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

- 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

<table>
<thead>
<tr>
<th>Date</th>
<th>Array</th>
<th>Freq.</th>
<th>Note</th>
<th>results</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018 Jan.</td>
<td>EHT</td>
<td>230</td>
<td>Fringe test</td>
<td>Fringe, low sensitivity ($\eta \approx 25%$?)</td>
</tr>
<tr>
<td>2018 Feb.</td>
<td>EB, Yb, PV</td>
<td>86/(230)</td>
<td>Fringe test</td>
<td>Missing one module</td>
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<tr>
<td>2018 Mar.</td>
<td>GMVA</td>
<td>86</td>
<td>Science run</td>
<td>Fringe, dual linear polarization</td>
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</tr>
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<td>2018 Oct.</td>
<td>EHT</td>
<td>345/230</td>
<td>Fringe test</td>
<td>No Fringe</td>
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<td>EHT</td>
<td>230</td>
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<td>Fringe</td>
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<td>Fringe test</td>
<td>No Fringe</td>
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<td>2019 Mar.</td>
<td>EHT</td>
<td>230</td>
<td>Science run</td>
<td>Canceled</td>
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<td>2019 Apr.</td>
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<td>86</td>
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<td>Fringe</td>
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Inclusion of GLT in EHT

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.
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

- Observed diameter \( d \) should scale with \( \theta_g = \frac{G M}{c^2 D} = \frac{r_g}{D} \)

\[
d = \alpha \theta_g
\]

- We calibrate \( \alpha \) by fitting models to a set of GRMHD models

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

US Astro2020 WP: Haworth et al. 2020

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
Expansion to space VLBI

ALMA-SPT-LEO at 690 GHz

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?
White Paper on East Asian Vision for mm/submm VLBI:

Toward Black Hole Astrophysics down to Angular Resolution of 1 Rs

Editors
Asada, K.1,2, Kino, M.2,3, Honna, M.2, Hirota, T.3, Lu, R.-S.4,5, Imone, M.1, Sohn, B.-W.6,7, Shen, Z.-Q.4, and Bo, P. T. P.1,7

Authors

2 Scientific Objectives
2.1 Shadow of Super Massive Black Holes
2.1.1 General Objectives
2.1.2 Sgr A* as the Nearest Accretion Flow
2.1.3 M87
2.1.4 Imaging with Sparse Modeling
2.2 Revealing Nature of Accretion Flow
2.2.1 General Objectives
2.2.2 Sgr A* as the Nearest Accretion Flow
2.2.3 Accretion flow of M87
2.2.4 Low Luminosity AGNs
2.3 Understanding Jet Formation Mechanism
2.3.1 General Objectives
2.3.2 On a possible jet in Sgr A*
2.3.3 M87 Jet
2.3.4 Blazars
2.3.5 Young radio Sources
2.3.6 Narrow Line Seyfert 1 Galaxies
2.3.7 Compact Symmetric Objects
2.4 Advancing Maser Science
2.4.1 General Objective
2.4.2 Young Stellar Objects and Interstellar Matters
2.4.3 Asymptotic Giant Branch Stars and Red Supergiants
2.4.4 Megamaser in AGNs
2.4.5 Galactic structure and astrometry
Asymmetric ~ 40-uas rings at different position angles

Wielgus et al. 2020
Wobbling Shadow

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.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Location</th>
<th>Diameter [m]</th>
<th>SEFD [Jy]</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALMA 37</td>
<td>Chile</td>
<td>37 × 12</td>
<td>100</td>
<td>2017 -</td>
</tr>
<tr>
<td>APEX</td>
<td>Chile</td>
<td>12</td>
<td>3600</td>
<td>operational</td>
</tr>
<tr>
<td>GLT</td>
<td>Greenland</td>
<td>12</td>
<td>7800</td>
<td>2018 (planned)</td>
</tr>
<tr>
<td>IRAM 30m</td>
<td>Spain</td>
<td>30</td>
<td>1400</td>
<td>operational</td>
</tr>
<tr>
<td>JCMT</td>
<td>Hawaii</td>
<td>15</td>
<td>4700</td>
<td>operational</td>
</tr>
<tr>
<td>LMT</td>
<td>Mexico</td>
<td>32</td>
<td>1400</td>
<td>operational</td>
</tr>
<tr>
<td>NOEMA</td>
<td>France</td>
<td>15</td>
<td>5200</td>
<td>operational</td>
</tr>
<tr>
<td>SMA</td>
<td>Hawaii</td>
<td>8 × 6</td>
<td>4000</td>
<td>operational</td>
</tr>
<tr>
<td>SMT</td>
<td>Arizona</td>
<td>10</td>
<td>11000</td>
<td>operational</td>
</tr>
<tr>
<td>SPART</td>
<td>Japan</td>
<td>10</td>
<td>10000</td>
<td>2018? (planned)</td>
</tr>
<tr>
<td>SPT</td>
<td>South Pole</td>
<td>10</td>
<td>9000</td>
<td>operational</td>
</tr>
<tr>
<td>SRAO</td>
<td>Korea</td>
<td>6</td>
<td>400000</td>
<td>2018? (planned)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>GLT</th>
<th>JCMT</th>
<th>KVN Ys</th>
<th>SRAO</th>
<th>SPART</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter [m]</td>
<td>12</td>
<td>15</td>
<td>21</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>SEFD [Jy]</td>
<td>4 900</td>
<td>4 500</td>
<td>78 000</td>
<td>18 000</td>
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<tr>
<td>Bandwidth [MHz]</td>
<td>2 048</td>
<td>2 048</td>
<td>2 048</td>
<td>1 024</td>
<td>512</td>
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<tr>
<td>Polarization</td>
<td>Dual circular</td>
<td>Dual circular</td>
<td>Dual circular</td>
<td>Dual circular</td>
<td>Single linear</td>
</tr>
<tr>
<td>Recorder</td>
<td>R2DBE Mark6</td>
<td>R2DBE Mark6</td>
<td>R2DBE Mark6</td>
<td>R2DBE Mark6</td>
<td>ADS3000+ OCTAVE</td>
</tr>
</tbody>
</table>
With JCMT-GLT-SRAO/SPART/KVN

Closure phase ~ 0

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

Closure phase ~ 180
- 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
<table>
<thead>
<tr>
<th>Correlator</th>
<th>DiFX-2.6.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post processing</td>
<td>HOPS-3.20</td>
</tr>
</tbody>
</table>

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