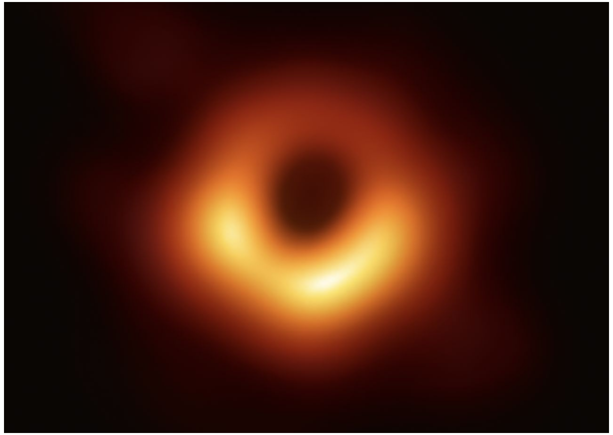
Status of GLT, East Asia VLBI Network-hi (EAVN-hi) observations

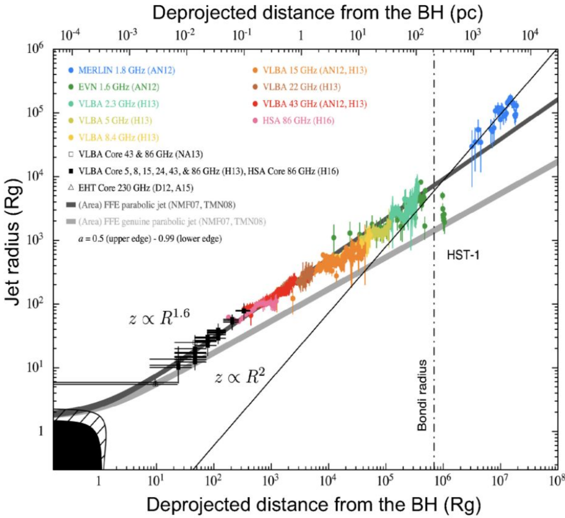
Keiichi Asada (ASIAA)

on behalf of GLT team/EAVN-hi team

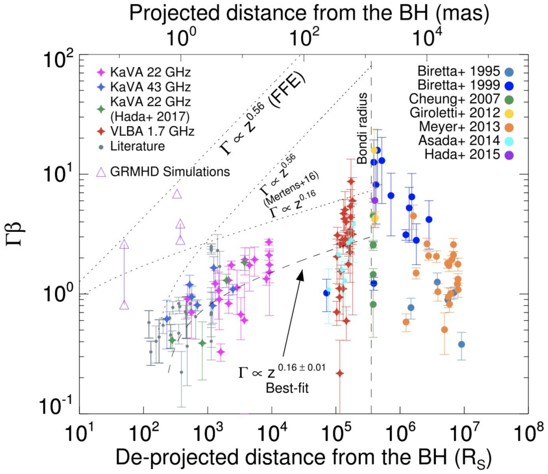
Still remaining issues of EHT observations: M87



EHTC et al. 2019



Nakamura et al. 2018



Park et al. 2019

- Mass (M/D) was determined, but what is the spin of BH?
- Where is the jet?
- Where is the accretion flow?

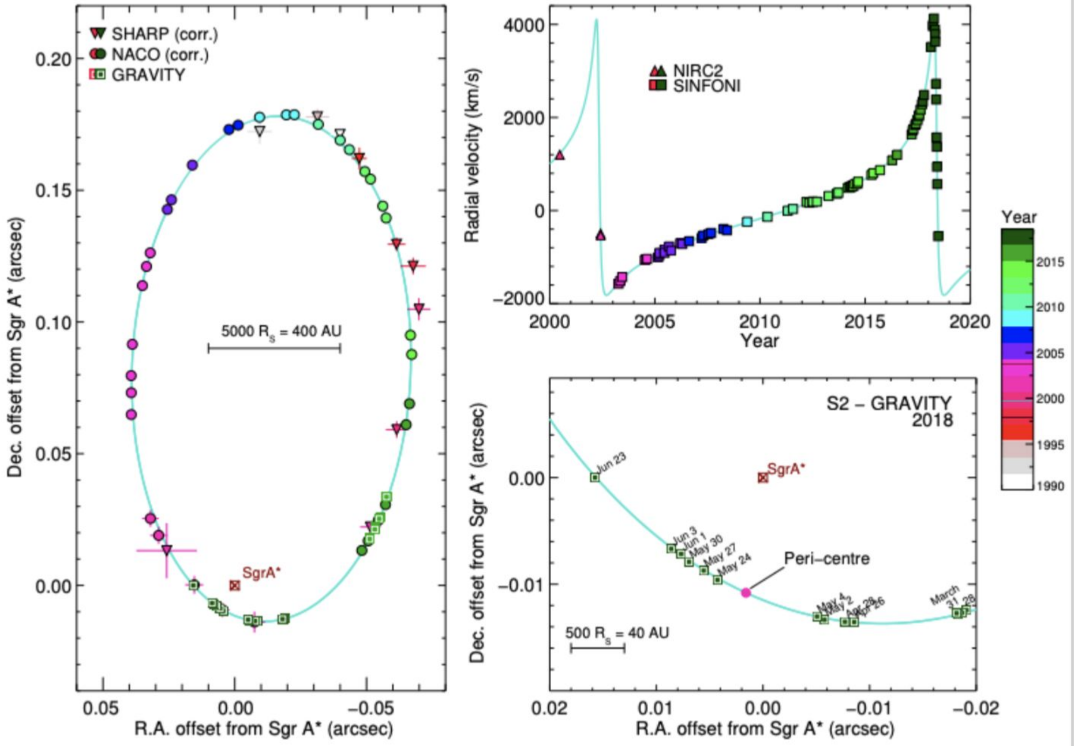
Still remaining issues of EHT observations: Sgr A

Even more where is the results?

Time variations: minutes scale

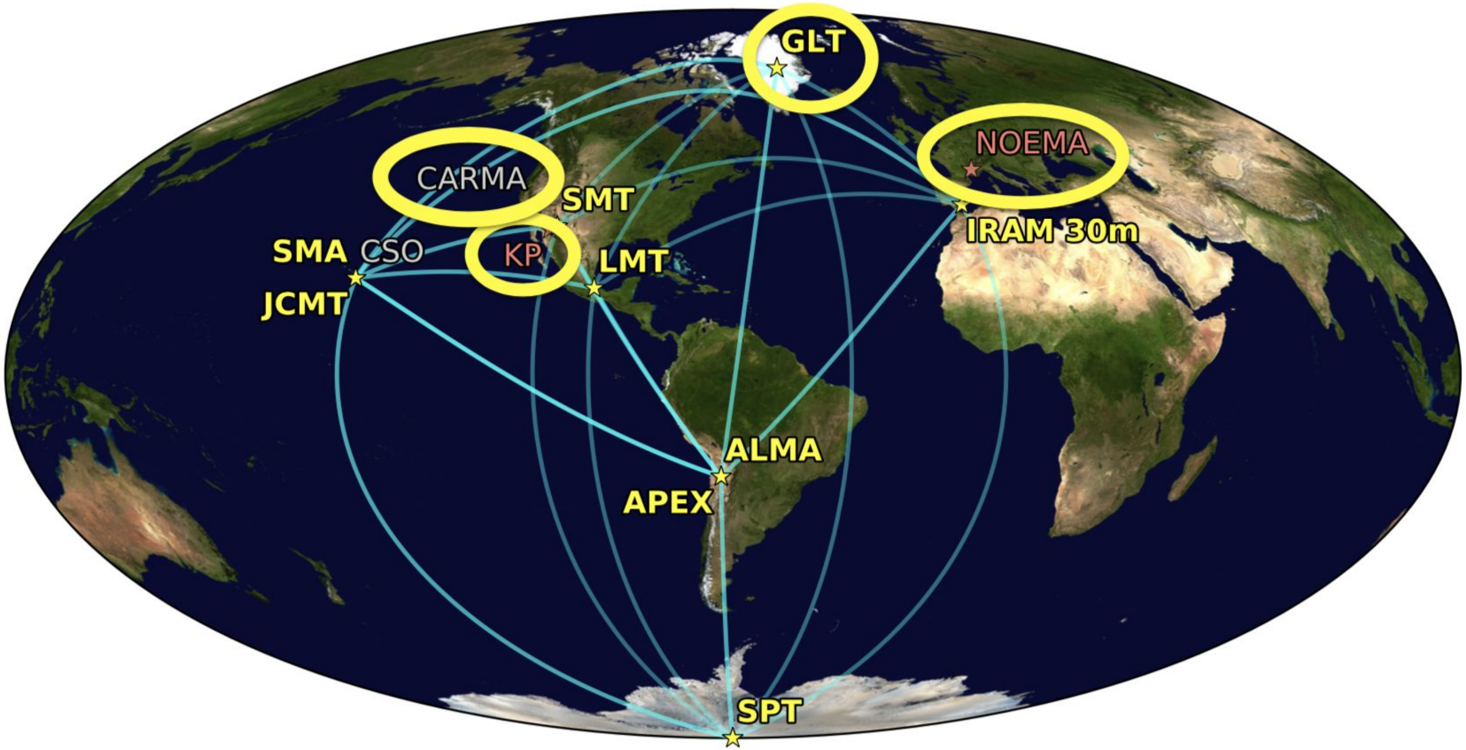
Large Interstellar scattering

We are still working on this....



