Relative astrometry and phase-reference mapping in the 1636+473 system using MERLIN and Global VLBI

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Abstract

We present astrometric results and maps from simultaneous MERLIN and Global VLBI observations of the very weak core of the double-lobed radio source 1636+47B, using as reference the bright, compact, flat-spectrum quasar 1636+473 A, 20 arcsec away. The observations were made in May 1995 at 5 GHz. The phase-referenced VLBI map of the weak core, of resolution 1.5 mas, contains a high percentage of the core flux density seen in the MERLIN map. Further hybrid mapping iterations reveal a faint, one-sided core extension on the same side as the MERLIN jet. We investigate the effect of the stucture in the strong quasar core on the astrometric separation measurement, and explore the effect of both temporal and other coherence losses on the phase-reference map. We relate our results to the structural asymmetry in weak AGN cores within the context of unification models.

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1 Introduction

At arcsecond resolutions the radio source 1636+473 (4C47.44) consists of two components separated by 20 arcsec in PA 20°. The southern, compact, flat-spectrum component (A) coincides with a quasar of redshift 0.740 (Porcas et al, 1980; Kapahi, 1981); the northern, steep-spectrum component (B) has a flux density of ~150 mJy at 5 GHz and is 10 arcsec in extent in PA 80°. There is no coincident optical emission visible on the Palomar Sky Survey.

The structure of 1636+473 was originally classified as of "D2" core-jet type (Browne et al, 1982; Saikia et al, 1984). However, recent higher-resolution radio observations (Saikia, priv. com.) reveal that B has a classical, double-lobe morphology, with a weak, central, compact core of ~7 mJy within its structure. Thus 1636+473 consists of two (presumably independent) AGNs. We have made a VLBI and MERLIN phase-referencing study of this system, exploiting the close angular proximity of the strong (A) core to the weak (B) core to make an astrometric measurement of their separation, and to permit phase-reference imaging of the latter.

2 Observations

We made simultaneous MERLIN and Global VLBI observations of 1636+473 at 5 GHz on 12/13 May, 1995. We used the EVN antennas at Effelsberg, Westerbork, Medicina and Jodrell Bank (Mk2), and in the US the VLBA antennas at FD, HN, NL and OV, the Green Bank 140ft antenna, and the VLA in phased array mode. For the VLBI we used the MK3 recording system in mode B ("double speed") giving a total bandwidth of 56 MHz for the LHC polarisation channel. Both components of 1636+473 could be observed simultaneously at all antennas except the phased-VLA, where we switched the pointing between the A and B sources during the continuous VLBI scans (A-B-A cycles of 1.5/3.5/1.5 minutes and 1.0/2.5/1.0 minutes for 6.5 and 4.5 min scans, respectively). The VLBI correlation was made at the MPIfR, Bonn processor, using separate correlation passes at accurate A and B core positions, obtained from an analysis of our MERLIN image of the sources. Editing out of the VLA "off-source" correlations, calibration of the visibility amplitudes using antenna radiometry and gain data, and all subsequent analyses were performed using the NRAO AIPS package.

3 Analysis and Results

Our MERLIN image of 1636+473 showed A to be unresolved at 60 mas resolution, with a total flux density of 635 mJy. In contrast, most of the extended structure of 1636+473 B is resolved out; our map of the B subfield (figure 1) reveals a compact, unresolved core of 9.17 mJy, with faint traces of the extended emission, and a weak jet in PA 80°. (All maps are made with uniform weighting, and are plotted with contours at levels of −2, −1, 1, 2, 4, 8... etc, times the specified contour interval in the figure captions)

We made a VLBI hybrid map of 1636+473 A (figure 2), using standard fringe-fitting to determine antenna-based residual delays and rates, and many cycles

