Event Horizon Scale Emission Models for Sgr A*

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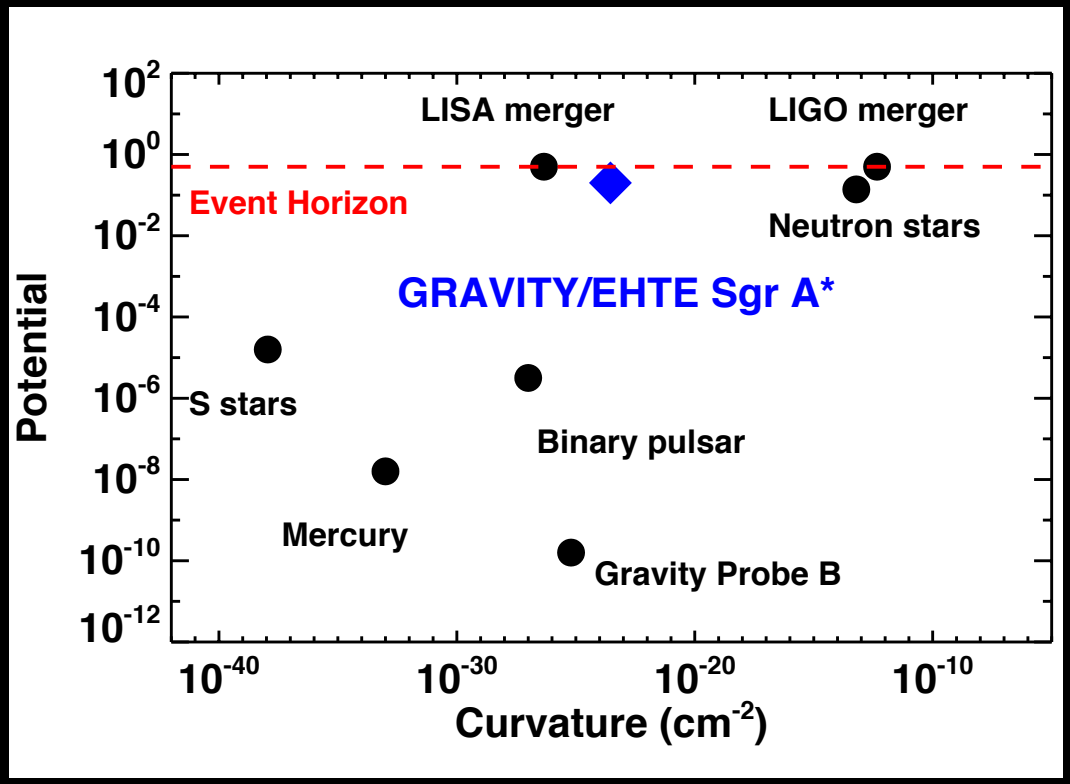
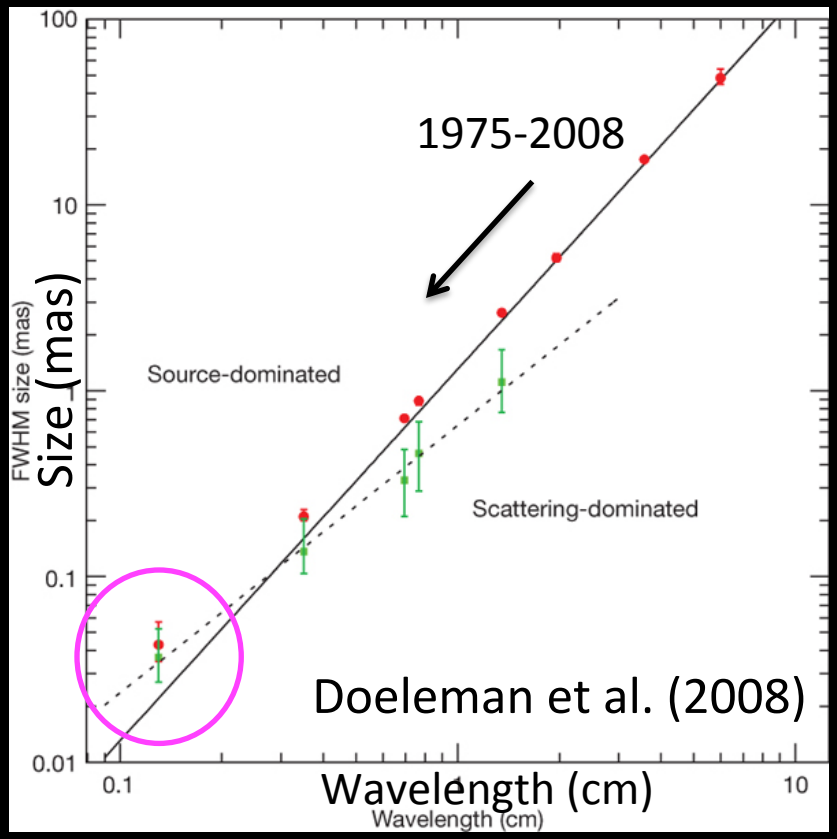
The Sgr A* Black Hole Laboratory

- Event Horizon Telescope, VLTI GRAVITY:
  exciting opportunities to probe strong gravity around BHs



