The Parsec Scale Structure of Markarian 501

G. Giovannini[1,2], L. Feretti[2], M. Giroletti[1,2],
G.B. Taylor[3], P.G. Edwards [4]

[1] Astronomy Dpt., Bologna University (I), [2]Radio Astronomy Inst. INAF Bologna (I),
[3] NRAO Socorro NM (USA), [4] Inst. of Space and Astron. Science (Japan)

1 Source Structure

- Mkn 501 [a] is a complex, core dominated source. We can distinguish the following regions:

  1. a first region, extending ∼ 10 mas from the core with a high brightness one-sided jet. The jet PA is not constant, being 150°–160° near the core (< 1 mas), ∼ 145° (1 to 4 mas from the core), and ∼ 90° (4 to 10 mas from the core; see Fig. 1a and [1])

  2. between ∼ 10 and 30 mas from the core the jet PA is ∼ 110° and it shows a clear limb-brightened structure (Fig. 1b), [1]

  3. at ∼ 30 mas from the core the jet shows a strong bending (PA ∼ 30°) and a large opening angle. In this region the jet PA is the same of the arcsecond scale one-sided emission (Fig. 1c and 2a)

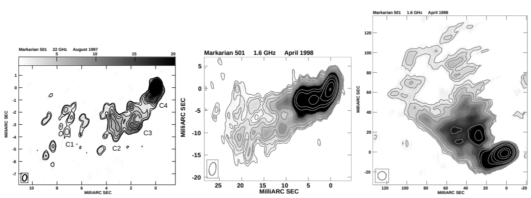

Fig. 1: VLBA [b]images of Mkn 501: 1a - 22GHz image, HPBW = 0.54 × 0.35 mas (left); 1b - 1.6 GHz image, HPBW = 3 × 1.5 mas (center); 1c - 1.6 GHz image; HPBW = 8.5 mas (right).

  4. on the arcsecond-subarcsecond scale (MERLIN, VLA high resolution) the source structure is still one-sided (Fig. 2a, [2]); it appears symmetric (PA ∼ 45°) in images with an angular resoltion of ∼ 7″ (Fig. 2b, [3]).

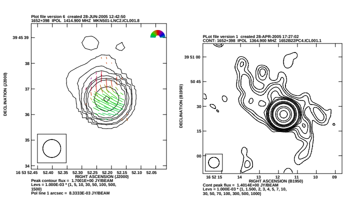

Fig. 2: VLA images of Mkn 501 at 1.4 GHz: 2a - HPBW = 0.7″ (left); 2b - HPBW = 6.5″ (right).

- High resolution images show an evident limb-brightened structure, beginning in the very inner jet (1 mas from the core) and visible up to ∼ 100 mas from the core. We interpret this structure as evidence of a velocity structure starting **very near to the core**: an inner high velocity spine could be de-boosted while a slower external layer could be less strongly de-boosted or even boosted if the jet orientation with respect to the line of sight (θ) is not too small (10° – 20°).

- No proper motion has been found comparing 9 different epochs in the time range from 1995.29 to 1999.55 [1].

[a] z = 0.034; 1 mas = 0.67 pc assuming H_0 = 70 km s^{-1} Mpc^{-1}

[b] VLBA and VLA are operated by NRAO as a facility of the NSF, operated under cooperative agreement by Assoc. Universities, Inc.

References

[1] Giroletti et al. 2004, ApJ 600, 127

[2] Conway and Wrobel 1995, ApJ 439, 98

[3] Cassaro et al. 1999, AAS 139, 601

3 Conclusions

New data confirm the presence of a highly relativistic parsec scale jet in Mkn 501, a dominant magnetic field perpendicular to the jet, and a jet orientation angle from $\theta \sim 4°$ to $\sim 15°$ with respect to the line of sight.
The jet velocity becomes not-relativistic at ∼ 5 kpc (de-projected) from the core in agreement with unified model predictions and low power (FR-I) radio galaxy properties. Jet velocity estimates at different de-projected distances from the core are:

Table 1: Jet velocity estimate

R_{obs}	R_{15}	β_{spine}	β_{layer}	‖	R_{obs}	R_{15}	β_{spine}	β_{layer}
mas	pc	v/c	v/c	‖	mas	pc	v/c	v/c
< 0.04	< 0.12	0.998	??	‖	30 - 40	80 - 120	0.995	0.95
0.04 - 0.2	0.12 - 0.6	0.998	0.995	‖	200	500	0.993	0.95
0.2 - 10	0.6 - 30	0.998	0.95	‖	1000	2500	0.95	0.95?
10 - 30	30 - 80	0.998	0.95	‖	2000	5000	0.2	0.2

R_{obs}: observed projected distance from the core in mas; R_{15}: de-projected distance from the core in pc with $\theta = 15°$; β_{spine} and β_{layer}: inner spine and external shear layer jet velocity.

2 High Sensitivity Array Data

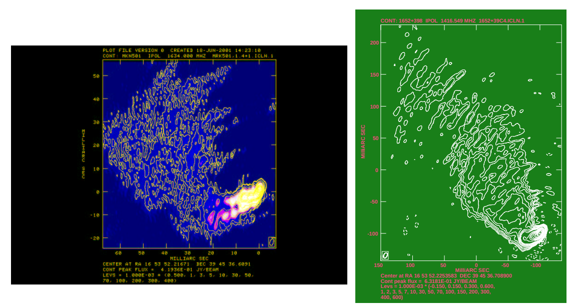

Fig. 3: HSA images of Mkn 501 at 1.4 GHz - HPBW = 3 × 1.5 mas (left); HPBW = 9 × 5 mas (right). 100 mas = 67 pc.

We observed Mkn 501 on 26-Nov-2004 with the High Sensitivity Array (HSA: VLBA, Y27, Eb, GBT) at 1.4 GHz for 8 hrs. We did not detect any counter-jet emission. We can use the jet morphology, the jet-sidedness, the core dominance, and the fit to the trend of the jet brightness and the FWHM to estimate constraints to the jet bulk velocity and orientation with respect to the line of sight (θ) [1]. In Fig. 4 we show results of the adiabatic model fit for a magnetic field perpendicular to the jet. The high jet counter-jet ratio near the core (R > 2860), and at large distance from the core (> 20 at 120 mas from the core) is not in agreement with a parallel magnetic field adiabatic model since it predicts [1] a jet velocity decrease at ∼ 80 mas from the core in contrast with the measured jet sidedness. **On the contrary a perpendicular magnetic field model predicts a large jet velocity in agreement with the not detection of a cj and a jet velocity decrease far from the core (arcsec. scale) in agreement with MERLIN and VLA images** (Fig. 2).

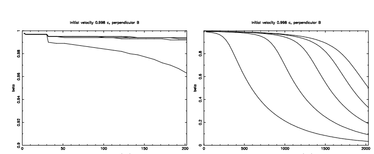

Fig. 4: Results of the adiabatic model fit. Orientation angles of 5°, 10°, 15°, 20°, and 25° are drawn. Fig. 4a (left) is from observed data ; Fig. 4b (right) has been obtained extrapolating HSA data and adding jet sidedness constraints (arrows).