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

Space-VLBI Observations of the Core-Jet in the Nearby Spiral Galaxy M81

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Abstract

M81 hosts the closest active galactic nucleus that can be imaged with VSOP. With a linear resolution of about 2,000 AU at 5 GHz the image shows the highest detail of any map of the core-jet yet. The jet can be traced over 3.5 mas or 12,000 AU and appears wavy with its orientation changing between about 60° and 70° reminiscent of a helical structure. On average the core-jet points towards the relatively weak lobe-like structure seen on kiloparsec scales and is approximately oriented along the rotation axis of the galaxy. The core-jet has structural similarities to the powerful AGN of radio galaxies and quasars and physical similarities to Sgr A*, and may therefore shed light on the structure and nature of the central source of our own Galaxy.

The nearby galaxy M81 is a grand-design spiral that resembles our own Galaxy in type, size, and mass (Figure 1). Like our Galaxy, it contains a nuclear radio source (see Kellermann et al. 1976 for first detection) that is most likely associated with a supermassive black hole in the gravitational center of the galaxy. But while the nucleus of our Galaxy, Sgr A*, is largely hidden behind scattering clouds of gas, M81's nucleus is virtually unaffected by scatter broadening at most radio frequencies. M81 is also, at a distance of 3.65 Mpc (Freedman et al. 1994) the nearest spiral galaxy with an active galactic nucleus (AGN) and, with the radio galaxy Cen A, the nearest galaxy with an AGN altogether. Its center consists of a stationary core with a short, one-sided, jittery jet (Bietenholz et al. 2000) towards the north-east.

The VSOP observations were made with a ground array of 12 telescopes at 5 GHz on 1 May 1999. Left circular. pol. (IEEE convention) was recorded with a bit rate of 128 Mb/s. The total flux density of the central source in M81 (M81*) was 158 ± 8 mJy. About 40% of all scans on baselines between HALCA and any of the ground array telescopes resulted in detections. The (u, v) coverage for the data with detections of M81* is given in Figure 2 (left part). The data were correlated with the processor in Socorro, NM, U.S.A. and further reduced with AIPS.

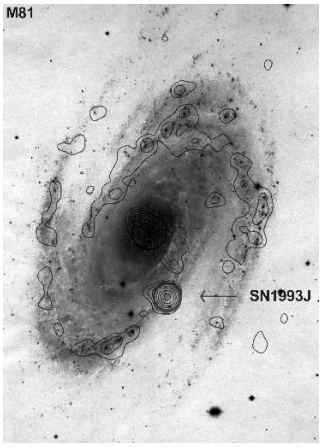

Figure 1: The galaxy M81 at 5.0 GHz observed with the VLA in the D array at 1997.87 superimposed on an optical image (Sandage, The Hubble Atlas of Galaxies, 1961). The radio contour levels are at 0.14, 0.3, 0.5, 0.7, 1, 2, 4, 8, 15, 20, 40, and 80 mJy/beam. The nucleus is the brightest source in M81 at 120 mJy/beam. The second brightest source is supernova 1993J. The width of the image is 13 arcmin on the sky. North is up and east to the left.

The following figures show three images of M81*, made with data from three different array configurations. In Figure 2 (right part) we show the image made with ground array data only. In Figure 3 we show images made with data from HALCA baselines only (left) and with the complete, VSOP, data set (right). The first image shows a rather compact source, elongated along the north-west south-east axis. Details become visible in the next two images obtained with HALCA. The image with data from HALCA baselines only shows that the source is more complex. Full details become apparent in the last image, from all the data. It appears now that the structure is wavy, changing its orientation over 3.5 mas from about 70° for the dominant component to about 60° and back to 70° for the structure further to the north-west.

The wavy structure in the image is a new feature never before seen in M81*. It is further supported if one considers ground array VLBI observations of the source at 8.4 GHz. From previous M81* work (Ebbers et al. 1998) we know that the higher frequency emission emanates predominantly at locations a bit south-west of the peak emission at 5 GHz. From astrometric work by Bietenholz et al. (2000) it follows then that

