Observing the collimation and acceleration region of AGN jets with the GMVA+ALMA at λ3 mm

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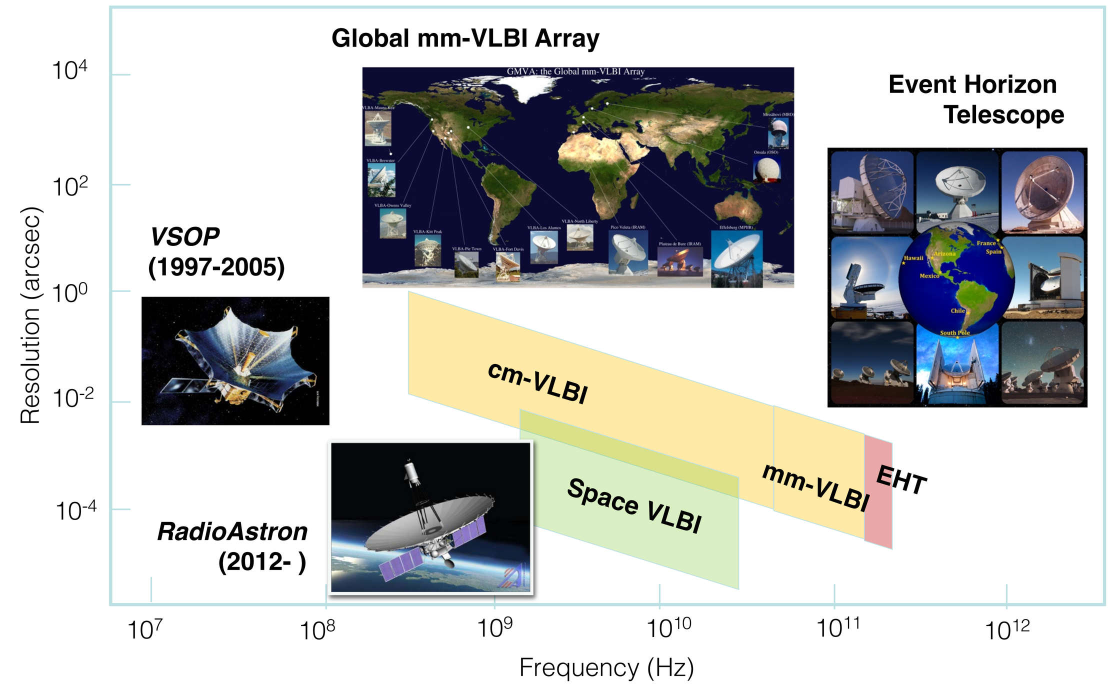
High-resolution observations of selected jets - Overview

