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Tracking the curved jet in PKS 1502+106

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Abstract. We carried out a multifrequency and multiepoch study of the highly polarized quasar, PKS 1502+106 at radio frequencies. The analysis is based on an EVN dataset at 5 GHz, archive VLBA datasets at 2.3, 8.3, 24.4 and 43.1 GHz and an archive MERLIN dataset at 5 GHz. The various datasets span over a period of 10 years. The source is characterized by a multi–component one–sided jet at all epochs. The VLBI images show that a complex curved jet is located to the southeast and east of the core, with the position angle (PA) of the jet axis wiggling between ~80° and ~130°. The MERLIN image reveals that the jet extends to 0.6″at a PA 135 ± 12°. The radio core in the VLBI images has a brightness temperature approaching the equipartition limit, indicating highly relativistic plasma beamed towards us. ΔPA in the source, the misalignment of the kpc– and pc–scale radio structure, is estimated about 32°, suggesting that PKS 1502+106 belongs to the aligned population. Four superluminal components are detected in the parsec scale jet, whose velocities are $24.2h^{-1}c$, $14.3h^{-1}c$, $6.8h^{-1}c$ and $18.1h^{-1}c$. Our analysis supports the idea that the relativistic jet in PKS 1502+106 is characterised by extreme beaming and that its radio properties are similar to those of γ–ray loud sources.

1. Introduction

One of the most significant observational results of extragalactic γ–ray active galactic nuclei (AGNs) is that all EGRET–identified objects are radio–loud sources (Mattox et al. 1997). Relativistic beaming in the jet is used to explain the EGRET identification in radio–loud AGNs. The EGRET–identified sources have on average much faster apparent superluminal motions than the general population of radio–loud sources (Jorstad et al. 2001). Hong et al. (1998) concluded that γ–ray loud quasars typically show aligned morphologies on parsec and kiloparsec scales based on a statistical analysis of the ΔPA distribution. However, it is still a matter of debate if the γ–ray emission in AGNs is related to higher beaming in these sources.

PKS 1502+106 (4C 10.39, OR103), z=1.833 (Veron-Cetty & Veron 1998), is a 18.6 mag highly polarized quasar (Hewitt & Burbidge 1989; Tabara & Inoue 1980). A high and variable degree of polarization in the optical band is reported by Impey & Tapia (1988). It is known to be active and variable at radio, optical and X–ray wavelengths (George et al. 1994 and references therein). A VLA image at 1.64 GHz (Murphy, Browne & Perley 1993) shows that a continuous jet extends to the southeast and leads to a lobe located ~ 7″from the core. VLBI observations (Fey, Clegg & Fomalont 1996; Fomalont et al. 2000; Zensus et al. 2002) exhibit a well–defined jet starting to the southeast and sharply bending to the east at a distance of 3 – 4 mas from the core.

Our interest in PKS 1502+106 is related to the misalignment between the pc– and kpc–scale radio structure in AGNs and its relation to the γ–ray emission. A flux density upper limit of 7×10^{-8} photons cm^{-2}s^{-1} (2σ) at γ–ray energies was given by EGRET in the Phase I observation (Fichtel et al. 1994), while no detection is reported in in the following EGRET observations (Thompson et al. 1995; Hartman et al. 1999). The gamma–ray properties of this source are therefore unclear. We observed PKS 1502+106 with the EVN as a gamma–ray source candidate, as part of a project (Hong et al. 2002) aimed at studying the relation between the ΔPA and γ–ray emission . More details are given in An et al. (2004).

2. Results

Figure 1 shows images of PKS 1502+106 made with the VLA, MERLIN, EVN and VLBA, illustrating the complex curved jet morphology on very different scales. Figure 2 presents the distribution of jet position angles along the projected radial distance in PKS 1502+106:

- The VLA map in Fig. 1a (Murphy, Browne & Perley 1993) shows a strong core and a straight jet directed to the southeast. The core is unresolved at the resolution of 3″. A low-brightness lobe is located 7″ from the core, in a PA ~157°. No counterjet is found at the dynamic range of of the image, i.e. 5000:1.
- The MERLIN image in Fig. 1b, obtained with the archive 5 GHz data, exhibits the jet extending to the southeast up to 0.6″ from the core. The jet starts out from the core at PA~120° within 0.1″, and then gradually bends in the direction of the arcsec–scale lobe (7″ from the core) after a curve at ~ 0.3″. The jet is resolved into a number of knots.
- The VLBI images displayed in Figs. 1c to 1f, obtained with the EVN and VLBA, show a complex curved jet with a length of 15 mas. Several distinct components follow a continuous curved path. The innermost component within 0.2 mas shows no radial motion but significant changes in position angle, and the components from 0.5 mas to 4 mas move out to the southeast at a PA~ 125° (Figure 2). There is a clear bending at 3 – 4 mas, from PA~ 130° to PA~ 80° (Figure 1 and Figure 2).

