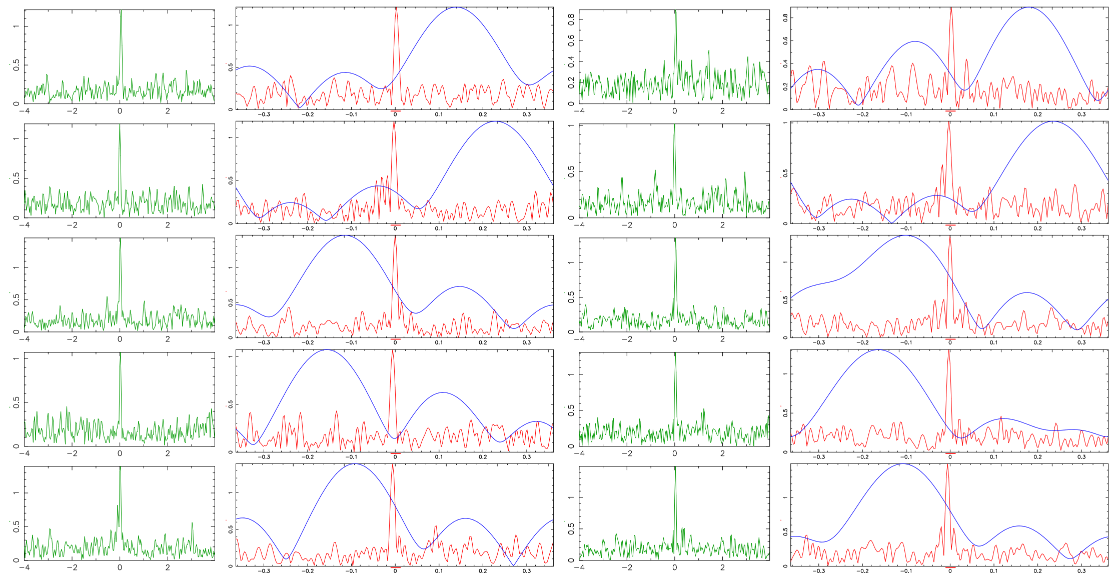

Figure 1. Residual single-band delay and fringe-rate functions for RHC polarization (left) and LHC polarization (right) for the 5 detected sources with the lowest listed flux densities in the FIRST catalogue (1.03, 1.11, 1.21, 1.27 and 1.28 mJy).

of the distribution of source visibilities will allow these effects to be investigated further.

6. Acknowledgements

We thank Dave Graham for assistance with observing at Effelsberg, Emmanuel Momjian for assistance at Arecibo, and 2 generations of Effelsberg and Arecibo schedulers, Rolf Schwartz, Alex Kraus, John Harmon and Hector Hernandez, for their patience in supporting this project.

References

[1] Becker, RH, White, R.L. & Helfand, D.J. 1995, Ap.J. 450, 559

[2] Garrington, S. T., Garrett, M. A. & Polatidis, A. 1999, New A.R. 43, 629

[3] Lawrence, C. R., Readhead, A. C. S., Linfield, R. P., Payne, D. G., Preston, R. A., Schilizzi, R. T., Porcas, R. W., Booth, R. S. & Burke, B. F. 1985, Ap.J. 296, 458

[4] Preston, R.A., Morabito, D. D., Williams, J.G., Faulkner, J., Jauncey, D. L. & Nicolson, G. 1985, A.J. 90, 1599

[5] White, R.L., Becker, R.H., Helfand, D. J. & Gregg, M.D. 1997, Ap.J. 475, 479