

A New Strategy for the Routine Detection & Imaging of Faint Radio Sources with VLBI

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Abstract

In this paper I outline a new strategy for the routine detection and imaging of faint (sub-mJy and microJy) radio sources with VLBI and SVLBI. The strategy relies on a combination of in-beam phase-referencing, wide-field VLBI imaging and simultaneous correlation of multiple field centres. A combination of these techniques, together with the steeply rising radio source counts observed at cm wavelengths, permit routine high resolution observations of radio sources previously considered too faint for conventional VLBI.

1 Introduction

VLBI is sensitivity limited. Most sources that can be robustly detected by conventional self-calibration techniques have peak fluxes in excess of 10 mJy. The success of phase-referencing techniques, as applied to mJy and a few sub-mJy radio sources, are often limited (particularly in terms of image fidelity) to the brighter sources for which subsequent self-calibration (over much longer solution intervals) is then possible. So far, few attempts have been made to detect sub-mJy sources, despite the fact that with a coherent integration time of 24 hours, global VLBI arrays can routinely produce images with 1σ rms noise levels better than $30\mu\text{Jy}/\text{beam}$.

Nevertheless, the focus of VLBI over the last 3 decades (and in particular Space VLBI – SVLBI) has been directed towards the study of the brightest and most compact radio sources in the sky. At these flux levels ($> 10\text{mJy}$), the radio sky is virtually empty, with most radio sources associated with relatively distant AGN. As a result the overlap with other wave-bands is sometimes limited. In this paper, I suggest a new strategy for the *routine* detection and imaging of faint sub-mJy and μJy radio sources. The strategy relies on a combination of in-beam phase-referencing (with obvious advantages for SVLBI but also VLBI

generally - see Fomalont et al. 1999), wide-field VLBI imaging (see Garrett et al. 1999) and simultaneous correlation of multiple field centres. These techniques, together with the steeply rising radio source counts at λ cm wavelengths, should permit high resolution, VLBI investigations of the faint sub-mJy and microJy source populations to begin.

2 Towards Routine Imaging of Faint Radio Sources

It is a well known and auspicious fact that the radio source counts increase steeply as one goes to fainter flux levels. At λ 18cm the source counts derived from WSRT observations of the Hubble Deep Field, HDF, (Garrett et al. 2000) imply source counts of up to $\sim 40S_{\mu\text{Jy}}^{-1}$ per square arcmin. Thus within the central regions of the primary beam of a typical 25-m VLBI antenna, one can expect to find over ~ 100 potential target sources with $S > 120\mu\text{Jy}$ (the 3σ noise level routinely achieved in ground based VLBI images). If we extrapolate the preliminary results of Garrington, Garrett and Polatidis (1999), we can deduce that for every continuum VLBI observation conducted today, there are perhaps a dozen or so faint radio sources in the beam that might be compact enough to be detected and imaged, *in addition* to the brighter target source! This suggests a new strategy for the routine imaging of a large number of faint radio sources:

(i) *Reverse* the traditional approach of selecting the target before the calibrator (see also Garrington, Garrett & Polatidis 1999). The field chosen should satisfy the following criteria: (a) it should be an area for which high quality optical/IR, and deep, sub-arcsec resolution radio data are available (several such fields are expected to become available over the next year) and (b) the same field should also contain a reasonably bright radio source (but not too bright) that can act as a in-beam (secondary) phase-calibrator.

(ii) Split the antenna primary beam into manageable $4' \times 4'$ patches (the size of these patches is currently determined by the limiting integration time and frequency resolution provided by current generation correlators, not to mention throughput, offline storage sizes and processing speed!). Each patch can be generated via simultaneous multi-field centre processing (currently being developed for the JIVE correlator, Pogrebenko 2000) or standard multiple-pass correlation, and can share the phase corrections provided by the in-beam phase-calibrator located close to the centre of the beam.

