*Astrophysical Phenomena Revealed by Space VLBI*
*H. Hirabayashi, P.G. Edwards and D.W. Murphy (eds.)*

# Multi-Epoch Global+VSOP/HALCA Observations of Virgo A at $\lambda 6$ cm

W. JUNOR[1], J.A. BIRETTA[2], F.N. OWEN[3] & M.C. BEGELMAN[4]

[1] *UNM, 800 Yale Blvd., N.E., Albuquerque, NM 87131, USA*
[2] *STScI, 3700 San Martin Drive, Baltimore, MD 21218, USA*
[3] *NRAO, P.O. Box 0, Socorro, NM 87801, USA*
[4] *JILA/University of Colorado, Box 440, Boulder, CO 80309, USA*

**Abstract**

Images from 4 epochs of VSOP+Global observations at $\lambda 6$ cm of the nearby active galaxy, Vir A, are presented. No proper motions are detected in 1.5 years to a limit of $\approx 10^{-2}\,c$. Sequential brightening of two components on either side of the jet's axis is seen, however.

## 1 Introduction

The nearby ($D = 14.7$ Mpc) E0p galaxy M87 in the Virgo Cluster is the host for the bright radio source Virgo A (3C274, J1230+1223). This active galaxy contains the prototype extragalactic jet (Curtis 1918). The jet is roughly $25''$-long and has been studied extensively across the electromagnetic spectrum. Jets are conduits for the transport of material and energy from the center of an active galactic nucleus (AGN) to the outer regions of the galaxy. The central "engine" in an AGN is believed to be a super-massive black hole with an orbiting accretion disk fed by material raining in from the host galaxy. In M87, there is distinct evidence for a central mass of $\approx 3 \times 10^9\,M_\odot$ (Harms et al., 1994; Macchetto et al., 1997). The mechanism by which jets are formed and collimated is uncertain though magneto-hydrodynamic (MHD) models are currently favored. In these models, MHD "fluid" from the accretion disk is accelerated along poloidal magnetic field lines threading the disk to Alfvénic speeds which are much greater than the local sound speed. These models have the advantage of removing angular momentum from the accretion disk. (See Livio 1999 for a review.) Collimation of the MHD wind is achieved through "hoop stresses" where the field becomes predominantly toroidal. Since the field lines are anchored in the accretion disk, a toroidal field will be generated naturally by the rotation of the disk. Recent work by Junor et al. (1999) indicates that collimation of the Vir A jet begins within a projected distance of a few tens of Schwarzchild radii ($r_S$) of the core and is not complete until several $\times 10^3\, r_S$ from the central engine.

## 2 Global + VSOP/HALCA Images of Vir A Jet

The VLBI core of Vir A was observed with VSOP/HALCA and global arrays on four occasions at $\lambda 6$ cm. Vir A is one of the sources in VSOP's *Key Sources* program. Table 1 summarizes the details of these observations. The quoted beam is for the best 'V'-weighted image *i.e.* using the fourth root of the visibility weights to emphasize the contribution of the highest spatial frequencies to the image. The data were analyzed within NRAO's AIPS package. The images are shown in Figure 1 and Color Figure 4.

Table 1: Observing summary for Vir A at $\lambda 6$ cm

| Epoch | Antennas | Beam (mas$\times$mas, $^\circ$) | Figure |
|---|---|---|---|
| 1997.97 | VLBA, EB, RZ, Y, NZ | 2.03, 0.38, +17.1 | 1 |
| 1999.27 | VLBA, GZ, Y, TZ | 2.83, 0.40, −12.3 | |
| 1999.32 | VLBA, EB, GZ, HH, Y, TZ | 2.33, 0.51, −2.1 | 2 |
| 1999.49 | VLBA, EB, GZ, TZ | 2.28, 0.93, +6.4 | |

## 3 Discussion

Although superluminal motion has been seen reliably on VLA and HST scales (Biretta et al. 1995; Biretta et al. 1999), observed proper motions on VLBI scales seem to be moderately sub-luminal at best (Reid et al. 1989; Junor & Biretta, 1995; Biretta & Junor, 1995). A similar result is seen with these VSOP images; proper motions are $\leq 10^{-2}\, c$ although there is some evidence for brightening and dimming of static features. The rapid sampling of the 4 epochs goes some way to overcoming reservations about the results derived from earlier VLBI with limited temporal sampling. The bright component at $\approx 8$ mas from the

