Recent Results of KaVA AGN Science WG

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Abstract

KaVA stands for KVN and VERA Array which is a Korean-Japanese joint VLBI facility. Here we briefly present the imaging capabilities of KaVA array which actually achieves more than three times better dynamic range than that achieved by VERA or KVN alone. The KaVA images clearly show detailed structures of extended radio jets in AGNs. With the improved imaging capabilities, we proposed the KaVA AGN Large Program. We launched the intensive monitoring observations of two super-massive black holes, Sgr A* and M87. The main scientific goals of the program are (i) testing magnetically-driven-jet paradigm by mapping velocity fields of the M87 jet and (ii) obtaining tight constraints on physical properties of radio emitting region in Sgr A*.

KaVA image capability see Niinuma et al. (2014) for details

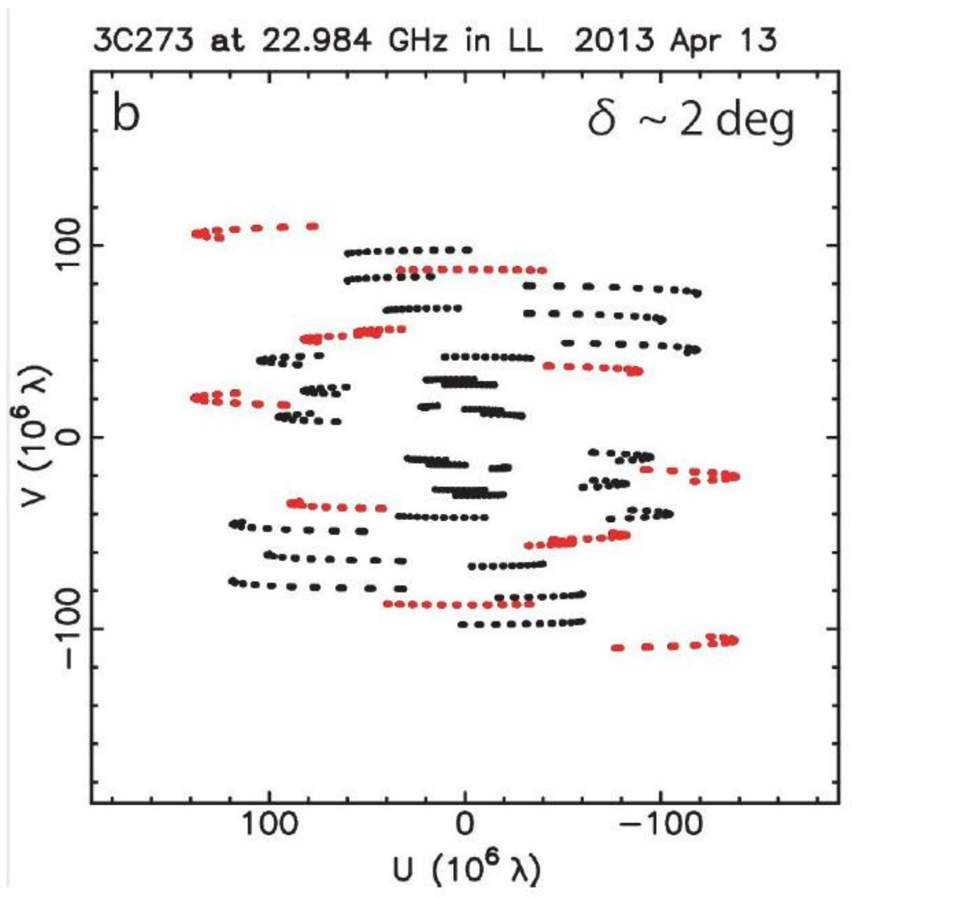

Figure 1. uv–coverage of 3C 273 (declination $\delta \sim 2°$). Red plots show the one obtained by only VERA baselines, and black+red plots show the one obtained by KaVA baselines.

