
+ Sparse imaging of the event-horizon-scale structure
+ Scientific Impact of Nobeyama Baselines at 1.3 mm

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NAOJ Mizusawa VLBI Observatory

=> MIT Haystack Observatory (2015. September - )
## Angular radius of Super Massive Black holes

<table>
<thead>
<tr>
<th>Source</th>
<th>BH Mass ($M_{\text{solar}}$)</th>
<th>Distance (Mpc)</th>
<th>Angular radius of $R_s$ ($\mu$as)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sgr A* (Galactic Center)</td>
<td>$4 \times 10^6$</td>
<td>0.008</td>
<td>10</td>
</tr>
<tr>
<td>M87 (Virgo A)</td>
<td>$3 - 6 \times 10^9$</td>
<td>17.8</td>
<td>$3 - 7$</td>
</tr>
<tr>
<td>M104 (Sombrero Galaxy)</td>
<td>$1 \times 10^9$</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Cen A</td>
<td>$5 \times 10^7$</td>
<td>4</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Shadow diameter: several x Schwarzschild radius
Event Horizon Telescope in Early Phase (~ March 2012)

still under development!!
History of EHT: nostalgic journey to 1970s

Image $I(x,y)$ \rightleftharpoons \text{Fourier Transformation} \Rightarrow \text{Compex Visibility} $V(u,v)$

\[ V(u,v) = A(u,v) \exp(-i \phi(u,v)) \]

Visibility Amplitude
Visibility Phase

Only Amplitude

2007 Obs.
Sgr $A^*$
(Doeleman et al. 2008, Nature)

2009 Obs.
Sgr $A^*$
(Fish et al. 2011, ApJL)

M87
(Doeleman et al. 2012, Science)

Correlated flux density (Jy)
Baseline (10^6 \lambda)
Baseline Length (M \lambda)

Visibility Amplitude (Jy)

5 April

Point Source
3.7 Rs

Point Source
5.5 Rs
**History of EHT: nostalgic journey to 1970s**

Image $I(x,y)$ \quad Fourier Transformation \quad Complex Visibility $V(u,v)$

$$V(u,v) = A(u,v) \exp(-i \phi(u,v))$$

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<tr>
<th>Only Amplitude</th>
<th>Amplitude + Closure Phase</th>
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<td>2007 Obs.</td>
<td>2009 Obs.</td>
</tr>
<tr>
<td>Sgr A*</td>
<td>1921-293</td>
</tr>
<tr>
<td>2009 Obs.</td>
<td></td>
</tr>
<tr>
<td>Sgr A*</td>
<td>2011 Obs.</td>
</tr>
<tr>
<td>(Fish et al. 2011, ApJL)</td>
<td>3C 279</td>
</tr>
<tr>
<td>M87</td>
<td>NRAO 530</td>
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<td>(Doeleman et al. 2012, Science)</td>
<td>(KA, Lu &amp; Fish in prep.)</td>
</tr>
</tbody>
</table>
The First Closure Phase detections on M87

Closure Phase on CARMA-SMT-MK triangles are \( \sim 0 \)
Physically-motivated models for M87

Approaching jet
(Broderick & Loeb 2009)

Counter jet
(Dexter et al. 2012)

Accretion Disk
(Dexter et al. 2012)

All models are broadly consistent with 2009 data.
The First Closure Phase detections on M87

[Graph showing Closure Phase detections on M87 with various data points and error bars, along with a color-coded phase map and u(10^5 λ) axis.]
The First Closure Phase detections on M87

Hawaii - Arizona - California triangle
Hawaii - Mexico - California triangle
Hawaii - Chile - California triangle

Greenwich Sidereal Time (hour)
Crucial information to clarify $R_s$-scale structure will be surely obtained after 2015!!
EHT 2015-2016 + Sparse Modeling “LASSO”

M87, Shadow Diameter \(\sim 20\) uas (for the case of \(M_{BH} = 3 \times 10^9\) \(M_{\odot}\))

(Honma, \textbf{KA}, Uemura & Ikeda 2014, PASJ)
EHT 2015-2016 + Sparse Modeling “LASSO”

M87, Shadow Diameter ~ 40 uas (for the case of $M_{BH} = 6 \times 10^9 \, M_{\odot}$)

(KA & F. Tazaki+ in prep.)
EHT 2015-2016 + Sparse Modeling

“PRECL+LASSO” or “non-linear LASSO/TV”
Image Reconstruction from the Visibility Amplitude and Closure Phase

(PRECL: Ikeda & KA+ to be subm, Non-linear LASSO & TV minimization: KA+)

Model

Diffraction Limit

PRECL + LASSO
(Model-independent Phase Reconstruction)

Non-Linear LASSO

Non-Linear TV Minimization

We no longer need the visibility phase and phase self-calibration!!
230 GHz VLBI Experiment at Nobeyama (MICE 2015)

Fujisawa & ALL-Japan Team, April 27, 2015
uv-coverage for M87 (EHT+Nobeyama; EL>20°)

Baseline Length ~ 5000-10000 km
NRO baselines are exactly located between the first and second null regions (uv-coverage is really effective to study the presence of the shadow)

→ Why not performing 1.3 mm-VLBI observations with Nobeyama (SPART and 45m Telescope)!!?