VLBI Observation of Radio Jets in AGNs

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Abstract Very Long Baseline Interferemetry (VLBI) with its high angular resolution plays an important role in the study of radio jets in AGNs. We present the preliminary results of the ongoing works in our group in recent years, including observations of EGRET AGNs, intermediate BL Lac objects and broad absorption line quasars.

1 Introduction

Very Long Baseline Interferometry (VLBI) has made many important contributions to the study of the radio jets in Active Galactic Nuclei (AGNs). The superluminal motions detected in the VLBI jets of the radio-loud AGNs suggest there are relativistic bulk motions of the emitting particles. The alignment between the pc scale jet and kpc scale jet suggests the energy transportation from the central engine to the radio emission region at large scale. The VLBI observation at 43 GHz of nearby active galaxy M87 shows that the jet is formed and collimated on the very small scale (Junor, Biretta, & Livio 1999). The VLBI observations of the H_2O megamaser in the nucleus of NGC4258 provided the strong evidence of the supermassive black hole in the center (Miyoshi et al. 1995, Greenhill et al. 1995). The VLBI observations of NGC4162 revealed there is a gap between the counter-jet and VLBI core which is mostly due to the absorption of the accretion disk (Jones et al. 2000). The relativistic beam model can explain most of the VLBI observational results, and the morphology of the radio jet in the AGNs depends strongly on the observing direction. VLBI still plays the important role in the investigation of radio jets in AGNs. This paper presents the preliminary results of some VLBI investigations of the AGNs in our group in the recent years.

2 VLBI Observations of the EGRET AGNs

The Energetic Gamma-Ray Experiment Telescope(EGRET), on the Compton Gamma Ray Observatory (CGRO), has detected the γ-ray emission at energies above 100 MeV from the 66 AGNs with high-confidence identification (Hartman et al. 1999). All the EGRET AGNs are radio-loud, and most of them belong to the class Blazars in which a high fraction of the superluminal motions (SLM) were detected. On the basis of 22 GHz and 43 GHz VLBA multiepoch observations carried out for 42 of the 66 EGRET AGNs , Jorstad et al. (2001) concluded that the superluminal motions in $\gamma - ray$ loud quasars are higher than those in γ-ray quiet population. To study the connection between the radio structure and γ-ray emission and to enlarge the sample, we applied the VLA, Very Long Baseline Array (VLBA) and European VLBI Network (EVN) observations for 15 EGRET sources which previously have no good pc and/or kpc scale images, and 13 sources are quasars and 2 are BL Lac Objects. This is an ongoing project.

The preliminary results show a variaty of morphology at VLBI scale: 7 sources are core dominated as expected for strongly beamed sources, 5 sources have a long and well defined jet, one source contains a lot of extended emission, 2 sources are symmetric/double. The extended emissions in 4 sources are detected at VLA scale. The VLA C-configuration 8.5 GHz observation (the lowest resolution) reveals that the 3 sources, 1604+159, 2022-077 and 1229-021, have the two-sided asymmetric structure, and the jets become one-sided at higher angular resolutions. Fig.1 shows the images of 1604+159 at different angular resolutions. Such structure would not be expected for presumably highly-beamed sources of the γ-ray loud AGNs. It is essential to search the proper motion in the inner jet to estimate the beaming levels in these sources. If these sources are not highly beamed in radio wavelength, one possible explanation is that the beaming direction in the γ-ray is different from that in the radio band.

