Astrophysical Phenomena Revealed by Space VLBI
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VSOP Observations of 3C 216

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Abstract

We present VLBI Space Observatory Programme (VSOP) observations of the extremely misaligned quasar 3C 216. The observed brightness temperature of the radio core is comparable to the inverse Compton limit, and the source emission is probably relativistically boosted towards us.

1 Introduction

We carried out VSOP observations of 3C 216 ($z = 0.67$), a peculiar compact steep spectrum (CSS) quasar. The source is remarkable for its jet extending from the core to 140 mas, oriented almost perpendicularly to the arcsecond scale structure (Fejes et al. 1992). The jet follows a gently curved path, with underlying wiggles, and ends in a sharp bend (Akujor et al. 1996). These earlier observations could be interpreted with a precessing jet scenario; however, the very high rotation measure observed in the bend (Venturi & Taylor 1999) and the recently detected H I absorption in the source (Pihlström et al. 1999) indicate that the jet is probably deflected by an interstellar cloud in the host galaxy.

In the innermost part of the source, components emerge at superluminal speeds (Barthel et al. 1988). Venturi et al. (1993) showed that deceleration takes place in the inner few mas (10–20 parsecs). There is also a quasi-stationary component at ~ 1.5 mas from the radio core at 5 GHz. Our main goal was to investigate this region in more detail.

2 Observations, Data Reduction and Imaging

The observations took place on 14/15 February 1999 using HALCA, the 43m Green Bank telescope and the western part of the European VLBI

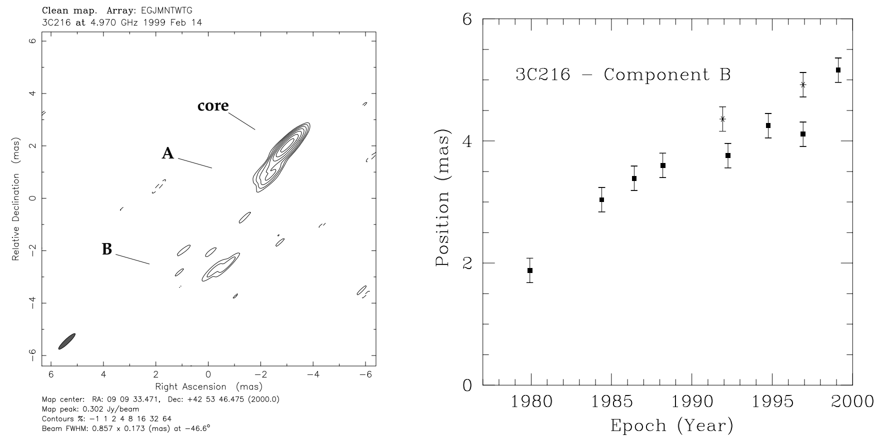

Figure 1: **a** Full resolution space VLBI image. Contour levels are −1, 1, 2, 4, 8, 16, 32, 64% of the peak brightness of 302 mJy/beam, the size of the restoring beam is 0.86×0.17 mas at $PA = -47°$. **b** Motion of the superluminal component B from the earliest VLBI observations. The 1979–89 data are taken from Barthel et al. (1988) and Venturi et al. (1993), the 1991–98 data are taken from Venturi et al. (in prep.). Asterisks indicate observations at 8.4 GHz

Network (EVN) at 5 GHz. There were three tracking passes during the 8.5 hour experiment using the Green Bank, Tidbinbilla and Goldstone tracking stations. The data were correlated at the NRAO-VLBA correlator. We experimented with a variety of cellsizes and data weighting in imaging, in order to reconstruct the source structure on different spatial scales.

3 Results

The space VLBI image is shown in Fig. 1a. Components are labelled in the same way as in Venturi et al. (1993). The results of model fitting of the self-calibrated data are listed in Table 1. The core region is resolved; however, the clean beam is highly elongated roughly along the jet direction. Using a 0.5 mas circular restoring beam, Component A is apparently well separated from the core (image not shown). The separation is estimated as 1.25 ± 0.05 mas. This is not in agreement with the results of model fitting; an elongated component closer to the core (0.87 mas) gives the best fit to the data (see Table 1.). Component B is clearly resolved, and seems to be edge brightened on the western side. It is difficult to estimate the positional uncertainty of component B; we will use 0.2 mas in further analysis (as well as for other epochs). The position angle of the inner jet components ($PA = 152°$) is slightly misaligned with respect to the 100 mas scale jet ($PA = 146 - 149°$).

In order to scale angular sizes to projected linear sizes, we used $H_0 = 100\,h\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and $q_0 = 0.5$; 1 mas corresponds to $3.9\,h^{-1}$pc at the distance of 3C 216. The observed brightness temperatures of the source components are listed in Table 1. For the radio core, $T_\mathrm{b} = 7.85 \times 10^{11}$ K, which is comparable to the inverse Compton limit.

4 Discussion

The position of component B from earlier VLBI measurements is shown in Fig. 1b. These data are consistent with a constant proper motion of 0.14 ± 0.01 mas/yr between 1979 and 1999. This corresponds to $\beta_\mathrm{app} = (3.0 \pm 0.2)\,h^{-1}$ apparent transverse velocity.

The nature of component A is rather unclear. Its separation from the core is 1.25 mas (in the super-resolved image), compared to the earlier reported quasi-stationary position of 1.4–1.6 mas (Venturi et al. 1993). The beam orientation is not suitable to decide whether this feature is a separate component, or just an extension to the core emission. As we could not model the source structure with a stable component at a distance of 1.25 mas in the model-fitting process, the latter seems more favorable. It is very probable that the "core" and "component A" together form the so-called ultracompact jet region of 3C 216 (see Lobanov 1998). In this case we can apply the equipartition jet model of Blandford and Königl (1979) in which the limiting brightness temperature is about $3 \times 10^{11}\,\delta^{5/6}$ K. A comparison with the observed value results in a lower limit to the Doppler factor: $\delta \gtrsim 3.17$.

A lower limit to the Lorentz factor of the jet (γ) and an upper limit to the viewing angle to the line of sight (θ) can be calculated using β_app and δ determined above. Our results are $\gamma \gtrsim 3.16$ and $\theta \lesssim 18.4°$ (assuming $h = 0.7$). Much higher Doppler factors for 3C 216 have been determined by other methods ($\delta = 33$ in Ghisellini et al. 1992 and $\delta = 65$ in Güijosa & Daly 1996). These Doppler factors would result in very large Lorentz factors of $\gamma \gtrsim 16$ and much smaller angles to the line

Table 1: Fitted elliptical Gaussian model parameters of the source

Component	S (mJy)	r (mas)	Θ (°)	a (mas)	b/a	Φ (°)	$T_{\rm b}$ (10^{12} K)
Core	381.6	0.00	–	0.36	0.31	−32	0.785
A	122.8	0.87	151.5	1.37	0.21	−62	0.025
B	45.1	5.16	152.3	1.93	0.14	−31	0.007

of sight, but are not in contradiction with our lower and upper limits determined from $\delta \gtrsim 3.17$.

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