Greenland Telescope for submm VLBI

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Greenland Telescope (GLT) Project

- Goal: Image Supermassive \((7 \times 10^9 \, M_{\odot})\) Black Hole (SMBH), and measure its mass and spin (1st time ever)
- Awarded: NSF to ASIAA/Smithsonian AO Team (04.2011)
  ALMA-NA 12-m prototype telescope
- Site survey
- Many works are ongoing
  - Science, Antenna, Site construction, etc.
- Project Timeline: 2012 retrofit telescope
  2013 build ice/snow base on Greenland
  2014 re-assemble and test at Thule
  2014/15 transport telescope across ice sheet
  2016/17 first light
Objectives of SMBH studies

1. Imaging of Supermassive Black Hole Shadow
2. GR study under strong gravity field
3. Nature of Accretion disk and flows
4. Origin of Relativistic jets
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Submm VLBI Observations so far

**LETTERS**

Event-horizon-scale structure in the supermassive black hole candidate at the Galactic Centre


The cores of most galaxies are thought to harbour supermassive black holes, which power galactic nuclei by converting the gravitational energy of accreting matter into radiation. Sagittarius A* (Sgr A*), the compact source of radio, infrared and X-ray emission at the centre of the Milky Way, is the closest example of this phenomenon, with an estimated black hole mass that is 4.000.000 times that of the Sun. A longstanding astronomical goal is to resolve structures in the innermost accretion flow surrounding Sgr A*, where strong gravitational fields will distort the appearance of radiation emitted near the black hole. Radio observations at wavelengths of 3,5 mm and 7 mm have detected intrinsic structure in Sgr A*, but the spatial resolution of observations at these wavelengths is limited by interferometry scattering. Here we report observations at a wavelength of 1.3 mm that set a size of 3.3 ± 0.2 mas corresponding to the intrinsic diameter of Sgr A*. This is less than the expected apparent size of the event horizon of the presumed black hole, suggesting that the bulk of Sgr A* emission may not be constrained by the black hole, but arises in the surrounding accretion flow.

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Jet Launching Structure Resolved Near the Supermassive Black Hole in M87

Shepherd S. Doeleman,²,¹ Vincent L. Fish,¹ David E. Schenck,¹,‡, Christopher Beaudoin,¹,‡, Ray Blundell,⁴,‡ Geoffrey C. Bower,⁴ Avery E. Broderick,¹,‡ Richard Chamberlin,¹,‡ Robert Freund,⁴ Per Frifelt,⁷ Mark A. Gurwell,¹ Paul T. Ho, Marsden Hummel,¹,‡ Makoto Inoue,¹ Thomas P. Krichbaum,¹,‡ James Lamb,¹,‡ Abraham Loeb,¹ Colin Lonsdale,¹ Daniel P. Marrone,⁴,‡ James M. Moran,⁴,‡ Tomoki Oyama,¹ Richard Plumbeck,⁴ Rurik A. Primiani,¹ Alan E., E. Rogers,⁴,‡ Danilo Tellini,¹,‡, Thomas P. Krichbaum,¹,‡ Peter Strittmatter⁹,¹,‡ Remo P. J. Tilanus⁶, Michael Titus,¹,‡ Jonathan Wright,⁴,‡ Ken H. Young,¹,‡ Lucy Ziurys⁹

Guided by millimetre interferometry, we seek jet launching structures near the supermassive black hole (M 87) in M 87, using very long baseline interferometry observations at millimetre wavelengths (1.3 mm) to resolve structures in the inner region of the radio jet. We report the detection of a jet launching structure at a distance of 40 mas from the black hole, which is consistent with the location of the black hole horizon. This result supports the hypothesis that black holes are the engines that drive the relativistic jets observed in active galactic nuclei.

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**Sgr A**

Gaussian size ≈ 40 µas (≈4 r_s)

**Vir A** (M 87)

Gaussian size ≈ 40 µas (≈5 r_s)
λ1.3-mm Observations
Issues to achieve

• Higher angular resolution
  – Longer baselines
• Good uv coverage
  – More stations
• High sensitivity
  – Phased ALMA
• Image simulations
  – GR, Disk model, MHD Jet, etc.
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Site selection

For the submm VLBI site

1. Low Precipitable Water Vapor (PWV)
   Low temperature/High mountain/Desert
2. Outstanding contribution to submm VLBI
3. Mutual visibility with ALMA and SMA
4. Easy to access (including infrastructures)
## SMBH Shadow size

\[ D_{\text{shadow}} \approx 5 \, R_{\text{sch}} \]

<table>
<thead>
<tr>
<th>Name</th>
<th>Shadow (μas)</th>
<th>Mass ((10^6 M_{\text{sun}}))</th>
<th>Dist (Mpc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sgr A*</td>
<td>50</td>
<td>4.1±0.6</td>
<td>0.008</td>
</tr>
<tr>
<td>M87</td>
<td>39</td>
<td>6600±400</td>
<td>17.0</td>
</tr>
<tr>
<td>M31</td>
<td>18</td>
<td>180±80</td>
<td>0.80</td>
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<tr>
<td>M60</td>
<td>12</td>
<td>2100±600</td>
<td>16.5</td>
</tr>
<tr>
<td>N5128</td>
<td>7</td>
<td>310±30</td>
<td>4.4</td>
</tr>
</tbody>
</table>
M87 properties

• Huge SMBH mass
  ✓ Comparable angular size with Sgr A*
  ✓ Longer rotation period in accretion disk $> 1$ day

• Prominent jet

Compared to Sgr A*;

• Easier
  ✓ Period $\approx 20$ days
  ✓ Orientation by jet

• Complex
  ✓ jet
Expected uv coverage with GLT

uv coverage for M 87 with GLT, SMA, ALMA, SMT, LMT and IRAM 30m. The Baselines with GLT are shown in red.

Baselines >9,000 km provides 20 µas resolution at 345 GHz!
ALMA Phase-up Project

• To get high sensitivity
• Post Processing tasks in DiFX
  – Different sampling rate: 125 vs. 128 MHz
    • Apply Zoom Band Mode in DiFX: ASIAA
  – Polarization conversion: Linear to Circular
    • Direct correlation (XY ⊗ RL): MPIfR
• DiFX Enhancements and ...
  – DiFX correlator for submm VLBI
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Tracing the Photon “Backward in Time”

Ray Tracing

Figure credit: Muller + 2004

curved space-time

observer frame
flat space-time

thin standard disk

black hole - disk system

camera screen

Disk model provides:
• Matter distribution
• Emissivity/absorption (in local frame)
• Dynamical structure (in local frame)

courtesy of Pu H.-Y.
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Jet Launching Structure Resolved Near the Supermassive Black Hole in M87

Doeleman et al. 2012

Jet can be described with two power-law lines

Parabolic stream with \( z = r^{1.7} ( - 10^5 r_s ) \)

Conical stream with \( z = r^1 (10^5 r_s - ) \)

Gaussian size \( \sim 40 \mu \text{as} \)

VLBA at 43 GHz
VLBA at 15 GHz
VLBA core at 43 GHz
VLBI at 6 GHz
VLBI core at 230 GHz

Nakamura & Asada 2013
Outer jet
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• Other studies
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Important constraint to accretion disk model and jet-disk connection. Essential for understanding the BH shadow property.
Summary

• Submm VLBI is capable to image SMBH shadow
• ASIAA is building a submm VLBI station in Greenland: GLT Project to observe M87
• Image simulations to understand physics and observed images
• Jet studies to investigate the origin and MHD performance
• Studies of SMBHs, accretions, ...
• Collaborations: RX, DiFX, cold environments, etc.