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Japanese VLBI Network Observations of a Gamma-Ray Narrow-Line Seyfert 1 Galaxy 1H 0323 + 342

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Abstract. We made simultaneous single-dish and VLBI observations of a gamma-ray narrow-line Seyfert 1 (NLS1) galaxy 1H 0323 + 342. We found significant flux variation at 8 GHz on a time scale of one month. The total flux density varied by 5.5% in 32 days, corresponding to a variability brightness temperature of 7.0×10^{11} K. We also obtained brightness temperatures of greater than 5.2×10^{10} K from the VLBI images. These high brightness temperatures suggest that the source has nonthermal processes in the central engine. The source structure could be modelled by two elliptical Gaussian components on the parsec scales. The flux of the central component decreases in the same way as the total flux density, showing that the short-term variability is mainly associated with this component.

Key words. Galaxies: active—galaxies: individual (1H 0323 + 342)—galaxies: Seyfert—radio continuum: galaxies.

1. Introduction

Observations made with the EGRET (Energetic Gamma-Ray Experiment Telescope) gamma-ray detector onboard the CGRO (Compton Gamma-Ray Observatory) spacecraft resulted in the identification of a few hundreds of gamma-ray emitted Active Galactic Nuclei (AGNs). Most of them were categorized as blazars, suggesting a close connection between gamma-ray emission and radio activity. Recently, observations with Fermi Large Area Telescope (LAT) have revealed the existence of a new class of gamma-ray emitting AGNs, which are narrow-line Seyfert 1 galaxies (NLS1s). NLS1s are a subclass of AGNs discovered by Osterbrock & Pogge (1985) and identified by their optical properties. First detection of gamma-ray emission in a radio-loud NLS1 was made for PMN J0948 + 0022 (Abdo *et al*. 2009a) and seven NLS1s are listed as gamma-ray sources detected by Fermi/LAT to date (Foschini 2011). They are very interesting objects because most of the NLS1s are hosted in a spiral galaxy, while blazars are hosted in an elliptical galaxy. The gamma-ray NLS1s are known as radio-loud objects and milliarcsecond (mas)-scale images are obtained for several gamma-ray NLS1s with Very Long Baseline Interferometer (VLBI) observations (Doi *et al*. 2006, 2011; Giroletti *et al*. 2011; D'Ammando *et al*. 2012; Orienti *et al*. 2012). Some of them have revealed the presence of a closely aligned relativistic jet, while there are still large uncertainties for the derived parameters and it is therefore important to investigate the parsec-scale properties.

In this paper we report detection of the short-term radio variability in a radio-loud NLS1 1H 0323 + 342, which has been detected by Fermi/LAT (Abdo *et al*. 2009b). Detailed discussion will be made in another paper (Wajima *et al*. 2014). The redshift, z is 0.0629 ± 0.0001 (Zhou *et al*. 2007), which corresponds to an angular-to-linear scale conversion of 1.20 pc mas^{-1} and the source is the nearest one among gamma-ray emitted NLS1s.

2. Observations and data reduction

We made simultaneous single-dish and VLBI observations of 1H 0323 + 342. The total flux density of 1H 0323 + 342 was monitored by Yamaguchi 32-m radio telescope (hereafter Y32) at 8.38 GHz at 25 epochs from 2010 November 9 to 2011 February 5. Observations with the Japanese VLBI Network (JVN) were also made at 8.424 GHz at three epochs on 1, 15 and 30 November 2010 using six radio telescopes, VERA (the VLBI Exploration of Radio Astrometry) – 4 telescopes, the Kashima 34-m telescope, and the Hitachi 32-m telescope. The JVN data were reduced using the Astronomical Image Processing System (AIPS) software for amplitude and phase calibration, and the Caltech software Difmap for imaging and self-calibration.

3. Results and discussion

The left panel of Figure 1 shows the VLBI image of 1H 0323 + 342 on 1 November 2010. The source consists of two components, a bright central component labeled C and a weak jet-like component labeled D1 on the southeast of C. Our image is similar to that of previous VLBI observation (Beasley *et al*. 2002). All images obtained by JVN were modeled satisfactorily by two elliptical Gaussian components. Angular separation between C and D1 is about 7 mas and does not change significantly within three epochs.

