EATING VLBI monitoring of the M87 jet

Hyunwook Ro[1], Kazuhiro Hada[2], Kunwoo Yi[3], Motoki Kino[4], Yuzhu Cui[5], Kiyoaki Wajima[1], Yosuke Mizuno[6], Kawashima Tomohisa[7], Jongho Park[8], Bong Won Sohn[1], Marcello Giroletti[9], Gabriele Giovannini[9], Shinji Horiuchi[10]
and EATING VLBI collaboration

[1]Korea Astronomy and Space Science Institute, Korea. [2]Nagoya City University, Japan, [3]Seoul National University, Korea, [4]Kogakuin University of Technology & Engineering, Japan, [5]Zhejiang Laboratory, China, [6]Shanghai Jiao Tong University, China, [7]Institute for Cosmic Ray Research, Japan, [8]Kyung Hee University, Korea, [9]INAF Istituto di Radioastronomia, Italy, [10]Commonwealth Scientific and Industrial Research Organisation, Australia

hwro@kasi.re.kr

Abstract

We present high-cadence monitoring of the M87 jet using EATING VLBI, a joint facility between the East Asian VLBI Network (EAVN) and three Italian telescopes. EATING VLBI is the only array dedicated to the regular monitoring of the sub-mas-scale structure of the M87 jet. Here, we present the first images from this program, detecting jet emissions up to ~10 mas from the core with typical angular resolutions of ~0.3 mas (naturally weighted) or ~0.2 mas (uniformly weighted). In particular, images of joint observations with the Tidbinbilla-70m telescopes effectively resolve the transverse jet structure by extending the N–S baseline. This high-resolution monitoring, with a 3-week interval, enables us to investigate the connection between long-term position angle changes at horizon-scale and mas-scale. We also aim to uncover the origin of the small-scale fast transverse oscillations. Preliminary results of the ridgeline analysis are presented, along with plans for regular joint observations of EATING VLBI and Long Baseline Array (LBA). These results will provide deeper insights into the jet structure of M87, contributing to our understanding of relativistic jet physics.

The EATING VLBI

- EATING VLBI (East Asia to Italy: Nearly Global VLBI) is a global array which consists of East Asian VLBI Network (EAVN) and INAF radio telescopes.
  - ✓ Currently, 14 stations are participating in regular observations.
  - ✓ Maximum baseline length of ~10,000 km in East – West direction.
  - ✓ Part of the observations has been jointly conducted with Quasar VLBI Network to fill the uv-coverage between Europe and East Asia.
  - ✓ Joint observations with the Tidbinbilla 70-m telescope in Australia enable significant extension of the North – South baseline as well (see Result 2).
- Currently operating at 22 GHz, 256 MHz bandwidth (1 Gbps recording rate) and single polarization.
  - ✓ Future upgrades are planned (see Future Plans and Prospects).
- The data are correlated with the Daejeon hardware correlator located at the Korea-Japan Correlation Center (KJCC) in KASI.
- The project history, early results, and future prospects are reviewed in Giovannini et al. (2023).

EATING VLBI monitoring of the M87 jet

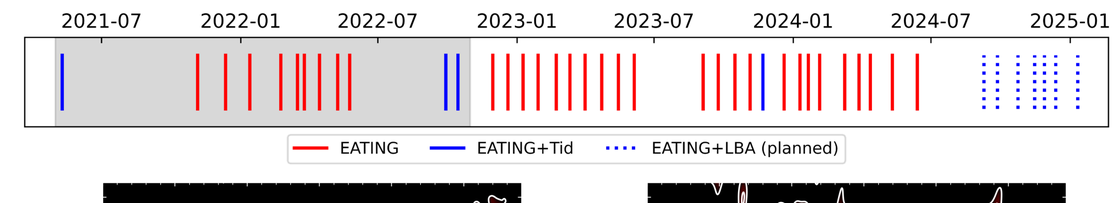
- As an expansion of the existing EAVN monitoring, EATING VLBI has been monitoring M87 since late 2019.
  - ✓ Some of the early observations in 2019 and 2020 were used to study the changes in the position angle of the innermost jet (Cui et al. 2023).
- Currently the only regular monitoring of M87 with global baselines.
  - ✓ **High cadence:** ~ 3 weeks interval
  - ✓ **High sensitivity:** Detecting jet emission up to ~10 mas from the core
  - ✓ **High angular resolution:** $\lesssim$ 0.2 – 0.3 mas (i.e., $\lesssim$ 100 R_S)
- The key scientific goals of this project are summarized as follows:
  1. **Fast transverse oscillations:** Revealing the origin of the fast transverse oscillations (~1 year period) which propagates along the jet with superluminal speeds (Ro et al. 2023; 2024).
  2. **Position angle changes of the sub-mas-scale jet**: Connection between long-term (~10 year period) position angle variations in horizon-scale (Wielgus et al. 2020) and mas-scale jet (Cui et al. 2023).
  3. **Innermost jet speeds:** Measurement of jet propagation speeds at scales below ~ 100 R_S, which are not yet well explored (e.g., Park et al. 2019).
  4. **EHT multi-wavelength campaign:** Participate in EHT multi-wavelength campaign to obtain the broadband spectral energy distribution (SED) of M87 (e.g., EHT MWL SWG 2021; 2024).

