Title: Probing Dynamical Activity near the Event Horizon with the EHT

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Abstract: 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.

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)

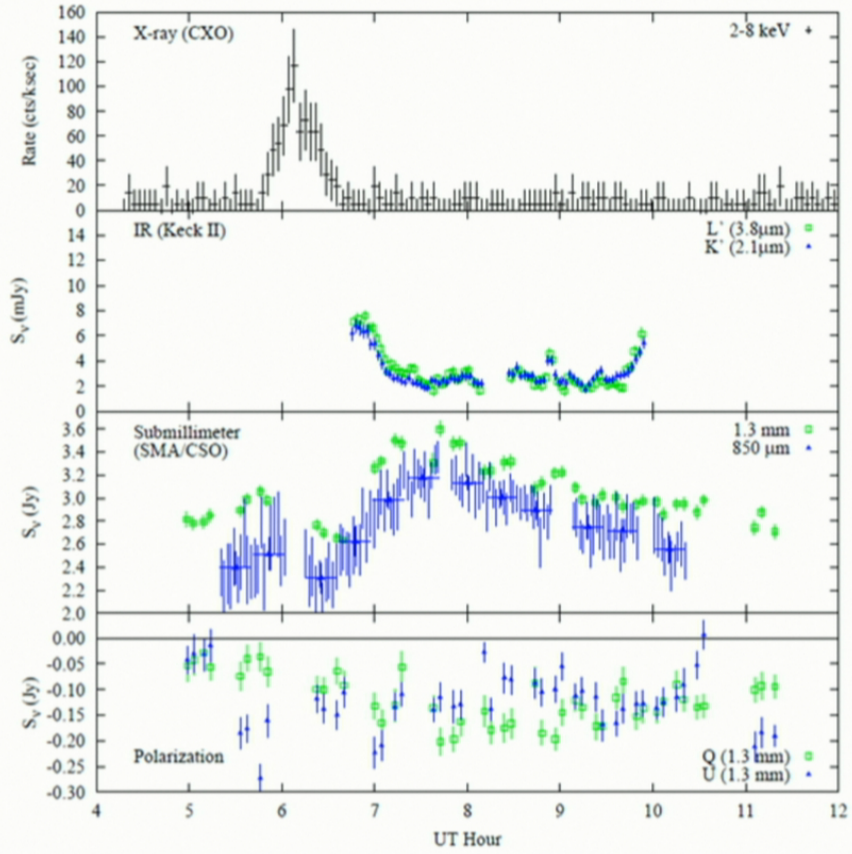
Time Scales

- 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



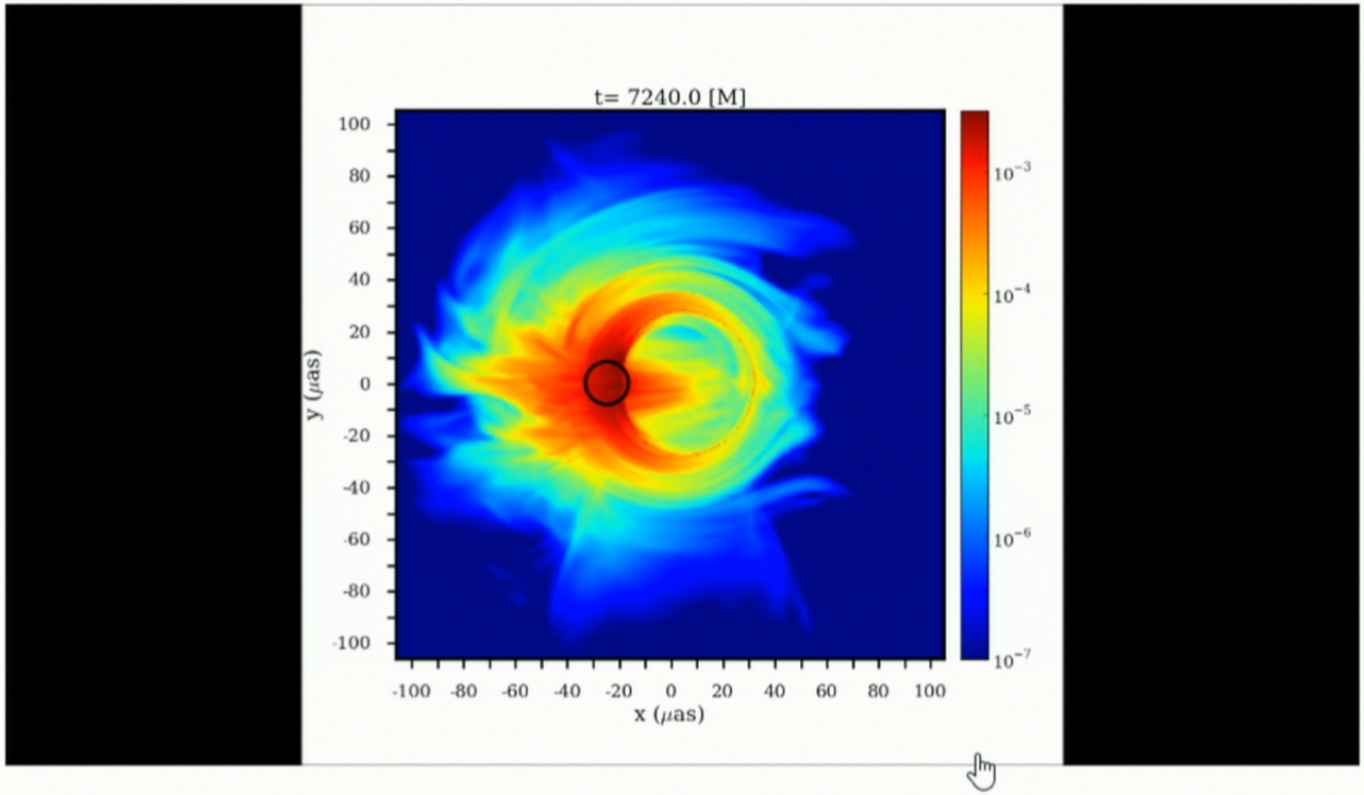
Marrone et al. 2008

Two Problems

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

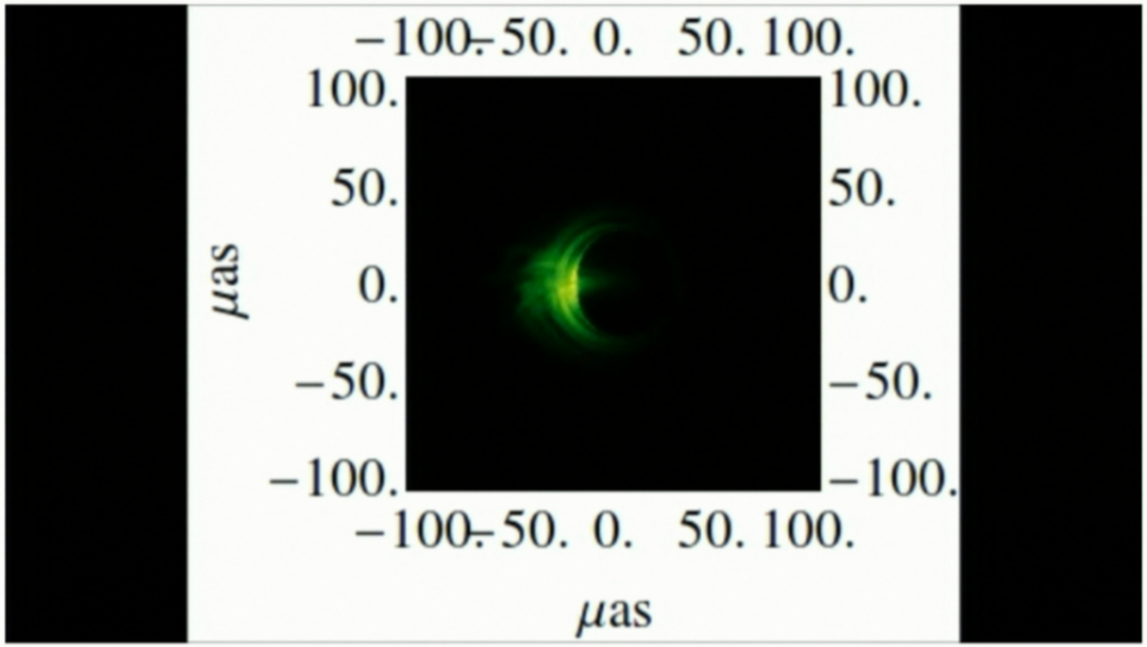
How do we extract physics of the variability from VLBI observables?