The right panel of Figure 1 shows the light curve of 1H 0323 + 342 at 8 GHz by Y32. Our results are in good agreement with observations by the F-GAMMA Program (Fuhrmann *et al*. 2011) at 8.35 GHz. The total flux varied significantly during Y32 monitoring compared with the constant flux. We applied a third-order polynomial to all measurements to estimate the local maximum and minimum of the flux densities. The epoch and flux densities of the local maximum and minimum are 325 mJy at the epoch 2010.956, and 344 mJy at the epoch 2011.043, corresponding to a flux variation of 5.5% in 32 days. Our results clearly show the existence of short-term radio variability on a time scale of one month.

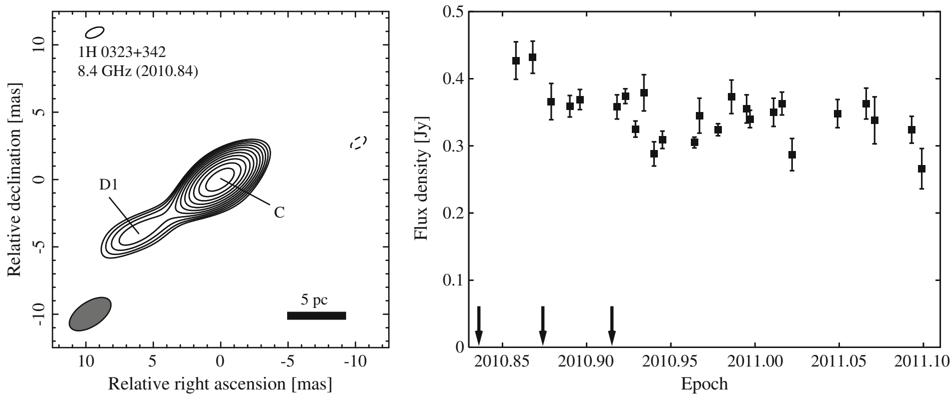

Figure 1. *Left panel*: Image of 1H 0323 + 342 at epoch 2010.836 obtained by JVN. The restoring beam is 3.52 × 1.81 mas at a position angle of 124.0°, which is indicated at the lower left corner. The contour levels are $-9.3, 9.3 \times (\sqrt{2})^n$ ($n = 0, 1, 2, \ldots, 10$) mJy beam^{-1}, and the peak intensity is 397 mJy beam^{-1}. The labels C and D1 show components with the Gaussian model fitting. *Right panel*: 8 GHz light curve of 1H 0323 + 342. Filled squares show the total flux obtained with Y32. Arrows on the horizontal axis show JVN observation epochs. From Wajima *et al*. (2014).

Results of three-epoch JVN observations show that the sum of flux densities of the components C and D1 is in good agreement with the total flux obtained by Y32. On the other hand, only the flux density of C gradually decreases, similar to the total flux density, showing that the short-term variability is mainly associated with this component. The detailed results will appear in another publication (Wajima *et al*. 2014).

We can estimate the variability brightness temperature from the single-dish monitoring results as (Wagner & Witzel 1995)

$$T_{\mathrm{B,var}} = 4.1 \times 10^{10} \left[\frac{D_{\mathrm{L}}}{\Delta t (1+z)} \right]^2 \frac{\Delta S_\nu}{\nu^2} \ [\mathrm{K}], \tag{1}$$

where D_{L} [Mpc] is the luminosity distance to the source, ΔS_ν [mJy] is a change in the observed flux density at an observing frequency ν [GHz] during a period of Δt [days]. Given the single-dish monitoring result of $\Delta S_\nu = 19$ mJy, $\Delta t = 32$ days, and applying $D_{\mathrm{L}} = 270$ Mpc, we obtain $T_{\mathrm{B,var}} = 7.0 \times 10^{11}$ K. We can also obtain the brightness temperature with an image as

$$T_{\mathrm{B,image}} = 1.77 \times 10^9 (1+z) \frac{S_\nu}{\nu^2 \theta_{\mathrm{maj}} \theta_{\mathrm{min}}} \ [\mathrm{K}], \tag{2}$$

where θ_{maj} and θ_{min} [mas] are the FWHM sizes of the Gaussian components in the major and minor axes, and S_ν [mJy] is the flux density at an observing frequency ν [GHz]. Given the model fitting results for component C, we obtain $T_{\mathrm{B,image}} >$ (5.2-8.3) $\times 10^{10}$ K, depending on the JVN observation epoch. $T_{\mathrm{B,image}}$ indicates the lower limit because we cannot resolve the central component. The obtained T_{B} is comparable to other gamma-ray NLS1s (e.g., Doi *et al*. 2006; Giroletti *et al*. 2011), suggesting that the source has nonthermal processes in the central engine.

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