VLBI Observations of Mkn 501 and Mkn 421

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Abstract. We present here two epochs of Space VLBI Observations at 18 cm of the BL-Lac type object Mkn 501. Thanks to the high resolution of these new data we have found that the inner jet is centrally brightened at its beginning but becomes extended and limb brightened at $\sim 8$ mas from the core. Moreover a comparison between the two epochs shows the presence of a possible proper motion with apparent velocity $= 6.7c$. VLBI data at 6 and 18 cm of the BL-Lac type object Mkn 421 are also presented. Observational data have been used to constrain the jet velocity and orientation.

1. Introduction and Observations

Mkn 501 and Mkn 421 are two nearby BL-Lac type objects at $z = 0.034$ and $0.030$, respectively. They are well studied sources in radio, optical and X-ray bands being among the brightest BL-Lac objects at all wavelengths. Mkn 421 was the first source to be detected at TeV energies, followed by Mkn 501. In the radio band, both sources show a kpc scale morphology and a total radio power consistent with the expectation of unified scheme models that BL-Lac type sources are FR I galaxies oriented at small angles to the line of sight.

We present here new Space VLBI observations of Mkn 501 and VLBI data of Mkn 421. Mkn 501 was observed at 18 cm on August 4th, 1997 and April 8th, 1998 in a space VLBI project using the HALCA satellite and 12 ground stations. Mkn 421 was observed at 6 cm in July 1995 with the VLBA and at 18 cm in February 1996 with the global VLBI. The data of both sources were correlated in Socorro (NM - USA) and reduced with the AIPS package.

A Hubble constant of 50 km sec$^{-1}$ Mpc$^{-1}$ is assumed throughout.
Figure 1. Left: Space VLBI map of Mkn 501 at 18 cm. The HPBW is $2.9 \times 1.5$ mas at PA = -10°. The noise level is 0.3 mJy/beam. Right: VLBI map of Mkn 501 at 18 cm using only ground stations. The HPBW is 8.5 mas and the noise level is 0.35 mJy/beam.

2. Jet Morphology

*Mkn 501.* At parsec resolution Mkn 501 shows a one-sided jet which, at $\sim 20$ mas from the core, changes its orientation from $\sim 140°$ to $\sim 30°$. From the analysis of the map (Fig. 1-left) we note a clear change in the jet structure: at the beginning the jet is resolved and its brightness is centrally peaked, but at $\sim 8$ mas from the core, it becomes limb-brightened with the maximum of the surface brightness on both sides of the parsec scale jet. We interpret this observational result as indication of a change in the jet physical properties at $\sim 8$ mas (7.4 pc) from the core. The limb-brightened jet is well visible for 20-25 mas ($\sim 20$ pc). This result is in agreement with the polarization properties of this source presented by Aaron et al. (present proceedings). At a larger distance from the core ($\sim 20$ pc), the jet shows a large change in its position angle and a dramatic expansion. In our low resolution map (Fig. 1-right) the jet is visible for more than 100 mas and appears still edge-brightened. No evidence of a helical structure is visible in our maps.

*Mkn 421.* At 6 cm Mkn 421 shows a core emission and a one-sided jet. The jet is well collimated at the beginning, but at $\sim 5$ mas (4 pc) from the core it shows many wiggles and changes in the position angle (Fig. 2-left). This complex structure is confirmed by the 18 cm map (Fig. 2-right) at lower resolution and on a larger scale. At $\sim 20$ mas from the core, the parsec scale jet shows a dramatic
expansion, its transversal size being comparable with its longitudinal dimension. Present data do not have enough resolution or sensitivity to distinguish between a centrally peaked or a limb-brightened jet.

3. Jet Orientation and Velocity

We used the available VLBI data to derive information on the jet velocity and orientation. Assuming that parsec scale jets are intrinsically two-sided and symmetric, we can constrain the jet velocity ($\beta = v/c$) and inclination to the line of sight ($\theta$) from the observed jet asymmetry. For Mkn 501, the Jet/CounterJet ratio is $\gtrsim 200$, which leads to $\beta \cos \theta \gtrsim 0.79$. Moreover, from the known correlation between the core power and the unbeamed total radio power (Giovanelli et al., 1988) we can infer the expected intrinsic core radio power from the observed total radio power. Comparing the expected and the measured core radio power, we obtain that Mkn 501 has to be oriented at $\theta \lesssim 26^\circ$ with $\beta$ in the range 1 - 0.88. We produced identical maps from the first and second epoch space VLBI data of Mkn 501 at 18 cm. A comparison of the two maps suggests the existence of a possible proper motion between the two epochs with apparent velocity $\sim 6.7c$. We are aware that to measure a proper motion with only two epoch data may give unreliable results, however we note that the present data are of good quality and the structures in the two maps are in good agreement. More Space VLBI Observations have been requested to confirm this result. Such an apparent velocity implies that the real jet velocity has to be $\gtrsim 0.989c$ and the jet has to be oriented at an angle smaller than $17^\circ$. If we assume that the bulk and pattern jet velocity are comparable, we can compare the observational constraints previously discussed with the measured proper motion. From these results we derive that Mkn 501 is oriented at $\sim 10^\circ - 15^\circ$ with a velocity in the range 0.990 - 0.999c. It implies high values of the Lorentz factor: $\gamma \sim 7 - 22$.
but a relatively low Doppler factor: $\delta \sim 1.3 - 5.6$. From the jet sidness and core dominance of **Mkn 421** we derive for this source an inclination angle $\theta \lesssim 30^\circ$ and $\beta$ in the range $1 - 0.84$. The measured proper motion for Mkn 501 and the derived intrinsic jet velocities suggest that Bl-Lac type objects may have parsec scale jets with intrinsic velocities of the same order of parsec scale jets in radio quasars.

### 4. Discussion and Conclusions

Thanks to the high resolution provided by the VSOP we have imaged the parsec scale jet of Mkn 501 in great detail. It shows a change in its physical properties at 8 mas from the core: the innermost jet is centrally brightened, but at $\sim 8$ mas from the core it becomes limb-brightened. Such a structure is expected by the central spine - shear layer jet model (Laing, 1996). The observational data discussed here imply that the shear layer is not visible at the jet beginning but appears at $\sim 7$ pc from the core corresponding to a deprojected distance of $40 - 45$ pc assuming $\theta = 10^\circ$. At $\sim 20$-25 mas from the core, the jet shows a prominent bend and a rapid expansion.

A similar expansion is found also in Mkn 421, where the jet dramatically expands at about the same distance from the core. We interpret this result as evidence of a strong interaction with the surrounding medium which affects the jet dynamics, causing the jet velocity decrease observed in FR I radio galaxies.

Current models of gamma ray emission and intra-day variability suggest for these sources that in the innermost region (0.003 - 0.03 pc) the jet should be oriented at $\theta \lesssim 5.7^\circ$ and should have a Lorentz factor $\gamma \gtrsim 10$ which implies $\beta \sim 0.995$ and $\delta \sim 10$ (see Spada et al. present proceedings and Salvati et al., 1998). These results seem to be in contrast with the derived constraints from VLBI radio data, however we note that the regions where the radio emission (the core region) and the gamma and X-Ray emission are produced, are not coincident, the former being at a larger distance from the active core than the latter. We estimate that the radio core has a size $\gtrsim 0.05$ pc. Therefore radio and gamma ray data are in agreement if when travelling between the distance of 0.003 pc to 0.05 pc, the jet orientation changes from $\sim 5^\circ$ to $\sim 10^\circ$. Such a change in the jet orientation is plausible given the distorted morphology found on the parsec scale of Mkn 501 and Mkn 421.

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