GRMHD Simulation



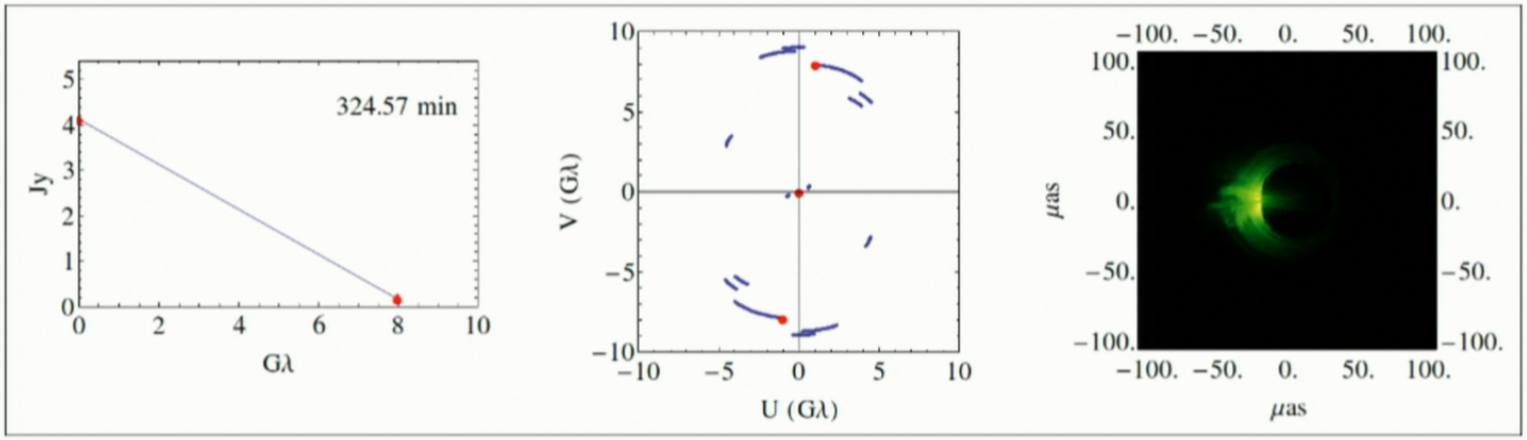
Simulation from Hotaka Shiokawa

GRMHD Simulation

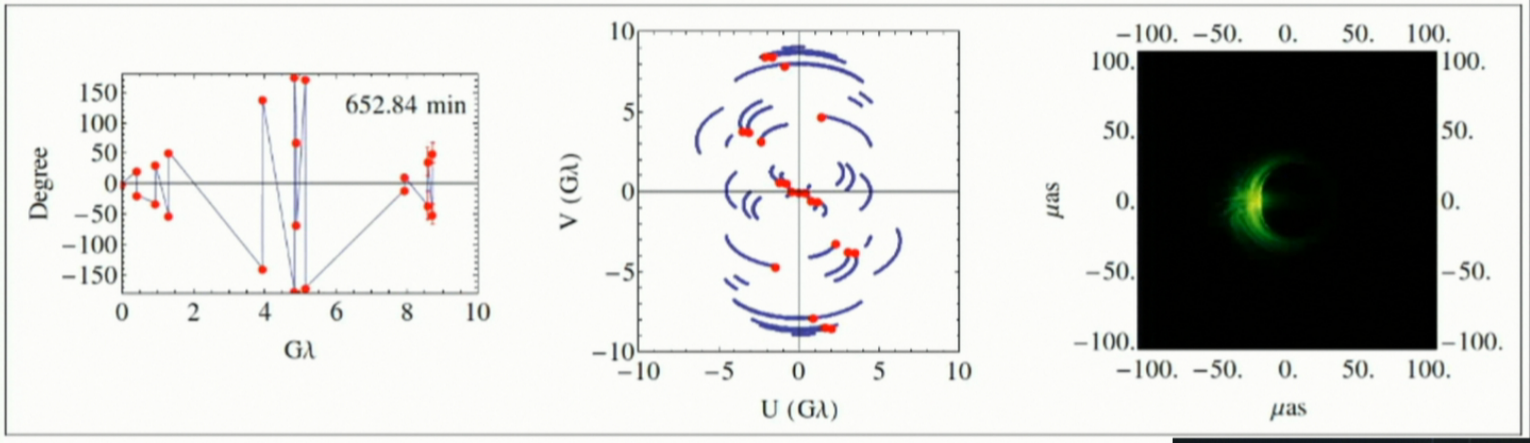


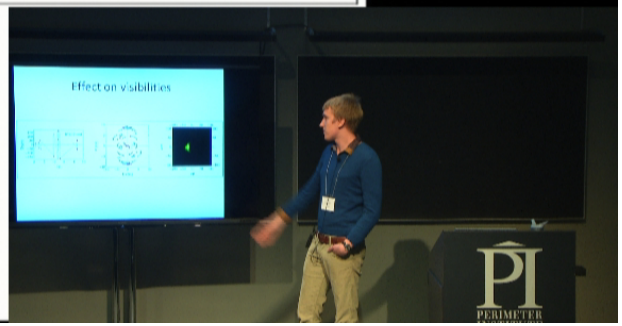
Simulation from Hotaka Shiokawa

Effect on visibilities

