Imaging Magnetic Fields at the Event Horizon of a Black Hole

Michael Johnson (CfA)
The Event Horizon Telescope

- 230 GHz = 1.3 mm
- Full Polarization
- Resolution: ~20 µas

2017: First science observations with EHT+ALMA
2018: 5× Increase in total BW (2× recorded BW)
The Spectrum of Sgr A*
The SED of Sgr A* 

Unpolarized

Energetically dominant emission

Polarization is expected and traces the magnetic fields

7% pol $> 100$ GHz, but unresolved

Magnetic field order is unknown

Ordered Fields
Low %Pol

Tangled Fields
High %Pol
Why Study Polarization?

Strong Gravity:
- Parallel Transport
- Relativistic Aberration

BH Accretion and Outflow:
- Field morphology
- Turbulence

Global Accretion:
- Faraday rotation & conversion

The accretion rate of Sgr A* was not determined until submillimeter polarization was detected!

(Aitken et al. 2000; Marrone et al. 2007)
Polarimetry with the EHT

Image Credit: APEX, IRAM, G. Narayanan, J. McMahon, JCMT/JAC, S. Hostler, D. Harvey, ESO/C. Malin
Resolving Sgr A* with the EHT

First polarimetric VLBI at 230 GHz;
First resolved polarization of Sgr A* at any wavelength

Johnson et al. (2015)
Asymmetry is special!

Implies spatial changes in polarization direction

Resolving Sgr A* with the EHT
Ordered Fields Near the Horizon

Increasingly Resolved Image

Ordered Fields

EHT Data

Turbulent Fields

(All these models appear identical when unresolved)

Johnson et al. (2015)
Time Variability of Sgr A*

See also: Marrone et al. (2007), Fish et al. (2009)

No corresponding changes in total flux

~2.5 Hours
Relative Offset of the Polarization Centroid

Model-independent morphology constraints via the polarization angle

An Analogy

For a California-Arizona Baseline: $1 \ R_{\text{Sch}}$ offset $\leftrightarrow 10^\circ$ in polarization direction
Tracking Dynamical Activity of Sgr A*

Johnson et al. (2015)
Dynamical astrometry to $\pm 3 \mu\text{as} = 0.3 R_{\text{Sch}}$

Shortest EHT baseline already outperforms the goal of GRAVITY!

See astro-ph:1705.02345
Working with Sparse Information

It's a jet!

It's a RIAF!

Source: balajiviswanathan.quora.com
Next Steps (2017-2018): Imaging

EHT imaging simulations are encouraging:

**But**, conventional Earth-rotation synthesis imaging is not appropriate for Sgr A*! (e.g., Lu+ 2016, Gold+ 2016, Roelofs+ 2017, Medeiros+ 2017)
Dynamical Imaging with Interferometry

**Simulation:**
- An orbiting “hot spot” (Broderick & Loeb 2006)
- Earth rotates 7° per hot spot orbit (27 minutes)

**Reconstruction:**
- Assumes the sites and sensitivities of the expected 2017 EHT
- Snapshot images (~1 minute of data per frame)
- An entire movie is reconstructed, favoring frame-to-frame continuity
7mm VLBA Observations of M87

Computing Time: ~hours
Framework is flexible
- Irregularly spacing
- Inhomogeneous beam
A calibration/imaging framework
Results can be post-processed; e.g., wavelet analyses (Mertens & Lobanov 2015)

← Equivalent to ~3-hr for Sgr A*

with Craig Walker, Andrew Chael, Katie Bouman, Lindy Blackburn, Shep Doeleman

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Dynamical Imaging with Interferometry

Andrew Chael (Harvard Physics)
Katie Bouman (MIT Computer Vision)
Lindy Blackburn (SAO Astronomy)
Andre Young (SAO Astronomy)
Kazu Akiyama (MIT Astronomy)
Julian Rosen (UGA Mathematics)

The First EHT Imaging Hackathon

Also:
Alan Marscher
Svetlana Jorstad
John Wardle
Craig Walker
Shep Doeleman
Recent EHT results:

- Compact structure in total flux of Sgr A*, only ~5 Schwarzschild radii in size
- Ordered magnetic fields and strong polarization near the event horizon
- Also a component with small-scale polarization structure
- Intense variability in polarization

In the next few years (7-9 sites):

- Images of the black hole shadow and magnetic fields near Sgr A*
- Movies of dynamical activity, flares, and polarization of Sgr A* and M87
- Faraday rotation images of Sgr A* in 2018+
- Other Targets: OJ287, 3C273, 3C279