Gravity collaboration et al. 2018

Scope of current EHT



EHT 2017: observations at 230 GHz with 8 stations at 6 sites
EHT 2023: observations at 230/345 GHz with 12 stations at 10 sites

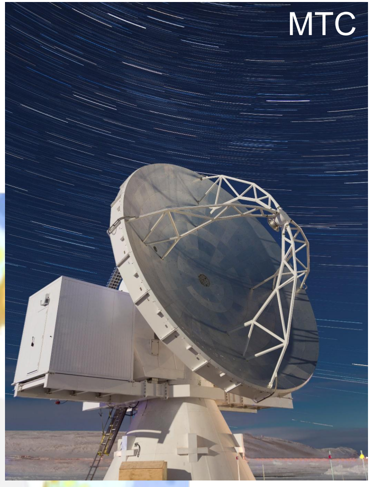
Greenland Telescope Project

GLT Phase 1:

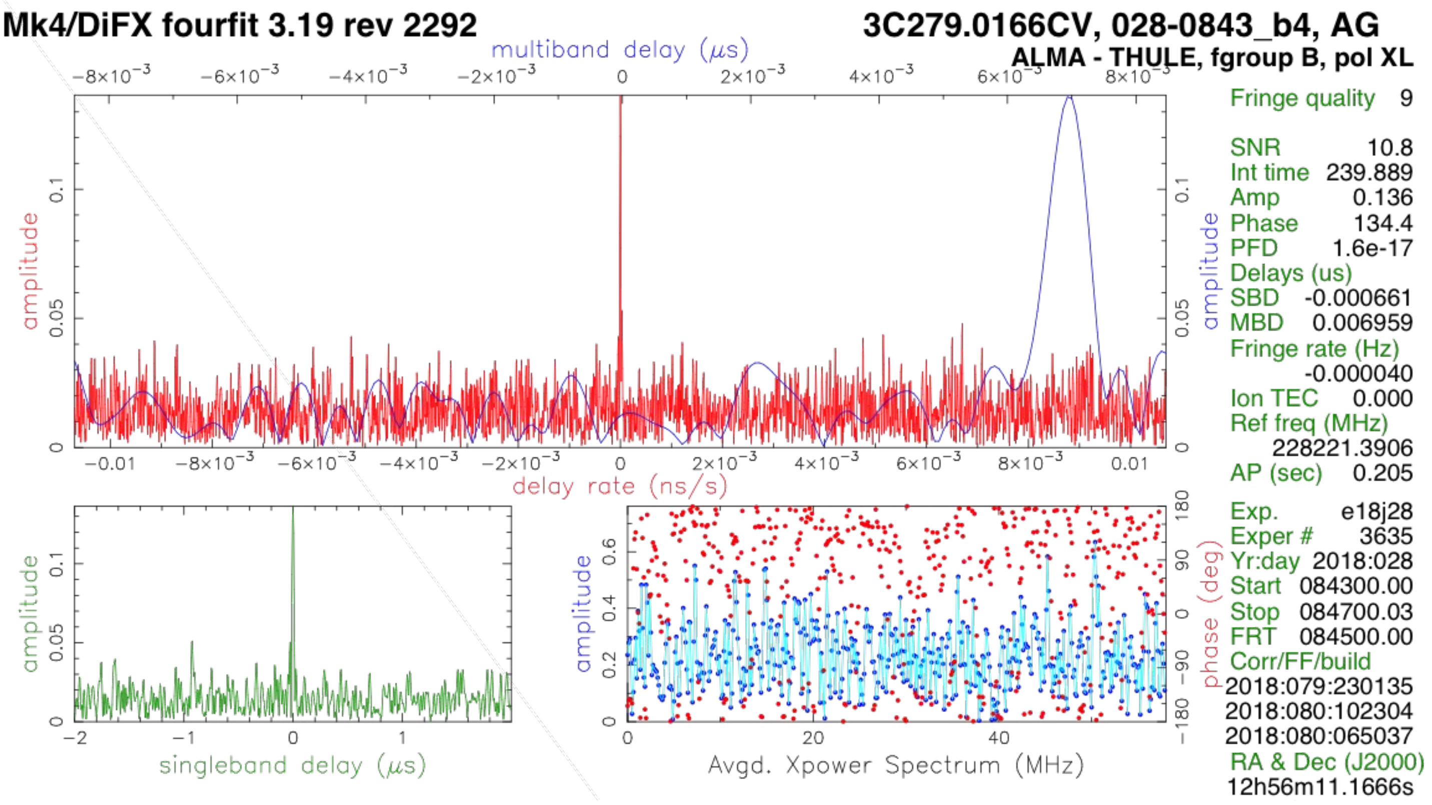
- Establish mm/submm VLBI station at Thule Air force Base in Greenland.
  Primary objective: demonstrate VLBI at 86/230 GHz

GLT Phase 2:

- Establish mm/submm VLBI station at Summit on Greenland Ice Cap.
  Primary Objectives: VLBI at 86/230 GHz and higher
  (sub-)/THz single dish sciences



GLT has been participating in EHT/GMVA observations

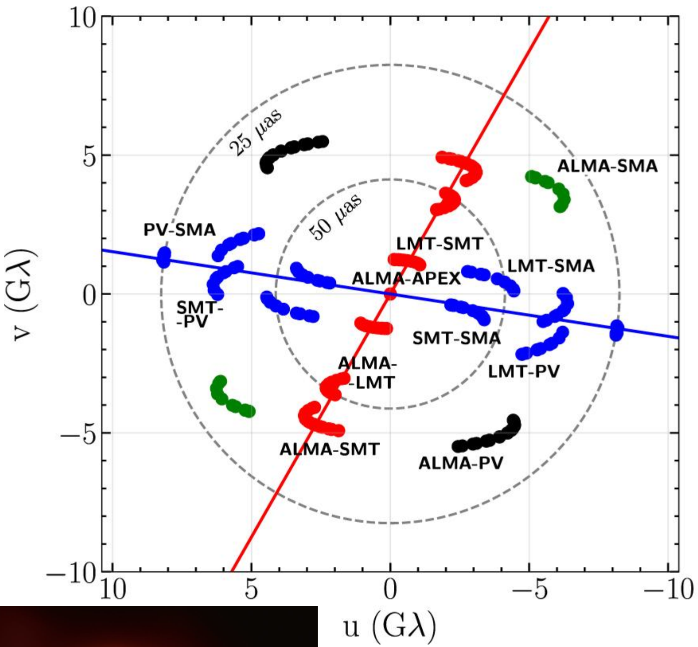


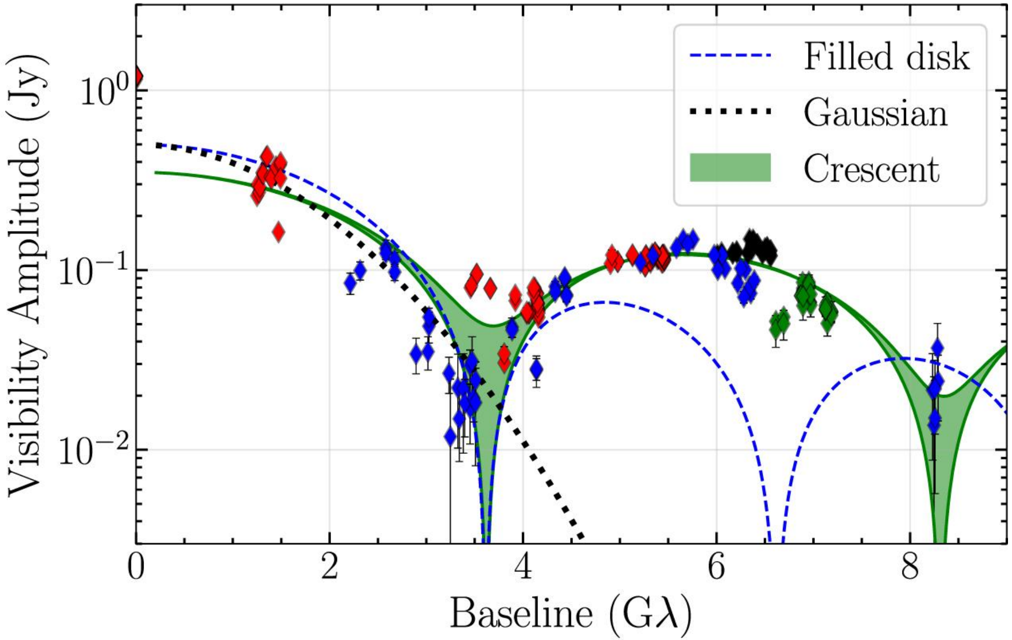
GLT has been participating in EHT/GMVA observations

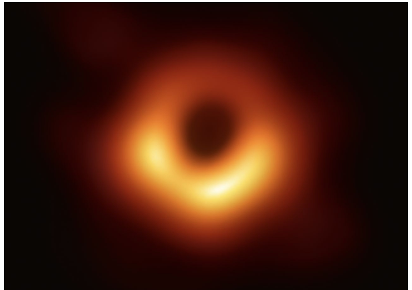
Date	Array	Freq.	Note	results
2018 Jan.	EHT	230	Fringe test	Fringe, low sensitivity (η~25%?)
2018 Feb.	EB, Yb, PV	86/(230)	Fringe test	Missing one module
2018 Mar.	GMVA	86	Science run	Fringe, dual linear polarization
2018 Apr.	EHT	230	Science run	Fringe, low sensitivity (η~25%?)
2018 Sep.	GMVA	86	Science run	Fringe, dual linear polarization
2018 Oct.	EHT	345/230	Fringe test	No Fringe
2019 Jan.	EHT	230	Fringe test	Fringe
2019 Mar.	EAVN -hi-	230	Fringe test	No Fringe
2019 Mar.	EHT	230	Science run	Canceled
2019 Apr.	GMVA	86	Science run	Fringe
2019 Sep.	GMVA	86	Science run	Fringe
2020 Jan.	EHT	230	Fringe test	Fringe
2020 Feb.	EAVN -hi-	230	Fringe test	Fringe

