VLBI observations of five compact radio sources

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

1. Introduction

The 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 the line of sight and hence that the observed radiation is strongly amplified by beaming effect (Blandford & Rees 1978).

In the radio band, blazars usually have very compact, flat-spectrum cores, which are appropriate for VLBI observation. The brightness temperature of a core can be estimated by VLBI observation. Multi-frequency VLBI observation can obtain the spectrum of a 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 $\delta$ and viewing angle (Marscher 1987).

Shen et al. and Hong et al. carried three VLBI surveys of compact radio sources on southern-hemisphere in November 1992 (Shen et al. 1997), May 1993 (Shen et al. 1998) and October 1995 (Hong et al. 1999). In these surveys, source 0420-014, 1334-127, 1504-166, 2243-123 and 2345-167 show some jet structures. 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 were discussed in detail in 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 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
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 observation carried out at 5GHz in 1986.9
Table 1. Model descriptions of 1334-127, 1504-166, 2243-123 and 2345-167.

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

(Wehrle et al. 1992) indicated that the source was barely resolved. A jet component was detected at 1.7 mas 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. ≈ 170° (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 β₀⁻¹ = 2.4 ± 0.5 h⁻¹.

Our image, shown in Figure 1(A), indicates a jet structure extending to 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 a apparent velocity of β₀⁻¹ = 3.9 h⁻¹.

3.2. 1504-166

1504-166 (z=0.876) is classified as a highly polarized 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 in the position with radius of 1.12 mas and P.A. of -156°; the other is in the position with radius of 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 in 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 β₀⁻¹ = 1.4 h⁻¹.

3.3. 2243-123

2243-123 (z=0.630) is a highly polarized quasar. Emission at X-ray and γ-ray energies was 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. Compare 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 $\beta_{\text{app}} = 3.8h^{-1}$. The jet component was 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). It 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. $=-130^\circ$. In milli-arcsecond scale, the jet moves out along the direction of $\sim 110^\circ$. 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 $0.08 \pm 0.03$ 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 3D). The jet component is located about 3.4 mas from the core with P.A. $= 138^\circ$. Compare to the results of Shen et al. (1997) and Hong et al. (1999), we obtain a proper motion of 0.085 mas yr$^{-1}$. The corresponding apparent velocity is $\beta_{\text{app}} \approx 1.7 h^{-1}$, which is comparable to Hong's (1999) results.

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