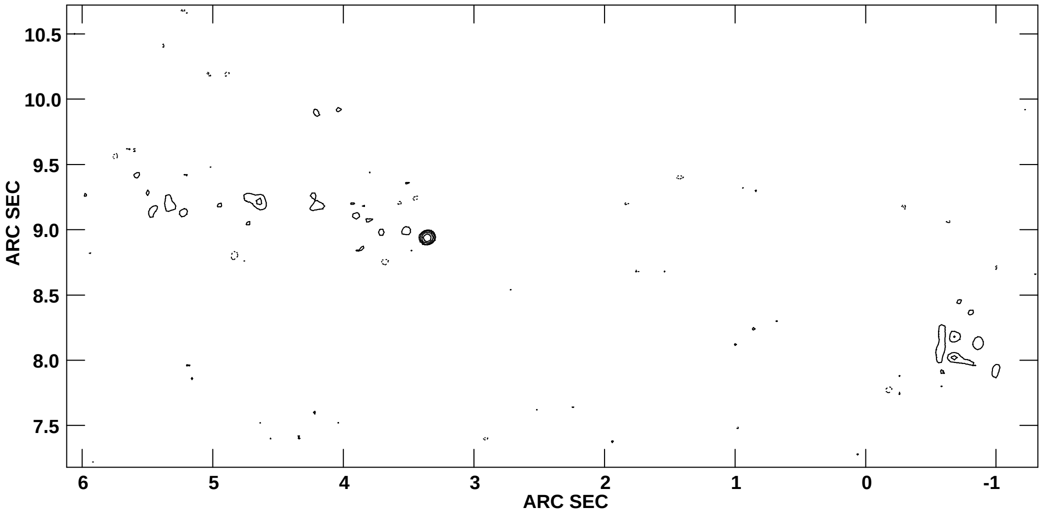

Fig. 1. MERLIN 5 GHz image of 1637+473 B; beam 60 x 60 mas; contour interval 0.6, peak 8.91, rms 0.20 (mJy/beam)

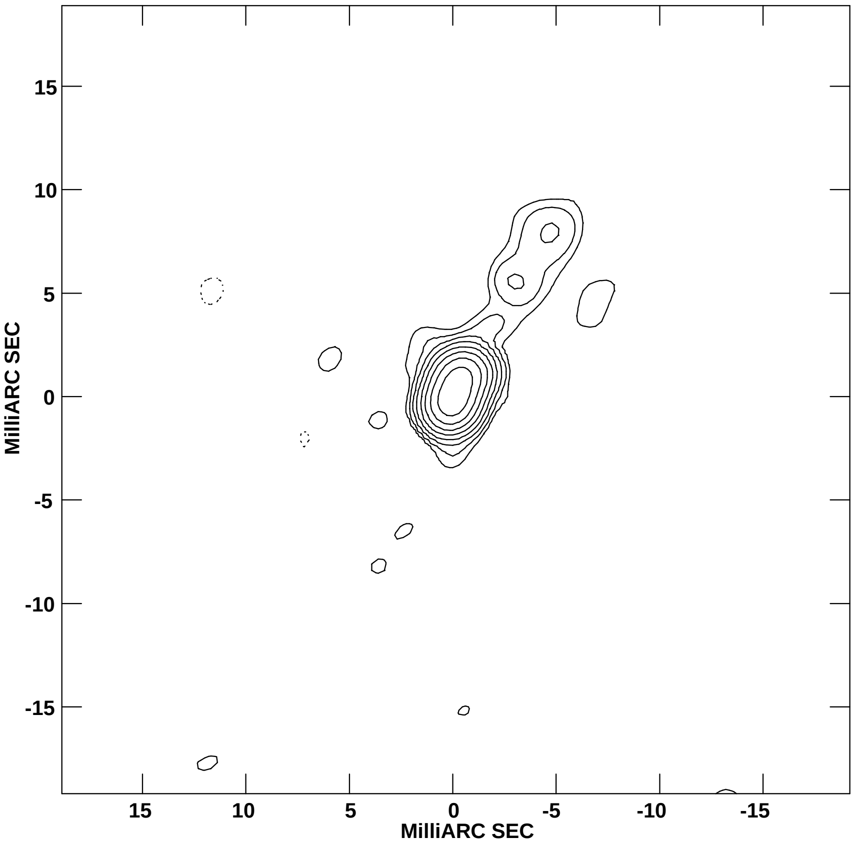

Fig. 2. VLBI 5 GHz hybrid map of 1636+473 A; beam 1.5 x 1.5 mas; contour interval 1.4, peak 331.3, rms 0.43 (mJy/beam)

of phase self-calibration, mapping and CLEAN deconvolution. Amplitude self-calibration was also applied in the last stages. At 1.5 mas resolution this quasar exhibits an extended core (1.9 x 0.3 mas in PA $-22°$) and a faint, one-sided jet in PA −30°, traceable out to ∼10 mas. The sum of the core and jet flux densities in the map is 603 mJy, some 94% of the MERLIN flux density. This may indicate missing, low-brightness emission, but is also the level of the relative calibration uncertainty between the MERLIN and VLBI data sets.

