Astrophysical Phenomena Revealed by Space VLBI
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VSOP Observations of Cen A

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Abstract

We have observed and imaged Centaurus A at light-month scale. The jet near the core bends by 60 degrees at 2 light-month from the core. Because of the large viewing angle of Cen A, this bending is not apparent but a true one. Discussions about physical mechanisms of bending jet are presented.

1 Introduction

We have observed Centaurus A (Cen A, NGC 5128) at unprecedented high resolution. The processes by which the jets of Active Galactic Nuclei (AGN) are formed and collimated have been investigated. Cen A is a unique object which lets us study the physical processes of the radio jet of AGN because of its proximity of only 3.5 Mpc from our Galaxy. One milli-arc-second (mas) is 24 light-days at this distance, and one can image the structure of light-month scale by VLBI. Structures in such small-scale near the central region reflect the process of jet formation. The angle between our line of sight and the jet is large, 50–80° (Tingay et al. 1998), while typical AGN jets are seen end-on. This side-on jet is a good opportunity for investigating the jet structure with less ambiguity.

2 Observation

Observations of Cen A were carried out in 1999 January. Although these observations were in the course of VLBI Space Observatory Programme (VSOP, Hirabayashi et al. 1998), no fringe was found at upper limit of 0.1 Jy for space baselines at all epochs. The observation was made at 5 GHz, standard VSOP mode. The participanting telescopes are phased 6 telescopes of Australian Telescope compact array (ATCA), Mopra, and three VLBA (MK, FD, OV) telescopes. Left circular polarization data were recorded on S2 terminals at Australian sites (ATCA and Mopra), and VLBA terminal at VLBA sites. Those tapes of two different types were copied to VSOP tape at the Mitaka correlation center of National Astronomical Observatory in Japan, and correlated.

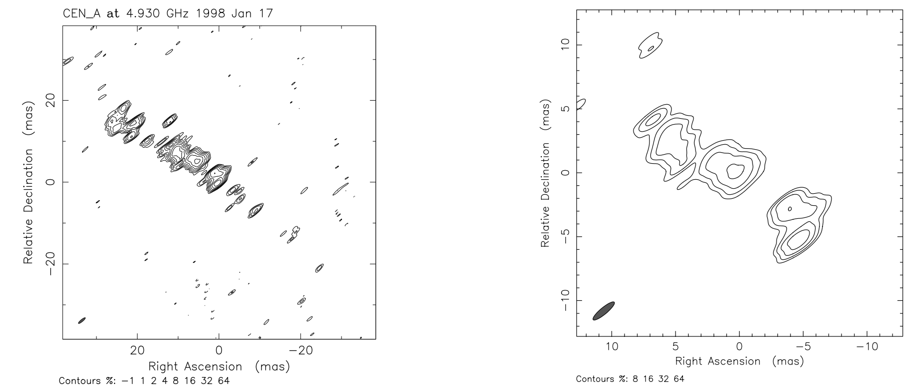

Figure 1: (left) Image of Cen A. (right) A close-up region of core.

Fringes with enough Signal-to-Noise ratios were found at all ground-ground baselines. The data including space baselines were rejected for the reductions later. The data were processed using AIPS in the normal procedure. The image was made with mapping software Difmap. The uniform weighting was applied for high-resolution imaging, and the final beamsize of 2.15×0.52 mas with position angle of -50.4 degree from north was achieved. The obtained image is shown in Figure 1.

3 Result and Discussion

There is no dominant component in the image of Cen A. A large, complex structure elongates from southwest to northeast at 30 mas range at PA= 60° with a compact peak near the edge of southwest. Also three complex components are seen at 7 mas, 10 mas, and 23 mas from the peak, respectively. This 30 mas scale structure well coincides with the previous 5 GHz image by Tingay et al. (1998). They identified the core as the most southwest component, which is coincide with the peak in our image. Although further considerations would be required, we identify the peak as the core. Figure 1 (right) shows a close-up of the region of core component. It is clear that the jet is not straight. The jet starts from the core toward about north (PA= 0°) until 3 mas, then bends to PA= 60°. No brightness enhancement is seen at the locus of bending.

3.1 Bending Jet

It is known that jets of AGN often exhibit strong bends on the pc scale. Such bends, however, are believed to be apparent. The bending angles in such jets are intrinsically small, but amplified by their small viewing angle (e.g. Conway and Murphy 1995).

The viewing angle of Cen A is large, 50–80° (Tingay et al. 1998), and the observed large bending at light-month scale jet is not an apparent one. The apparent angle of bending of the innermost jet of Cen A is 60° at 2 mas from the core. The true angle of bending Φ is expressed as follows: $\cos\Phi \leq \sqrt{\cos^2\phi + \cos^2\theta \sin^2\phi}$, where ϕ is apparent angle of bending, and θ is angle between the large-scale jet and the line of sight. To determine the geometry of the bending jet, one more parameter p, the position angle of the small-scale jet around the large-scale jet, is required. Setting ϕ=60° and θ=65° (the median of 50° and 80°), we have Φ >30°. The extreme case, Φ=30°, is a conservative estimation and probably Φ >45°.

The observed structure around the core might be different from the true one due to the strong absorption. The absorption is significant below 8 GHz, but negligible at higher frequencies. The bending structure is slightly seen at 22 GHz image (Tingay, private communication). Therefore, it is supposed that the bending structure observed at 5 GHz is real, not an absorption effect. Hence we conclude that the jet of Cen A bends with angle of at least 30°, probably >45°, at 2 light-month scale.

3.2 Formation of Bending Jet

A simple model for the bending jet is squeezing with unseen matter, like a large molecular cloud. The jet collides with the matter and then changes its direction, as observed in some Compact-Steep Spectrum sources (CSSs) or Giga-Hertz Peaked Spectrum sources (GPSs) . However, this is not likely to be the case for Cen A. No brightness enhancement is observed at the locus of bending, while such a jet colliding with ambient matter should cause a shock and a brightness enhancement. A large fraction of kinetic energy would be released as observed in CSS/GPS sources.

Another model of jet bending is the change of jet ejection angle. The large-scale jet knots could be ejected when the jet ejection angle was toward the PA= 60°, and the innermost knots could be ejected toward north. This model is also not to be likely the case. The jet in

Cen A is straight at scales from sub-pc to kpc, at a PA of 60°. If this changing angle of ejection model would be true, the ejection angle had been fixed for at least 10^3 year, and recently changed suddenly. This model would be tested with monitoring of the innermost component.

It is a widely accepted idea that the magnetic field plays a significant role for jet creation. A collimating structure is reported for M87 (Vir A, Junor et al. 1999). They found a jet with opening angle of 60° under 0.1 pc scale. The wide-opened jet is collimated into a limb-brightened narrower jet continuing up to 1 kpc. Junor et al. (1999) noted that magneto-hydrodynamic (MHD) models involving accretion disks are favored for the acceleration and collimation of jets based on the collimating structure found in M87 (Shibata and Uchida, 1985; Ouyed and Pudritz 1997). The structure of bending jet in Cen A is quite similar to one side of two ridges of collimating jet of M87. Moreover, the spatial scale of bending is roughly the same (a few light-months). Thus the jet in Cen A could be bent due to the same origin with that of M87, although it is not certain why only one side of ridges is seen in Cen A.

Tingay et al. (1998) suggested that there is a high-speed, unseen jet, based on the internal structure change of knots. They discussed that the observed knots are slow-moving patterns of the flow. The bending jet could be a filament structure enclosing the high-speed jet along with their interpretation.

These possible interpretations of the bending jet would be tested by future monitoring the changing of the structure.

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