PROCEEDINGS OF SCIENCE

Multi-epoch, quasi-simultaneous 22/43 GHz observations of the M84 nucleus with VERA

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Supermassive black-hole activities in the local universe are primarily in the lower end of luminosity function of active galactic nuclei (low-luminosity AGN; LLAGN). The detailed accretion and ejection processes acting in these nuclei are still not well understood. To address this issue, we need to investigate a close vicinity of the central engine using high-resolution VLBI. The nearby elliptical galaxy M84 is one of the representative LLAGN, and its proximity along with the large black hole mass allows us to examine the nuclear structure at a privileged linear/gravitational scale. Here we report high resolution multi-epoch observations of the M84 nucleus with VERA at 22 and 43 GHz. The nuclear structure was resolved down to 443 R_s (or 0.036 pc) at 43 GHz, while at 22 GHz we detected an elongated, jet-like structure in the northern side of the core, which is consistent with previous mas-scale observations. At most of the observed epochs the radio core shows flat-to-steep spectra between 22 and 43 GHz, suggesting that the core emission at these frequencies is dominated by the synchrotron-self-absorbed jet base.

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1. Introduction

Low-luminosity Active Galactic Nucleus (LLAGN) is a well-known subclass of AGN that is identified as Hα luminosity being $< 10^{40}$ erg sec^{-1}. In terms of the bolometric luminosity, LLAGN typically has only 10^{-4} $L_{\rm Edd}$ ($L_{\rm Edd}$; Eddington luminosity) or less, suggesting that the accretion state is radiatively inefficient at a very low accretion rate. However, the origin of the nuclear radio emission is still not well understood compared to luminous AGN because of its difficulty of observation.

There are two possibilities for the origin of the nuclear radio emission; one is non-thermal synchrotron emission from the base of jet [3] while the other is from radiatively inefficient accretion flow (RIAF) or advection dominated accretion flow (ADAF) [10]. To distinguish these emission models, it is important to constitute the nuclear structure, spectral properties, and radio power by using high-resolution VLBI observations [1, 6].

M84 is one of the nearest LLAGN. It is located in the center of Virgo cluster at a distance of 17 Mpc [5] and has a central supermassive black hole weighing $8.5^{+0.9}_{-0.8} \times 10^8$ $M_\odot$ [11]. The combination of its proximity and a large estimated black hole mass yields a linear resolution down to 1 mas ~ 0.082 pc ~ 1015 $R_{\rm S}$, allowing us to investigate a close vicinity of central black hole with VLBI.

2. Observations and Data Reduction

We performed dual frequency quasi-simultaneous observations at 22 and 43 GHz with VLBI Exploration of Radio Astrometry (VERA). The observations were performed every 3 weeks from Feb 2012 to May 2012 and Feb 2013 to May 2013 for a total of 10 epochs. For each epoch, we have 8-hour integration time in total, where each of the 4 hours is spent for 22/43 GHz. Since M84 is too faint to detect fringes directly with fringe search, we used dual-beam phase referencing technique using M87 as a reference calibrator, which is separated by 1.5 degree on the sky. Typical angular resolutions are 1.4×0.8 mas at 22 GHz and 0.65×0.44 mas at 43 GHz, respectively.

3. Preliminary Results and Discussion

In Figure 1, we show representative VERA images of M84 at 22 and 43 GHz. Thanks to the dual-beam phase-referencing technique, we successfully detected the faint radio emission from this source at both frequencies. The nuclear structure was resolved down to $\lesssim 812$ $R_{\rm S}$ (0.066 pc) at 22 GHz and to $\lesssim 443$ $R_{\rm S}$ (0.036 pc) at 43 GHz, respectively. To quantify the structure, we performed a modelfitting to the calibrated visibility data (Figure 2). At 22 GHz, the structure was best modeled by a core (elliptical Gaussian) plus jet (point source), while the 43 GHz structure was modeled by a single elliptical Gaussian model. This suggests that the extended component has a steep spectrum. The detection of a jet structure to the north in our VERA 22 GHz images is consistent with previous VLBI observations of M84 at other frequencies [4, 7].

In Figure 3 we show the obtained 22-43 GHz core spectra at every epoch. We found that 7 out of the 10 spectra are flat-to-steep, while there are no highly inverted spectra which is expected from a thermal ADAF model ($\alpha > 0.4$; [8]; here we define spectral index α as $F_\nu \propto \nu^{+\alpha}$ where