Inclusion of GLT in EHT

EHTC et al. 2019



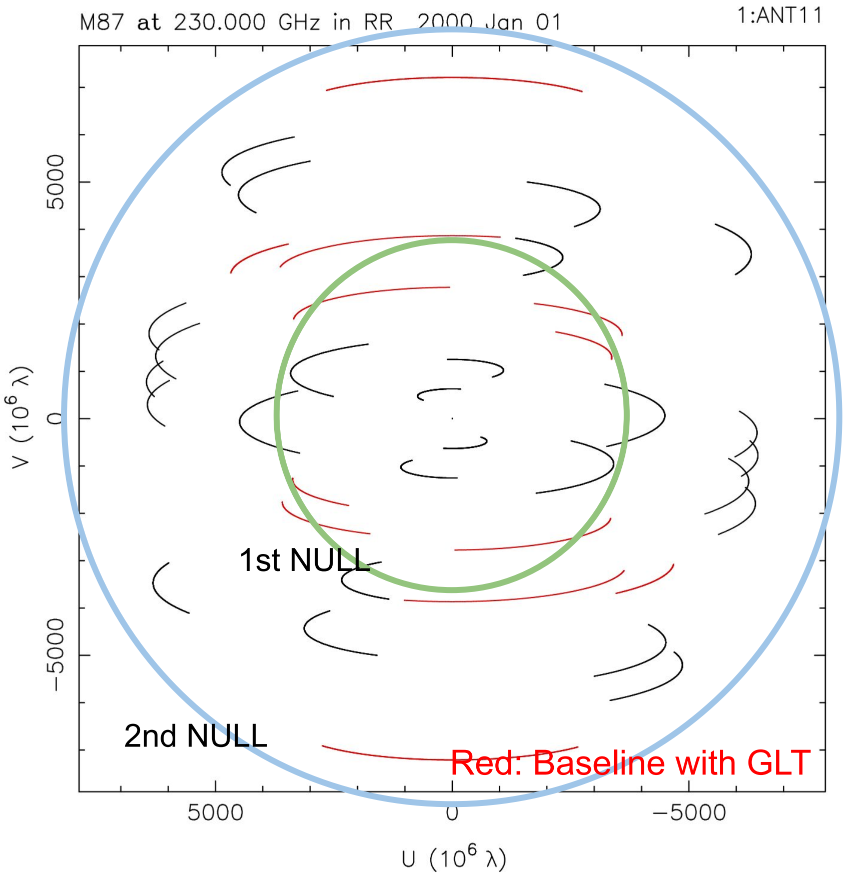


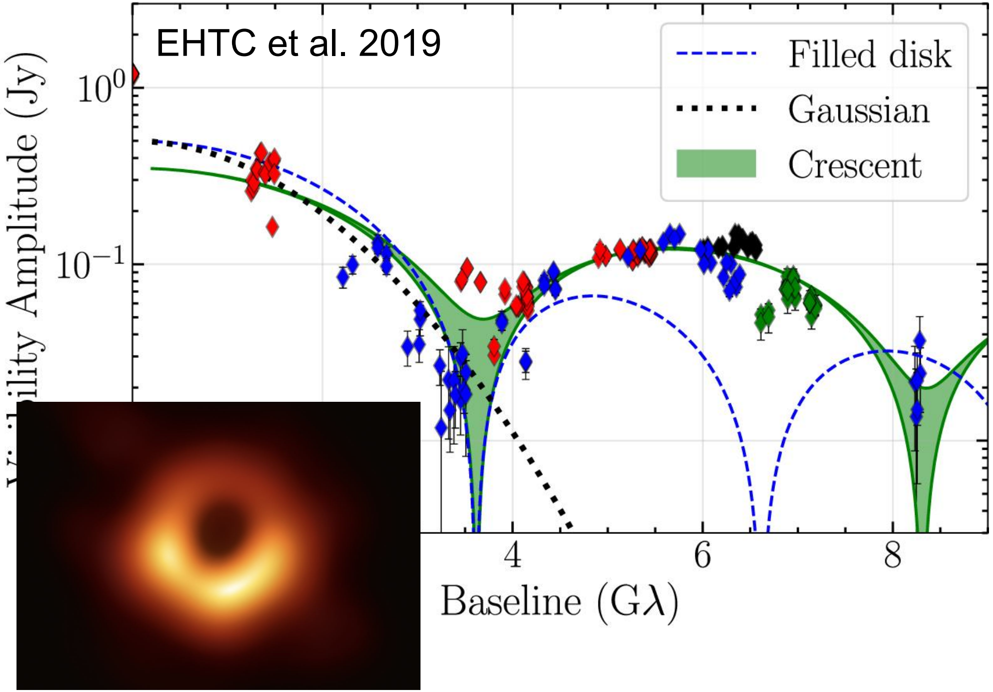


East-West: Deeper null (blue) indicates symmetric structure

North-South: Shallower null (red) indicates asymmetric structure

Inclusion of GLT in EHT





GLT baselines will nicely cover the 1st NULL, which will give us unique opportunity to probe asymmetry.

Important information on BH spin.

Inclusion of GLT in GMVA with ALMA

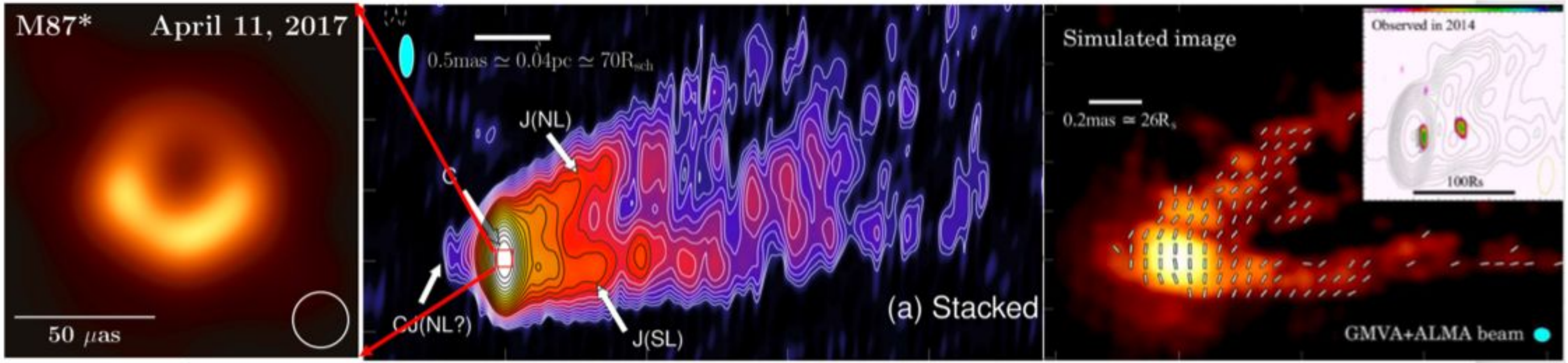
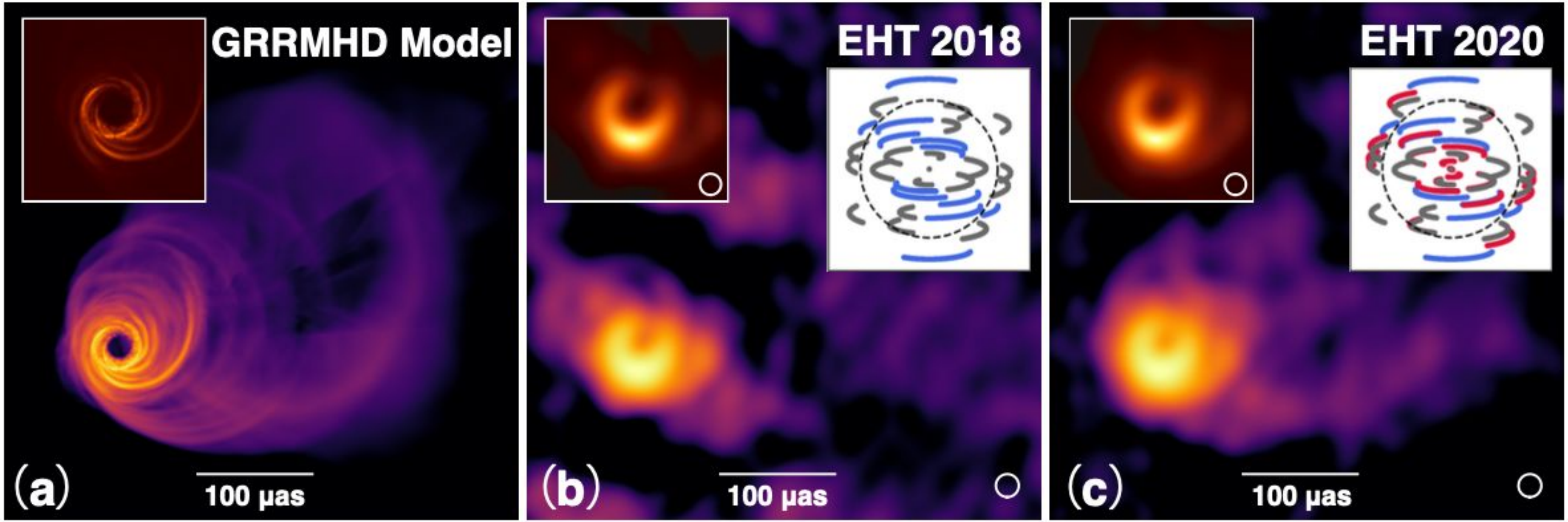


Figure 1: *Left: Image of the BH shadow in M87 obtained at 1.3 mm by the EHT collaboration+ 2019. Middle: Stacked GMVA-only 3.5 mm image (Kim+ 2018). Right: Simulated GMVA+ALMA image with the inset showing a real VLBA+GBT 3.5 mm polarization map (Hada+ 2016). In the inset the polarized intensity is color coded, ticks mark the EVPAs. We note that for optically thin emission, the EVPAs are orthogonal to the B-field direction.*

From GMVA+ALMA proposal in 2020: Lu et al.