Table 1. Parameters of the images

Figure	Epoch	Band	Freq. (GHz)	Beam (mas)	S_P (Jy/b)	*r.m.s.* (mJy/b)	Contour (mJy/b)	Ref.
Fig.1a	1985.10	L	1.64	1510×1480,48.6°	2.20	0.1	0.44×(-1,1,2,...,512)	1
Fig.1b	1992.37	C	5.0	79×49,24.4°	1.63	0.1	3.0×(-1,1,2,...,1024)	2
Fig.1c	1994.52	X	8.3	7.18×3.78,-1.7°	1.81	1.1	3.5×(-1,1,2,...,128)	3
Fig.1d	1997.85	C	5.0	1.36×1.21,64.7°	0.80	0.7	3.1×(-1,1,2,...,256)	3
Fig.1e	2002.65	K	22.4	0.64×0.28,0°	0.73	0.9	2.8×(-1,1,2,...,256)	3
Fig.1f	2002.37	Q	43.1	0.37×0.16,0°	0.82	1.0	3.0×(-1,1,2,...,256)	3

Ref: 1– Murphy, Browne & Perley 1993; 2– archival MERLIN data; 3– An, et al. 2004

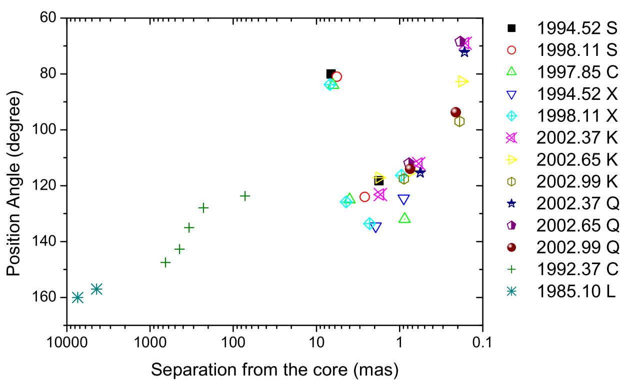

Fig. 2. Position angles of jet components along the radius.

– Considering the complex parsec–scale jet structure, we define the jet axis PA on parsec scale as the PA measured at 10 pc (∼ 1.6 mas at z=1.833) from the core, i.e. ∼ 125°. The jet PA on kpc scale is defined as the position angle of the lobe in the VLA image, ∼157°. Hence, ΔPA is 32°, indicating that PKS 1502+106 an aligned quasar.

The compact core component in the VLA and MERLIN images contains more than 98% of the total flux density, indicating strong Doppler beaming effect.

The multifrequency VLBI datasets allow us to estimate the spectral index ($S_\nu \propto \nu^\alpha$) distribution of the source. As expected, the shape of the spectrum differs in the core and in the jet components. The spectrum is flat in the core ($\alpha_{43}^{24} \sim 0$), while it is in the range $-0.7 \div -1.5$ along the inner jet. We note that the spectrum at epoch 2002.99 is steeper in each component compared to other epochs. It could be related to the jet expansion. We also estimated the brightness temperature of the core based on 5, 8.3, 24.4 and 43.1 GHz VLBI observations. The result gives $T_r = (2.0 \pm 0.5) \times 10^{11}$K in the source frame. It approaches the upper limit constrained by equipartition (Kellermann & Pauliny-Toth 1969; Readhead 1994), suggesting highly relativistic plasma close to the line–of–sight.

We detected four superluminal components along the parsec–scale jet, whose velocities are $24.2h^{-1}c$, $14.3h^{-1}c$, $6.8h^{-1}c$ and $18.1h^{-1}c$, respectively. The speeds are much higher than the average level of radio loud quasars (3.2c, Pearson et al. 1998), and are found in agreement with the average speed of gamma–ray loud quasars ($15.9\pm6.6h^{-1}c$, Jorstad et al. 2001). We note that the highest superluminal motion is associated with a component passing through the jet bending at 3–4 mas from the core. The apparent motion could be magnified to this even higher level by projection effects.

3. Conclusions and Future Work

We carried out a mutlifrequency and multiepoch analysis of PKS 1502+106 at mas and arcsec resolutions. The source morphology is highly variable and the jet structure is very complex. The jet PA wiggles in 80°–130°–80° in the inner 20 mas, and changes to 120°–160° on a scale of hundreds of mas to several arcsec. The overall oscillated jet trajectory could be described by a helical pattern. We note that the wide range of PA on the mas scale could be the result of amplification by projection effects due to a jet alignment close to the line–of–sight. Similar wiggling structures have also been found in other extragalactic jets, such as 3C 273, 3C 345, 3C 120, MrK 501, M87. They could be interpreted as motions along a helix lying on the surface of a cone. Helical trajectory in relativistic jets could originate from regular precession of the jet flow at the central engine, or from random disturbance at the jet base. The initial disturbed jet might evolve into helical motion at larger scales (Hardee 1987 2003). Other dynamical processes, such as bent shocks, could also result in a projected helical path (Gómez, Alberdi & Marcaide 1994). PKS 1502+106 could be a good case for a morphological study of helical jets.