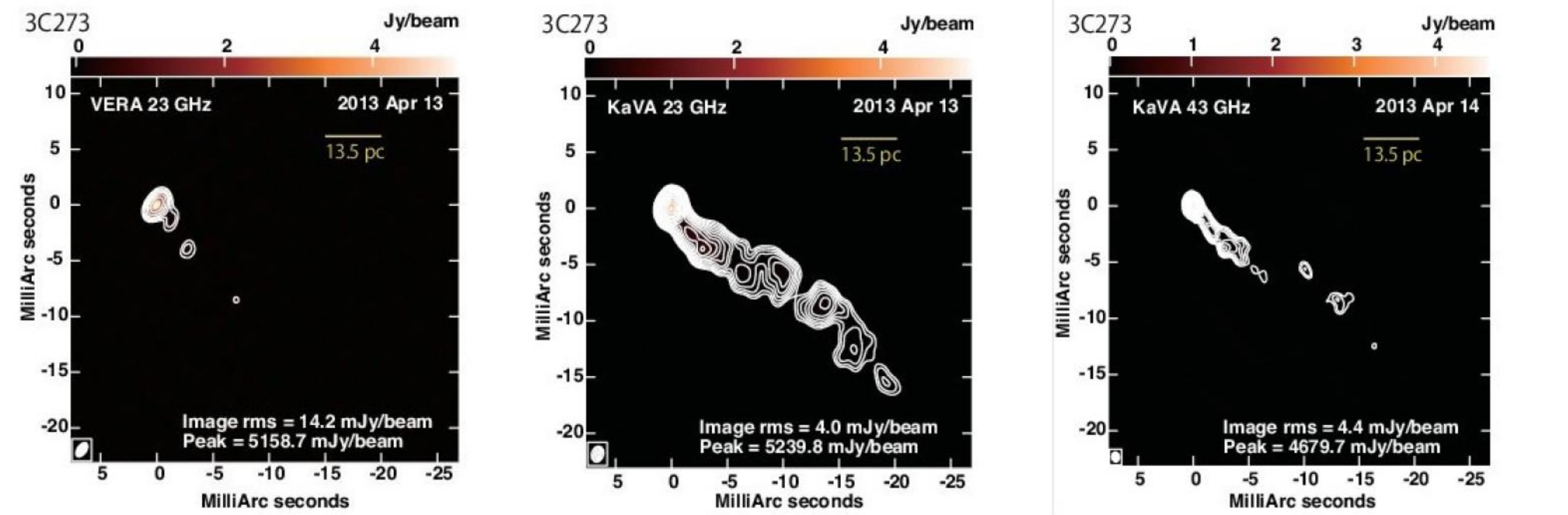

Figure 2. *Left*–, *middle*–, *right*–panels: VLBI images of 3C 273 observed by VERA at K-band and KaVA at K-/Q-bands, respectively. In each panel, peak intensities and image noise levels are indicated in the bottom-right corner and synthesized beams are also shown in the bottom-left corner in each image. In the top-right corner, the date and linear scale at the distance of each source are shown. Contours of each image begin at five times of image rms, and increase in $\sqrt{2}^n$ steps.

KaVA baseline lengths range from 305 to 2270 km (Figure 1). Observing frequencies of 23 GHz (K-band) and 43 GHz (Q-band) are available. It consists of 7 radio telescopes in Japan and Korea. To evaluate the imagine capability of KaVA, we performed imaging observations of three bright active galactic nuclei (AGNs) known for their complex morphologies: 4C 39.25, 3C 273, and M87 by KaVA at K-/Q-band. Our KaVA images reveal extended outflows with complex substructure such as knots and limb brightening, in agreement with previous observations by other VLBI facilities. Angular resolutions are better than 1.4 and 0.8 milli-arcsecond (max) at K-/Q-band, respectively. KaVA achieves a high dynamic range of 1000 (with 128 Mbps data rate; now we have 1 to 8 Gbps rate), more than three times the value achieved by VERA or KVN. We conclude that KaVA is a powerful array with a great potential for the study of AGN outflows, at least comparable to the best existing radio interferometric arrays.

KaVA AGN Large Program

Testing the magnetically-driven jet paradigm (M87)

Understanding the formation mechanism of relativistic jets in active galactic nuclei (AGNs) is one of the holy grails in astrophysics. According to the current leading scenario, AGN jets are driven by magnetic force, and subsequently accelerated through the progressive conversion of the magnetic energy into the kinetic one. Relativistic MHD models have indicated a slow conversion of magnetic energy into kinetic one in relativistic jets. The nearby radio galaxy M87 (Virgo A; distance = 16.7 Mpc) is known as the best target to test this scenario because of its proximity and its large black hole. One of the goals of this proposal is mapping the velocity field of the M87 jet for testing "B-driven jet" paradigm. Indeed, mapping the velocity field of M87 has been intensively explored in previous works. Surprisingly, the apparent velocities in literatures are significantly different (0.05c~2c) and controversial. One of the possible reasons may be due to the misidentification of components sparse interval of previous monitoring and/or mismatching of components measured at different frequencies i.e., 15 and 43 GHz. The other possibility may be different velocity fields in different period. A promising way to get definitive conclusion is to conduct a dual-frequency (22 and 43 GHz) monitoring of M87 jet with sufficiently short time interval.