Source [B1950.0/ID]	D_L [Mpc]	*RadioAstron* $\lambda\lambda$18cm$^{\alpha}$/ 6cm$^{\beta}$/ 1.3cm$^{\gamma}$	GMVA+ALMA λ3.5mm	EHT λ1.3mm
1322−428/Cen A	3	Feb14$^{\gamma,\ddagger,\mathrm{T}}$	—	Apr17$^{\mathrm{Mu}}$+Apr18$^{\mathrm{Mu}}$ +Apr19$^{\mathrm{J},✤}$
1228+126/M 87	16	Mar14$^{\beta,\mathrm{S}}$+Jun14$^{\alpha,\mathrm{S}}$+ May18$^{\gamma,\mathrm{S}}$	Jan17$^{◆,\mathrm{Lu}}$+Apr17$^{*,\mathrm{As}}$+ Apr18$^{\mathrm{Lu}}$+Apr19$^{*,\mathrm{H}}$+Apr20$^{\mathrm{Km}}$	Apr17$^{\mathrm{D},1\text{-}6}$+Apr18$^{\mathrm{D}}$+Apr20$^{\mathrm{D}}$
0238−084/NGC 1052	18	Sep16$^{\gamma,\ddagger,\mathrm{Bk}}$	Apr17$^{*,\mathrm{Bk}}$	Apr17$^{\mathrm{Ka}}$
1652+398/Mrk 501	142	Mar15$^{\beta+\gamma,\mathrm{Gi}}$	Apr17$^{*,\mathrm{Ma}}$+Apr18$^{*,\mathrm{Ma}}$ +Apr19$^{*,\mathrm{Ko}}$	Apr17$^{\mathrm{Ko}}$ +Mar19$^{\mathrm{Ko},✤}$ +Apr20$^{\mathrm{Ko}}$
1957+405/Cyg A	232	Sep18$^{\gamma,\mathrm{Bh}}$	Oct18$^{*,\mathrm{Bh}}$+Oct19$^{*,\mathrm{Bh}}$	Apr19$^{\mathrm{Ki},✤}$
1226+023/3C 273	787	Jan14$^{\gamma,\mathrm{Go},7}$+Jun14$^{\alpha,\mathrm{Go}}$+ Feb15$^{\gamma,\mathrm{S}}$ +Feb18$^{\alpha,\mathrm{Go}}$	Apr17$^{\mathrm{Ak},8}$+Apr18$^{\mathrm{Lo}}$	Apr17†+Apr18†+Apr19$^{\mathrm{S},✤}$ +Apr20$^{\mathrm{S}}$
0851+202/OJ 287	1637	Apr14$^{\gamma,\mathrm{Go}}$+Apr16$^{\alpha+\gamma,\mathrm{Go}}$+ Mar17$^{\gamma,\mathrm{Go}}$+Apr18$^{\gamma,\mathrm{Go}}$+ Mar19$^{\gamma,\mathrm{Go},✪}$	Apr17$^{\mathrm{Go}}$+Apr18$^{\mathrm{Go}}$+ Apr19$^{\mathrm{Go},✯}$ +Apr20$^{\mathrm{Go}}$	Apr17$^{\mathrm{Go}}$+ Apr18$^{\mathrm{Go}}$ +Mar19$^{\mathrm{Go},✤}$
1510−089/OR −017	1804	—	Apr17$^{*,\mathrm{Ma}}$ +Apr19$^{\mathrm{Mc},✯}$	Mar19$^{\mathrm{Mc},✤}$
1253−055/3C 279	3180	Mar14$^{\gamma,\mathrm{Go}}$+Feb15$^{\gamma,\mathrm{S}}$+Jan18$^{\gamma,\mathrm{Go}}$	Apr18$^{\mathrm{Lo}}$	Apr17$^{\mathrm{Kr},4,9}$+Apr19$^{\mathrm{Lo},✤}$
1641+399/3C 345	3580	Mar16$^{\alpha,\mathrm{Go}}$+May16$^{\gamma,\mathrm{Go}}$	Apr19$^{\mathrm{Go},✯}$	—
1055+018/4C 01.28	5560	—	May16$^{*,\mathrm{A}}$ +Apr18$^{◆,\mathrm{R}}$	Apr17†+Apr18$^{\mathrm{A}}$

Green, scheduled for next ALMA Cycle; **boldface, presented below;** *: No ALMA; †: As calibrator; ‡: No space fringes detected; ◆: HSA; ✤: Session cancelled; ✪: No Spekt-R available; ✯: ALMA lost due to bad weather
Projects led by following PI: A: Alberdi, Ak: Akiyama, As: Asada, Bh: Bach, Bz: Baczko, D: Doeleman, Gi: Giovannini, Go: Gómez, H: Hada, J: Janßen, Ka: Kadler, Ki: Kino; Km: JY Kim; Ko: Koyama, Kr: Krichbaum; Lo: Lobanov, Lu: Lu, Ma: Marscher, Mc: MacDonald, Mu: Müller (transferred to ER+MK, processed by Janßen), R: Ros, S: Savolainen, T: Tingay.
1-6: EHTC et al. ApJ 875, L1-L6, 2019; 7: Bruni et al. A&A 604, A111, 2017; 8: See talk by Okino et al. on Tue 15oct; 9: JY Kim et al. in prep.
Notice that also Sgr A* is being observed by the three high-resolution facilities.

