Imaging the black hole shadow of M87

Fumie Tazaki (NAOJ)
First Imaging of Black Hole Shadow

M87

5000光年
5000 light-year

NASA, ESA and the Hubble Heritage Team (STScI/AURA)

0.5光年
0.5 light-year

EAVN Collaboration

0.01光年
0.01 light-year

EHT Collaboration

EAVN Workshop 2019 @Ibaraki Univ., Sep. 23rd, 2019
Flow of M87* Imaging

- Calibrated data was delivered to Imaging WG members.

- Blind imaging with 4 teams.

- Evaluation of Imaging Parameters.

- Imaging with “good” imaging parameters.
Regularized Maximum Likelihood (RML) Method

Credit: Katie Bouman, Kazu Akiyama

\[ \hat{x}_{\text{MAP}} = \arg\max_x \left[ \log p(y|x) + \log p(x) \right] \]

Inverse FT

Closure quantities

Event Horizon Telescope

EAVN Workshop 2019 @Ibaraki Univ., Sep. 23rd, 2019
Tools for EHT imaging

- **RML Method**
- **CLEAN + Selfcalibration (traditional)**

- **eht-imaging** *(Chael+2016,2018)*
- **DIFMAP** *(Sheperd+1997,1998)*

- **SMILI** *(Akiyama+2017a,b)*

3 software tools are used for whole imaging processes.
Blind imaging with 4 teams

Kazu’s slide

**Team 1**
**Americas**
US & Chile  
(SAO, U. Arizona, U. Conception)  
Leader: K. Bouman & A. Chael

**Team 2**
**Global**
US, Japan, Netherland  
(MIT, NAOJ, Hiroshima U., Radboud U.)  
Leader: K. Akiyama & S. Issaoun

**Team 3**
**Cross Atlantic**
US, Spain, Germany, Finland  
(Boston U, MPIfR, IAA, Aalto)  
Leader: A. Marscher

**Team 4**
**East Asians**
Korea, Japan & Taiwan  
(ASIAA, KASI, NAOJ)  
Leader: S. Koyama
Blind imaging with 4 teams

- 4 teams successfully reconstructed asymmetric ring structure independently.

- Slightly different appearance between each image.

Parameter sets we choose affect to the result? Which parameter space brings plausible images?
Simulation data for imaging parameter test

Image domain: respective different structure
Visibility domain: same feature as M87*

Event Horizon Telescope

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Evaluation of imaging parameters

**Model Image**
- Ring
- Crescent
- Disk
- Double

**Model Visibility**

**M87 Observed Data**

**Parameter Sets**
- $5 \times 10^4$

**2000 M87 Images**

**Successful Parameter Sets:**
- 2000

Workshop 2019 @ Ibaraki Univ., Sep. 23rd, 2019
Final images of M87

We confirmed the consistent asymmetric ring structure with 2000 images for each observation day.
Ring Parameters

Diameter: Consistent in dates and tools
Angular: Consistent in tools

systematic change (~20°) in a week

→ Hotspot position was changed.
Unified image of M87
Summary

- 4 teams successfully made consistent images independently.

- Evaluate 50,000 parameter sets for imaging.

- All 2000 images of M87* show asymmetric ring whose south side is brighter than the other.

- Ring diameter is consistent between all observation dates and tools.

- Ring angular systematically changes.