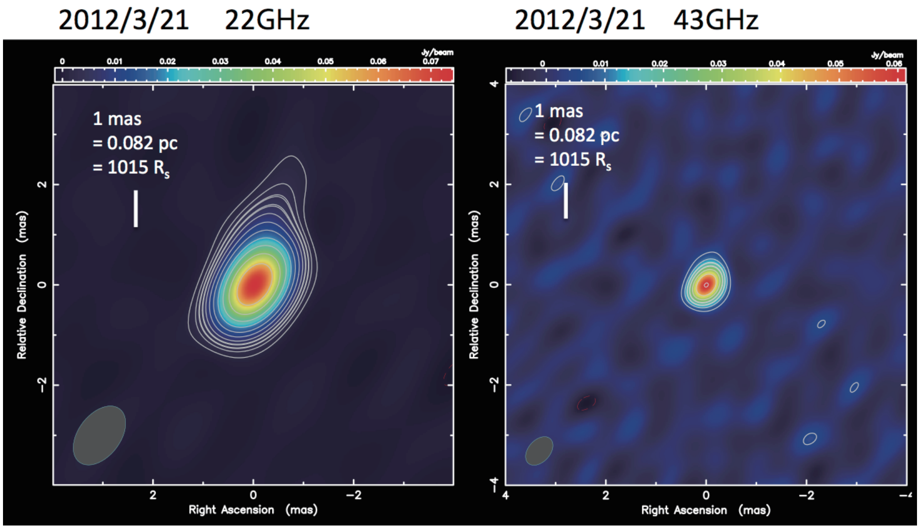

Figure 1: (Left) CLEAN image of M84 at 22 GHz. (Right) CLEAN image of M84 at 43 GHz. The contour starts from -1,1,2 times of 3σ image rms and thereafter increasing by factor of $\sqrt{2}$. The peak fluxes are 71 and 64 mJy/beam for 22 and 43 GHz images, respectively.

F_ν denotes flux density at a frequency ν). An averaged spectrum was found to be $\alpha = -0.13 \pm 0.07$. The observed flat-to-steep spectra are consistent with previous observations of M84 at other radio frequencies [2, 9]. The observed radio power of the M84 core in the 22/43 GHz bands is $\sim 4 \times 10^{28}$ erg s^{-1}Hz^{-1}, an order of magnitude larger than that expected from thermal synchrotron emission from ADAF [8].

These results naturally suggest that the nuclear radio emission of M84 is dominated by the optically-thick self-absorbed jet base, where the physical scale is likely to be within a jet formation and collimation scale. Further analyses including proper motion measurements and dual-beam astrometry are currently in progress, which will allow us to constrain a jet velocity field, nuclear opacity and magnetic field structure for the M84 jet base.

Acknowledgments.

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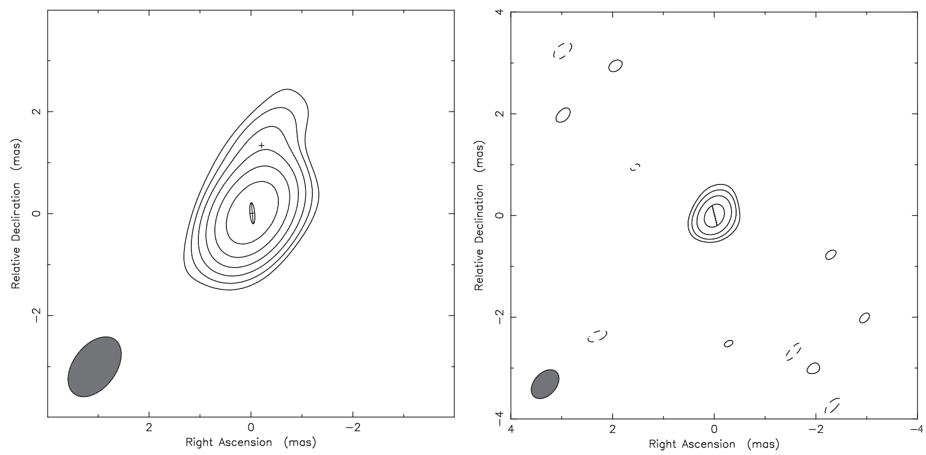

Figure 2: (Left) Elliptical Gaussian plus point source model fitted image of M84 at 22 GHz. We detected jet like component extended to the north. (Right) Elliptical Gaussian model fitted image of M84 at 43 GHz. The contour starts from -1,1,2 times of 3σ image rms and thereafter increasing by factor of 2.

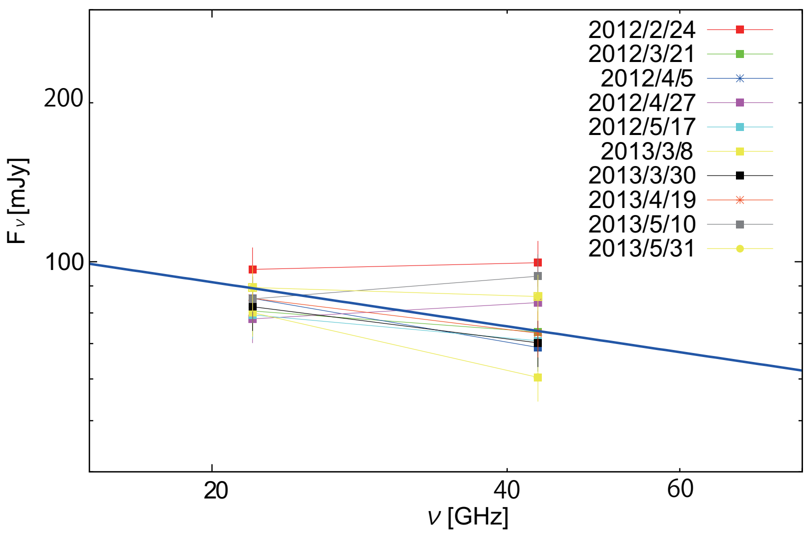

Figure 3: Model-fitted radio core spectra of M84 between 22 and 43GHz. We obtained simultaneous spectra for a total of 10 epochs in 2012 and 2013. Core spectra of all spectra in 2012-2013. A thick blue line shows averaged spectrum with a spectral index $\alpha = -0.13 \pm 0.07$.

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