We made phase-reference maps of 1636+473 B (figure 3) after applying to

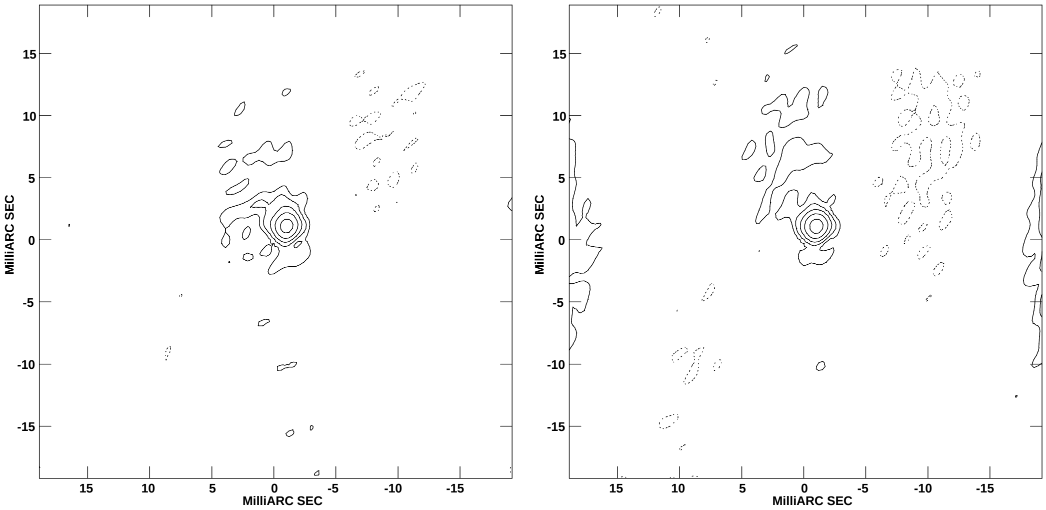

Fig. 3. VLBI 5 GHz phase-reference maps of 1636+473 B; beam 1.5 x 1.5 mas, contour interval 0.3 mJy/beam. Left: Using all data; peak 6.56, rms 0.13 mJy/beam. Right: Excluding baselines to VLA; peak 6.81, rms 0.12 mJy/beam

the B data the rate and delay corrections determined from fringe-fitting the A data, and the total phase and amplitude corrections from self-calibration. This procedure assumes an accurate separation of instrumental and structural phase contributions for A, a sufficiently precise geometrical model for correlation, atmospheric spatial coherence over 20 arcsec, and temporal coherence over the VLA source-switching interval for baselines to the VLA. The peak flux densities for maps made with and without VLA baselines are 6.56 and 6.81 mJy, respectively; this difference may be attributed to the coherence loss due to temporal phase fluctuations on baselines to the VLA.

The rms noise levels in these maps of B are 3 to 4 times lower than the noise level in the A map, but both are considerably above the "thermal noise" level expected. In the A map the residual noise level is probably dominated by data calibration errors and "mapping" noise. In the B maps there may be contributions from "coherence" errors in the transfer of instrumental phase between the two sources, and there may also be contributions from any unsuppressed response from the strong A source in the weak visibility data for B on short baselines.

We also made a hybrid map of 1636+473 B (figure 4), using the phase-reference map as an input for phase self-calibration and a longer solution interval (3 mins). As expected, in this map the peak flux density is higher, and the rms