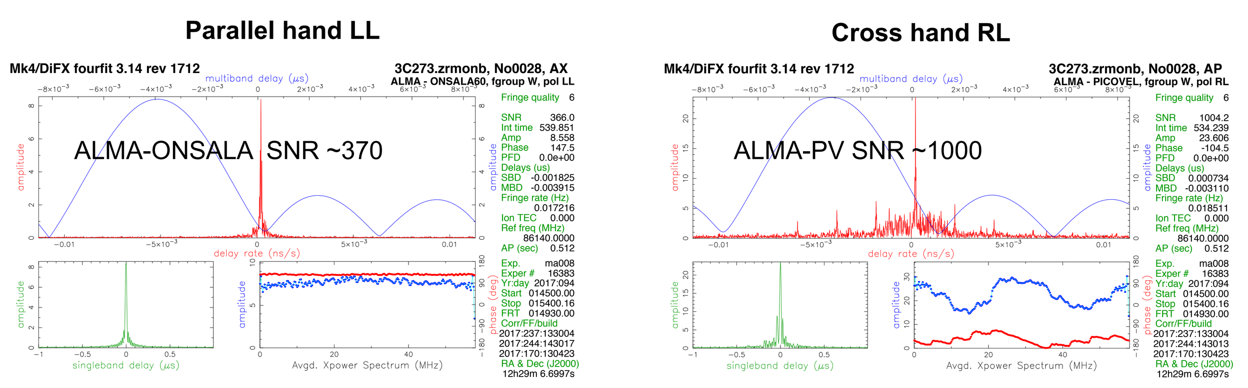
Record-breaking arrays



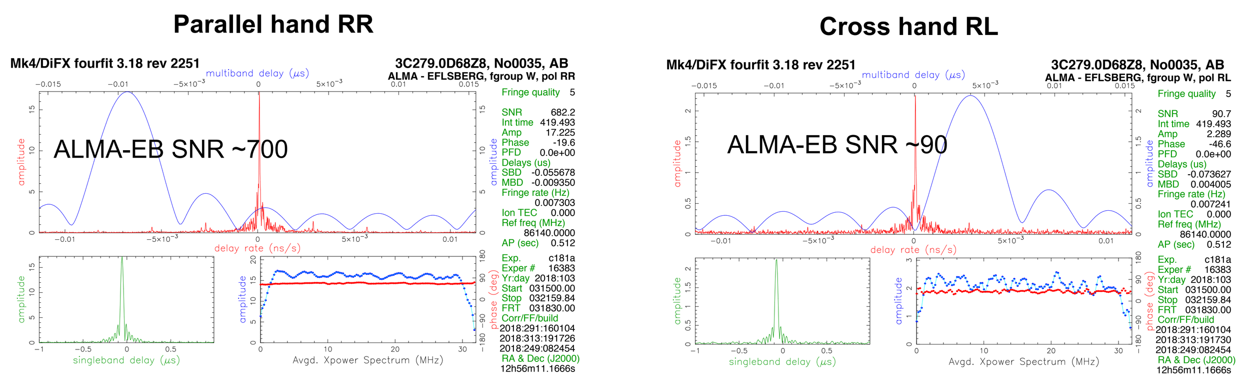
VLBI resolution is enhanced by making observations at shorter wavelengths (millimeter VLBI) or at longer baselines, for instance by employing an orbiting radio telescope (space VLBI). At mm-wavelengths, the coherence times are shorter, atmospheric absorption becomes important, and less antennas are available: the addition of beamformed ALMA to the Global Millimetre-VLBI Array (GMVA) at λ3.5 mm (and to the Event Horizon Telescope (EHT) at λ1.3 mm) enhances dramatically the SNR in the observations and the image fidelity with the sparse arrays. ALMA is the only large antenna operating at λ3.5 mm in the Southern hemisphere and provides therefore unprecedented N-S resolution (also now with the inclusion of the Greenland Telescope in the array).

Bona-fide detections of AGN

Baselines to ALMA provide detections with SNR larger than 1000. Here examples from 2017 and 2018.



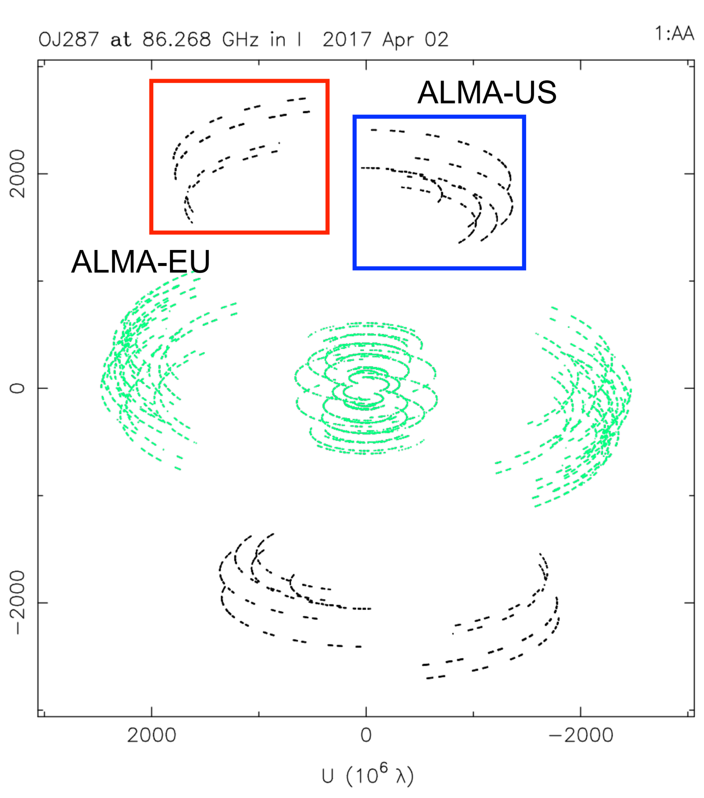
2017 observations: fringe plots for 3C 273 (PI K. Akiyama), see Okino's talk and Okino et al. (in prep.)



