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Peculiar Physical Properties of HST-1 in M87

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Abstract. We report on VLA observations of HST-1 in M87 at 8 GHz from 2003–2007, during which a long major outburst occurs from radio to X-ray wave bands. At the VLA resolution, the flux density of HST-1 rises rapidly from 2003, peaks at the end of 2004, and then falls slowly in subsequent stages, which is similar to that in optical and X-ray wave bands. It appears that HST-1 moves with an apparent speed of $1.23c \pm 0.91c$, and the fractional polarization keeps rising through the whole major outburst. The persistent increase in polarization level may mainly be attributed to the formation of a couple of new 'subcomponents' of relatively high degree of polarization within HST-1, and the weakening depolarization due to Faraday rotation and/or opacity through the whole major outburst.

Key words. Polarization—galaxies: active—galaxies: individual (M87)—galaxies: jets—radio continuum: galaxies.

1. Introduction

Due to its proximity ($D = 16$ Mpc; Tonry 1991) and activity in the whole wave band from radio to γ-ray (e.g., Harris *et al*. 2009; Aharonian *et al*. 2006), M87 is well studied from various frequencies and spatial scales. It shows a long and resolved jet in the X-ray, optical and radio wave bands (Wilson & Yang 2002), which are widely used to explore the radiative process down the jet (Liu & Shen 2007). With its proximity, bright jet with a relatively large viewing angle of larger than 15°, and very massive black hole ($M = 6.4(\pm 0.5) \times 10^9 M_\odot$) (Gebhardt & Thomas 2009), M87 also serves as a good target in studying jet relativistic physics (Acciari *et al.* 2009).

HST-1 in M87 was defined as a jet feature or component separated by $\sim 0.86''$ from the central black hole, which contains several 'subcomponents' with one stationary and some others moving superluminally at mas resolution (Cheung *et al*. 2007). The flux densities monitoring at multi-wave bands show that a major outburst of HST-1 occurred from 2003 to 2007, which was regarded to be a synchrotron at frequencies from radio to X-ray (Harris *et al*. 2003). Furthermore, a γ-ray outburst was also argued to be associated with HST-1 (Cheung *et al*. 2007). These make the emission region of HST-1 very special, and attract a lot of concern for its physical process.

Here, we present the observational results of HST-1 in M87 at 8 GHz, which are derived from VLA observations in the same A array to roughly keep consistency in

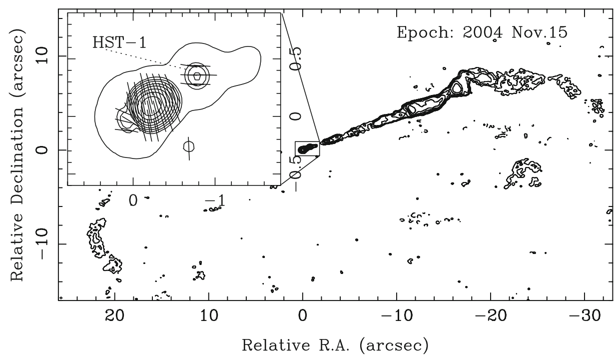

Figure 1. Total intensity image of M87 at 8.4 GHz plus a zoom-in EVPA distribution overlaid by linear intensity contours of its core region (inset). The restoring beam is 0.22 arcsec$\times$ 0.28 arcsec at P.A. $= 86.8°$. Contours start at 1.8 mJy/beam for the total intensity and 2.3 mJy/beam for the linear intensity distribution and an increase by factors of 2 and $\sqrt{2}$, respectively.

resolution and sensitivity. For the assumed distance of 16 Mpc, the linear scale is 78 pc arcsec^{-1}, and the motion at 1 mas yr^{-1} corresponds to an apparent velocity of $0.254c$.

2. Observations and data reduction

The data are collected from the NRAO Data Archive[1]. Here, eight epochs of VLA observations in A array are included spanning the period 2003–2007 to roughly keep consistency in resolution and sensitivity. The observations utilized two adjacent 50 MHz wide intermediate frequencies centered at 8.48 GHz in a full polarization mode.

