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NATIONAL RADIO ASTRONOMY OBSERVATORY

Newsletter

Issue 112

*High Frequency VLBI Imaging of the
M87 Jet Base*

*VLA Reveals Missing Mass in
Galactic Collisional Debris*

Mercury's Molten Core

*VLA and Haystack Demonstrate
Real-Time VLBI*

Also in this Issue:

ALMA Construction Project Progress

Current Status of the EVLA Project

*VLBA Sensitivity Upgrade Project:
DBE Developments*

GBT Azimuth Track Project

*NRAO-GLAST Collaborative Science
Agreement*

2007 Jansky Lecturship

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Cover: Radio-optical composite image of the nearby merging galaxy, NGC 4038/9, also known as "The Antennae". Investigator(s): J. E. Hibbard, J. M. van der Hulst, J. E. Barnes & R. M. Rich.

SCIENCE

High Frequency VLBI Imaging of the M87 Jet Base

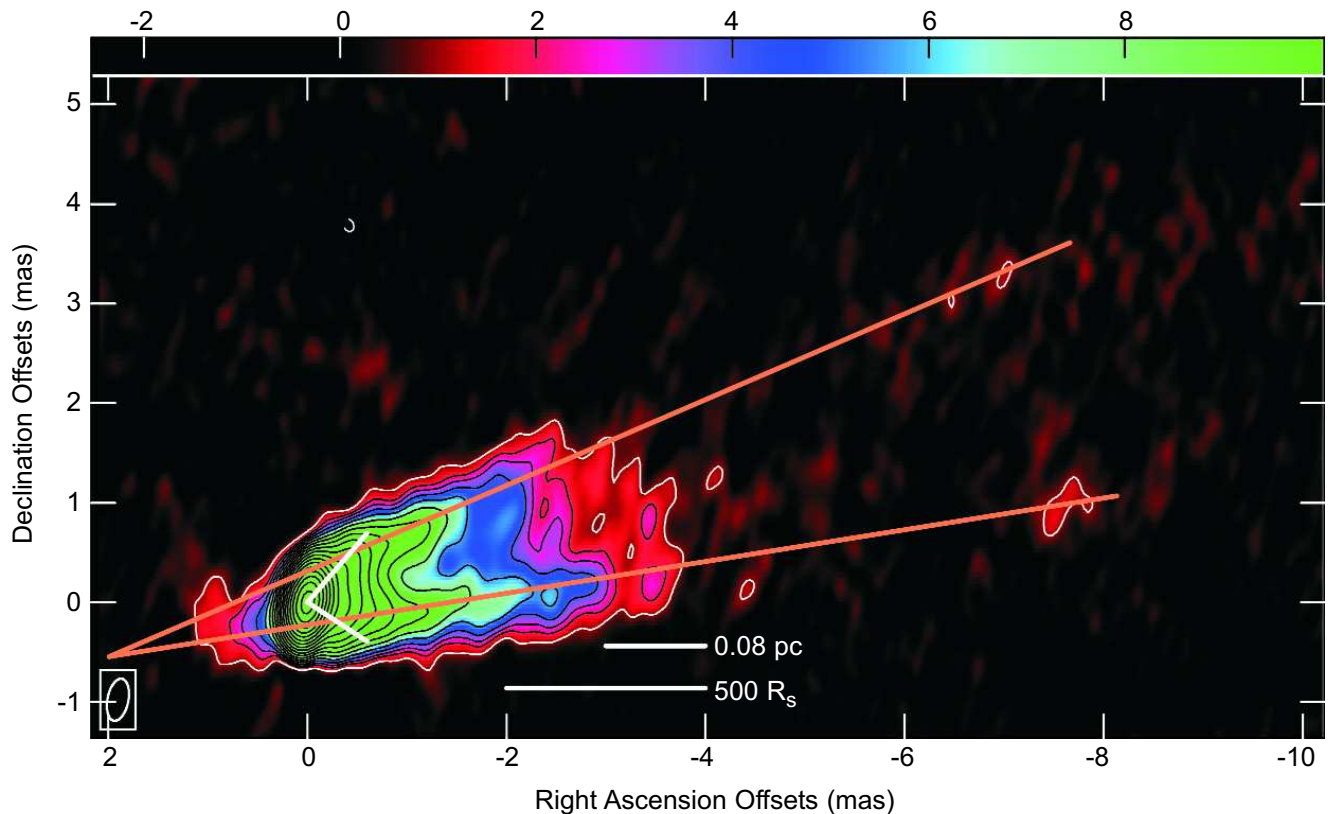


Figure 1. An averaged image from five 43 GHz observations. The orange lines follow the edge-brightened jet emission from 10 mas west of the core while the white lines represent the wide opening angle proposed by Junor, Biretta, & Livio (1999). The resolution is $0.43 \text{ mas} \times 0.21 \text{ mas}$. The color scale is from -2.5 to 10 mJy beam^{-1} with contour levels of $-1, 1, 2, 2.8, 4, 5.7, 8$, and multiples of $\sqrt{2}$ thereafter until $512 \text{ mJy beam}^{-1}$. Note that the apparent smoothness of the structure is an artifact of averaging images from multiple epochs and should not be taken as an indication that the structure of the jet is featureless.

Current capabilities of Very Long Baseline Interferometry (VLBI) have made it possible to probe extragalactic radio jets on sub-parsec scales, which provides a better understanding of how jets are accelerated and collimated close to a super-massive black hole. These observations can be used to test jet collimation theories and simulations. M87, a giant elliptical galaxy located at the center of the Virgo cluster, is the best candidate for the study of jet collimation because of its bright jet, massive black hole ($3 \times 10^9 M_{\odot}$), and proximity (16 Mpc).

We report on five observations of M87 on 1999.17, 2000.27, 2001.78, 2002.42, and 2004.25 with VLBI at

43 GHz at a resolution of $0.43 \text{ milliarcsec} \times 0.21 \text{ milliarcsec}$. The 1999 and 2001 observations have been published in Junor, Biretta, & Livio (1999) and Ly, Walker, and Wrobel (2004), respectively. An average of all five epochs is shown above. This image nicely shows the edge-brightened structure, originally detected in the individual observation, extending out to about 4 mas. Such structure is consistent with previous numerical simulations that have found a sheath-like structure (Meier, Koide, and Uchida 2001). In addition, low-level emission from the jet is seen out to 10 mas, and the southern-half of the jet is detected about 1 mas (0.08 pc) further than the northern-half for the brighter