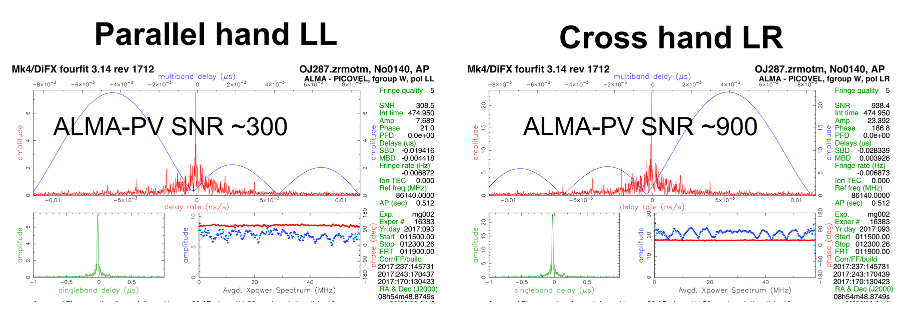
2018 observations: fringe plots for 3C 279 (PI A.P. Lobanov), from the ALMA-Effelsberg baseline.

Testing binary BH model and understanding jet formation in OJ 287

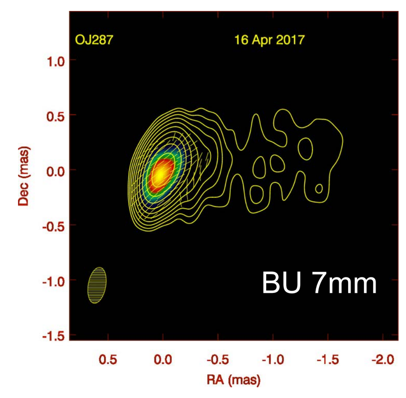
OJ 287 has been suggested as the most promising candidate for hosting a tight super-massive binary black hole system. A large observing campaign is addressing this target (PI J.L. Gómez)

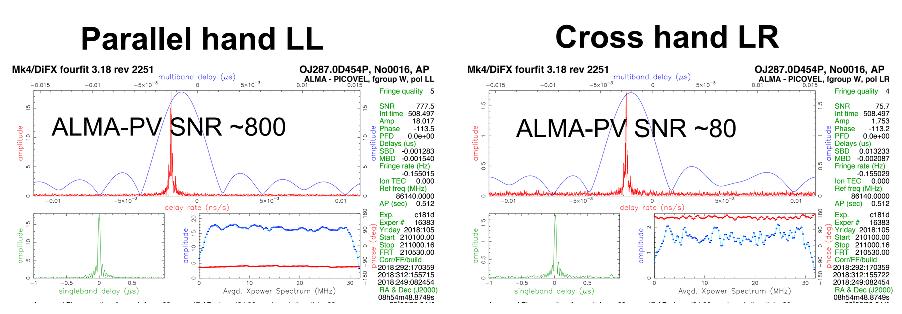


The source, observed on April 2, 2017, showed fringes to ALMA with detection SNR as high as 900. ALMA provides an increase in north-south resolution by a factor of ~4.

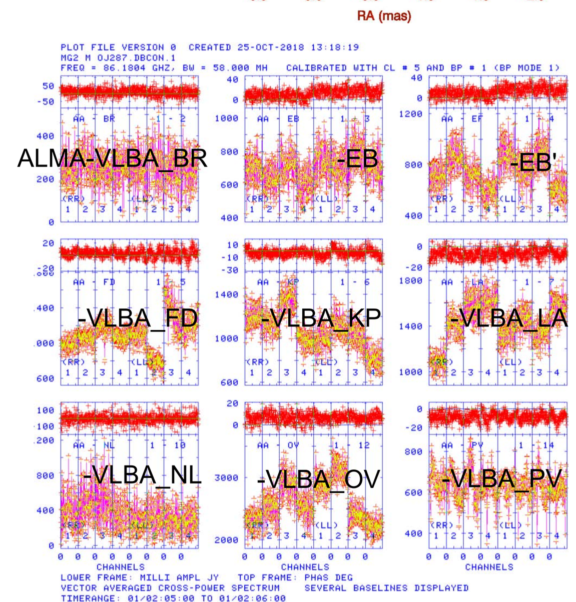


Fringe plots for the 2017 OJ 287 observations.