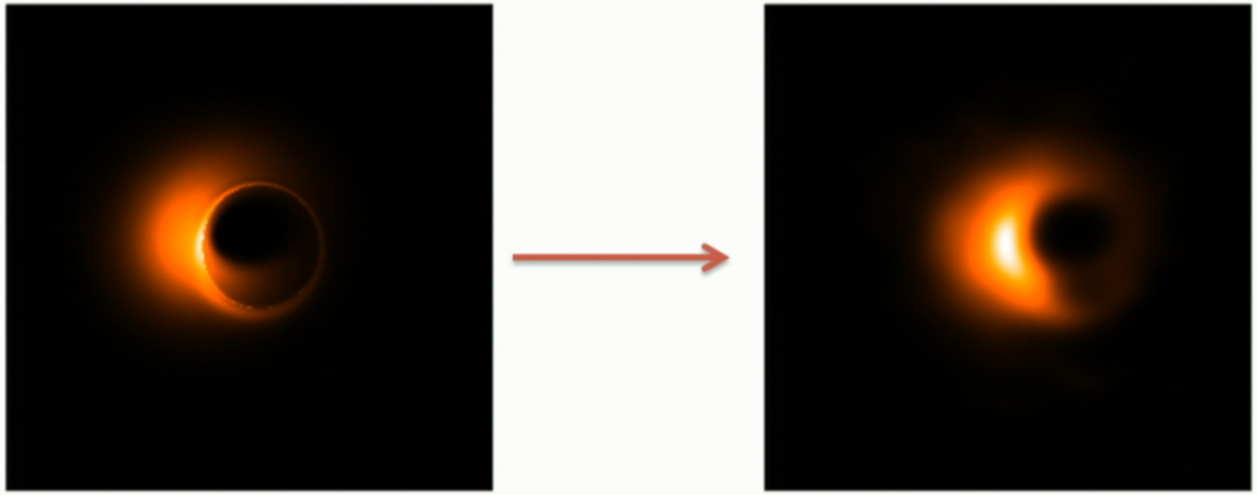


Effect on visibilities





Effect on imaging

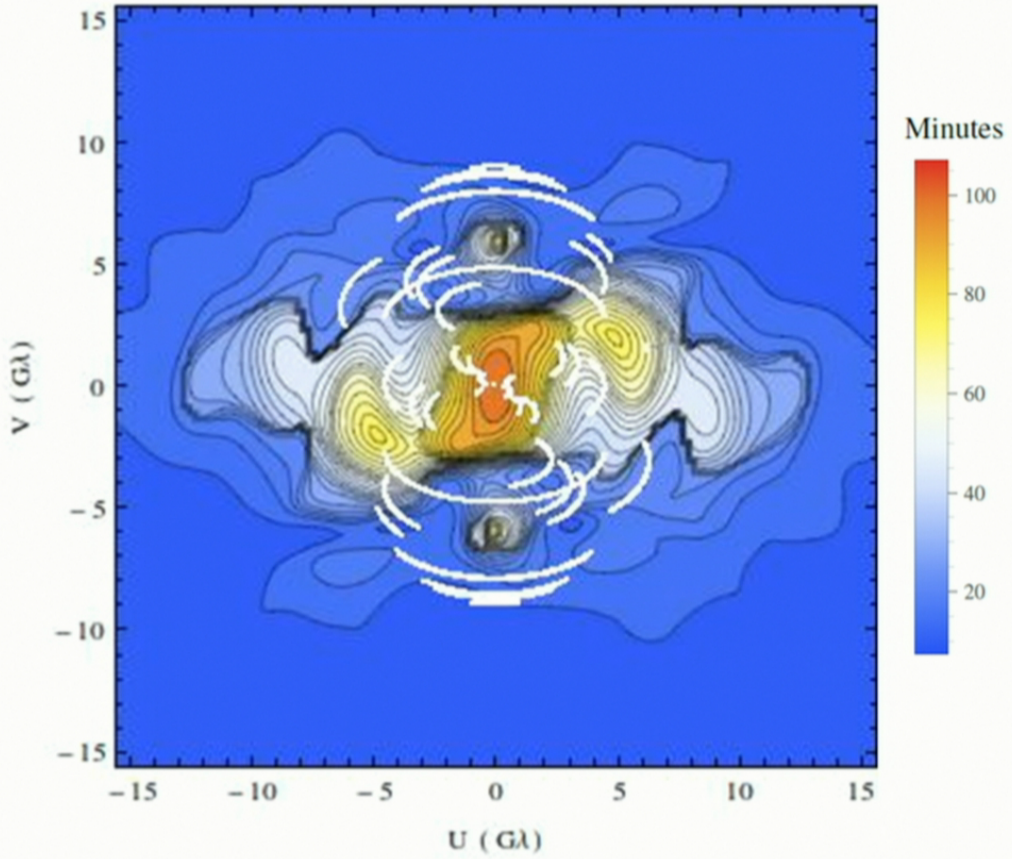


Averaged Model

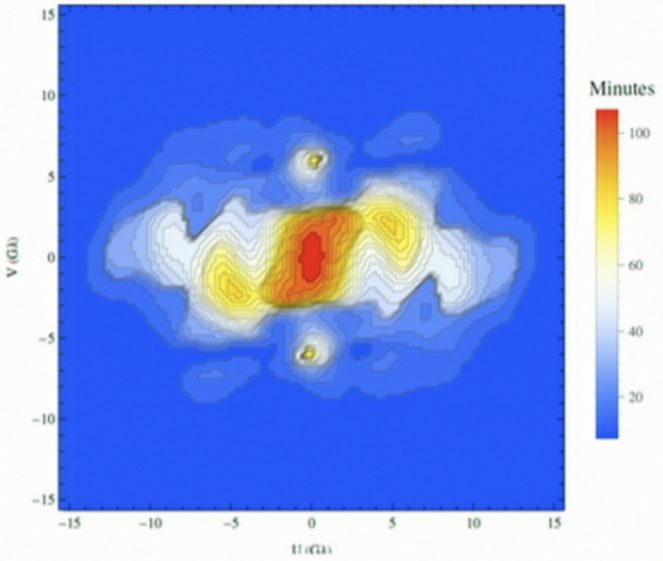
BSMEM reconstruction of static averaged image

