VLBI observations of five compact radio sources

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Five compact radio sources, 0420-014, 1334-127, 1504-166, 2243-123, and 2345-167, were observed at 5GHz by the EVN in June, 1996. The primary purpose of this observation was to confirm their superluminal proper motions. Here, the results for 1334-127, 1504-166, 2243-123 and 2345-167 are presented.

1. Introduction

Blazars exhibit the most rapid and the largest amplitude variations of all AGN (Stein *et al.* 1976; Angel & Stockman 1980). Extreme variability suggests the continuum is emitted by a relativistic jet close to the line of sight and hence that the observed radiation is strongly amplified by beaming effects (Blandford & Rees 1978).

In the radio band, blazars usually have very compact, flat-spectrum cores, which can be investigated via VLBI observations. In particular the brightness temperature of a core can be estimated From multi-frequency VLBI observations we can obtain the spectrum of the core as well as jet components. Also, if a jet component shows superluminal proper motion, then it is possible to estimate its Doppler boosting factor δ and viewing angle (Marscher 1987).

Shen et al. and Hong et al. carried out three VLBI surveys of compact southern-hemisphere radio sources in November 1992 (Shen *et al.* 1997), May 1993 (Shen *et al.* 1998) and October 1995 (Hong et al. 1999). In these surveys, sources 0420-014, 1334-127, 1504-166, 2243-123 and 2345-167 showed some jet structure. The aim of new EVN observations was to confirm the superluminal proper motions in these sources. Here, we present some results of 1334-127, 1504-166, 2243-123 and 2345-167. The results of 0420-014 are discussed separately by Zhou *et al.* (2000) because of its notable interesting properties. Throughout the paper, we assume $H_0 = 100h$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$.

2. Observation and data reduction

The VLBI observations were carried out from 1996 June 15 to 17 with the EVN. Eight telescopes took part in the observations, i.e. Shanghai, Crimea, Noto, Hartebeesthoek, Urumqi, Onsala, WSRT, and Torun. The recording modes was MkIII mode E (bandwidth 14MHz). The data were correlated at MPIfR Mk III correlator in Bonn.

A-priori amplitude calibration and fringe-fitting were carried out using the standard routines in the AIPS package. Imaging was done using the DIFMAP difference mapping software (Shepherd, Pearson, & Taylor 1994). Four final CLEAN maps of 1334-127, 1504-166, 2243-123 and 2345-167 are displayed in Figure 1. In order to carry out the image analysis, we used the program 'modelfit' in DIFMAP to fit the final self-calibrated UV data with circular gaussian components. The model fitting results are listed in Table 1.