Our goal is mapping the velocity field of the M87 jet that can give unique constraints on theoretical models of B-field driven jet. Since images at 22 GHz have higher dynamic ranges than those obtained at 43 GHz, extended downstream structure of the jet (~10 mas or even further) can be explored at 22 GHz. Hence we chose 22 GHz for our pilot observations (Figure bottom left). In our previous test monitoring of M87 with KaVA at 22 GHz with the interval of ~3-4 weeks, we have obtained a possible indication of a superluminal motion, although it was not conclusive. Therefore, in this program, we conduct the dual frequency (i.e., 22 and 43 GHz) monitoring during the same period aiming for quasi-simultaneous detections of same components both at 22 and 43 GHz which guarantee robust conclusion. Measurement of velocities of slowly moving component is also our important science goal in terms of understanding the velocity structure in vertical direction to the jet axis and it governs the total duration of this large program.

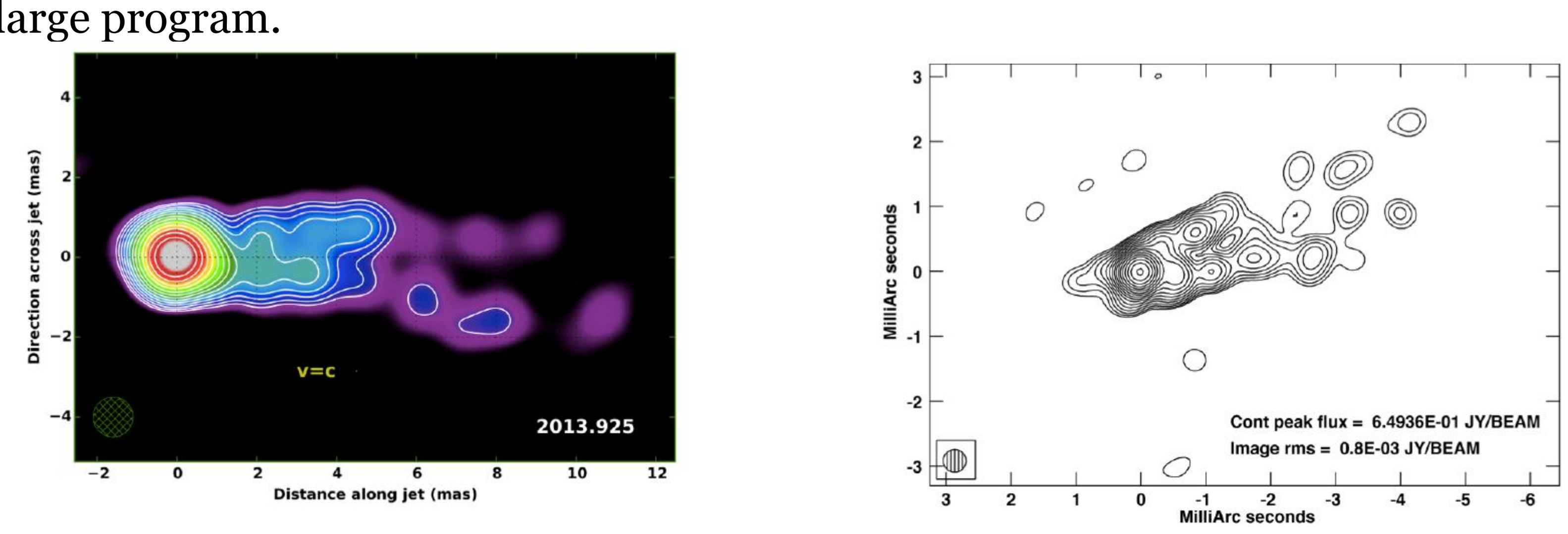

Figure 2.
Example of M87 images obtained by KaVA at 22 and 43 GHz in 2013-2014. The image at 22 GHz can clearly describe the global structure of the extending jet up to ~10-15 mas scale, while the 43 GHz image is suitable for probing the jet components within ~4 mas more closely located to the central engine.

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Probing the nature of accreting plasma onto SMBH (Sgr A*)

At the center of Milky Way, Sagittarius A* (distance = 8 kpc) hosts the SMBH ($4 \cdot 10^6$ M_{sun}) with Schwarzschild radius ~10μas (1 mas = 100 Rs). Hence Sgr A* is the best laboratories to explore mass accretion process onto SMBH. The G2 encounter event, in particular, provides us a rare chance for probing the nature of accreting plasma onto SMBH. Currently, no evidence for enhanced emission (i.e., enhanced accretion) are seen in one epoch GMVA observation on 1st Oct 2013 and multi-epoch observations VLA, SMA and ALMA during 2012-2014 while Ponti et al. (2015) shows evidence for a recent increase in the bright X-ray flare rate in Sgr A* based on 15 years of XMM/Newton and Chandra data. This could be a first sign of an excess accretion activity induced by G2 encounter, although further observations are necessary to draw a solid conclusion. We are the only team conducting regular monthly VLBI monitoring of Sgr A* and now we are summing up the KaVA observational results at 43GHz in the period (2013-2014). In the bottom right figure, we show a high dynamic range KaVA image of Sgr A* at 43 GHz. The outstanding advantage of KaVA array is the number of high quality radio telescopes and their dense short spacing coverage. In the case of VERA-alone observations for Sgr A*, more than 70% of the visibilities sampled with Ishigaki-jima station on average are invalid which prevents us conducting amplitude-self-calibration and/or measuring closure amplitude. On the other hand, KaVA normally get visibilities at more than four stations, there is no problem for conducting amplitude-self-calibration and/or measuring closure amplitude.