EHT2021

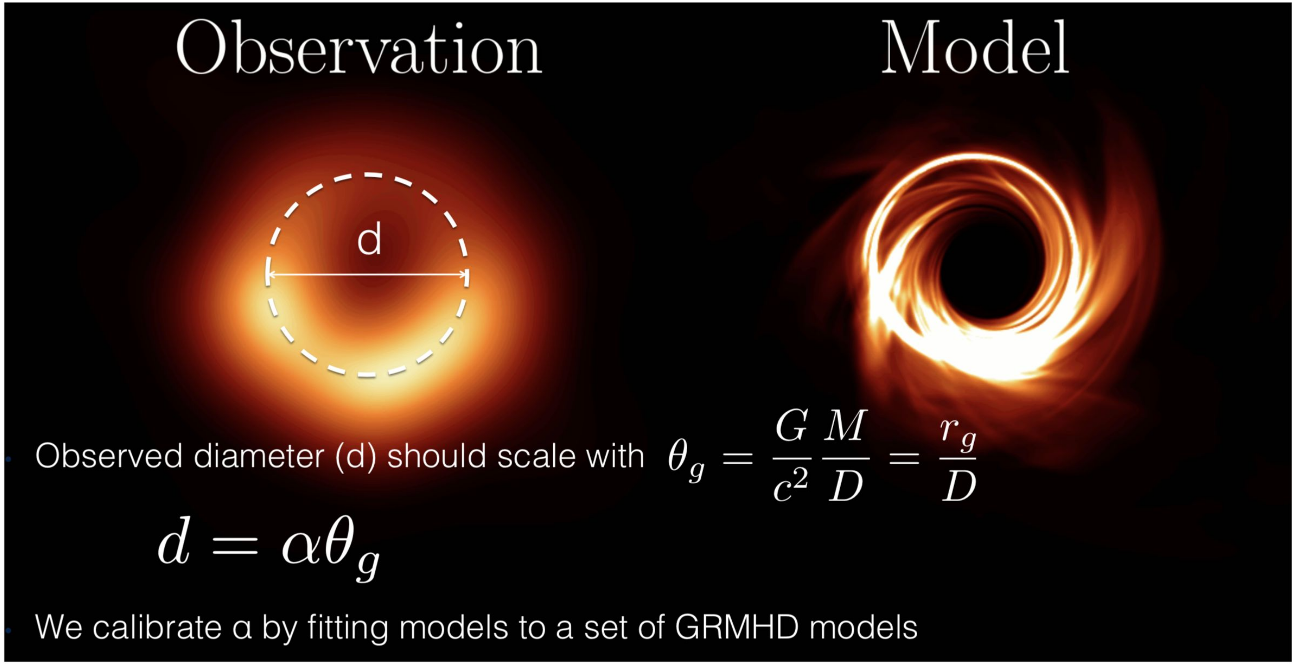
From EHT+ALMA proposal in CY7



From 2021, we expect that we will be able to recover the extended structure (jet emission) by inclusion of KP and NOEMA, those provide short baselines

Remaining Issues of EHT observations

EHTC



Observed ring = photon ring (GR) + accretion flow/jet (gastrophysics)

Separation between gastrophysics and GR test is difficult due to limited resolution

GR studies with direct imaging at event horizon scale

There are two directions:

1. Precious determination of the photon rings
2. Test using jet and accretion flow physics with ultra-deep understanding of those phenomena

We want to have array which has

(1) higher angular resolution

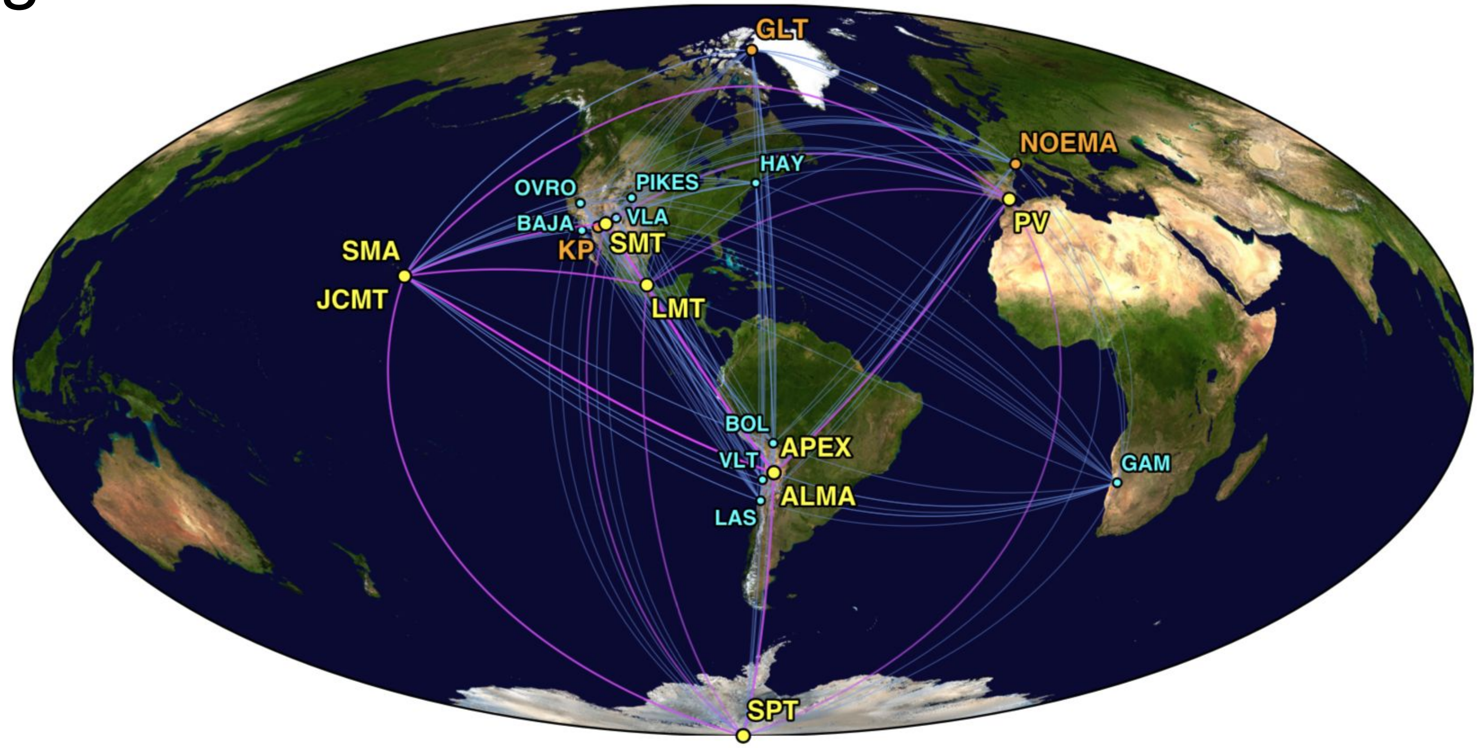
► High freq. and/or longer baseline

(2) capability to take snapshot images with high dynamic range

► More stations / More cadences

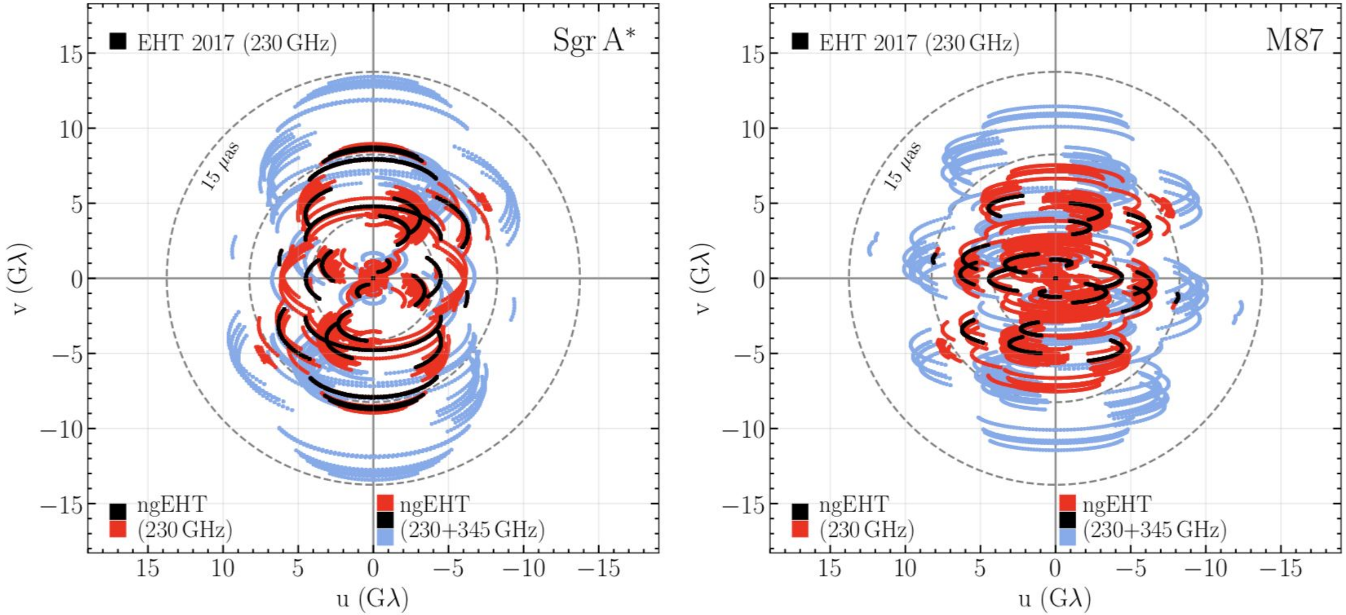
US Astro2020 WP: blackburn et al. 2020

ngEHT



Distribute 3m-dishes at additional 9 sites for better spontaneous uv coverage
2019-2023: Phase I (design phase), 2023 Phase II (production phase)