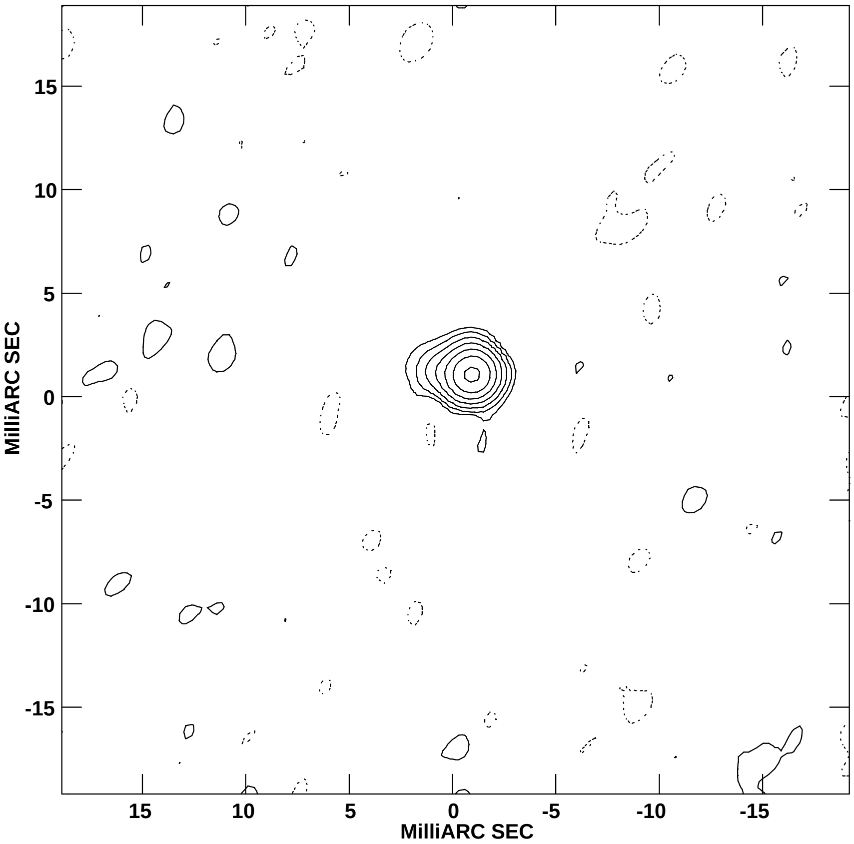

Fig. 4. VLBI 5 GHz hybrid map of 1636+473 B; beam 1.5 x 1.5 mas, contour interval 0.1, peak 7.38, rms 0.042 (mJy/beam)

noise lower, than in the phase-reference maps. The "coherence" losses of 8 to 12% in the phase-reference maps indicate that the requirements mentioned above for this procedure are not completely fulfilled. The hybrid map of B shows a faint ~2 mas extension of the core in PA ~80°, on the same side as, and pointing towards, the faint jet features seen in the MERLIN map. The total flux density of the core and extension is 8.75 mJy, i.e. 95% of the MERLIN core flux.

4 Relative astrometry

The 1636+473 A hybrid map and B phase-reference maps were made after applying identical phase corrections to the raw visibility outputs from the A and B correlations. Differences between the position offsets of features of A and B from their respective map centres thus measure corrections to the difference between the A and B positions used for correlation. These positions, and measurements of the position offsets of the A and B cores from their map centres (made using the AIPS task MAXFIT) are presented in table 1. The

Table 1
Positions used for correlation, and core position offsets in maps

Source	RA (J2000) hh:mm:ss.ssssss	Dec (J2000) dd:mm:ss.sssss	map type	RA offset (mas)	Dec offset (mas)
1636+473 A	16:37:45.136200	+47:17:33.80100	hybrid	–0.06	+0.09
			sup.res	+0.12	–0.43
1636+473 B	16:37:45.739200	+47:17:51.58100	ph.ref	–1.04	+1.17

very small correction of the B position (with respect to the A position) of ~1 mas in each coordinate is remarkable, since the MERLIN positions were measured with a beam of 60 mas. A conservative estimate of the precision of the measured VLBI position offsets is 1/15 of the beam (i.e. 0.10 mas).

The extended and asymmetric nature of both cores limits the accuracy with which their peak positions can be specified, however, since these may be resolution-dependent. We made "super-resolved" maps of both A and B, using smaller map pixel sizes and CLEAN restoring beams (figure 5); cuts across the

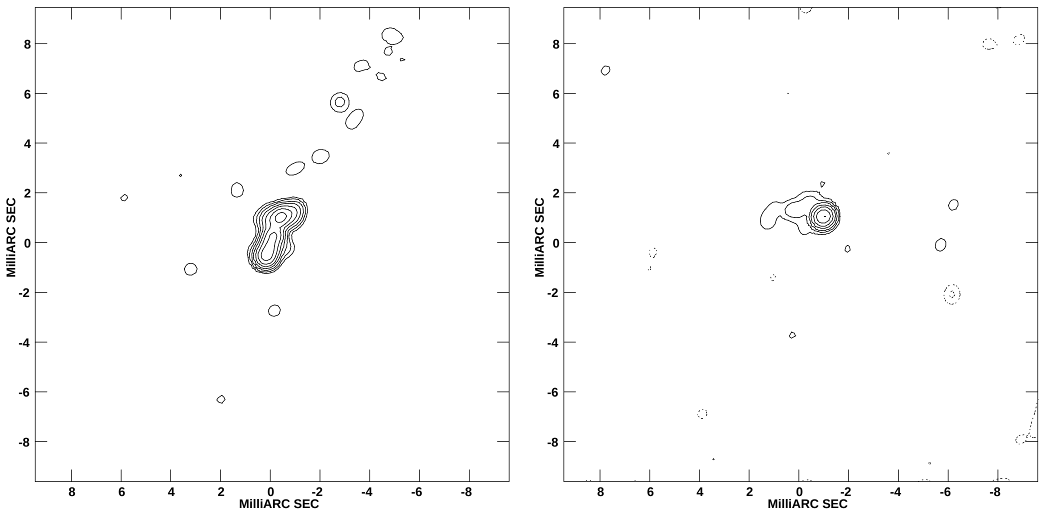

Fig. 5. VLBI 5 GHz "super-resolved" maps; beam 0.5 x 0.5 mas. Left: 1636+473 A, contour interval 1.4, peak 152.8, rms 0.39 (mJy/beam). Right: 1636+473 B, contour interval 0.1, peak 6.43, rms 0.030 (mJy/beam)