Simulations from Hotaka Shiokawa
Image credit: Freek Roelofs

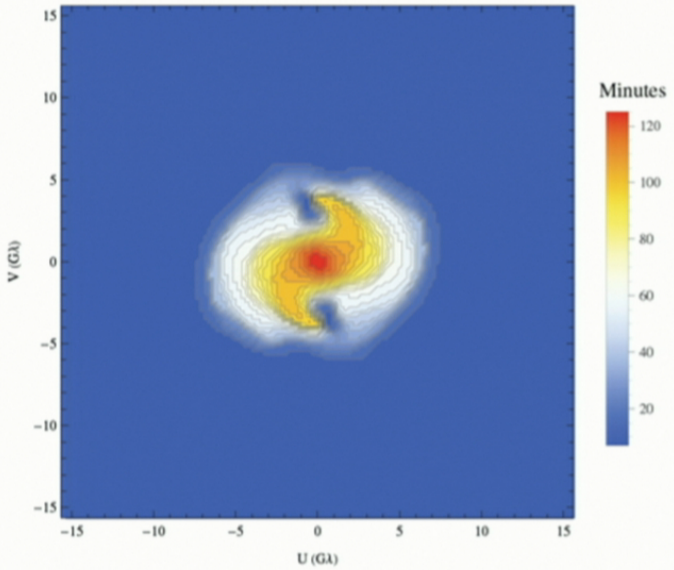
Autocorrelation Timescales



Autocorrelation Timescales



85 degree inclination



45 degree inclination