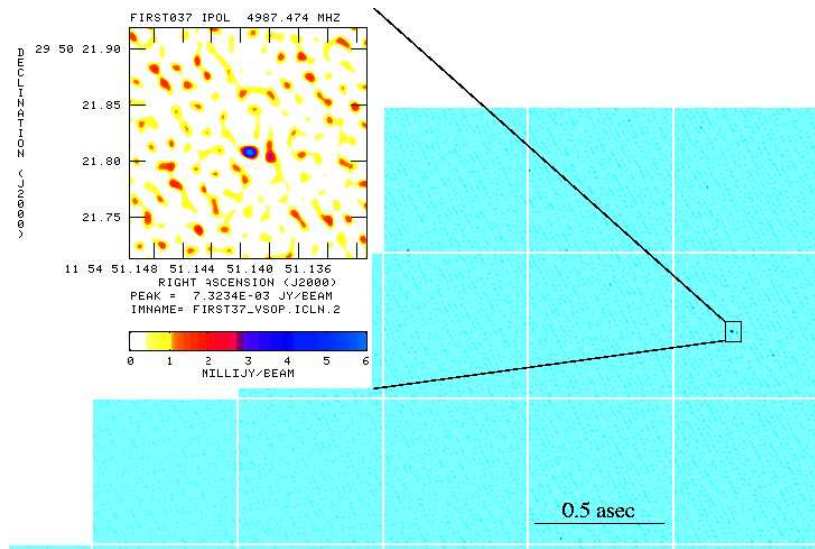


Figure 1: Wide-field VLBI dirty image of a region of sky located 1 arcminute from the phase-centre and target source. The detection of a previously known ~ 10 mJy VLA FIRST source in one of the sub-fields is produced from only 10 min of (unaveraged) global 6cm VLBI data.

(iii) Divide each phase calibrated (but unaveraged) data patch into many small sub-fields of a few arcseconds across (small enough to employ 2-D FFTs and not so large that the image size becomes unmanageable - at least in terms of casual inspection by eye). FFT the data and produce a dirty map of the sub-fields of interest.

Some simple “proof-of-concept” tests have been conducted with a total of 10 minutes of Global VLBI $\lambda 6\text{cm}$ data (taken from the $\lambda 6\text{cm}$ Global VLBI Faint Source Survey of Garrington, Garrett & Polatidis 1999). Fig. 1 shows the clear VLBI detection of a known VLA FIRST source in a sub-field that is part of a patch of the primary beam that is located ~ 1 arcminute from the phase-centre and target source. Details of the processing requirements for this (and longer runs) is beyond the scope of this paper but they are not unreasonable. A more important limitation is the minimum integration time provided by today’s working correlators (these are currently inadequate to cope with SVLBI satellites at perigee — using this particular strategy — but improvements can be expected over the next few years).

3 The Structure of Faint Radio Sources & SVLBI-2

Exceptionally deep radio observations of the HDF (Richards et al. 1999, Muxlow et al. 1999, Garrett et al. 2000) show that the bulk of the sub-mJy and μ Jy source population have steep radio spectra and are for the most part identified with distant disk or irregular, interacting galaxies (often with ISO detections). This argues strongly that these faint sources are associated with very luminous Starburst galaxies. Nevertheless, a significant fraction (perhaps as much as 30%) are probably faint AGN, especially the brighter sub-mJy sources. Using the techniques described here, the brighter AGN could be reasonable targets for the next generation of SVLBI missions now planned. Indeed, SVLBI observations are probably crucial: from simple SSA theory faint sources are also expected to be small. In addition, emission from both compact AGN and larger-scale star-forming regions (principally young SNRs, relic SNR emission and ultra-compact HII regions) might not be uncommon in the same system. Even for relatively distant (≤ 350 Mpc) but ultra-luminous star-forming disk galaxies, hypernovae (such as those SNR in Arp 220 and 41.95+575 in M82) might be detected, and more importantly *resolved* by SVLBI-2 missions. The prospects of detecting these faint, steep spectrum radio sources with next generation SVLBI missions depends crucially on the availability of L or S-band receivers. The contribution future SVLBI-2 missions could make to unravelling the nature, structure and composition of the faint radio source population cannot, and should not, be underestimated.

References

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