THE CALTECH–JODRELL BANK (CJ) VLBI SNAPSHOT SURVEYS

P.N.WILKINSON , A. POLATIDIS and D.R. HENSTOCK
University of Manchester, Nuffield Radio Astronomy Laboratories Jodrell Bank, Macclesfield, Cheshire, SK11 9DL, UK

and

A.C.S. READHEAD, W. XU, T.J. PEARSON, G. TAYLOR and R.C. VERMEULEN
California Institute of Technology, Owens Valley Radio Observatory Pasadena, Ca. 91125, USA

Abstract. Two large VLBI surveys are currently underway which utilise the snapshot technique pioneered on the VLA. With a 12-16 telescope array three $\sim$ 20 min snapshots are sufficient to make excellent hybrid maps. Recent advances in data analysis techniques enable surveys of several hundred sources to be undertaken and reduced in under two years.

Key words: VLBI – Surveys – Imaging

1. Introduction

The first systematic VLBI survey was performed by Pearson & Readhead (1988; PR). An analysis of maps of 42 sources at 5 GHz provided the first well-defined classification scheme for the milli-arcsecond scale structures of strong radio sources. However the size of the sample is too small for many interesting statistical studies. In order to extend the sample within the time likely to be available in the US and European VLBI Networks, we were forced to look for ways to observe many more than the usual 2-3 sources per day. After running imaging simulations we decided that three 'snapshot' observations, well-separated in hour angle, would provide sufficient data to make useful images—as long as the array contained $\sim$ 16 telescopes. Two surveys have been or are being undertaken with this technique:

The CJ survey: 94 out of 135 objects selected from the NRAO-MPI **S4** and **S5** surveys with flux density 1.3 Jy> S_{5GHz} >0.7 Jy, declination $\delta > 35°$ and galactic latitude $|b^{II}| > 10°$ can be imaged with Mark 2 VLBI. Observations were made at both 6 cm and 18 cm in order to increase the reliability of the classification of each source.

The CJ2 survey: 199 objects selected from the Jodrell Bank VLA flat–spectrum source surveys (Patnaik et al. 1992) in the same area sky as the CJ survey but with flux densities S_{5GHz} >0.35 Jy and spectral indices (between 1.4 GHz and 5 GHz) flatter than 0.5, can be imaged with Mark 2 VLBI.

Our main astronomical goals are: i) to improve the PR classification of compact radio sources and to see if the different classes evolve differently with cosmic epoch. ii)To provide first epoch observations for subsequent statistical studies of superluminal motion with redshift (Cohen and Vermeulen 1992). iii) To use the statistics of VLBI angular size vs. redshift (Kellermann 1993; Gurvits 1993) as a probe of universal geometry. iv) To look for evidence of gravitational lensing due to compact objects in the range $10^6 - 10^9$ solar masses.

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2. Observations and Initial Data Reduction

For CJ three 30 minute, and for CJ2 three 20 minute, scans are scheduled for each source enabling 16–24 sources to be observed per day – about an order of magnitude faster than PR's original rate. The scans are arranged to span the period of mutual visibility from Europe to the western US. A typical *uv* coverage obtained is shown in Fig. 1. For CJ often only 12–13 telescopes operated successfully but with the advent of the VLBA (which has Mk2 systems on 7 telescopes) 15-16 telescopes have been available for the two CJ2 sessions so far. Network time has been granted generously and in our longest, 68 hour, observing run in September 1992 we were able to observe 64 sources successfully.

Correlation is done, usually in one pass, on the Caltech/JPL Block 2 correlator. Fringe fitting is performed in AIPS and further analysis in the Caltech VLBI software package. Both packages run on SUN workstations. Amplitude calibration has proven to be surprisingly straightforward despite the fact that no completely unresolved sources have been found. With this large a number of telescopes both "*uv* crossing point" analyses and amplitude self–calibration are tightly constrained, even for resolved sources, and the relative station gains can be determined to $\sim 3\%$ rms.