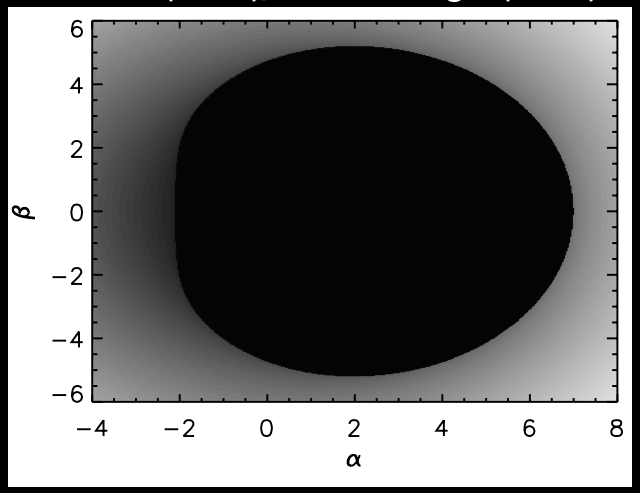
after Psaltis (2008)



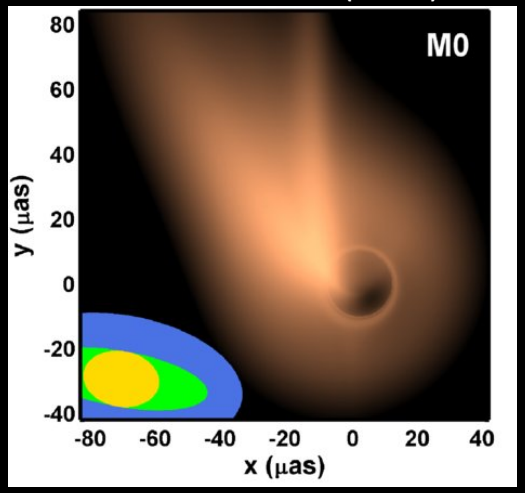
Doeleman et al. (2008)

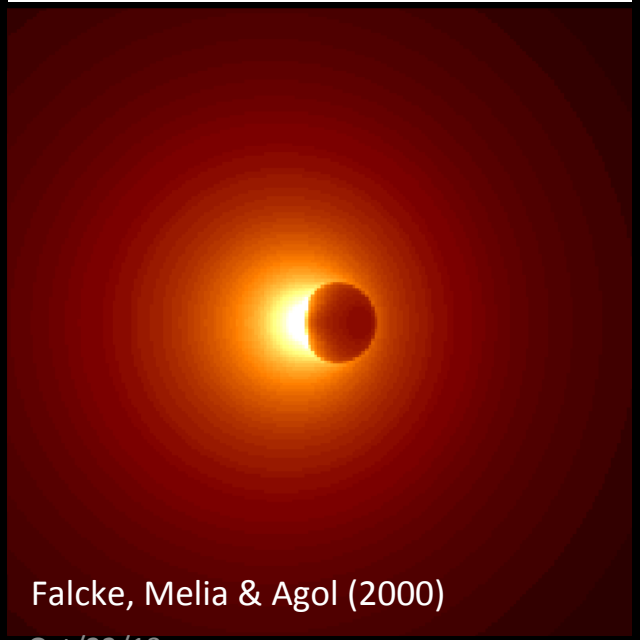
Black Hole Images & Shadows

Bardeen (1973); Dexter & Agol (2009)

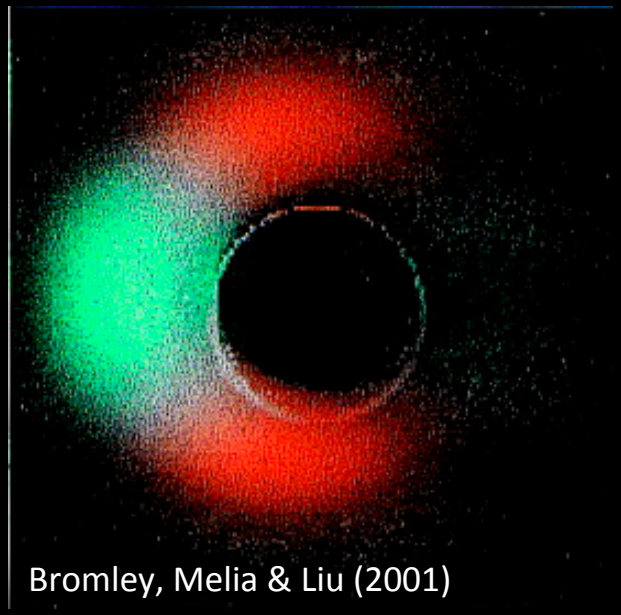


Broderick & Loeb (2009)





Falcke, Melia & Agol (2000)

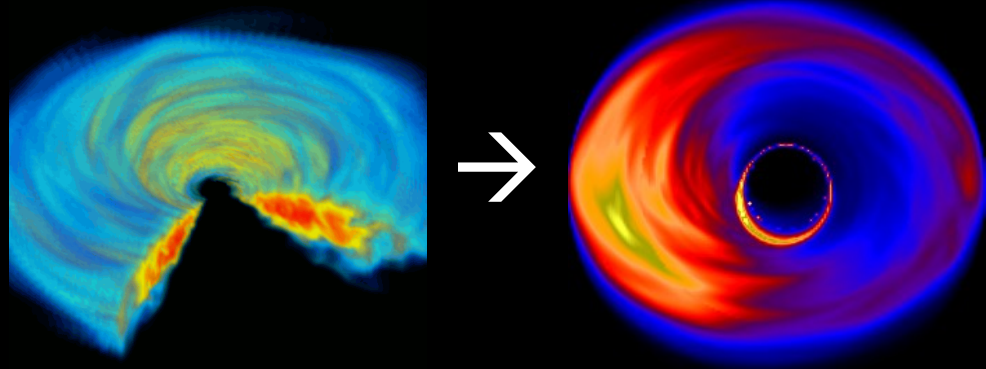


Bromley, Melia & Liu (2001)

