Astrophysical Phenomena Revealed by Space VLBI
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Multi-Frequency VSOP Observations of 3C 380

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Abstract

We report the first-epoch VSOP observations of the superluminal quasar 3C 380 at L- and C-band. A straight motion with a constant apparent speed of the component A is preferred, suggesting ballistic ejection from the core. The opening angle of the jet is $\sim 20°$ at both the pc- and kpc-scale. The distribution of spectral indices along the jet reveals shell-like spectral enhancements at the knots, possibly indicating an adiabatic expansion of the plasma blobs.

1 Introduction

The quasar 3C 380 is one of the most powerful radio sources at a redshift $z = 0.692$. This object is classified as a compact steep-spectrum (CSS) source, with an overall size of 10 kpc and a steep spectrum $\alpha = \frac{d \log S_\nu}{d \log \nu} = -0.7$ (Fanti et al. 1990). If we assume a Hubble constant of $H_0 = 75$ km s^{-1} Mpc^{-1}, 1 mas corresponds to 6 pc. VLA observations revealed

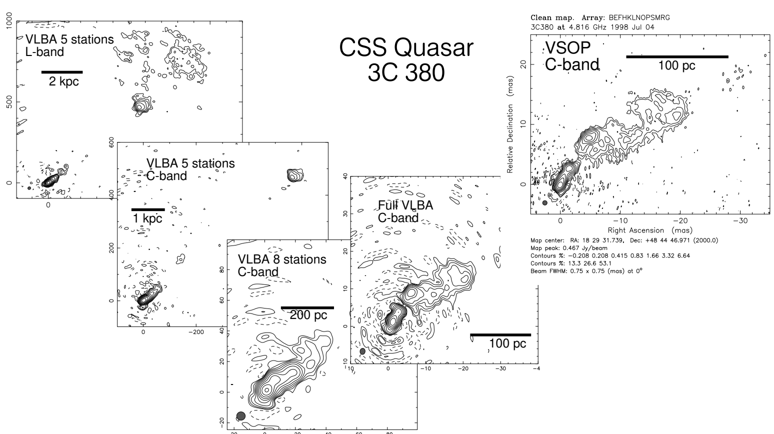

Figure 1: Images of 3C 380 in various scales with different arrays.

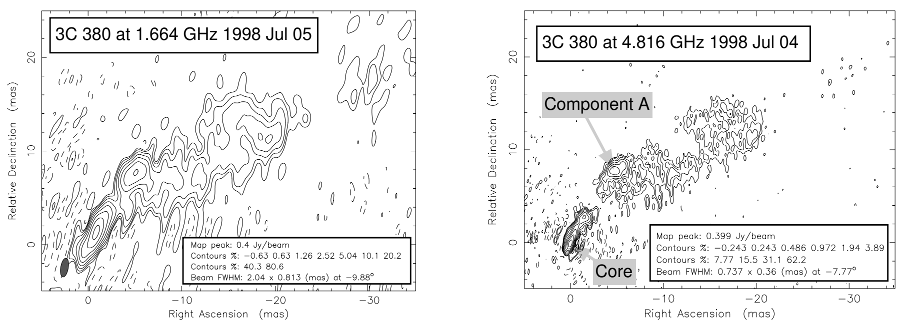

Figure 2: Full-resolution images of 3C 380 at 1.7 (*left*) and 5 GHz (*right*).

a one-sided jet emanating from the core to the north-west, a hot spot at 6 kpc from the core, and a cocoon-like radio lobe with a radius of $\sim$ 10 kpc (O'Dea et al. 1999). The jet shows a kinked structure on the 100-pc scale (Polatidis & Wilkinson 1998, hereafter PW98). Several knots are identified along the jet. PW98 have monitored the motion of knot A, which is located $\sim$ 50 pc from the core, revealing an apparent superluminal motion $\beta_{\rm app} = 5.9 \pm 0.7$. They found that this component curved along the bending jet and that its apparent speed changed from $\beta_{\rm app}$ = 2 to 10, leading them to consider the intersection of oblique shocks. This idea suggests an astrophysical interest; 3C 380 can be a good probe to investigate the interaction between a relativistic jet and the ambient gas. Simultaneous VSOP observations at 1.7 and 5 GHz will provide a distribution of spectral indices along the jet, and enable us to verify the interaction.