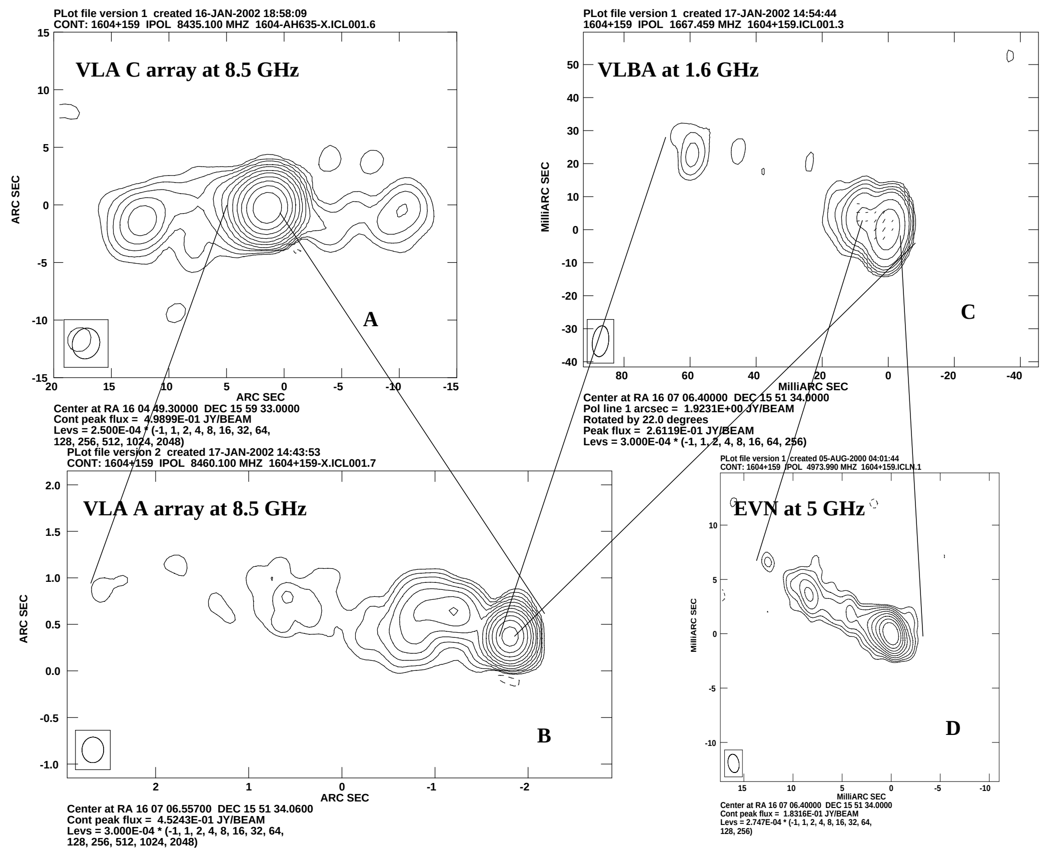

Fig. 1 The images of 1604+159 at different resolutions

3 The structure variation of the pc scale jet in some radio-loud AGNs

0420-014 is an EGRET detected source with the superluminal motion. Based on the multiepoch VLBI results and radio light curves, we found the flares in the radio bands could be classified as two types according to their geometric origin (Zhou et al. 2000). One type flare in the radio light curves may be due to the ejection of new component from the core. There are time lags of the flare observed at the different frequencies, and the peak time of the flare at low frequency is delayed compared with that at high frequency, because of the opacity effects of the synchrotron self-absorption. The second type of the flare is probably introduced by the sharply bending of the jet. When a component moves via the bending position, the flux density of this component will vary because of the variation of the Doppler boosting factor, in which case the flare time will be nearly the same at different radio frequencies.

The new VLBA observations of the radio source J1625+4134 at 22 and 15 GHz show a short and bending jet which has about 270 degree difference in position angle with the northern jet detected at lower frequencies. The new results, combined with the data available in the literature, allow us to identify one of the compact components as the VLBI core based on its flat spectrum. Relative to this core component, the jet appears to be bi-directional at VLBI scale. The proper motion measurement of the component and the estimate of the Doppler boosting factor suggest that the orientation of the jet is close to the line of sight. The projection effect of an intrinsically bending jet within a few mas from the core or the erratic change in the nozzle direction of the jet can explain the uncommon bi-directional structure of the jet (Jiang et al. 2002).