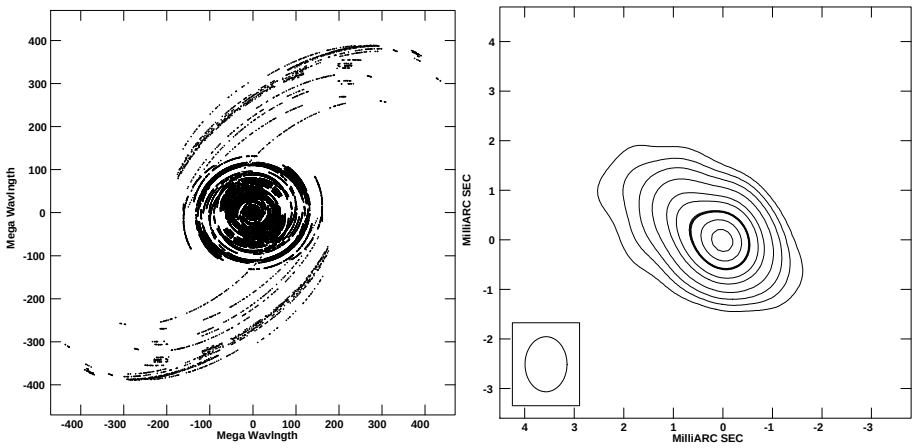

Figure 2: Left part: the (u, v) coverage for the VSOP observations for scans with detections only. The "wings" refer to baselines with HALCA. The ground array telescopes were the Effelsberg 100 m, Germany, the 130m (equivalent) phased VLA, near Socorro, NM, the Green Bank 43 m, WV, and nine 25 m VLBA antennas, all NRAO, U.S.A. Right part: image from ground array data only. The convolving beam here and hereafter is plotted in the lower left corner. The contours are at -1, 1, 2.5, 5, 10, 20, 30, **50**, 70, 90% of the peak brightness of 75 mJy/beam.

the stationary core is approximately located at the lower south-west contours. The dominant component at 8.4 GHz is expected to have a p.a. of 55–60°, in contrast to the 70° p.a. of the dominant component at 5 GHz. It is therefore conceivable that the wavy structure starts close to the stationary core with a p.a. of about 55–60° and oscillates in its orientation along the jet with a period of about 2 mas or 7,000 AU. A wavy structure may indeed be expected for a jet emanating from the vicinity of an accretion disk and a black hole. The magnetic field lines are expected to be warped due to the rotation of the central system, and charged particles travelling along the helical lines may give rise to radio structure that appears wavy in projection.

In terms of the length of the jet and its luminosity, M81* appears to be a scaled-down version of the core of radio galaxies and quasars — but probably a scaled-up version of the nucleus of our own Galaxy, Sgr A*. M81*'s radio spectrum is strikingly similar to that of Sgr A*, save for the higher turn-over frequency of the latter indicating that Sgr A* is a more compact source (Reuter & Lesch 1996). However M81*'s

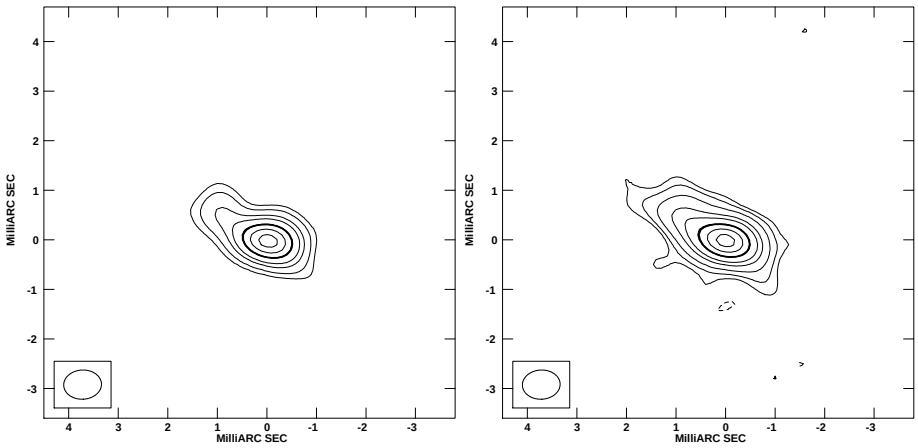

Figure 3: Left: image from data from baselines with HALCA only. Right: image from the full VSOP data set. The same beam was used for better comparison. The contours are at -5, 5, 10, 20, 30, **50**, 70, 90% of the peak brightness of 75 mJy/beam and at -2.5, 2.5, 5, ... % of the peak brightness of 70 mJy/beam for the two maps, respectively.

luminosity is four orders of magnitude higher than that of Sgr A*, and the jet is at least two orders of magnitude longer than any that may exist in Sgr A* (Lo et al. 1998; Krichbaum et al. 1998).

We gratefully acknowledge support provided through the VSOP Project.

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