Our goal is to conduct the monthly monitoring of Sgr A* at 43 GHz to look for imprints of G2 encounter. The enhancement of magnetic energy predicted by Kawashima et al. directly leads to the increase of synchrotron flux densities detectable with KaVA. Accurate measurement of source size can enable us to estimate B-field strength [Ref] and we will systematically continue to measure the B-field strength during the monitoring. As explained above, the overall duration of the monitoring is needed to be minimum ~5 years. As shown in the figure below, we have obtained high dynamic range Sgr A* images in our pilot observations and with higher data rate we are producing higher quality results which will be presented soon.

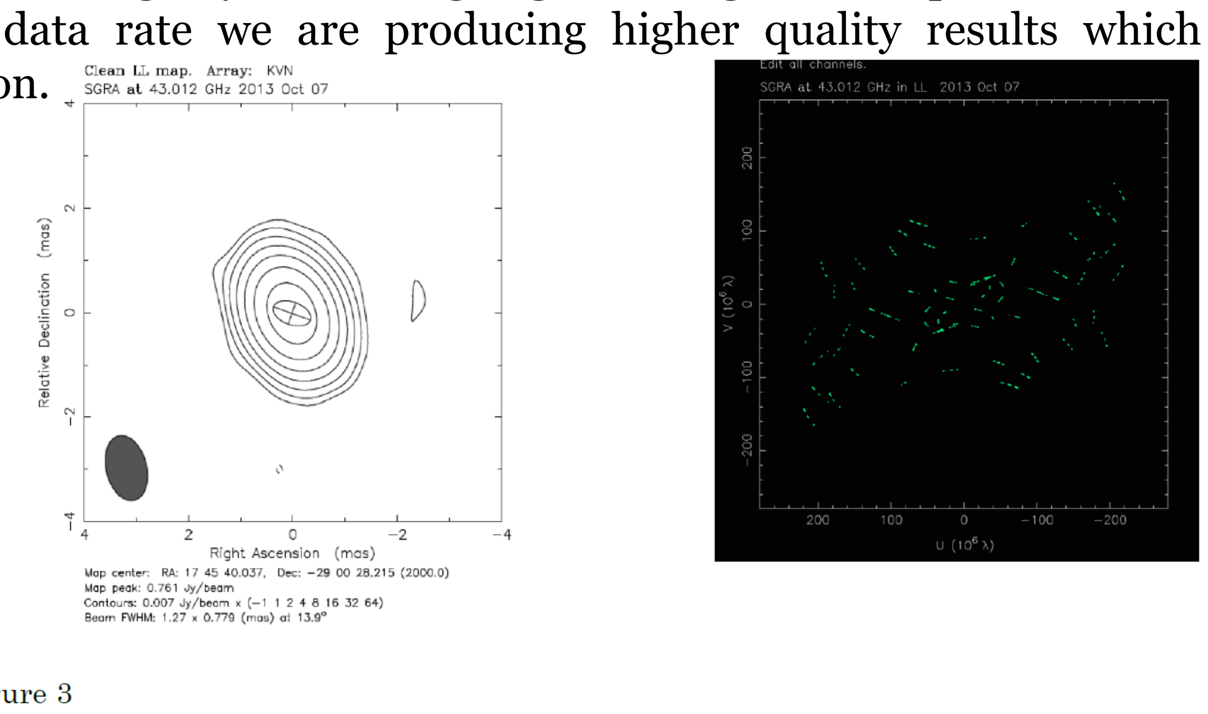

Figure 3
The corresponding KaVA image of Sgr A* with the best-fit elliptical Gaussian model (left panel) and the corresponding u,v coverage (right panel) (Zhao et al. in progress). The dynamic range of this KaVA image is more than 300. It is higher than the one than that of VERA with typically several times of 10.

For further details and references
Niinuma et al. 2014 2014, PASJ, 807, 14 (arXiv:1406.4356)
Kino et al. 2015, PKAS, 30, 633 (arXiv:1504.06399)