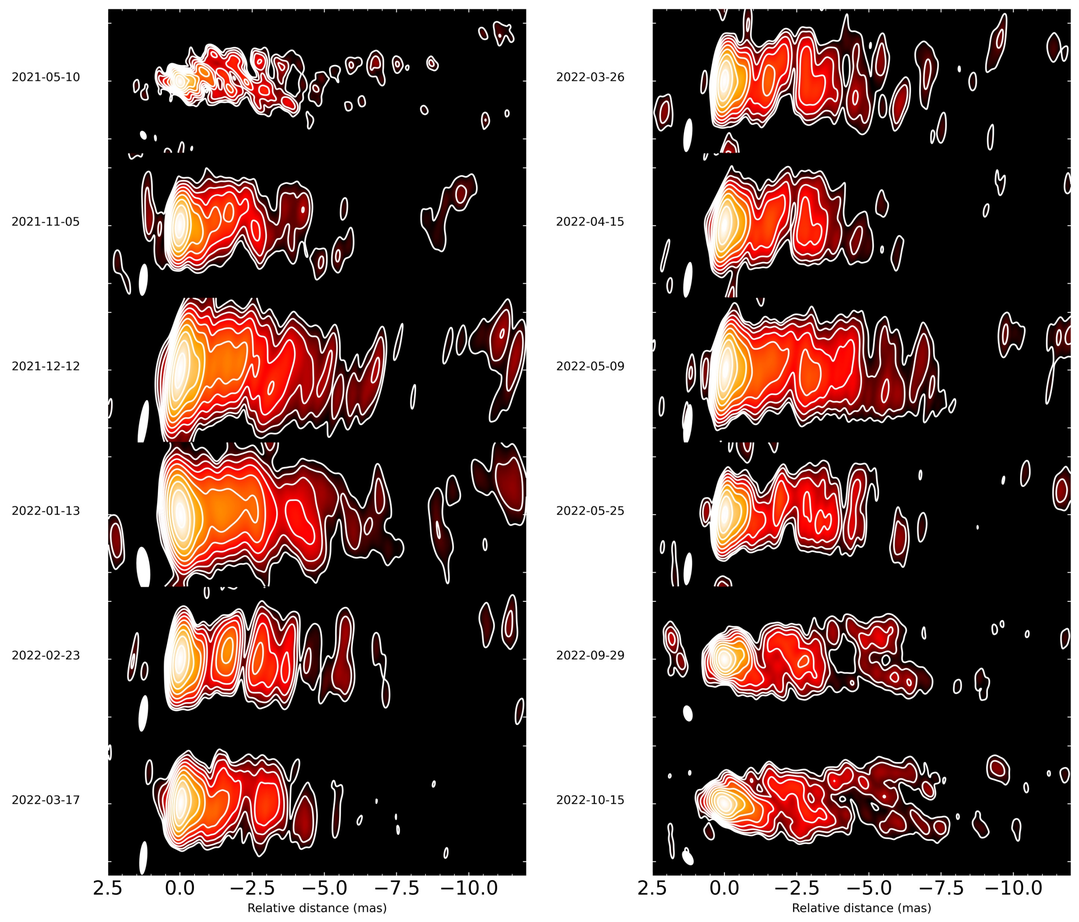
References

Park et al. 2019, ApJ, 887, 147; Wielgus et al. 2020, ApJ, 901, 67; EHT MWL SWG 2021, ApJL, 911, L11; Ro et al. 2023, Galaxies, 11, 33; Tazaki et al. 2023, Galaxies, 11, 39; Giovannini et al. 2023, Galaxies, 11, 49; Cui et al. 2023, Nature, 621, 711; EHT MWL SWG 2024, arXiv:2404.17623; Ro et al. 2024, in prep.