Most of the total flux density in the VLA and MERLIN images is dominated by an unresolved core component; the brightness temperature of the radio core on the parsec scale approaches the equipartition limit; four superluminal components with extremely high apparent speed are detected in the parsec–scale jet. All the observational results support the hypothesis of a highly relativistic jet flow aligned towards us.

The properties of ΔPA (∼30°) and superluminal motion in PKS 1502+106 are consistent with those of γ-ray loud quasars (Hong et al. 1998; Jorstad et al. 2001). These observed features, together with the uncertain γ–ray emission in this source, pose again the question of the intrinsic difference between γ–ray loud and quiet extragalactic radio sources. A confirmation of γ-ray emission from this source would be highly valuable for our understanding of the γ-ray loudness phenomenon in radio loud quasars.

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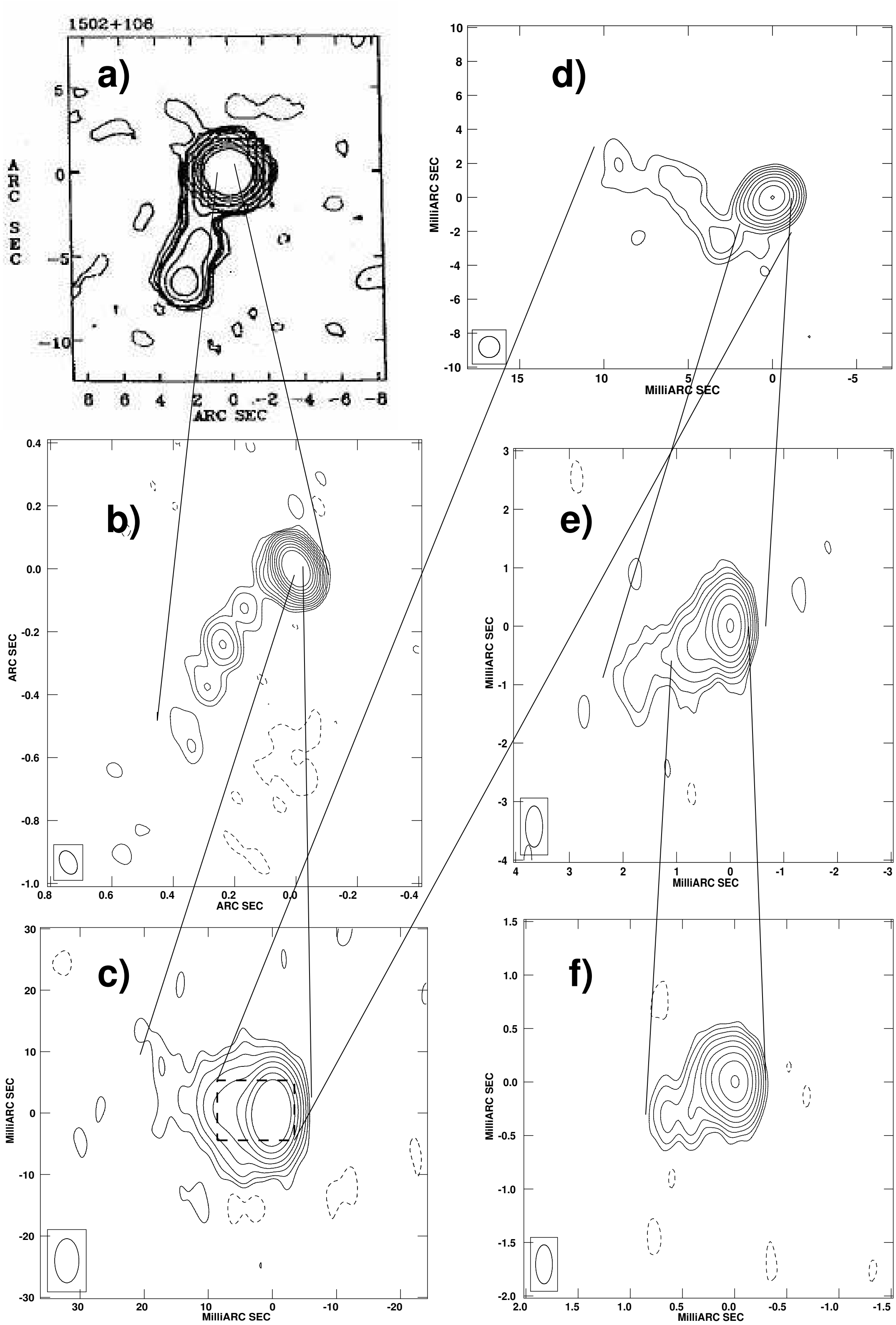

Fig. 1. Total intensity images of PKS 1502+106. Image parameters are referred to Table 1. VLA image (Murphy, Browne & Perley 1993); MERLIN image (archive 5 GHz data); others (An et al. 2004).