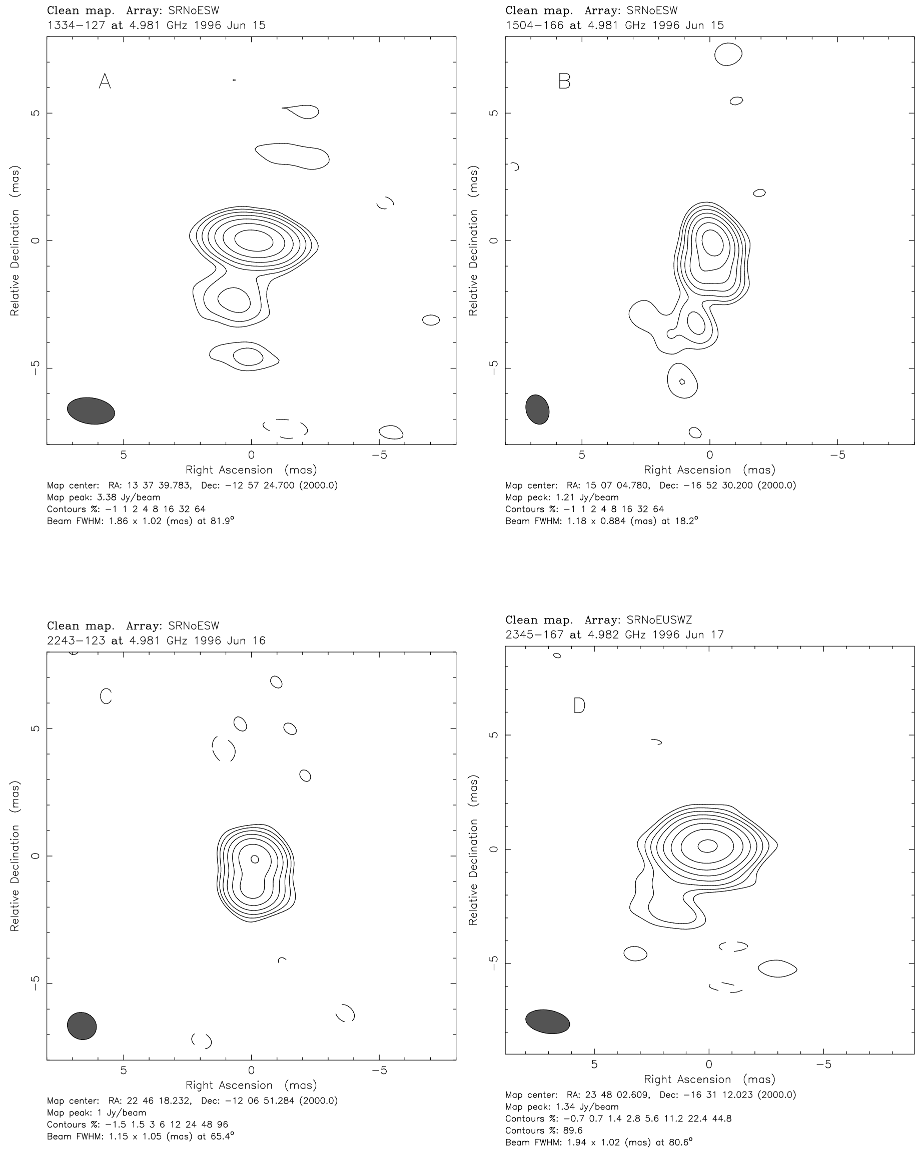

FIGURE 1. CLEAN maps of 1334-127(A), 1504-166(B), 2243-123(C) and 2345-167(D).

3. Results and discussion of individual sources

3.1. *1334-127*

PKS 1334-127 (z = 0.539) was classified as a highly polarized quasar by Impey & Tapia (1988). It is also a ROSAT (Brinkmann, Siebert, & Boller 1994) and an EGRET (Hartman *et al.* 1999) source.

The large scale VLA image at 1.4GHz shows a curved jet extending 6.5 arcseconds to the east of the core (Perley *et al.* 1982). VLBI observations carried out at 5GHz in 1986.9 (Wehrle *et al.* 1992) indicated that the source was barely resolved. A jet component was detected at 1.7mas from the core in $P.A. = -150°$ in November 1992 (Shen *et al.* 1997). In 1995, the jet component moved to the position with radius of 2.11 mas and $P.A. \approx 170°$

Source Name	Component Number	S (Jy)	Radius (mas)	P.A. (deg)	Major (mas)	Ratio
1334-127	1	3.3	0	0	$7.5e^{-5}$	1.0
	2	0.4	2.5	159	0.65	1.0
1504-166	1	1.2	0	0	0.39	1.0
	2	0.7	1.3	164	0.94	1.0
2243-123	1	0.7	0	0	$2.5e^{-7}$	1.0
	2	1.1	1.2	-10	0.27	1.0
2345-167	1	2.0	0	0	0.9	1.0
	2	0.1	3.4	138	0.7	1.0

TABLE 1. Model descriptions of 1334-127, 1504-166, 2243-123 and 2345-167.

(Hong *et al.* 1999). Shen *et al.* (1997) reported a proper motion of 0.28 mas yr^{-1} and Hong *et al.* (1999) presented an apparent velocity of $\beta_{\rm app} = 2.4 \pm 0.5h^{-1}$.