A recipe for time averaging

- Averaged visibilities over 8 different days

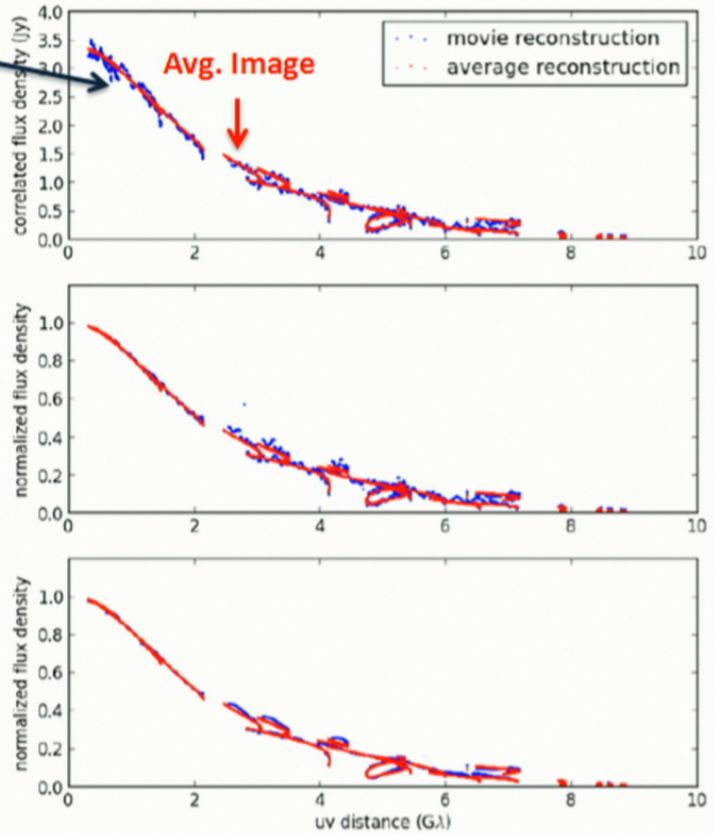
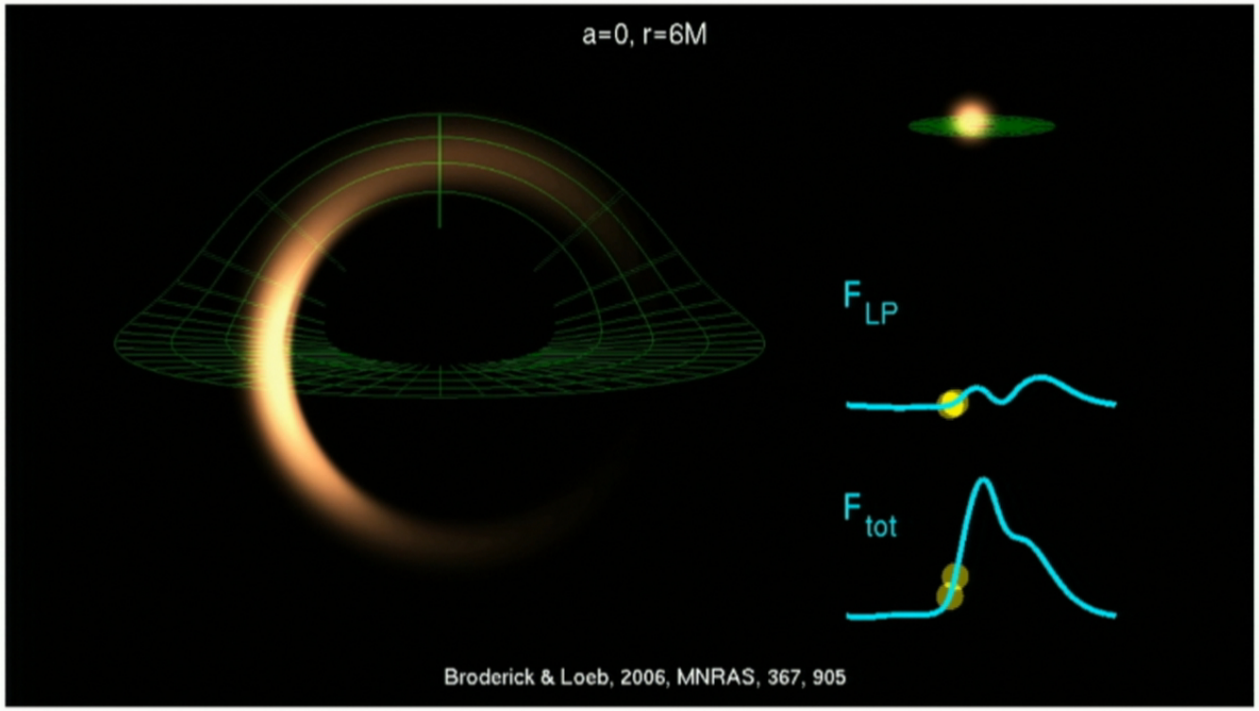
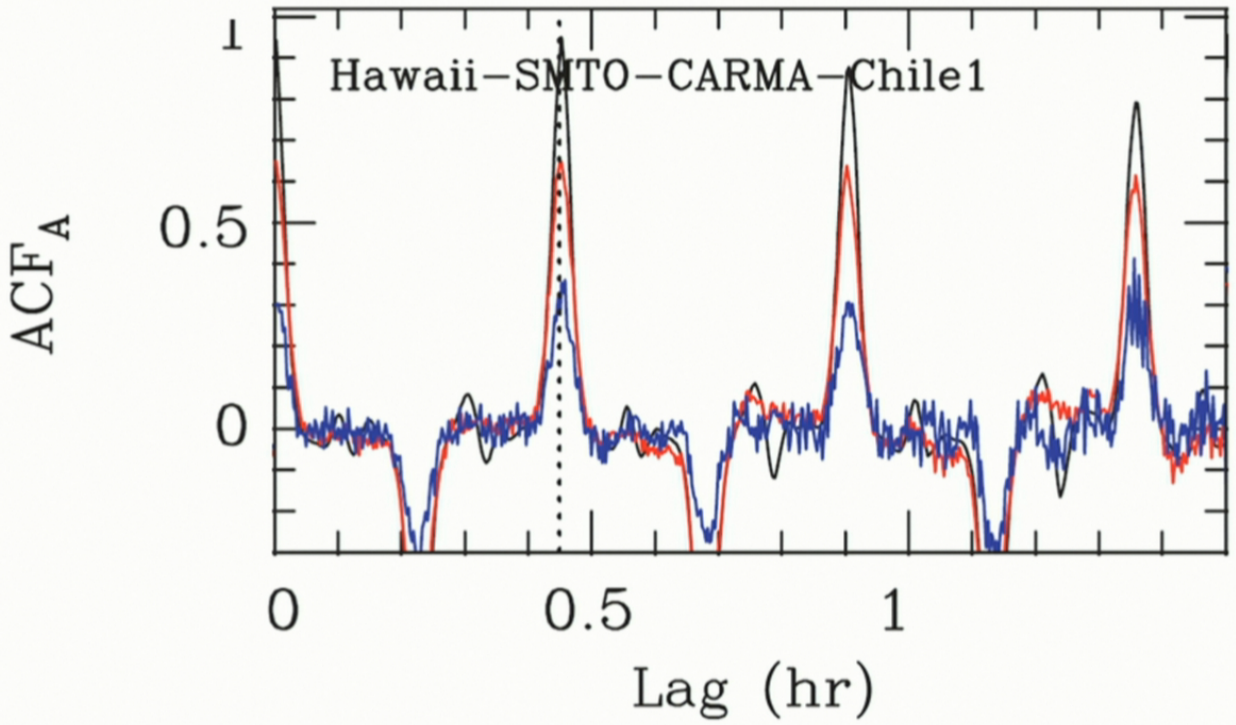