3. Imaging Methods and Image Quality

With only three short snapshots it is impossible to obtain much information from a visual inspection of the data on individual baselines. For the CJ survey we therefore adopted the following hybrid mapping procedure: i) make an initial hybrid map starting from a point source; ii) based on this map fit a multi–component gaussian model to the data; iii) remake the hybrid map starting from this model. A superior map results. For the CJ2 data we used a new "difference mapping" package DIFMAP written by M.C. Shepherd at Caltech inspired by the Jodrell Bank MAP program written by R.G. Noble. This method works with the "residual map" obtained from the Fourier transform of the difference between the currently corrected visibility data and the Fourier transform of the current list of CLEAN components. DIFMAP includes sophisticated data editing software and is highly efficient. We recently made six CJ2 maps in a working day – about an order of magnitude faster than we used to achieve at the beginning of the CJ survey.

The rms noise levels achieved in the final maps are close to those expected from thermal noise alone. For the CJ survey the typical rms noise in a uniformly–weighted map is $\sim$ 1 mJy beam^{-1} which reduces to 0.5-0.6 mJy beam^{-1} in a naturally weighted map. For the CJ2 survey the noise levels are $\sim 25\%$ lower which is simply due to the fact that 15-16 telescopes were available cf. 12-13 for the CJ survey. The dynamic range is always $> 100 : 1$ and can be 500:1 in a naturally weighted CJ2 map.

The reliability of the results can be assessed from a comparison of images made from data taken with full tracks and with snapshots. Fig 2 shows two images of the quasar 3C309.1. Fig 2a was made from 8–telescope data and a 10 hour track; Fig 2b was made from four 20 min snapshots with a 12–telescope array. Similar comparisons on other well known sources demonstrate that the fidelity of the snapshot images is more than adequate for our astronomical goals.

4. Summary

The observations for the two–frequency (1.6 and 5 GHz) CJ survey have been completed and the great majority of the images have been made. Observations of 76 out of 199 sources in the single frequency (5 GHz) CJ2 survey have been completed and the majority of the images have been made—only a few months after the observations were taken.

The snapshot observing technique with arrays of up to 16 stations and a total observing time of around one hour per source has removed the observational bottleneck which prevented large VLBI surveys being feasible. The combination of dedicated workstations and recent software advances has removed the data processing bottleneck—as a result the CJ2 survey of two hundred sources will be completed within less than two years. New astronomical problems—in particular cosmological ones—can be addressed with the survey data.

References

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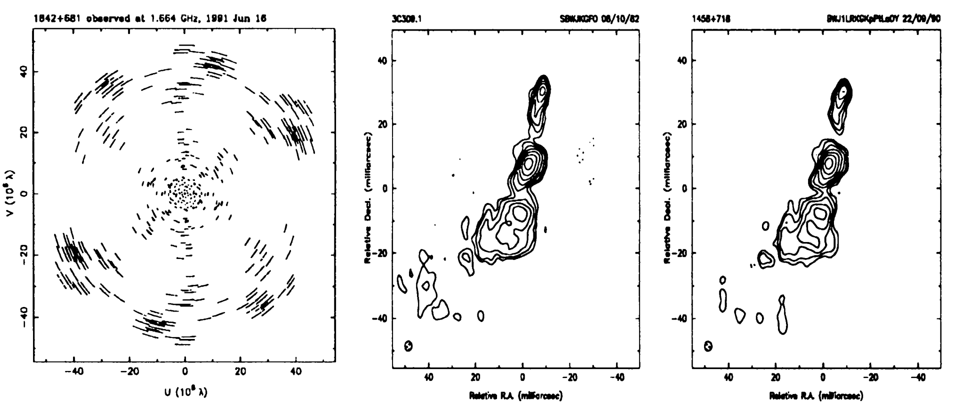

Fig. 1. (left) Typical *uv* coverage for the CJ and CJ2 snapshot VLBI surveys.

Fig. 2. a) (centre) VLBI image of 3C309.1 at 1.6 GHz made with an 8–telescope array and a 10 hour track; b) (right) VLBI image of 3C309.1 at 1.6 GHz made with a 12–telescope array and 4 × 20 min snapshots. Contours in both images are drawn at -1,1,2,48,16,32,64 % of the peak brightness.