Our image, shown in Figure 1(A), indicates a jet structure extending to the south-east, with radius of 2.5 mas and *P.A.* of 159° (Table 1). The jet is probably bending clockwise. Thus, it is natural that substructures appear in the east of large scale VLA map. With three epochs of VLBI observation at 5GHz, we estimate a proper motion of 0.21 mas yr^{-1} which corresponds to an apparent velocity of $\beta_{\rm app} = 3.9h^{-1}$.

3.2. *1504-166*

1504-166 (z=0.876) is classified as a highly polarised quasar (Impey & Tapia 1988), and is known to be a low frequency variable source (McAdam 1982). It was unresolved at 1.4GHz by VLA (Perley *et al.* 1982).

Two jet components were detected in the 5GHz VLBI observations in 1992 (Shen *et al.* 1997). One is at radius 1.12 mas and P.A. of −156°; the other at radius 0.8 mas and P.A. of 161°. In the 5GHz VLBI observation in 1995, Hong et al. (1999) detected a jet component with radius of 1.35 mas and P.A. of 150°, which had a proper motion of 0.08 mas yr^{-1}.

Our VLBI image (Figure 1(B)) shows a slightly curved core-jet structure to the south-east. The jet position angle is consistent with that derived at 1.7GHz by Romney (1984). The model fitting results show a jet component extending in the south-east direction (*P.A.* = 164°). Assuming the jet component in our image is the same one as the jet component in Hong et al. (1999) and the component 2 in Shen et al. (1998), we can estimate a proper motion of 0.055 mas yr^{-1}, which corresponds to $\beta_{\rm app} = 1.4h^{-1}$.

3.3. *2243-123*

2243-123 (z=0.630) is a highly polarised quasar. Emission at X-ray and γ-ray energies has been detected (Maisack *et al.* 1994; Fichtel *et al.* 1994). The VLA image shows an unresolved core and an extended component at 4" from the core in *P.A.* = 40° (Morganti *et al.* 1993; Browne & Perley 1986; Perley 1982). In the 15GHz (Kellermann *et al.* 1998), 2.3GHz and 8.4GHz (Fey & Charlot 2000) VLBA images, the jet clearly bends to the north-east direction. Thus, the core is probably in the south. Hong *et al.* (1999) suggests a proper motion of 0.40 mas yr^{-1} assuming a jet component was ejected out in 1992.90.

Our new image (Figure 1(C)) shows a core-jet structure. The two components are about 1.2 mas apart. Compared to the results in 1995 (Hong *et al.* 1999), a proper motion of 0.19 mas yr^{-1} was estimated, which corresponds to an apparent velocity $\beta_{\rm app} = 3.8h^{-1}$. The jet component probably emerged in 1990 when a strong flare began.

3.4. *2345-167*

2345-167 (z=0.576) is an optically violent variable and a highly polarized blazar. X-ray emission was detected by ROSAT (Brinkmann, Siebert, & Boller 1994). This source has a complex radio spectrum with a peak around 5GHz, and is a low frequency variable source (McAdam 1982). VLA observations show a jet of 4.0 arcseconds in $P.A. = -130°$. In milli-arcsecond scale, the jet moves out along the direction of $\sim 110°$. Therefore, Shen et al. (1997) suggest that the jet may bend clockwise from south-east at milli-arcsecond scale to south-west at arcseconds scale. Proper motions of 0.26 mas yr^{-1} and 0.08 ± 0.03 mas yr^{-1} were reported by Shen *et al.* (1997) and Hong *et al.* (1999) respectively.

Our image of 2345-167 shows a compact core and a weak jet component in the south-east (Figure 1(D)). The jet component is located about 3.4 mas from the core with $P.A. = 138°$. Comparing our results to those of Shen et al. (1997) and Hong et al. (1999), we obtain a proper motion of 0.085mas yr^{-1}. The corresponding apparent velocity is $\beta_{\mathrm{app}} \approx 1.7\, h^{-1}$, which is comparable to Hong's (1999) results.

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