Image Credit: Freek Roelofs

“Simple” case-Hot Spots



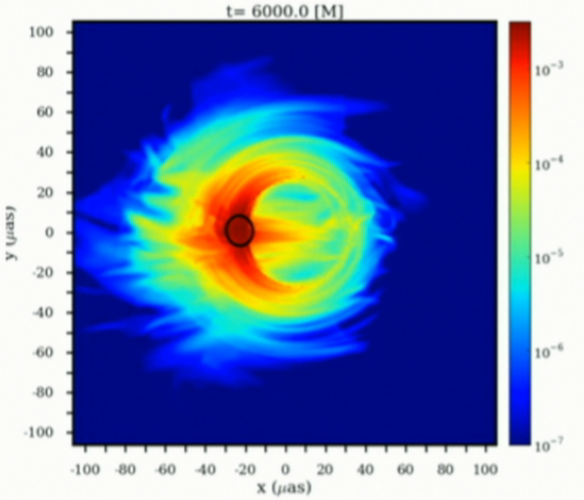
Hot Spot autocorrelation functions



Doeleman et al. 2009

Closure quantities for GRMHD simulations

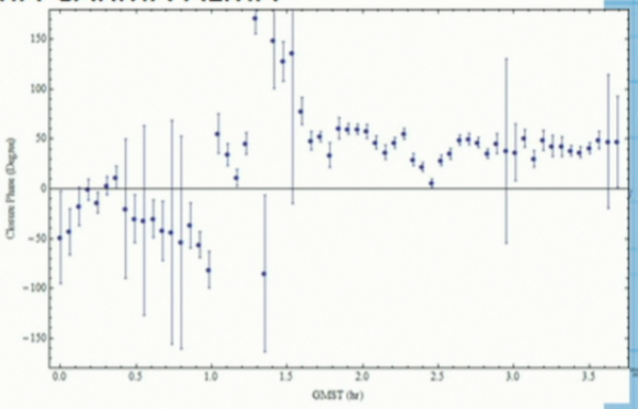
- Do not expect clean periodic behavior.
- Large bandwidth to increase time resolution is critical
- Can choose triangles/quadrangles intelligently to test different source hypotheses