4 EVN observations of Intermediate BL Lac Objects

The BL Lac Objects have been discovered through radio or X-ray survey, historically they were divided into two classes, namely radio selected BL Lac objects (RBLs) and X-ray selected BL Lac objects (XBLs). The XBLs have higher ratio of optical to radio luminosity than RBL, but both have the similar X-ray luminosity. The smaller and weaker degree of activity of XBL was attributed to the orientation effects. The emission from the XBL was less beamed than that of RBL, and XBLs are probably observed at larger inclination to the jet axis (Marashi et al. 1986). In the recent years, many works (Giommi & Padovani 1994, Fossati et al. 1998) based on the investigations of the broad band energy distribution suggested that the BL Lacs were most likely form one class, with a continuous distribution of syncrotron emission peak energies (frequency), of which HBLs (XBLs) and LBLs (RBLs) represent the extreme ends respectively. Laurent-Muehleisen et al.(1999) presented the RGB sample of intermediate BL Lacs. The results indicate that the simple unified scheme which postulates HBLs and LBLs differ solely by orientation may be in need of revision.

To explore the possible difference between the intermediate BL Lacs and the RBL, the information about the compact structure of the intermediate BL Lacs is important to understand if the orientation effects play the important role. Kollgaard et al. (1996) investigated 4 XBL objects using the VLBI technique, and found their core-jet morphology. The radio flux of most HBLs are too weak for VLBI observation, so we selected 7 intermediate BL Lacs from the RGB sample for EVN 5 GHz observation. Their peak frequencies of the broad band spectral energy distributions are in the range 8×10^{14} to 1.2×10^{16} Hz and the VLA core fluxes are higher than 0.1 Jy. The observation was carried out on 22 November 1999. At the VLBI scale, the 7 IBLs all have the one-sided core-jet structure and there is no evidence of the counter-jet emission, which suggests that the jet emission at the VLBI scale in these IBLs is Doppler boosted. Fig.2 is the EVN image of 1542+614 at 5 Hz. The model-fitting results of the VLBI data show that the brightness temperatures of the VLBI core in the source rest frame are relatively low, from 4×10^{9} to 3×10^{10} K. The core size may be limited by the VLBI angular resolution, the brightness temperature of the core is

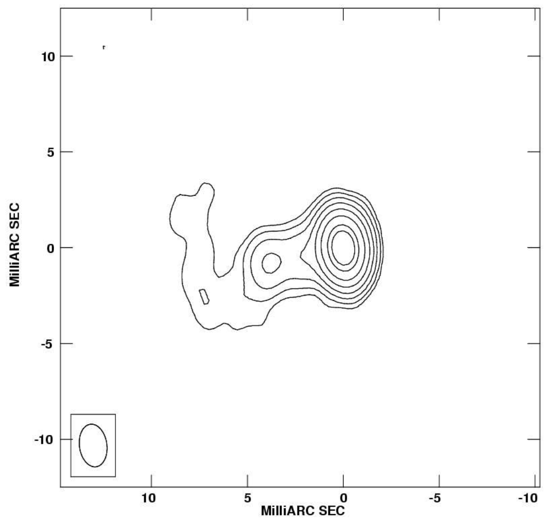

Fig. 2 EVN map of 1542+614 at 5 GHz; the restoring beam is 2.24 ×1.43 mas at P. A. =7.^{o}9; the contour levels are (-1, 1, 2, 4, 8, 16, 32, 64)× 0.69 mJy/beam; the peak flux density is 94.4 mJy/beam.

probably just a lower limit, it needs high resolution observations to confirm. If the brightness temperature of the VLBI core in these sources is intrinsically low, the possible explanation is that the emitting particle and magnetic field in the emission region are far from the energy equipartition, with lower electron number density and/or higher magnetic field.