ngEHT



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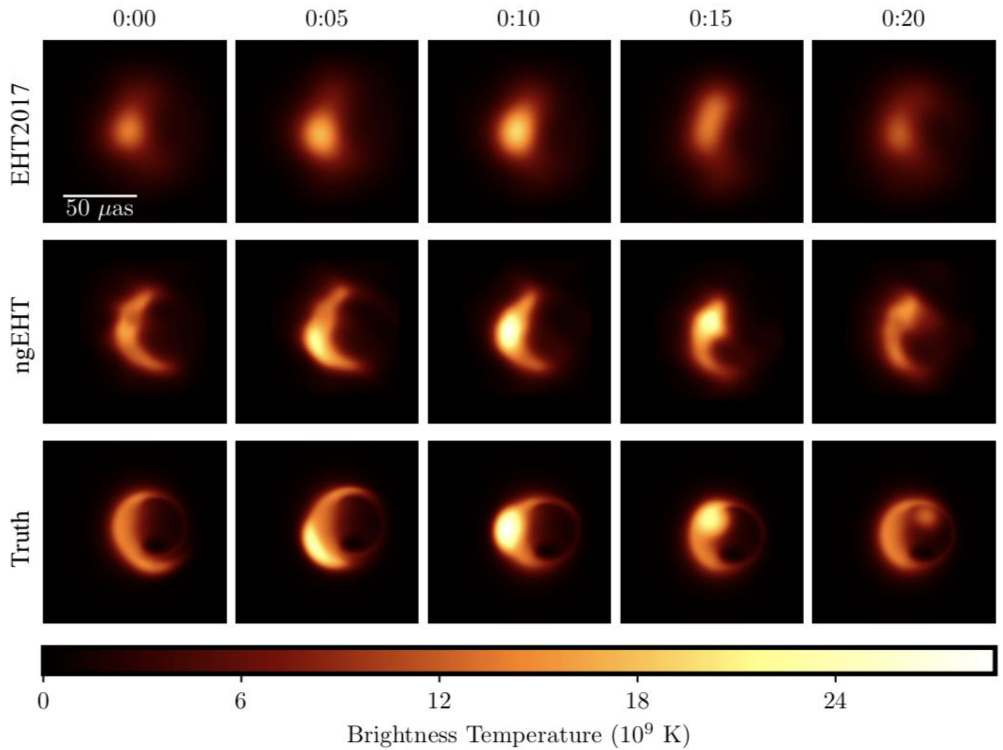
ngEHT



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Expansion to space VLBI

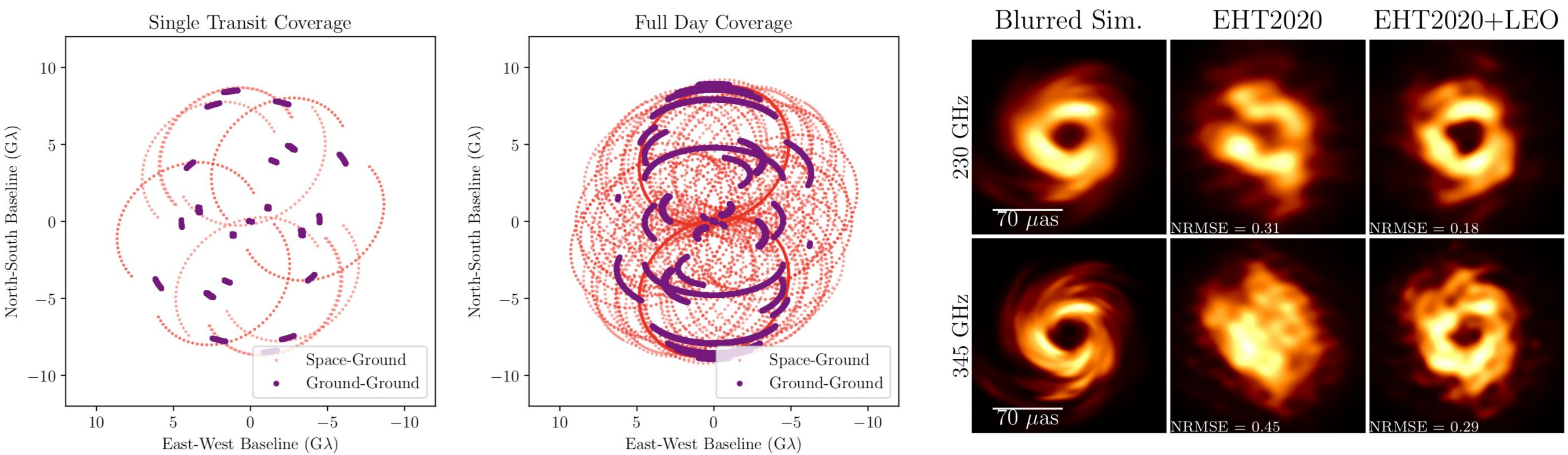
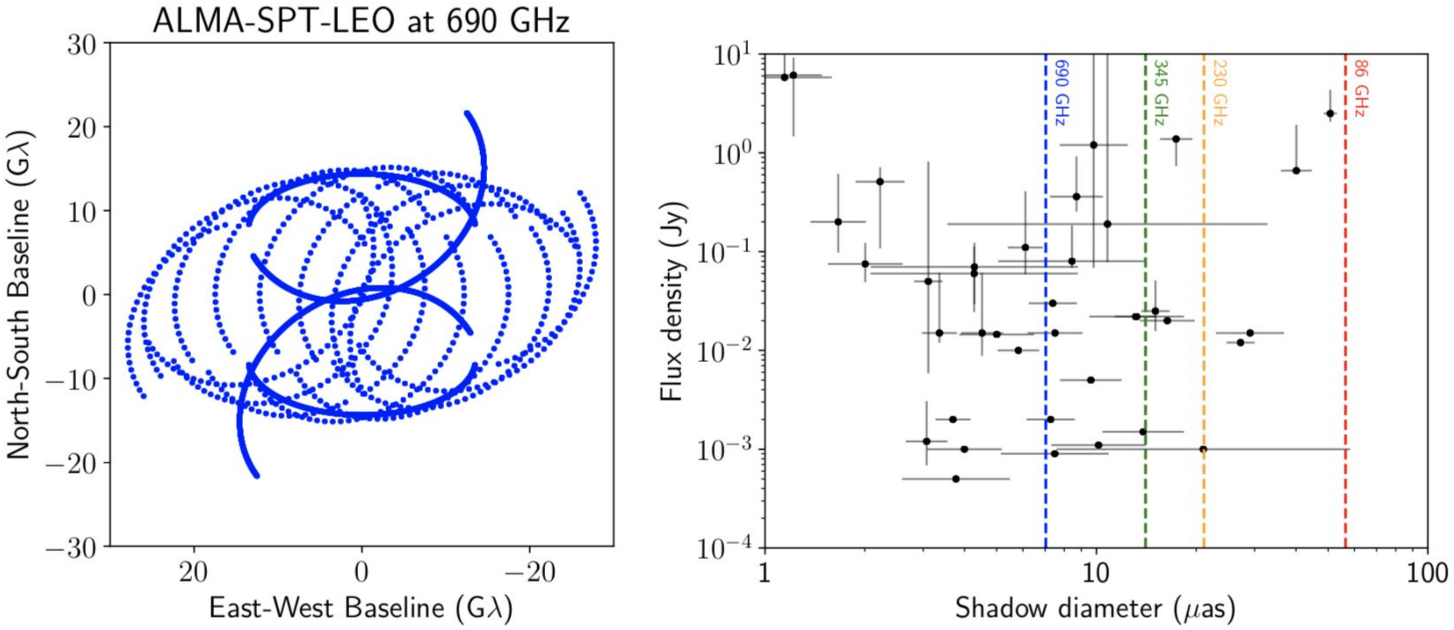


Figure 1: Left: 230 GHz baseline coverage of Sgr A* of the EHT2020 array with and without a polar LEO over 45 minutes. Right: Same as left, over a full day. In both cases, the addition of the polar LEO dramatically improves the baseline coverage.

Still pre-study phase

US Astro2020 WP: Haworth et al. 2020

Expansion to space VLBI



Still pre-study phase

Idea for direction

(1) higher angular resolution

► High freq. (up to 690 GHz or more?) and/or longer baseline (including space VLBI)

(2) capability to take snapshot images

► More stations with small dish size (3 m?)

1. New telescope should be able to provide mutual visibilities

2. Should be able to high. Frequency (Frequency Phase Transfer should be considered)

3. Sufficient sensitivities with small dish, like (pALMA, NOEMA, LMT)

East ASIA VLBI Network Observations at 230 GHz

Two important directions for mm/submm VLBI community in EA

a). Participate/contribute to global efforts (e.g., EHT and GMVA)

KVN participate GMVA
JCMT is one of the initial stations of EHT
GLT started to participate EHT and GMVA from 2018

EHT/GMVA+ALMA proposals: Koyama+:Mrk501, Kino+:Cyg A, Lu+/Kim+: M87

b). Do unique things as (regional) efforts

KVN is unique VLBI array observable at 86 and 129 GHz with FPT
NRO45m at 86 GHz led by Imai-san and Niinuma-san
We (will) have JCMT and GLT at (86) and 230 GHz

EAVN at 86 GHz, 230 GHz and even higher?