Data were mainly reduced in AIPS with flux density and electric vector positional angle (EVPA) calibrated using 3C286. Phases were initially corrected through a nearby point source 1224+035. Instrumental polarization was removed with the task 'PCAL' in AIPS. The calibrated data were then read into DIFMAP for imaging, with the resultant images loaded back into AIPS for model fitting using the task 'JMFIT'. Figure 1 shows one epoch of total intensity radio structure with linear intensity contours overlaid by EVPA (inset). All the eight epochs of observations have similar on-source time, and hence the resolutions and sensitivities are comparable from epoch to epoch.

3. Results and discussion

The imaging results show that the jet extends to northwest with a counter lobe structure clearly detected on the opposite side, and hence the detected emission region is as large as more than 50 arcseconds along the overall jet direction, as shown in Fig. 1

[1]The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

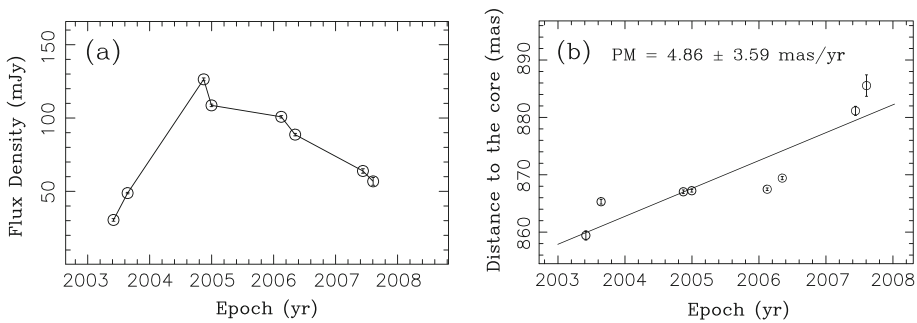

Figure 2. **(a)** Radio light curves of HST-1 at 8.4 GHz; **(b)** Distance of HST-1 from the core with solid line representing the fitted result using least squares method. The errors were obtained in the course of model fitting with 'JMFIT' in AIPS.

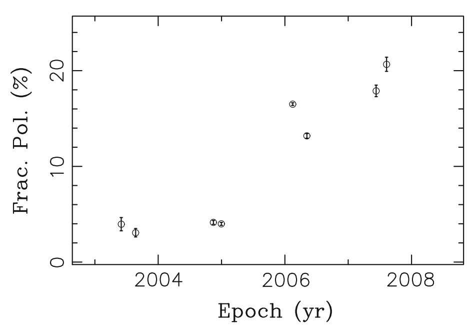

Figure 3. Fractional polarization with epochs. The errors are obtained by conversion of the fitted stokes *I, Q*, and *U* parameters into the quantity of fractional polarization.

for the epoch 15 November 2004. One can find that HST-1 is also quite prominent even in the linear intensity distribution.

Model fitting has been performed to the core region with 'JMFIT', which shows that the total flux density of HST-1 increases rapidly in the rising stage, and falls in a relatively slow way (Fig. 2a), which is analogous to that of optical and X-ray wave bands. Comparing with the light curve of HST-1 at 15 GHz given by Harris *et al*. (2009), one can find that the flux density of HST-1 is systematically higher at 8 GHz, which implies that it has a negative spectral index with $f \propto \nu^{\alpha}$ through the whole major outburst. The proper motion of the feature was fitted with least squares method, showing that it moves down the jet with an apparent speed of 4.86 ± 3.59 mas/yr, corresponding to $1.23c \pm 0.91c$ (Fig. 2b).

The fractional polarization variation with time is shown in Fig. 3, from which one can find that the degree of polarization keeps rising through all stages of the whole major outburst. Multi-epoch VLBA observations at 1.6 GHz show that a couple of new 'subcomponents' form during the outburst, which are expected to have a relatively high degree of polarization, and at least in part gives rise to the rise of fractional polarization. This behaviour is similar to that for the component *B* in NRAO 530 (Chen *et al*. 2010). Note that even in the decaying stage, the fractional polarization still keeps rising, which implies that the effect of depolarization due to Faraday rotation and/or opacity also gets small as the outburst proceeds (Homan *et al*. 2009). Multi-band VLA observations may provide further constraints on the physical process occurring within the HST-1.

Acknowledgements

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