inner regions. Following the bright edges of the jet back toward the brightest spot (orange lines in the figure), we find that the extrapolated point where they intersect is about 2 mas east (left) of the apparent start of the jet. Assuming that the brightest spot is the core—the location of the presumed black hole—these observations would indicate that the opening angle at the base of the jet is wider and collimation occurs further along the jet, confirming previous conclusions. An alternate possibility is that the jet does not light up immediately, and the black hole is located east of the brightest feature.

The counter-jet is believed to be detected east of the core. It was suggested to exist in the 2001 epoch by Ly, Walker, and Wrobel (2004), and is confirmed by the two most recent epochs where it appears to move away from the core. It is also detected in a 22 GHz observation, which is part of a multi-frequency project for the 2002 epoch. To test whether or not the counter-jet is a calibration artifact, several attempts were made to exclude it during the self-calibration and imaging process. After much effort, the counter-jet was still present, although reduced in intensity. The assumption that the emission to the east of the brightest spot is a counter-jet only holds if the brightest spot marks the location of the base of the jet. If the brightest spot is instead a shock occurring much further down the jet, then the presumed counter-jet would actually be part of the inner jet.

Assuming that the emission east of the brightest feature is a counter-jet, the jet and counter-jet apparent motions correspond to a deprojected jet speed of 0.3–0.5c with an orientation of 30–45° to the line-of-sight. Using this jet orientation angle, relativistic beaming would give the observed jet-to-counter-jet brightness ratio if the bulk flow is at 0.6–0.7c. Given the uncertainties in these arguments, these speeds are

reasonably consistent. Other studies have found similar orientation angles in the 40–65° range. However, much smaller angles to the line-of-sight are required by the observation of superluminal motions in some features further from the core. This inconsistency still needs to be understood.

Future work currently in progress includes making a properly sampled movie of M87 at 43 GHz. This will provide kinematical information about the jet and counter-jet's components and help localize the core to determine the opening angle of the jet. In addition, if the counter-jet is real, it will help determine the motion of the jet and the angle to the line-of-sight with more accurate brightness ratios and proper motions. Polarization measurements from the extended structure, if possible, will provide a better understanding of the magnetic fields and help to further constrain jet-collimation models.

This project is partly funded by the NSF Research Experience for Undergraduates (REUs) and the NRAO Graduate Research Programs. A detailed account of this work has recently been published by Ly et al. (2007).

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