EA mm/submm White Paper

White Paper on East Asian Vision for mm/submm VLBI: Toward Black Hole Astrophysics down to Angular Resolution of 1 R_S

Editors

Asada, K.[1], Kino, M.[2,3], Honma, M.[3], Hirota, T.[3], Lu, R.-S.[4,5], Inoue, M.[1], Sohn, B.-W.[2,6], Shen, Z.-Q.[4], and Ho, P. T. P.[1,7]

Authors

Akiyama, K.[3,8], Algaba, J-C.[2], An, T.[4], Bower, G.[1], Byun, D-Y.[2], Dodson, R.[9], Doi, A.[10], Edwards, P.G.[11], Fujisawa, K.[12], Gu, M-F.[4], Hada, K.[3], Hagiwara, Y.[13], Jaroenjittichai, P.[15], Jung, T.[2,6], Kawashima, T.[3], Koyama, S.[1,5], Lee, S-S.[2], Matsushita, S.[1], Nagai, H.[3], Nakamura, M.[1], Niinuma, K.[12], Phillips, C.[11], Park, J-H.[15], Pu, H-Y.[1], Ro, H-W.[2,6], Stevens, J.[11], Trippe, S.[15], Wajima, K.[2], Zhao, G-Y.[2]

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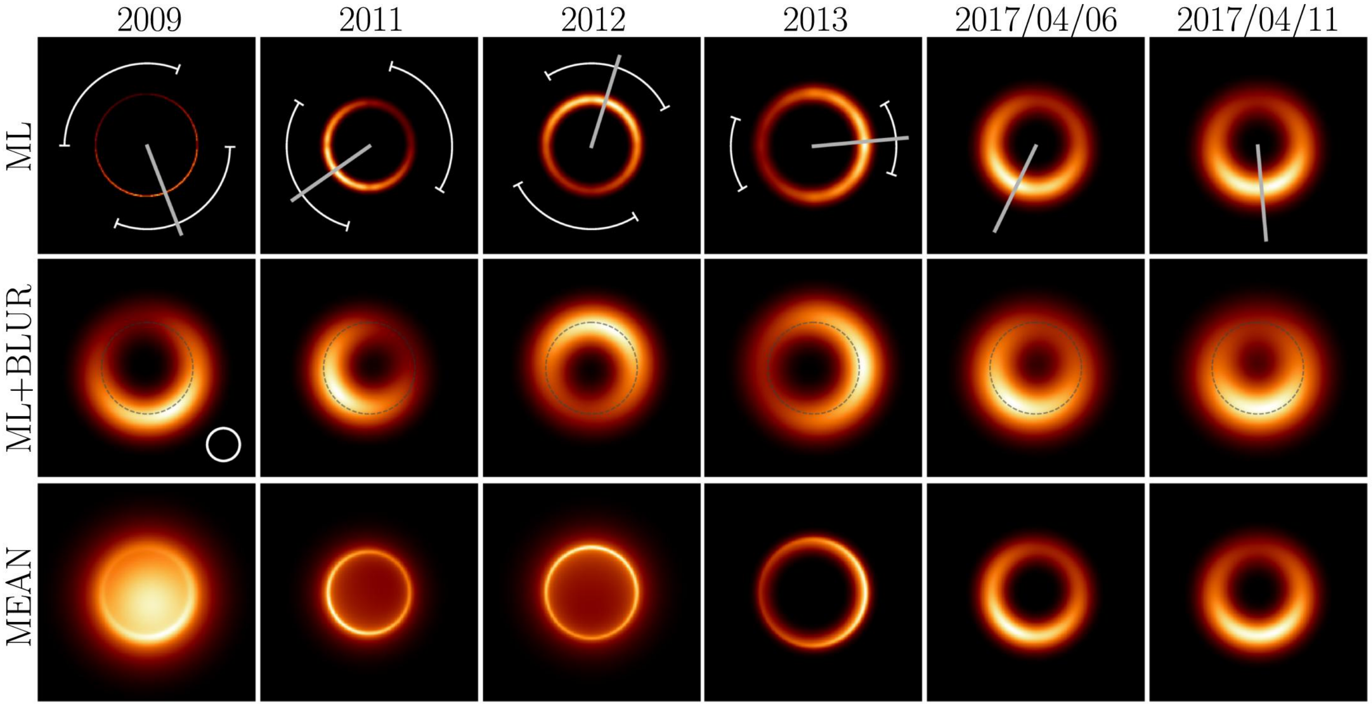
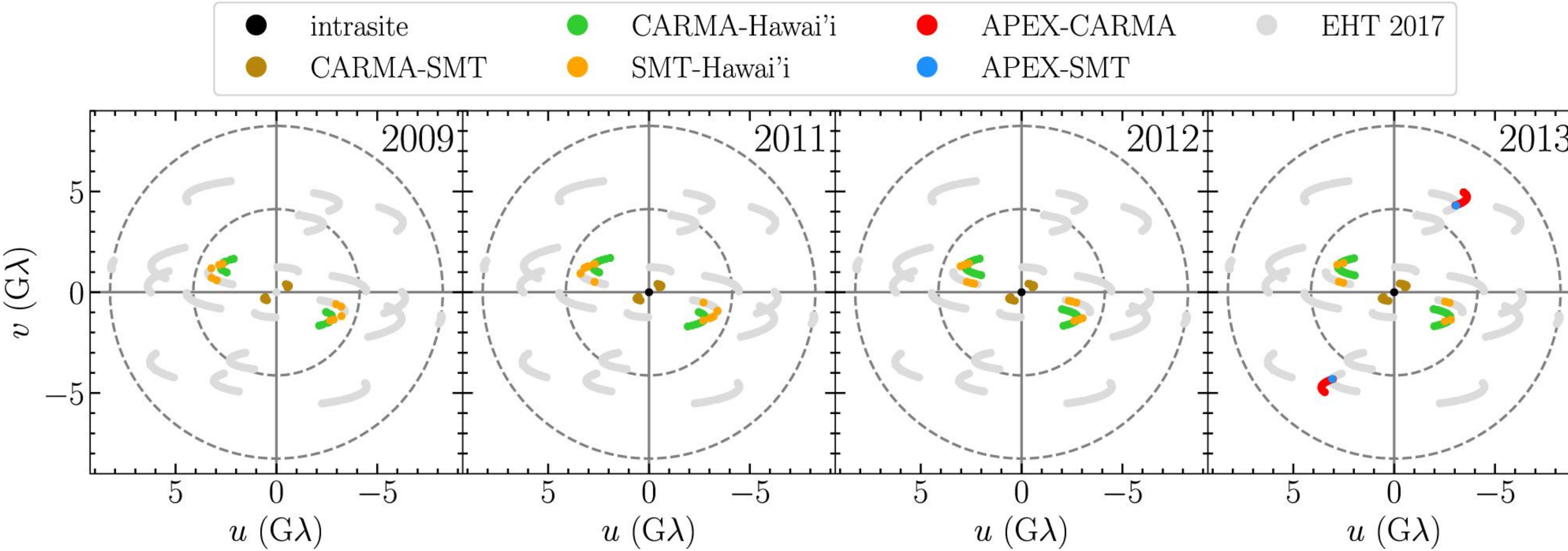
Wobbling Shadow