cores along the jet axes are given in figure 6. The extended core of A appears to consist of at least 2 or 3 sub-components. The position of the strongest of these is also given in table 1; it is offset from the lower-resolution "core" position by 0.55 mas in PA 161°. The extension of the B core appears to be caused by a weak, 0.4 mJy component, offset by ~1.3 mas to the east. However, as the B hybrid map was produced with additional cycles of phase self-calibration, position offsets cannot be directly related to those in the A

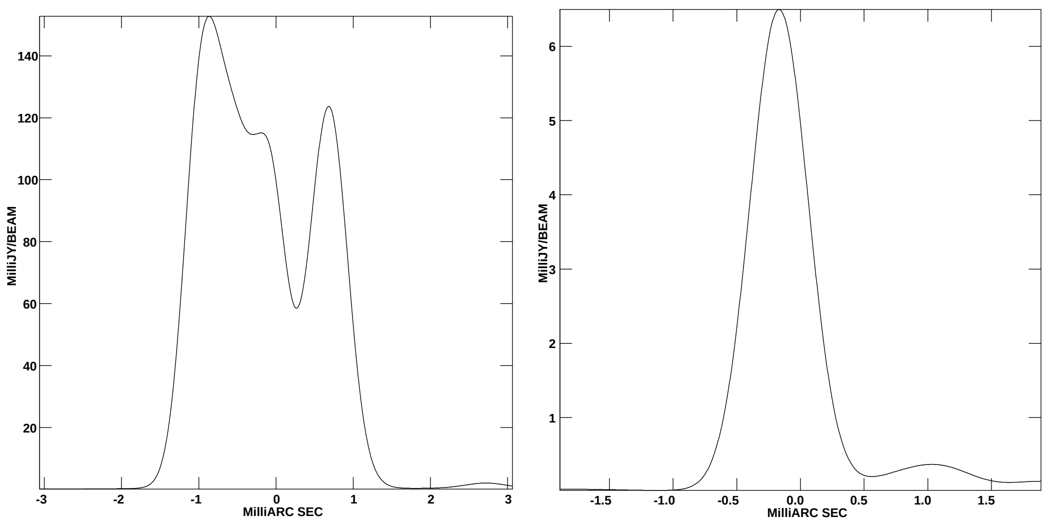

Fig. 6. Cuts across cores in super-resolved maps. Left: 1636+473 A in PA −17°. Right: 1636+473 B in PA +83°

map. (In fact, the B core position offset moved +0.08 and −0.11 mas in RA and Dec, respectively, between phase-reference and hybrid maps)

5 Discussion

We have successfully mapped the 9 mJy core located within the extended emission of 1636+473 B. Errors in determining antenna phases on the reference source (A) and in transfering them over 20 arcsec cause "coherence" losses in the phase-reference maps and limit their dynamic range; temporal phase interpolation produces further degradation. We have measured astrometric corrections to the MERLIN relative positions of the A and B cores, with a precision of ∼0.1 mas; however, the "position" of at least the A core is resolution-dependent.

The compact nature of the 1636+473 B core, and its one-sided extension which is closely aligned with the direction of the MERLIN jet, confirm beyond any remaining doubt that it is an independent radio-emitting AGN, unrelated to the quasar 1636+473 A. Its mas-scale properties are similar to those of the weak quasar cores investigated by Porcas et al (1990) and Hough et al (1999). 1636+473 B has a value of 0.06 for R, the flux ratio between the core and extended lobe emission. In unified schemes (e.g. Orr & Browne, 1982; Barthel, 1989) this would suggest a relatively large angle to the line of sight, consistent with the obscuration of any non-thermal optical quasar nucleus by a torus. Asymmetries in the radio structure caused by Doppler boosting should be relatively mild in 1636+473 B; from the absence of detectable emission greater than 3 times the rms noise in the hybrid map, we can put a weak lower limit to the jet/counter-jet brightness ratio of $\sim$3.

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