5 EVN Observations of Broad Absorption Line Quasars

About 10% of optically selected quasars display broad absorption troughs, which extends up to 0.1 c, in the blueward of high ionization resonant lines (Weymann et al. 1991). Another ten percent of them also show absorption troughs but in low ionization lines. The high ionization level and continuous absorption over a large velocity range indicate that the absorption lines are intrinsic to the nucleus. The blueshift of lines implies that absorbing gas is flowing outward from the nucleus. A general paradigm has been established that Broad Absorption Line (BAL) region exists in both BAL and non-BAL quasars, and BAL quasars are normal quasars seen along a particular line of sight. The spectropolarimetry results can be best explained by an equatorial BAL region which intersects the line of sight in a BAL QSOs (Goodrich & Miller 1995; Hines & Wills 1995; Cohen et al. 1995). Hence, the absorbing material can be a wind from an acrretion disk or torus which is accelerated by radiation pressure, and BAL QSOs are seen at large inclination. The BAL QSOs were found preferently in radio quiet quasars, but not as radio loud until FIRST quasar survey was carried out. The survey discovered more than 20 BAL QSOs which can be formally classified as radio-loud quasars based on the radio to optical flux ratio as well as on the radio power (Becker et al. 1997, 2000, Menou et al. 2001). Brotherton et al. (1998) discovered 5 radio-loud BALs detected by NRAO VLA Sky Survey (NVSS). Most of them are unresolved on the VLA resolution at 20 cm with either flat or steep radio spectra. Based on the large scatter in radio spectral indices, Becker et al. (2000) argue that BAL quasars are not viewed at any particular orientation. An alternative picture is that BALs are an early stage in the development of new or refueled quasars. Voit et al. (1993) suggested that the low-ionization

BAL quasars are the nascent QSOs embedded in a region with a high rate of massive start formation.

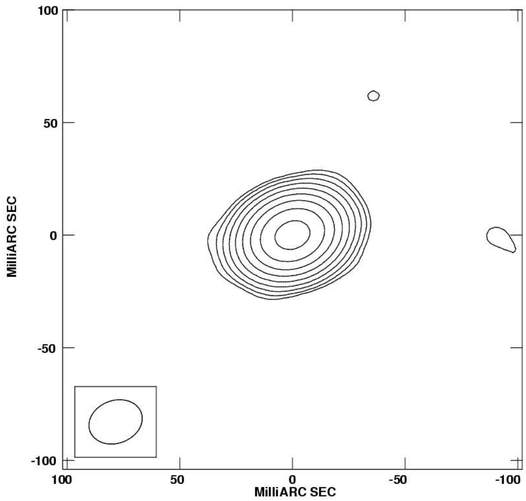

Fig. 3 EVN map of J1312+2319 at 1.6 GHz; the restoring beam is 24.5 ×19.3 mas at P. A. =−69.°2; the contour levels are (-1, 1, 2, 4, 8, 16, 32, 64, 128, 256)× 0.34 mJy/beam; the peak flux density is 131 mJy/beam.

The High resolution radio observations are important in the BALs study, the radio morphology can serve as an inclination indicator of these QSOs, therefore, yields direct test of the orientation model. It is general expected that the axis of accretion disk is aligned with the radio jets. If the BAL region is equatorial, we would expect that we will see two side jets in these objects. The EVN 18 cm observation of 3 BALs was carried out in May 2001. The phase referencing technique was used, since the radio fluxes are weak. We obtained the preliminary results, two sources have point-like structure and one source has two side jet structure. An EVN image of J0957+2319 at L band is shown in Fig.3. If the compact and bright components in the 2 unresolved sources are the core (this needs the spectral index to confirm), this means that we observed directly the base of the jet and the jet orientation may not be near the line of sight. The EVN images suggest that the accretion disk or torus (if it exists) should not be edge-on, and the absorption gases may not locate in the equatorial plane at least for the 2 unresolved sources. Since the number of sources is small, more observations of a large sample are needed for the statistic study. This ongoing project collaborates with Wang Tinggui.

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