Asymmetric ~ 40-uas rings at different position angles

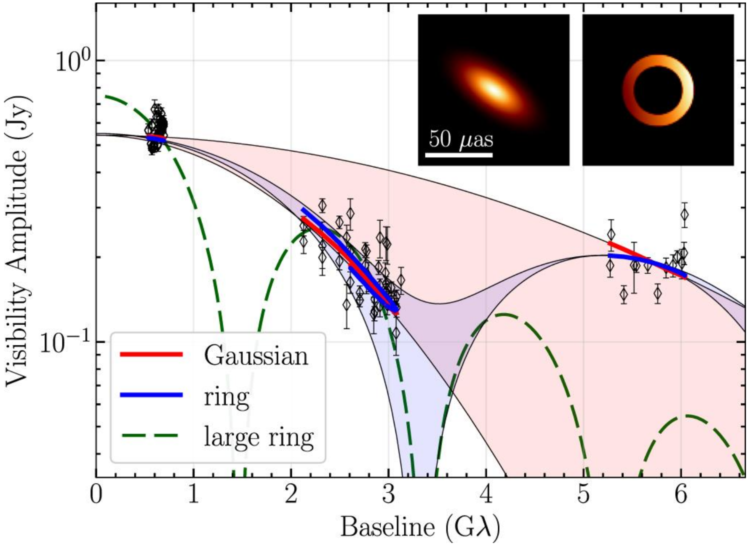
Wielgus et al. 2020

Wobbling Shadow



Wielgus et al. 2020

Wobbling Shadow



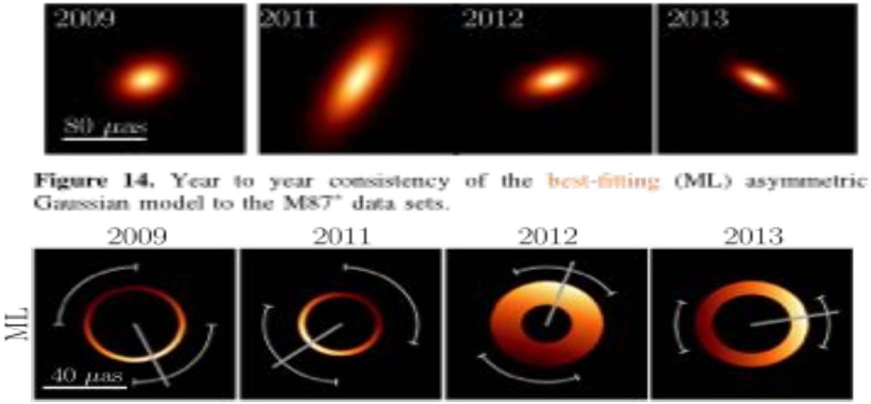
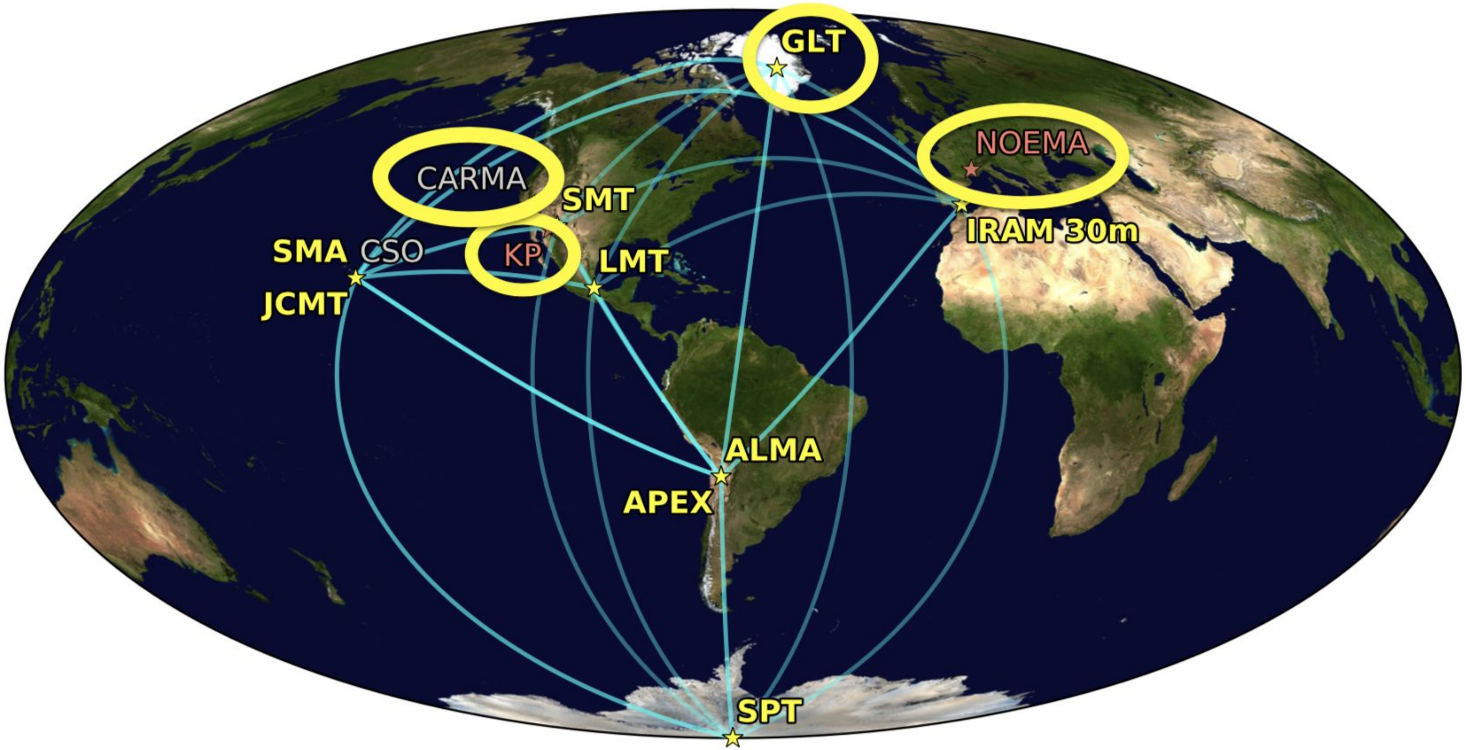


Figure 14. Year to year consistency of the best-fitting (ML) asymmetric Gaussian model to the M87* data sets.

Wielgus et al. 2020

Two possibilities are degenerated: asymmetric ring vs asymmetric Gaussian
This is very difficult to distinguish them with visibility amplitude,
but should be easy with visibility phase.
But visibility phase is not reliable measurements for VLBI so that we need closer phase

Scope of current EHT



EHT 2017: observations at 230 GHz with 8 stations at 6 sites
EHT 2023: observations at 230/345 GHz with 12 stations at 10 sites

Further Possible expansion

Table 2: Current and planned stations for 1.3 mm VLBI. EA contributions are shown in bold.

Stations	Location	Diameter [m]	SEFD [Jy]	Status
ALMA 37	Chile	37×12	100	2017 -
APEX	Chile	12	3600	operational
GLT	Greenland	12	7800	2018 (planned)
IRAM 30m	Spain	30	1400	operational
JCMT	Hawaii	15	4700	operational
LMT	Mexico	32	1400	operational
NOEMA	France	15	5200	operational
SMA	Hawaii	8×6	4000	operational
SMT	Arizona	10	11000	operational
SPART	Japan	10	10000	2018? (planned)
SPT	South Pole	10	9000	operational
SRAO	Korea	6	40000	2018? (planned)

1. the EKVN as a new EA 230GHz station will be available from 2024
2. Balloon - Borne VLBI led by ISAS/JAXA?
3. Re-activate ASTE for VLBI ?
4. Seek the process to use ACA ?

Fringes test at 230 GHz with EA stations

1. JCMT became stand alone station under EAO

2. GLT has fully participated EHT/GMVA observations since 2018.

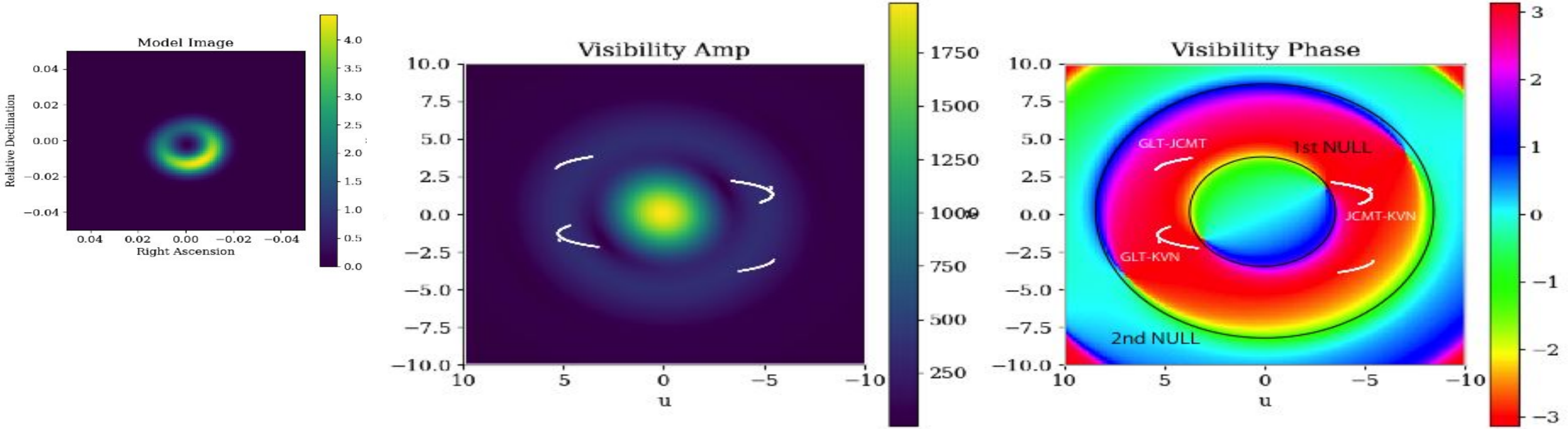
3. SPART experiments have already demonstrated mm-VLBI feasibility of SPART telescope

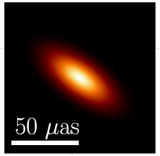
We are ready to start regional coherent efforts to form
230/(86 GHz) array

System Setup

	GLT	JCMT	KVN Ys	SRAO	SPART
Diameter [m]	12	15	21	6	10
SEFD [Jy]	4 900	4 500		78 000	18 000
Start Freq. [GHz]	230.200	230.200	230.200	230.200	230.200
Bandwidth [MHz]	2 048	2 048	2 048	1 024	512
Polarization	Dual circular	Dual circular	Dual circular	Dual circular	Single linear
Recorder	R2DBE Mark6	R2DBE Mark6	R2DBE Mark6	R2DBE Mark6	ADS3000+ OCTAVE

With JCMT-GLT-SRAO/SPART/KVN





Closure phase ~ 0

Closure phase ~ 180

- We will uniquely determine the ring parameter with non-zero CP
- Evenmore, succeeded, we can do high cadence observations

GLT

Observations ~ -30 degree

- ALMA-NA prototype 12 m

- 3 receivers (86, 230 and 345 GHz)

- 64 Gbps system with
  4 x Mark6 + 4 x R2DBE

- Phase stability test for receiver with tone injection
  before and after the observations

  ASD ~ 10^{-14} @ 1 sec

- Monitoring reference signal with respect to OCXO

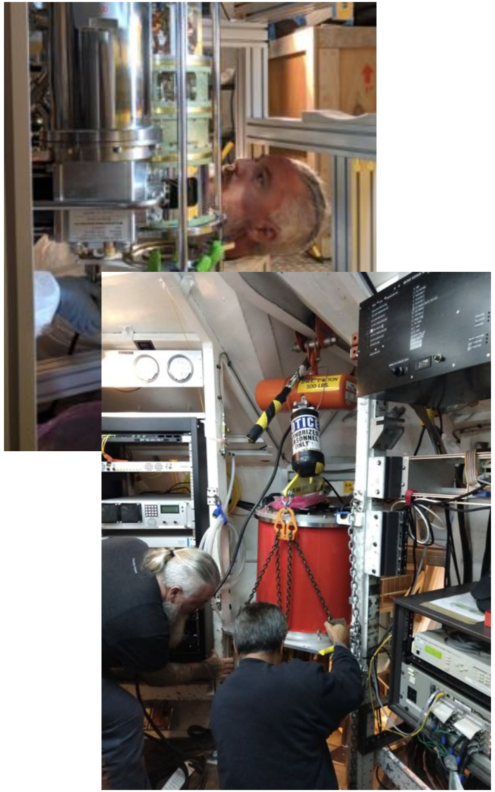
  ASD ~ 10^{-13} @ 1 - 10 sec

- Detection of Fringe for GMVA campaign 2019
  (just after the EAVN -hi-)