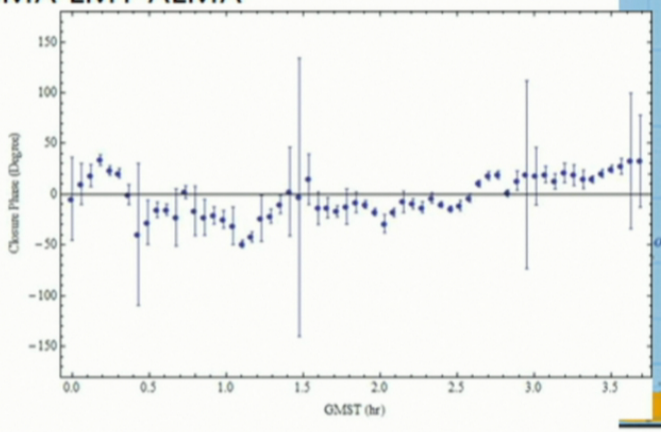
Simulation from Hotaka Shiokawa

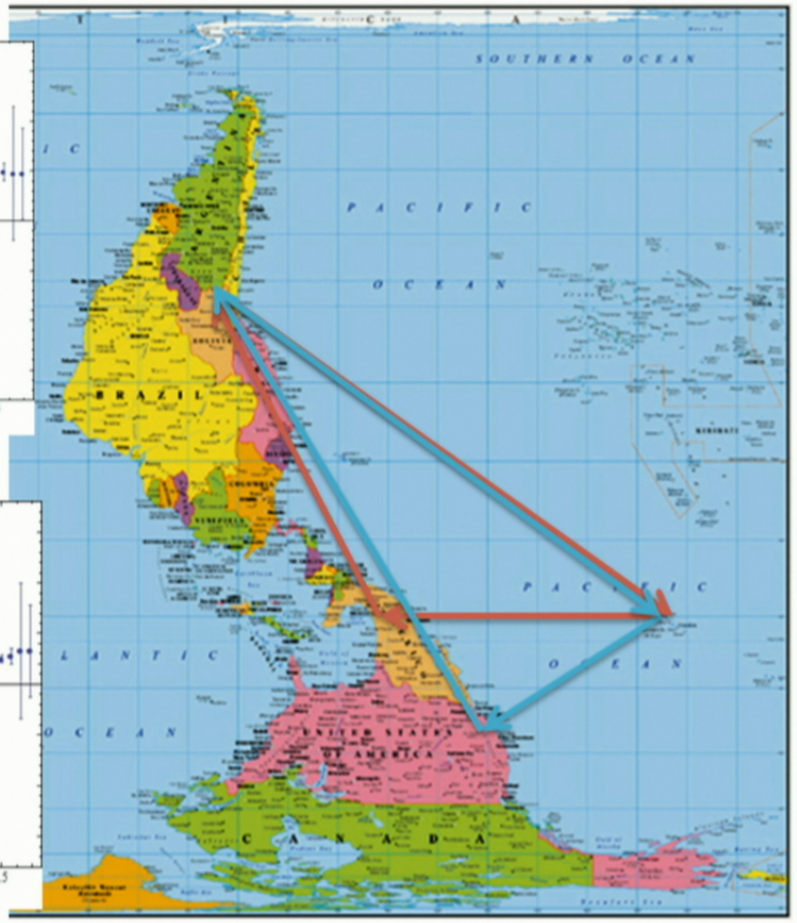
Closure Phases

SMA-CARMA-ALMA



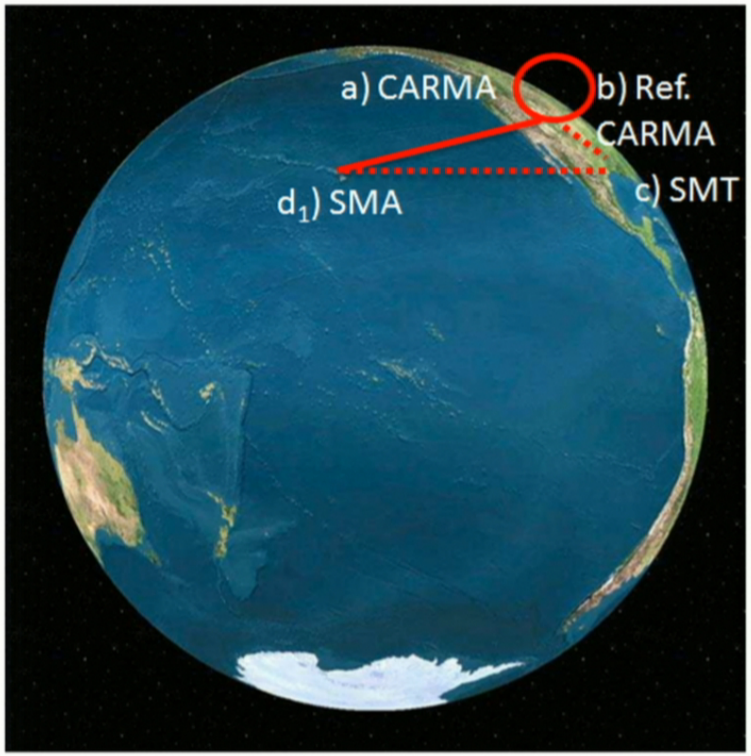
SMA-LMT-ALMA



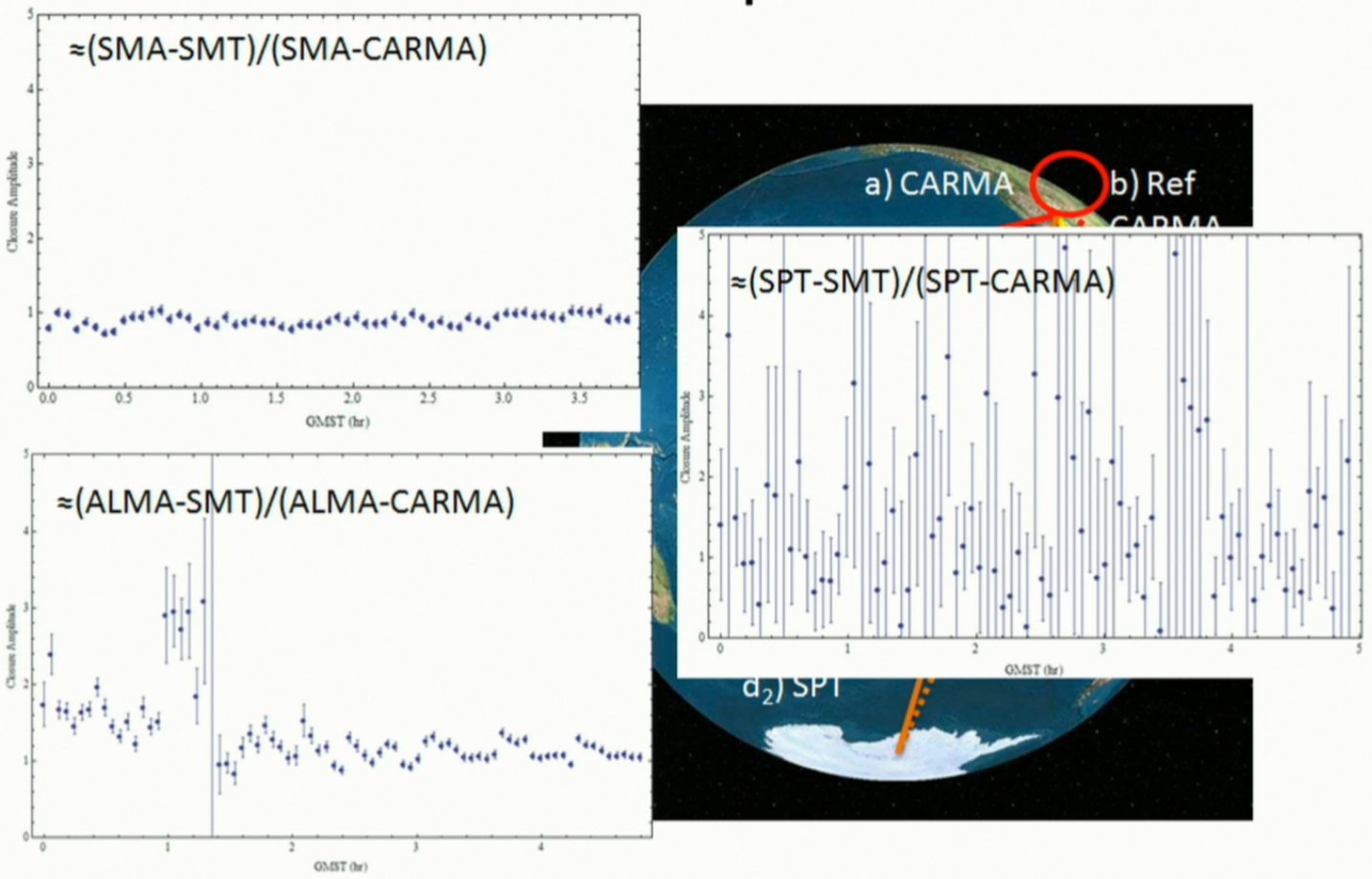


Closure Amplitudes

$$A = \frac{|A_{ab}||A_{cd}|}{|A_{bd}||A_{ac}|}$$



Closure Amplitudes



Simulation from Hotaka Shiokav

Closure Amplitudes

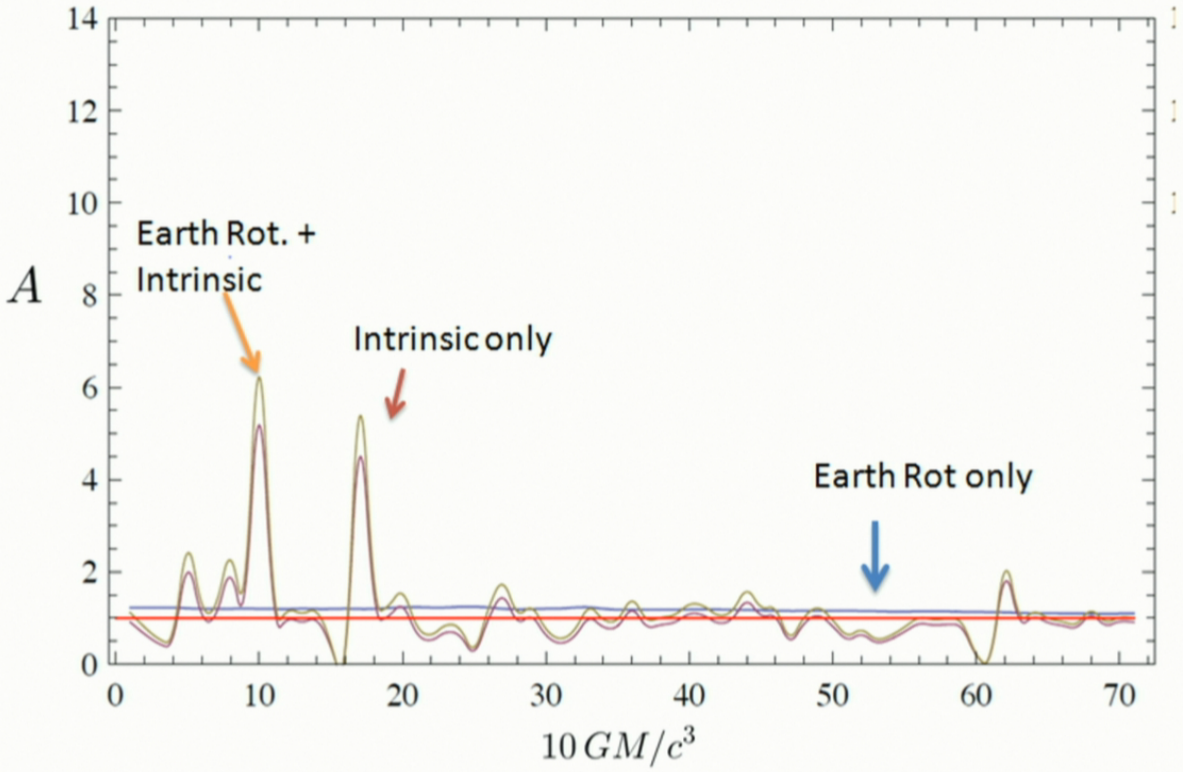


Image Credit: Nina Hooper
Simulation from Hotaka Shiokawa

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

$$\breve{m}(\mathbf{u},t) \approx \frac{\tilde{\mathcal{P}}_{\rm q}(\mathbf{u}) + \mathcal{P}_{\rm d}(t) e^{-2\pi i \mathbf{u}\cdot\mathbf{x}_{\rm d}(t)}}{\tilde{\mathcal{I}}_{\rm q}(\mathbf{u}) + \mathcal{I}_{\rm d}(t) e^{-2\pi i \mathbf{u}\cdot\mathbf{x}_{\rm d}(t)}}$$

•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