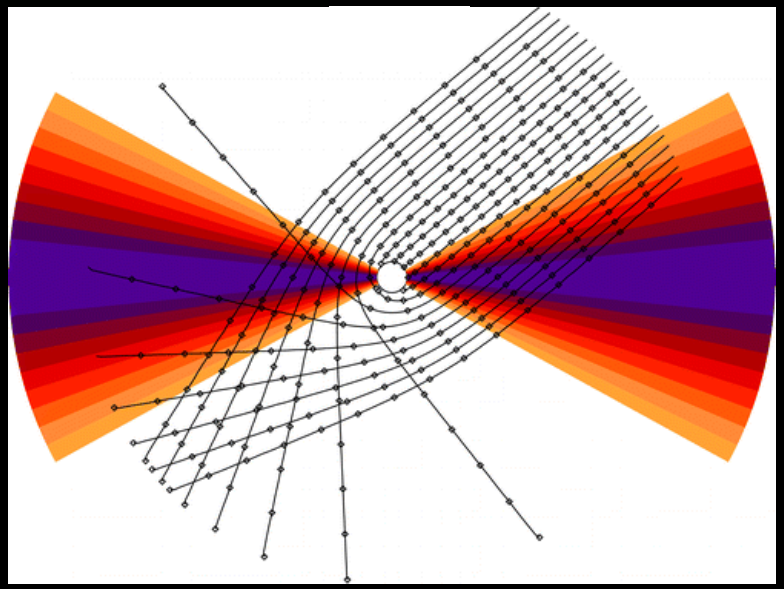
- Sensitive to viewing geometry & details of emission region

Ray Tracing

- Trace photon orbits
  - `geokerr`, Dexter & Agol (2009)
- 3D GRMHD simulations
  - Fragile et al. (2007, 2009), McKinney & Blandford (2009), McKinney et al. (2012)



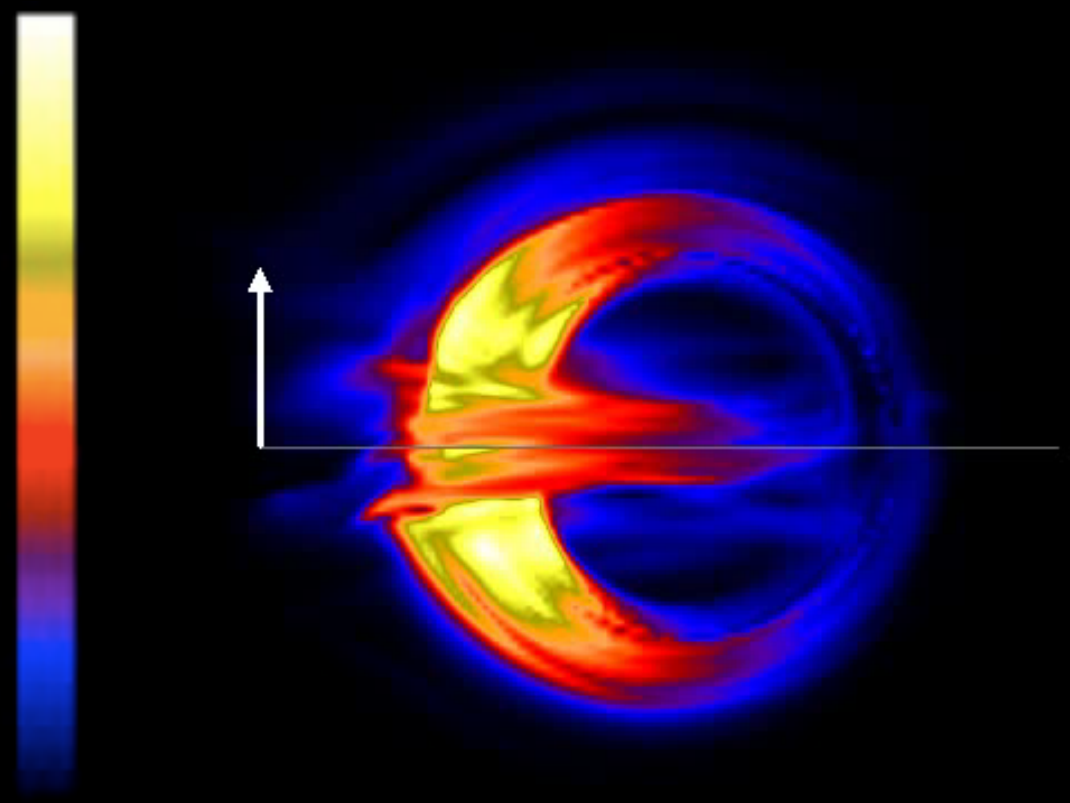
- Electrons
  - Disks: T_i/T_e, jets: power law
- Synchrotron emission
- Joint fits to mm data
  - Marrone (2006), Doeleman et al. (2008), Fish et al. (2011)