  Stability should be fine for GLT

JCMT preparations

Receiver Install



Cabling

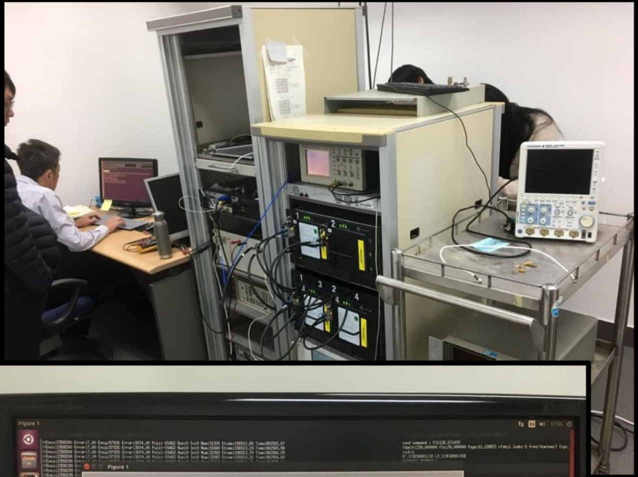
Software developments

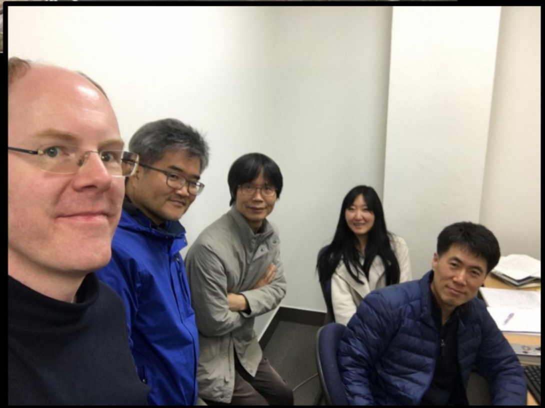
Mirror Adjustment

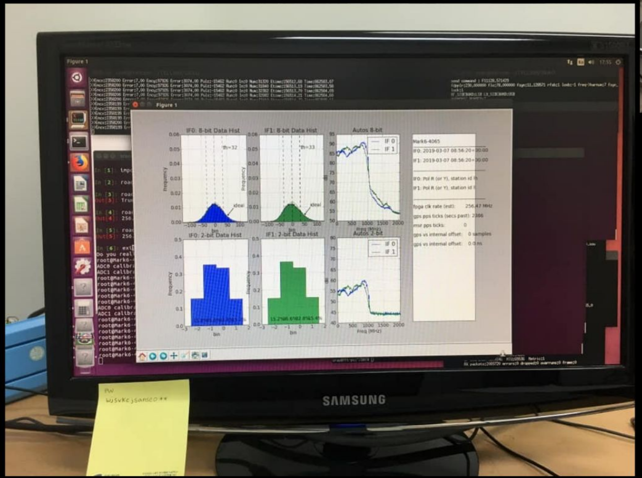
Measurements

SPART Preparation

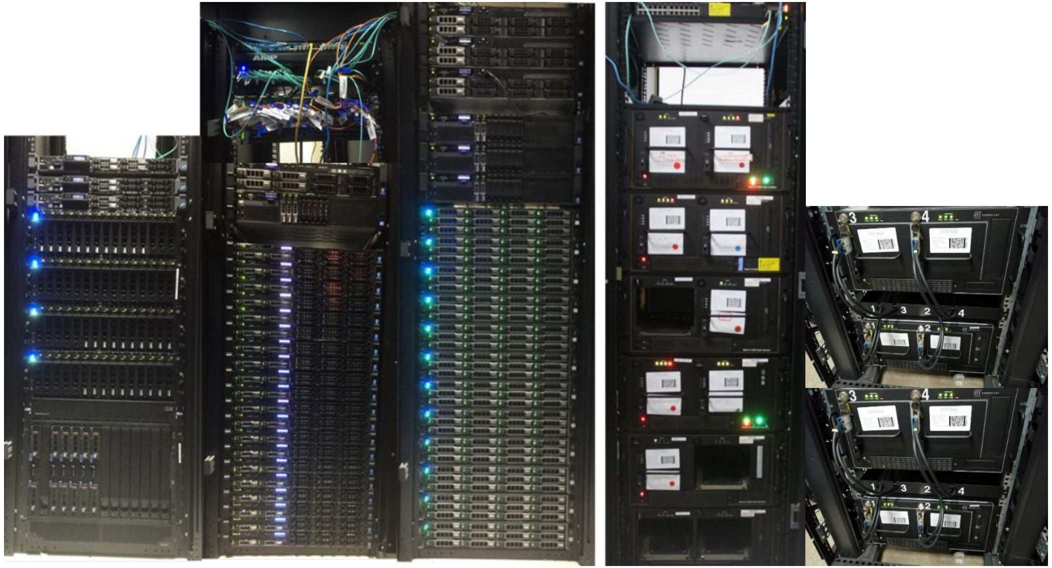
First VLBI run with SRAO
March 18+19, 2019







Correlator	DiFX-**2.6.1**
Post processing	HOPS-**3.20**



SHAO DiFX correlator

The 1st and 2nd EAVN -hi- test observations

Date: 2019 Mar. 18, 19

Duration: UT11-18, 7 h each day

Stations:

GLT-12m, SPART-10m, SNRAO-6m

Sources: M87, 3C345, 1633+382, 3C371, 1928+738, N6251, Mrk501,

CO2-1 sources for verification purpose

Weather: Cloudy (SPART),Cloudy (SRAO), Fine (GLT)

Date: 2020 Feb. 1st, 5th

Duration: UT8-15, 7 h each day

Stations:

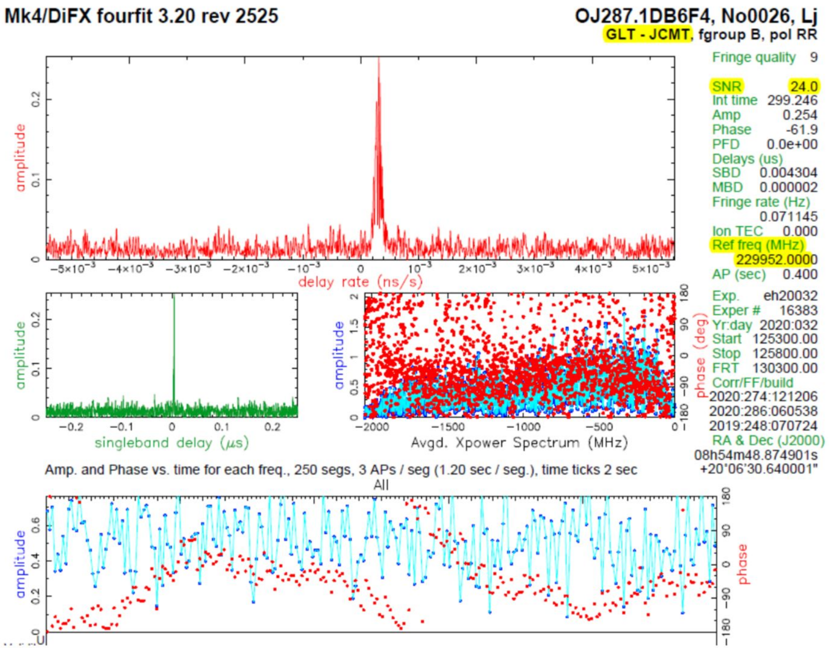
GLT-12m, JCMT-15m, SRAO-6m (only for the first epoch)

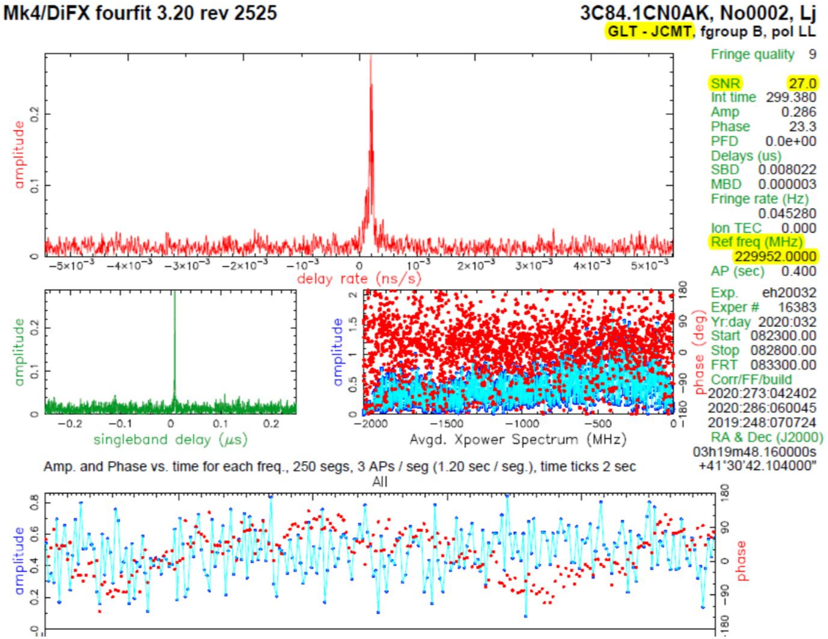
Sources: 3C 84 and OJ 287

CO2-1 sources for verification purpose

Weather: Cloudy (SRAO), Fine (GLT, JCMT)

The first fringes at 2nd epoch of observations





Fringes between JCMT and GLT were detected both for 3C 84 and OJ 287

Plan for this year

We plan to have observations with GLT-JCMT-KVN Ys

(1) verification and test observations to detect the fringes/closures phase towards M87
with three station experiments at 230 GHz
(2) VLBI fringe detection survey for northern sky
(~10-30 sources including BL Lac, 3C279/3C273, 3C454.3)
(3) Initiation of monitoring program towards several unique objects
(including 3C84, 3C 120, OJ287, Mrk 421 and Mrk 501)

(4) the first test observation at 345 GHz between GLT and JCMT

(5) possibly demonstration of VLBI observations at 86 GHz

Summary

- GLT has been fully participated to EHT and GMVA
- East Asia VLBI Network at 86 and 230 GHz activities are initiated
- The first fringe with EAVN hi were detected !!
- Plan to make more observations with EAVN hi