Results

1. EATING VLBI images of the M87 jet in 2021 – 2022

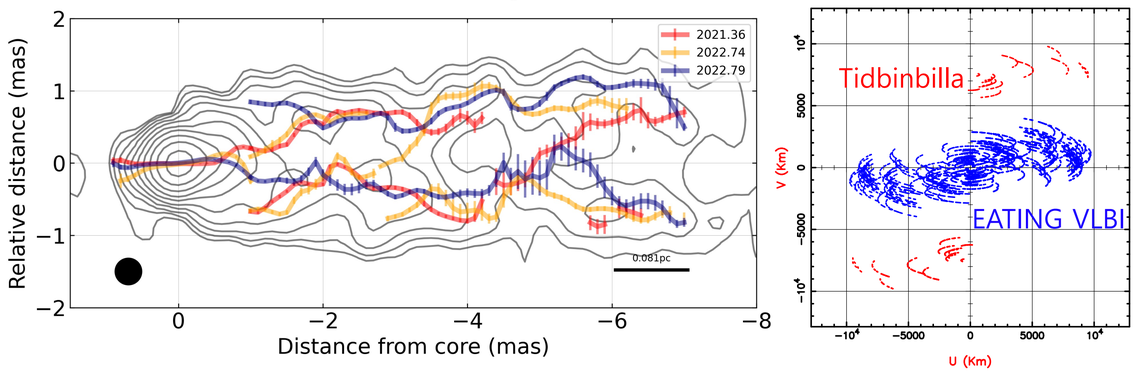




obs. date	beam size (natural) (mas × mas, deg)	beam size (uniform) (mas × mas, deg)
2021-05-10	0.328 × 0.207, 44.34	0.296 × 0.156, 33.9
2021-11-05	1.117 × 0.302, 13.52	0.928 × 0.198, 13.3
2021-12-12	1.701 × 0.296, 9.15	1.48 × 0.204, 8.34
2022-01-13	1.536 × 0.466, 23.15	1.24 × 0.249, 22.7
2022-02-23	1.274 × 0.308, 11.66	1.01 × 0.19, 11.7
2022-03-17	1.172 × 0.267, 13.21	1.04 × 0.212, 13.6
2022-03-26	1.173 × 0.293, 11.76	0.909 × 0.185, 10.9
2022-04-15	1.249 × 0.278, 10.43	1.06 × 0.211, 10.6
2022-05-09	1.41 × 0.289, 11.66	1.16 × 0.207, 12.5
2022-05-25	1.139 × 0.277, 12.35	0.958 × 0.189, 12.5
2022-09-29	0.568 × 0.317, 31.11	0.407 × 0.216, 32.6
2022-10-15	0.565 × 0.317, 50.61	0.396 × 0.207, 47.8

- We have detected jet emission up to 10 mas from the core with an angular resolution of ~0.3 mas (natural weighting) or ~0.2 mas (uniform weighting) in the jet direction.
- Imaging of the 2022B – 2024A observations, taken at approximately 3-week intervals, is underway.

2. EATING VLBI + Tidbinbilla joint observations



- Images from the EATING VLBI + Tidbinbilla-70m joint observations show a substantial improvement in angular resolution along the N – S direction (average beam size of 0.36 mas × 0.192 mas, uniform weighting).
- Preliminary results of ridgeline distributions follows structure of the M87 jet in great detail, allowing us to study structural changes on sub-mas-scales.

Future Plans and Prospects

- In 2024B, we will conduct joint observations with the Long Baseline Array (LBA) in Australia, including ATCA, Mopra, Hobart, and Tidbinbilla-70m, to enhance N – S baselines coverage.
- Compact triple-band receivers are being installed on the Italian telescopes, enabling EATING VLBI observations at 22, 43, and 86 GHz simultaneously.
- Test observations with dual-polarization and improved recording rates are currently underway.
- Advanced imaging techniques, including the Regularized Maximum Likelihood method (e.g., eht-imaging, SMILI) and Bayesian method (e.g., Comrade, Resolve) are expected to improve the fine structure of the ridgelines (e.g., Tazaki et al. 2023).