Schnittman et al. (2006)

Sgr A* Disk Images

100x100 μas

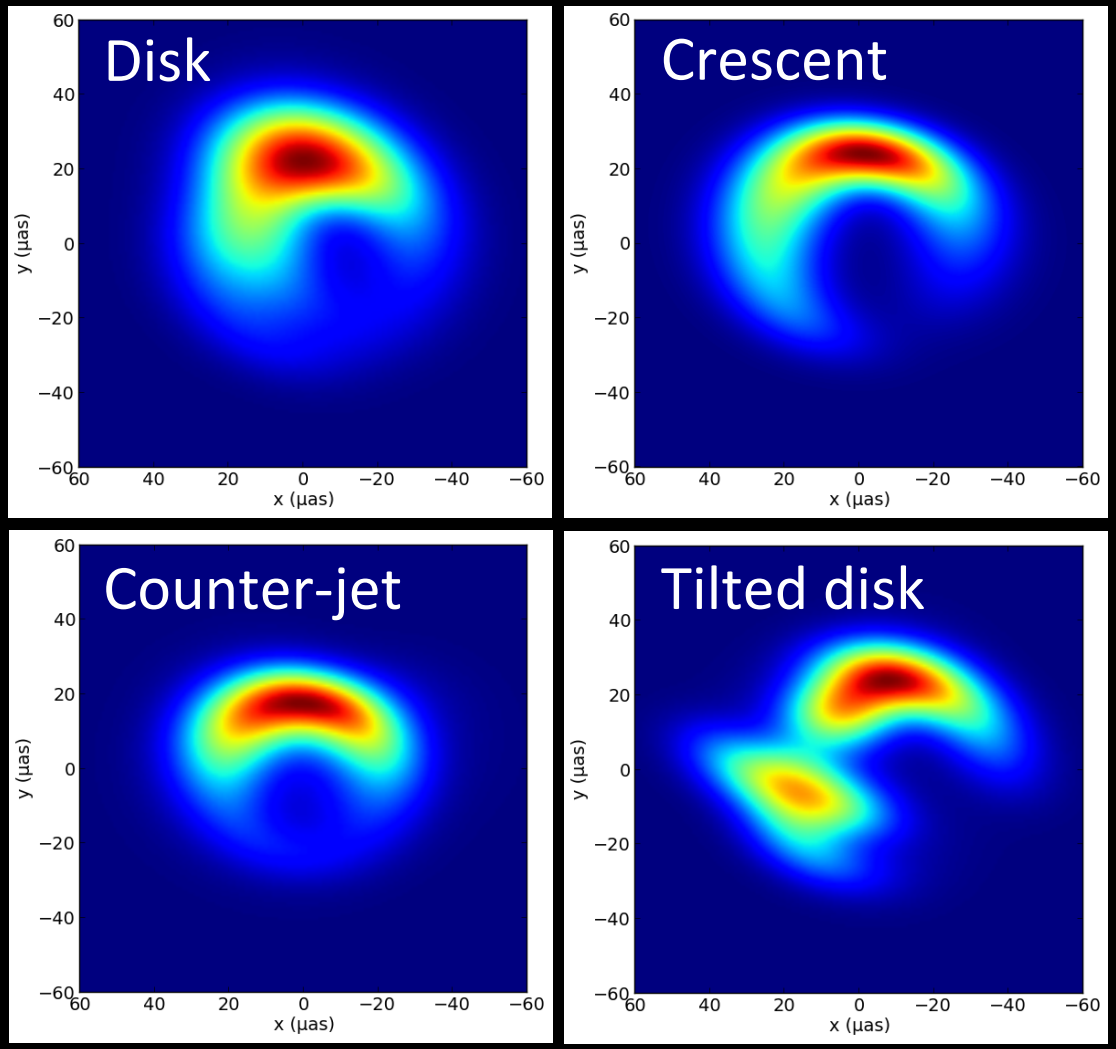


Dexter et al. (2009, 2010)

Simulation: McKinney & Blandford (2009)