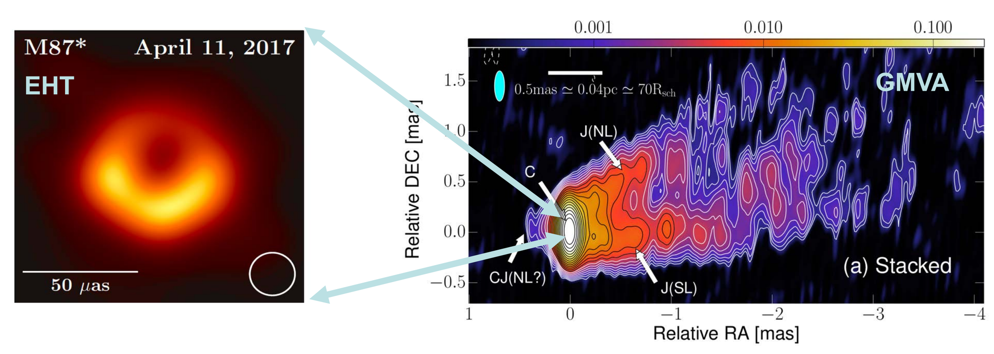


Fringe plots for the 2018 OJ 287 observations.



2017 data: POSSM ($A_{ij}(\nu)$ & $\varphi_{ij}(\nu)$) plot of parallel hands with ALMA – Notice amplitude calibration issues and phase good quality

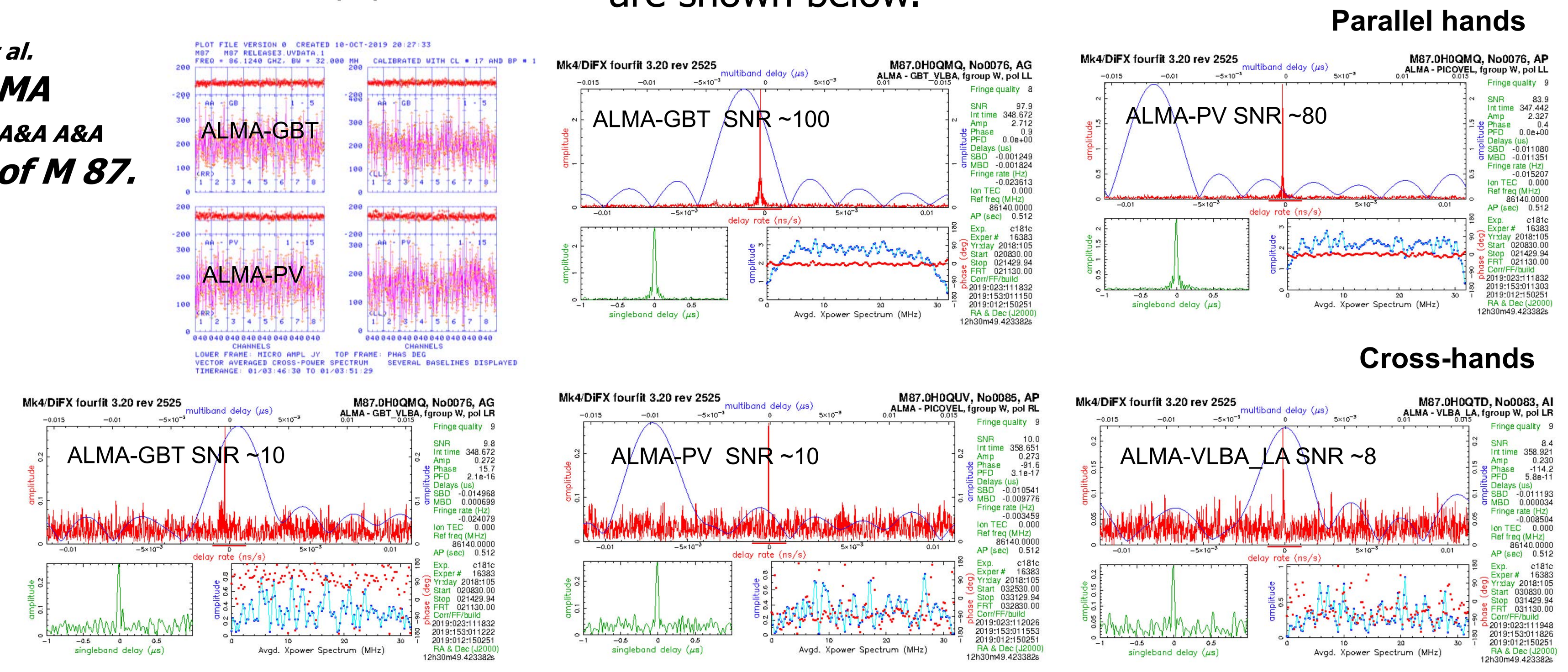
M 87: the jet emerging from the black hole shadow