2 VSOP Observations and Results

Our VSOP observations at 1672 MHz (L-band) and 4824 MHz (C-band) were carried out for 12 hours on July 5 and 4, 1998, respectively. Figure 1 shows the images at various scales and resolutions by different arrays. With the most compact array, which consists of PT, LA, FD, OV, and KP, we detect the hot spot 6 kpc from the core at a position angle (PA) of $-50°$. Full-resolution VSOP images are shown in Figure 2. We obtain resolutions of 2.0×0.8 mas at PA $-9.°9$ and 0.74×0.36 mas at PA $-7.°8$ at L- and C-band, respectively, with uniform weighting. Component A is clearly identified at both frequencies.

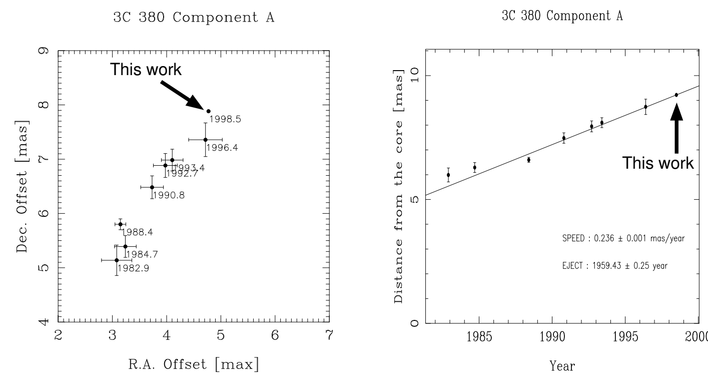

Figure 3: (*left*): Relative position of the component A from the core. Data points before 1996.4 are citations from PW98. (*right*): Angular distance of the component A from the core. The solid line indicates the best-fit linear motion.

3 Discussion

3.1 Jet Motion

The distance of the component A from the core is 9.22±0.01 mas at a PA of 323.°8. It is plotted in Figure 3 together with previous measurements by PW98. Although PW98 mentioned that the component A changed its direction and speed in 1988.4, our result indicates a straight motion with a constant apparent speed. The average proper motion of $\mu = 0.236 \pm 0.001$ mas yr^{-1} corresponds to $\beta_{\rm app} = 6.33 \pm 0.03$. The PA of 329°.3 is almost the same as that of the location of the component A. It may indicate a ballistic motion of the component A from the core.

3.2 Parsec- and Kiloparsec-Scale Jets

The jet has a straight extension from the core to the component A at ~50 pc at a PA of ~ 330°. In the low-resolution L-band image (see Figure 1), an extended diffuse emission at ~ 6 kpc can be seen at PA ~ 330°. We also see another straight ridge at PA ~ 310° from the 60 pc to 6 kpc scale. Considering the ballistic motion of the component A, the opening angle of ~ 20° is due to changes of the direction of the jet ejection.

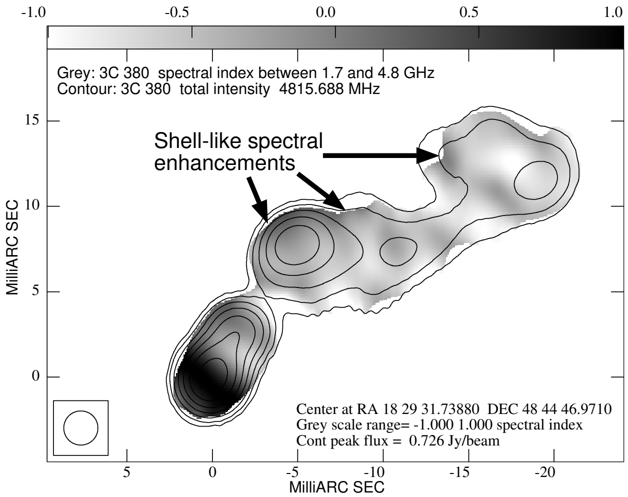

Figure 4: Spectral indices between L- and C-band (*grey scale*), overlaid on the total intensity image at C-band (*contour*). Both are restored with a 2 mas circular Gaussian beam.

3.3 Distribution of Spectral Index

The distribution of the spectral indices between L- and C-band is shown in Figure 4. While the inner 10 pc from the core is optically thick, downstream from component A shows an optically-thin feature with a negative spectral index. We found shell-like spectral enhancements along the jet, as shown in Figure 4. They are associated with the knots, and the radius of the shell is larger further downstream. We consider that these features indicate adiabatic expansion of plasma blobs.

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