Abstract: <span>Sgr A* regularly flares in the X-ray and near-IR on ~hour timescales, and the EHT has already detected interday variability in 1.3 mm emission on long and short baselines. The addition of highly sensitive long baselines in 2015 will allow for the resolution of time variable structure on sub-minute timescales. This opportunity to observe dynamical process on event horizon scales comes with the challenge of sparse visibility coverage, but several strategies can recover rich information from the limited samples. I will review sources of variability for the emission near supermassive black holes from minute to year timescales, and discuss the prospects of EHT observations for understanding event-horizon-scale dynamics.</span>
Probing Time Variability near the Event Horizon with the EHT

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Introduction

• Sgr A* is time variable in X-Ray and NIR on sub-hour timescales
• The EHT has already detected interday variability at 1.3 mm on multiple baselines (Fish et al. 2010).
• Time variability complicates imaging, but offers exciting potential for physics (e.g. the MRI)
Time Scales

- Minutes
  - MRI driven turbulence
- Minutes – Hours
  - Orbital periodicities
  - Flares
- Days
  - Refractive scattering
- Months-Years
  - Precession
  - Changes in accretion rate
  - Quasar Jets
  - Binary SMBH Orbits
Sgr A* Flares

- Sgr A* flares in NIR, X-ray, and sub-mm

- Flares in NIR and X-ray are highly correlated; X-ray flares likely generated by Synchrotron-Self-Compton excitation of NIR photons

- Large quiescent sub-mm component dampens relative amplitude
Sgr A* Flares

Marrone et al. 2008
Two Problems

How do we image quiescent structure/shadow underneath a variable source?

How do we extract physics of the variability from VLBI observables?
GRMHD Simulation

Simulation from Hotaka Shiokawa
GRMHD Simulation

Simulation from Hotaka Shiokawa
Effect on visibilities
Effect on visibilities
Effect on imaging

Averaged Model

BSMEM reconstruction of static averaged image

Simulations from Hotaka Shiokawa
Image credit: Freek Roelofs
Autocorrelation Timescales

85 degree inclination

45 degree inclination
A recipe for time averaging

- Averaged visibilities over 8 different days

Image Credit: Freek Roelofs
“Simple” case-Hot Spots

Closure quantities for GRMHD simulations

- Do not expect clean periodic behavior.

- Large bandwidth to increase time resolution is critical

- Can choose triangles/quadrangles intelligently to test different source hypotheses

Simulation from Hotaka Shiokawa
Closure Phases

SMA-CARMA-ALMA

SMA-LMT-ALMA
Closure Amplitudes

\[ A = \frac{|A_{ab}| |A_{cd}|}{|A_{bd}| |A_{ac}|} \]
Closure Amplitudes

\( \approx \frac{\text{SMA-SMT}}{\text{SMA-CARMA}} \)

\( \approx \frac{\text{SPT-SMT}}{\text{SPT-CARMA}} \)

\( \approx \frac{\text{ALMA-SMT}}{\text{ALMA-CARMA}} \)

Simulation from Hotaka Shiokaw
Closure Amplitudes

Image Credit: Nina Hooper
Simulation from Hotaka Shiokawa
Further ideas

• Applying methods from studies of quasar light curves to spatially-resolved data.
  – Autoregressive processes/damped random walks (Kelly et al. 2009, Dexter et al. 2013)

• Movie MEM imaging

• Collaboration!
Polarimetric Astrometry

• First order change in polarimetric ratios due to a compact flaring structure is position offset

\[
\tilde{m}(u, t) \approx \frac{\tilde{P}_q(u) + \tilde{P}_d(t)e^{-2\pi i u \cdot x_d(t)}}{\tilde{I}_q(u) + \tilde{I}_d(t)e^{-2\pi i u \cdot x_d(t)}}
\]

• Position offset -> Phase gradient in changing baseline length.

• Allows extremely precise tracking of flaring structure: 
  μas offset = 1° in EVPA on SMT-CARMA
Longer time scale variability

- Refractive Scattering – See Michael’s talk!
- Spin precession of the accretion disk
- Knots of material in quasar jets launching region
  - complement 7 mm VLBA observations
- Binary BH orbits – OJ 287?
  - 12 year period, next event expected in 2019
Summary

• The EHT has already detected day-to-day changes in visibility amplitudes on long and short baselines (Fish et al. 2011)
• Time variability in flux and polarization offers a window on dynamics at the event horizon (e.g. the MRI)
• Non-imaging techniques (closure quantities, polarimetric ratios) are particularly important for interpreting time-variable data