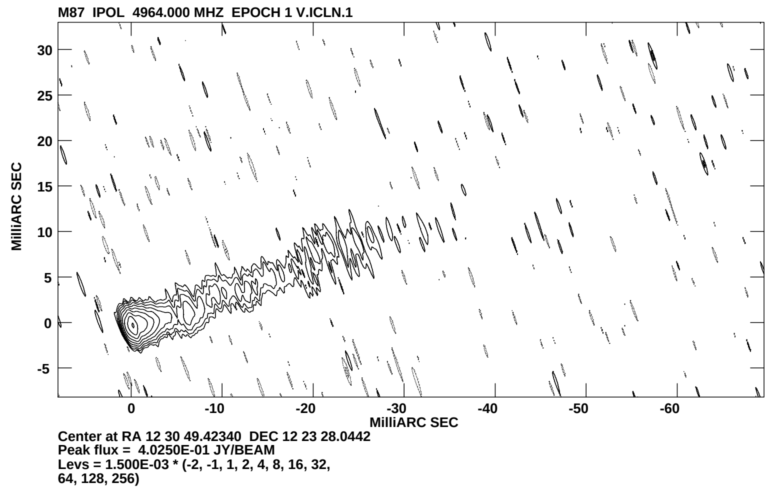


Figure 1: Epoch 1997.97 image of Vir A VLBI core at $\lambda 6\,$cm. Noise floor is $0.52\,$mJy beam$^{-1}$. Beam is $2.03\,$mas$\times 0.38\,$mas in PA=$+17.1°$.

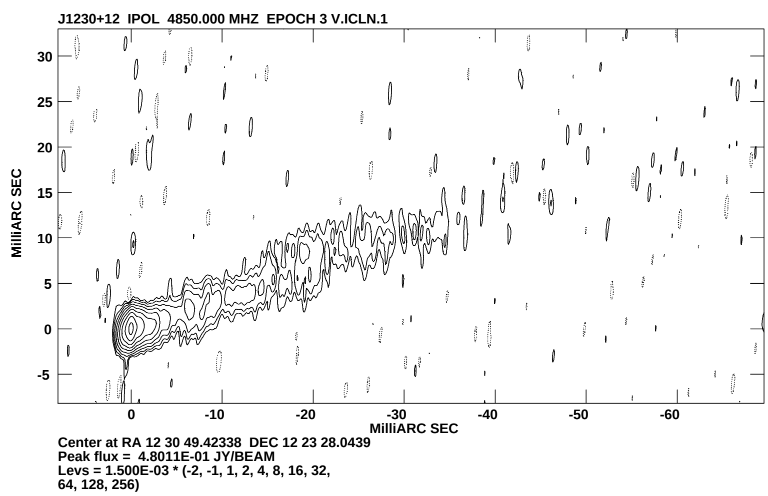


Figure 2: Epoch 1999.32 image of Vir A VLBI core at $\lambda 6\,$cm. Noise floor is $0.56\,$mJy beam$^{-1}$. Beam is $2.33\,$mas$\times 0.51\,$mas in PA=$-2.1°$.

core appears to move laterally, but other observations with higher transverse resolution reveal this to be a blending of two bright components on either side of the jet's axis. These components have flared sequentially in brightness thus giving rise to an apparent motion of $\approx 0.24\,c$. Uniformly- and naturally-tapered images made from these data show that the jet is clearly limb-brightened on scales larger than $\approx 20\,$mas. Other VLBI images at a variety of resolutions (Junor, Biretta & Livio, 1999; Junor & Biretta, 1995; Biretta & Junor, 1995; Junor et al. $\lambda 4\,$cm images, in preparation) also show limb-brightened structures. This suggests that the emission from the jet is related to slowly-moving surface phenomena though this is hard to reconcile with the need for relativistic speeds for the jet and counter-jet (Sparks et al. 1992). Further support for larger synchrotron emissivity from the surface of the jet rather than from throughout the jet comes from recent VLBA polarimetry results (Junor, Biretta & Wardle, in preparation) which show that the $\mathbf{B}$ field lies along the jet edges and that the field is smaller on the jet's axis.

**Acknowledgements.** We gratefully acknowledge the VSOP Project, which is led by the Japanese Institute of Space and Astronautical Science in cooperation with many organizations and radio telescopes around the world. WJ thanks the National Science Foundation and JPL for support.

## References

Biretta, J.A. and Junor, W. 1995, *Proc.Nat.Acad.Sci. USA*, **92**, 11364

Biretta, J.A., Zhou, F. & Owen, F.N. 1995, *ApJ*, **447**, 582

Biretta, J.A., Sparks, W.B. & Macchetto, F. 1999, *ApJ*, **520**, 621

Curtis, H.D. 1918, *Publ. Lick Obs.*, **13**, 55

Harms, R.J., Ford, H.C., Tsvetanov, Z.I., *et al.* 1994, *ApJ*, **435**, 35

Junor, W. and Biretta, J.A. 1995, *AJ*, **109**, 500

Junor, W., Biretta, J.A, & Livio, M. 1999, *Nature*, **401**, 891

Livio, M. 1999, *Physics Reports*, **311**, 225

Macchetto, F.D., Marconi, A., Axon, D.J., *et al.* 1997, *ApJ*, **489**, 579

Reid, M.J., Biretta, J.A., Junor, W., *et al.* 1989, *ApJ*, **336**, 112

Sparks, W.B., Fraix-Burnet, D., Macchetto, F. *et al.* 1992, *Nature*, **355**, 804