Crescent Images

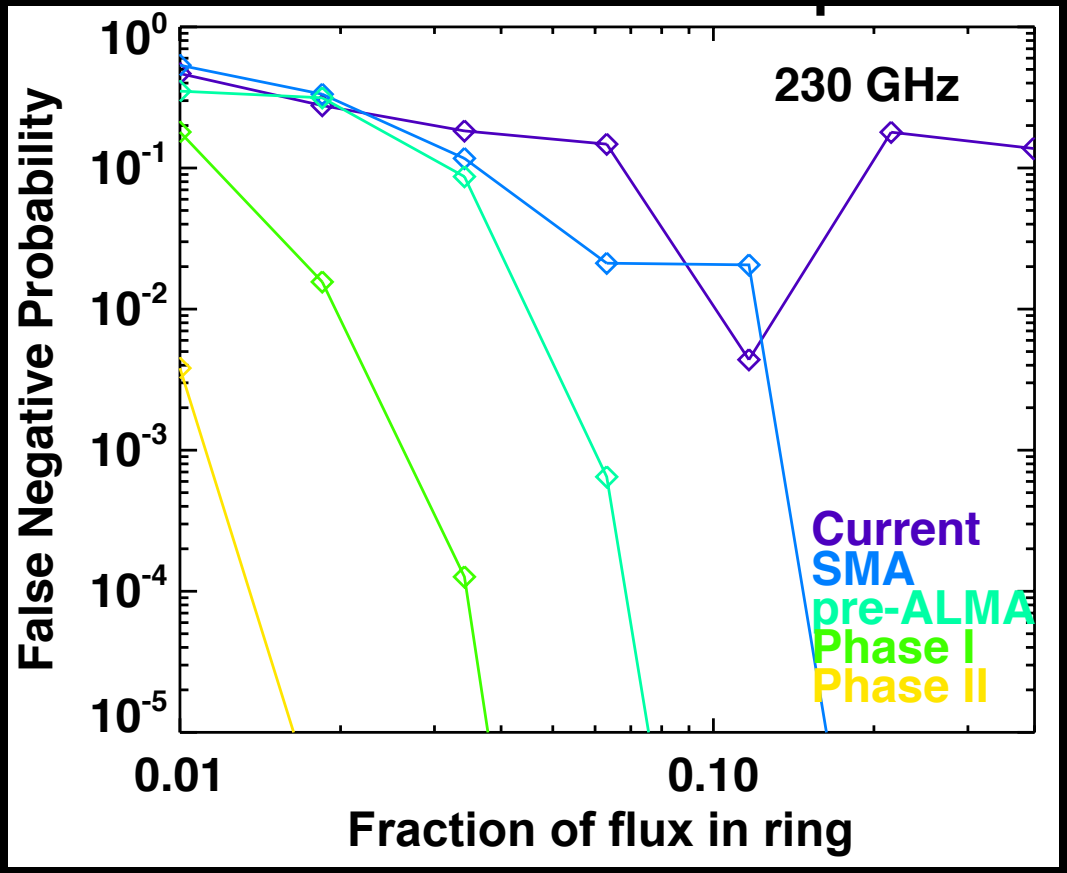
- Wide range of viable models: crescent images
- Better fits to mm-VLBI data than rings, Gaussians
  (Broderick et al. 2011, Bin Kamruddin & Dexter 2013)



When can the EHT…

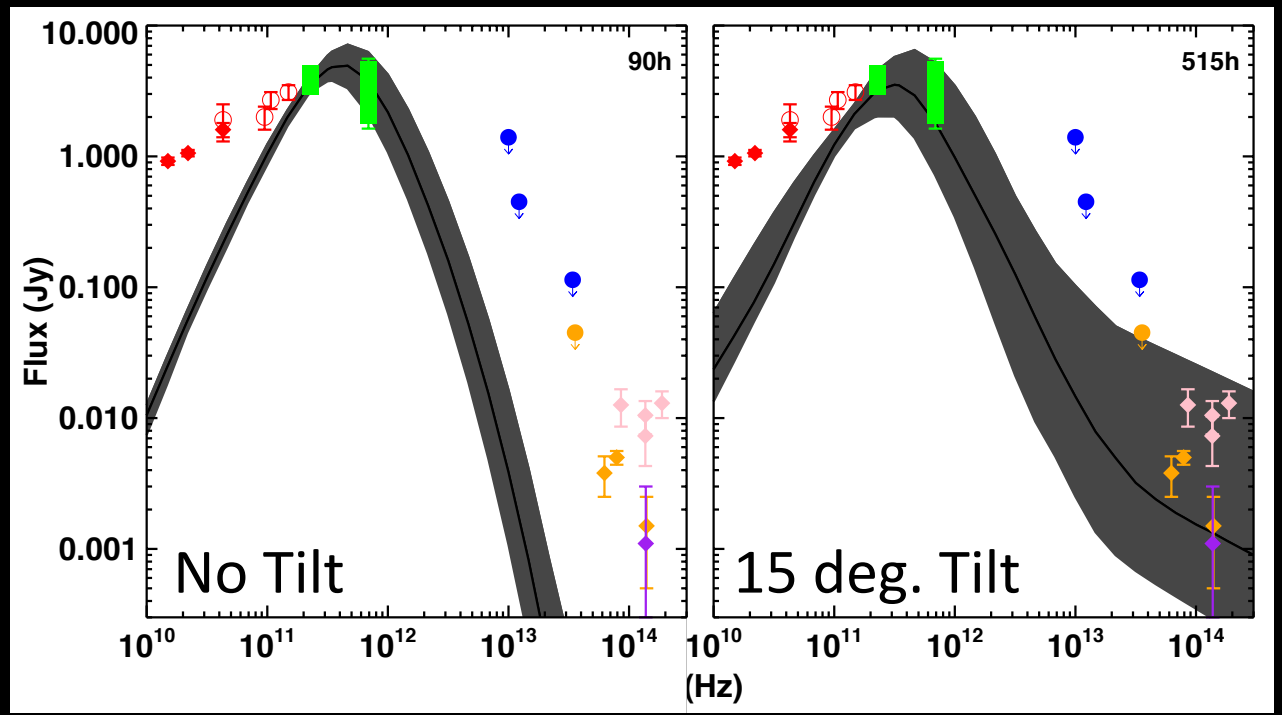
- Test the models? Now-ALMA.
- Detect photon ring? ALMA or beyond.