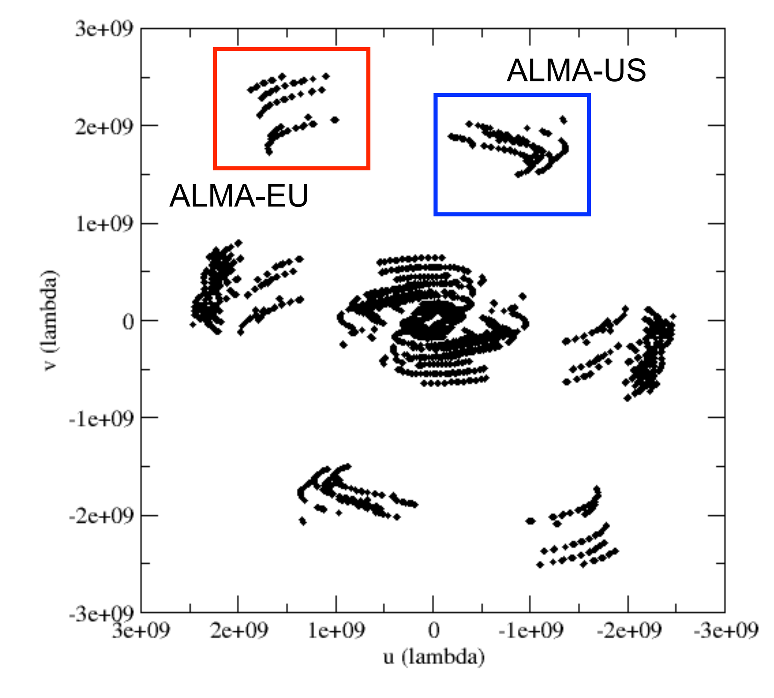


The resolved extended emission in the black hole shadow image of the EHT corresponds to the jet (and possibly also thecounter-jet) in the galaxy, as shown by the GMVA 3 mm images by Kim et al. (2018). The GMVA observations have a far improved *(u,v)* coverage (bottom right) with the inclusion of the north-south ALMA baselines. Preliminary results from 2018 are shown below.

Top: EHT (left; *EHTC et al. ApJ 875, L1****) and pre-ALMA GMVA (right;*** *Kim et al. A&A 616, A188, 2018****) images of M 87.***

Middle and bottom: post-calibration POSSM ($A_{ij}(\nu)$ & $\varphi_{ij}(\nu)$; top, left) and fringe plots (rest) of the GMVA+ALMA observations from April 2018 *(R.S. Lu et al., in prep)*





Acknowledgments

This work makes use of the following ALMA data: ADS/JAO.ALMA#2016.1.01116.V, ADS/JAO.ALMA#2016.1.01216.V, ADS/JAO.ALMA#2017.1.01514.V, ADS/JAO.ALMA#2017.1.00842.V, and ADS/JAO.ALMA#2017.1.00985.V.

The Global Millimeter VLBI Array (GMVA), consists of telescopes operated by the MPIfR, IRAM, Onsala, Metsähovi, Yebes, the KVN, GBT, and the VLBA. The data were correlated at the correlator of the MPIfR in Bonn, Germany. This work made use of the Swinburne University of Technology software correlator, developed as part of the Australian Major National Research Facilities Programme and operated under licence. This study makes use of 43 GHz VLBA data from the VLBA-BU Blazar Monitoring Program, funded by NASA through the Fermi Guest Investigator Program.

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