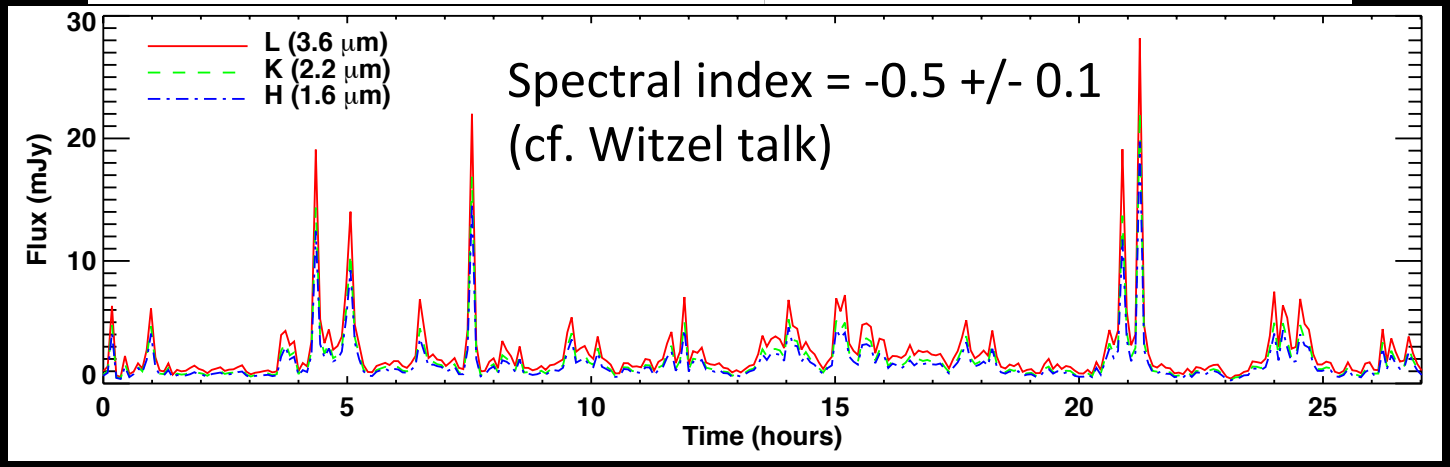
Ricarte & Dexter, in prep.



Sgr A* Flares from Tilted Disks

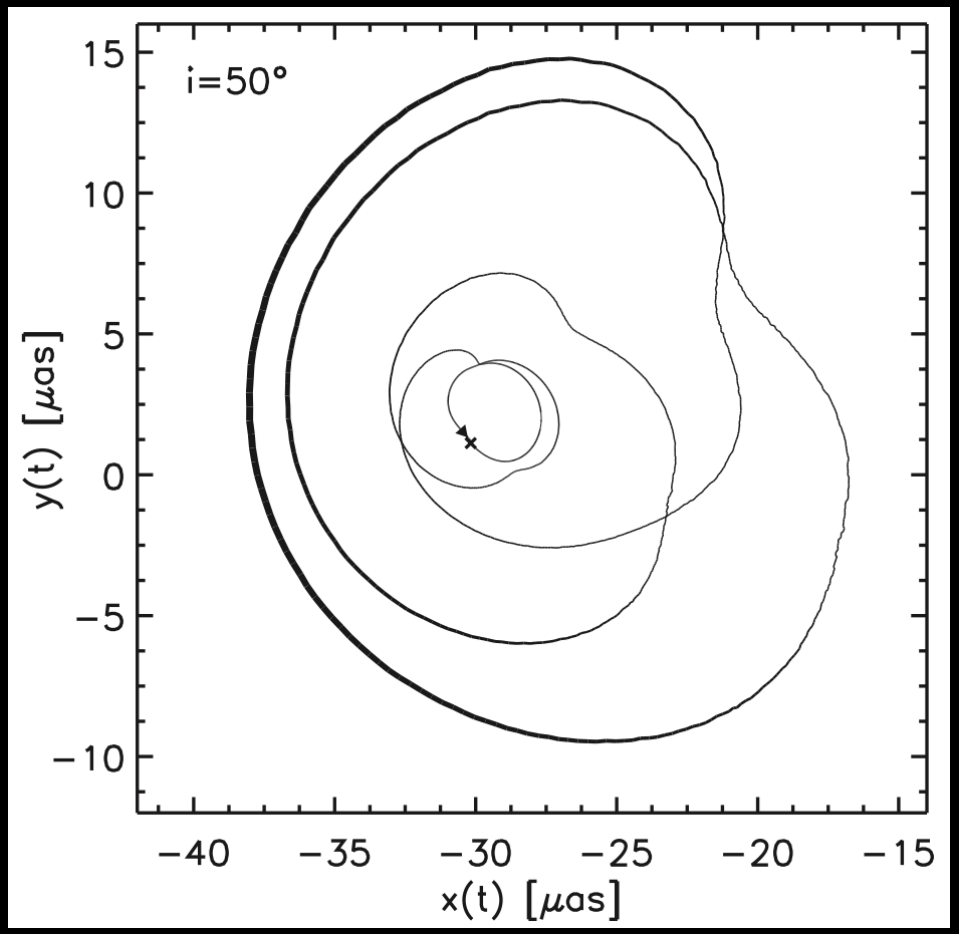
Dexter & Fragile (2013)



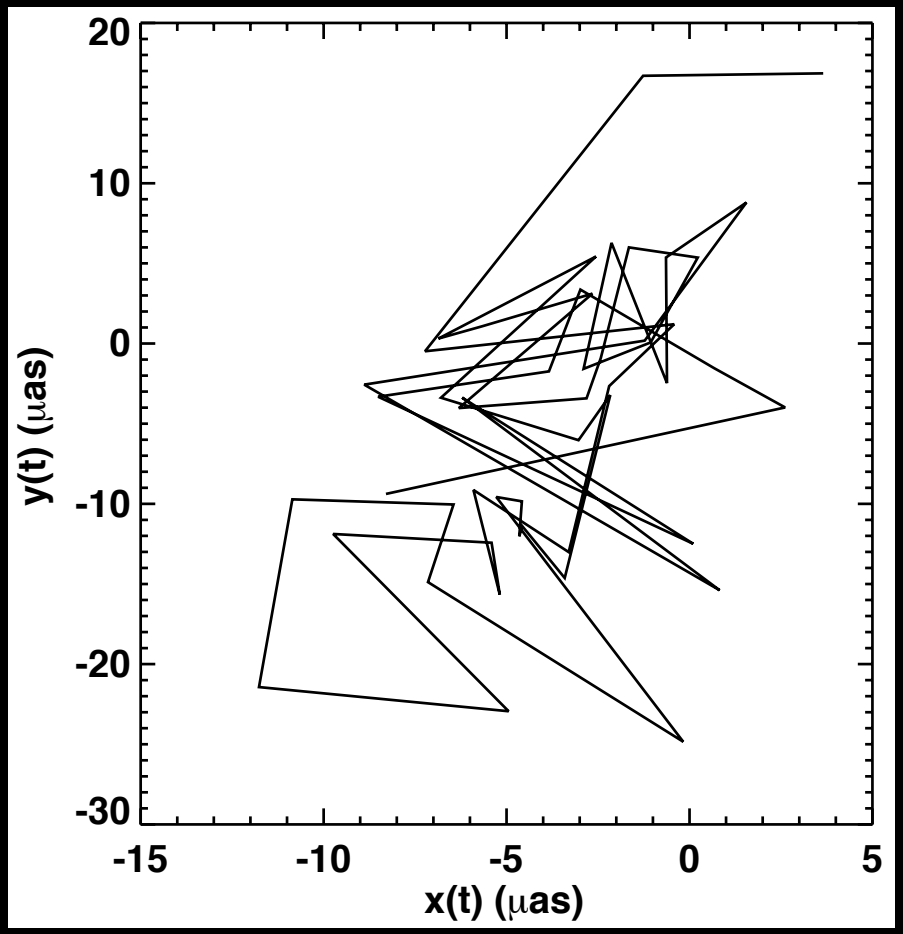


Predictions for GRAVITY

Hamaus et al. (2009)



Dexter & Fragile (2013)



Results so far

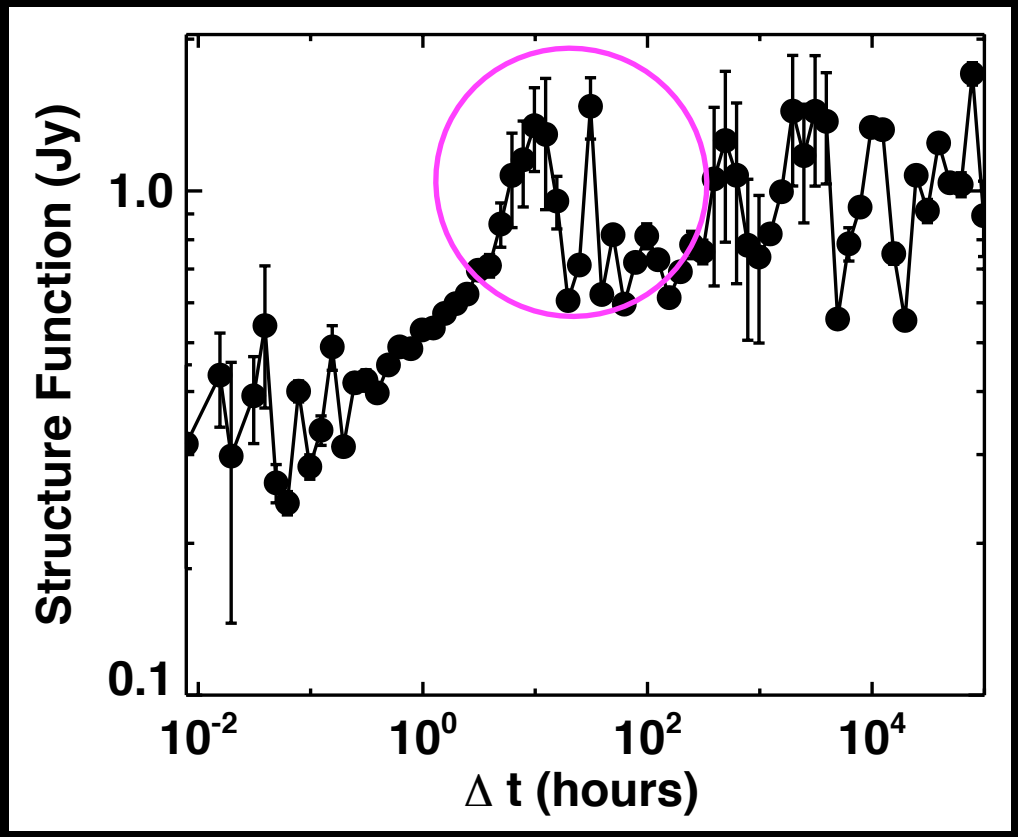
- Sgr A* (Dexter et al. 2009, 2010, Dexter & Fragile 2013)
  - GRMHD can explain mm data
  - Estimate Mdot, T_e, viewing geometry
  - mm variability from magnetic turbulence
  - NIR "flares" from standing shocks in tilted disks
- M87 (Dexter et al. 2012)
  - Disk or *counter-jet* mm images
  - Correctly predicted mm-VLBI size

- Crescent images
- Chance of BH shadow in few years with EHT

Sgr A* sub-mm variability

- Data: SMA, CARMA (Bower/Marrone), …
- Characteristic break timescale:
  τ = 8-4+7 hr (3σ)
- $\tau >> t_{orb}, \approx t_{visc}$

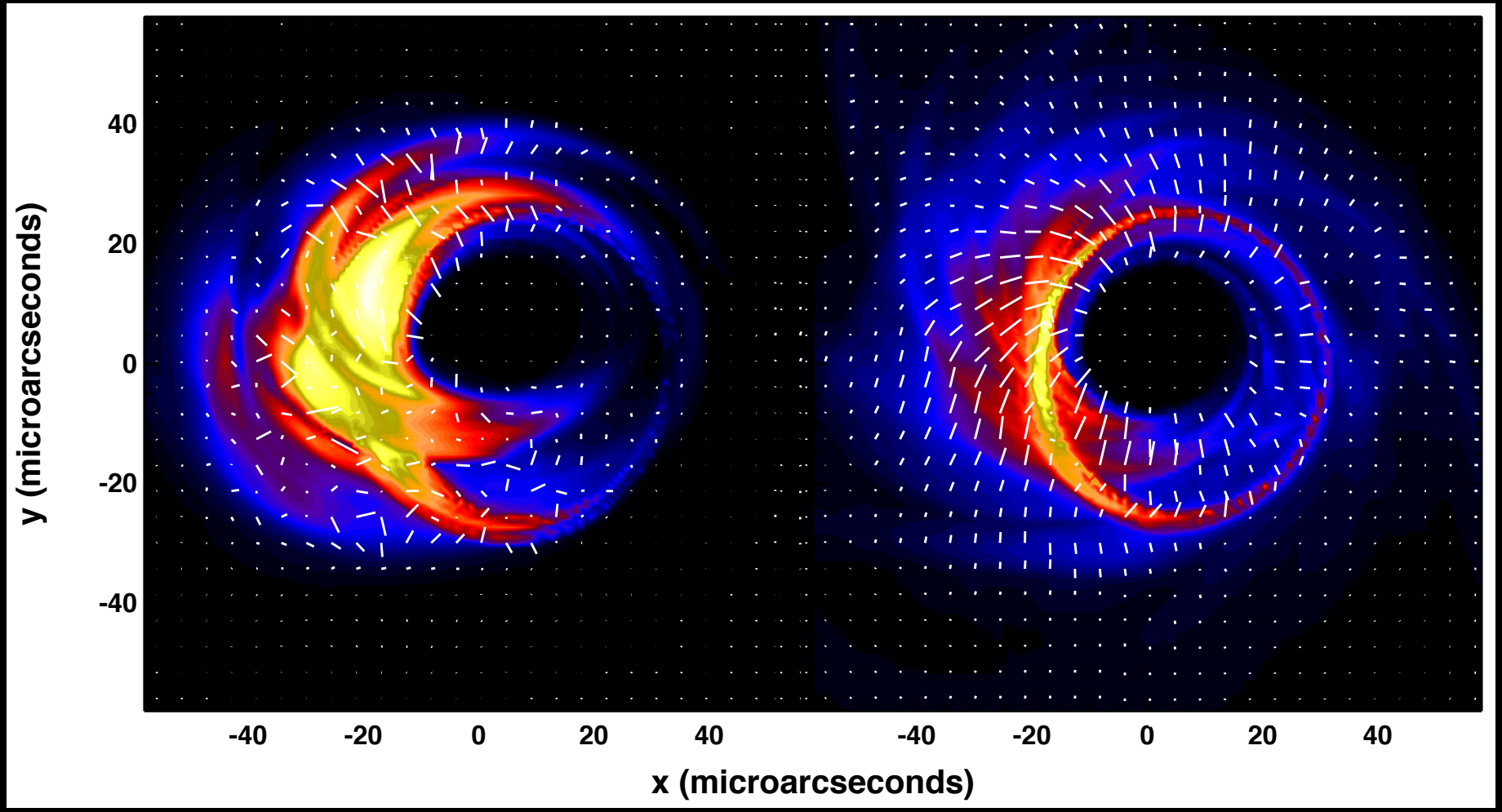
- Longer than equiv. NIR
- Compare: theory, G2



Dexter et al. (2013)

Sgr A* sub-mm polarization

- Predicted polarization maps of viable models



Dexter & McKinney (2013)

Summary

- EHT detecting event horizon scales around Sgr A* (GRAVITY soon)
- Explain current data with numerical simulations and make testable predictions
- Beautiful future

M87 Imaging

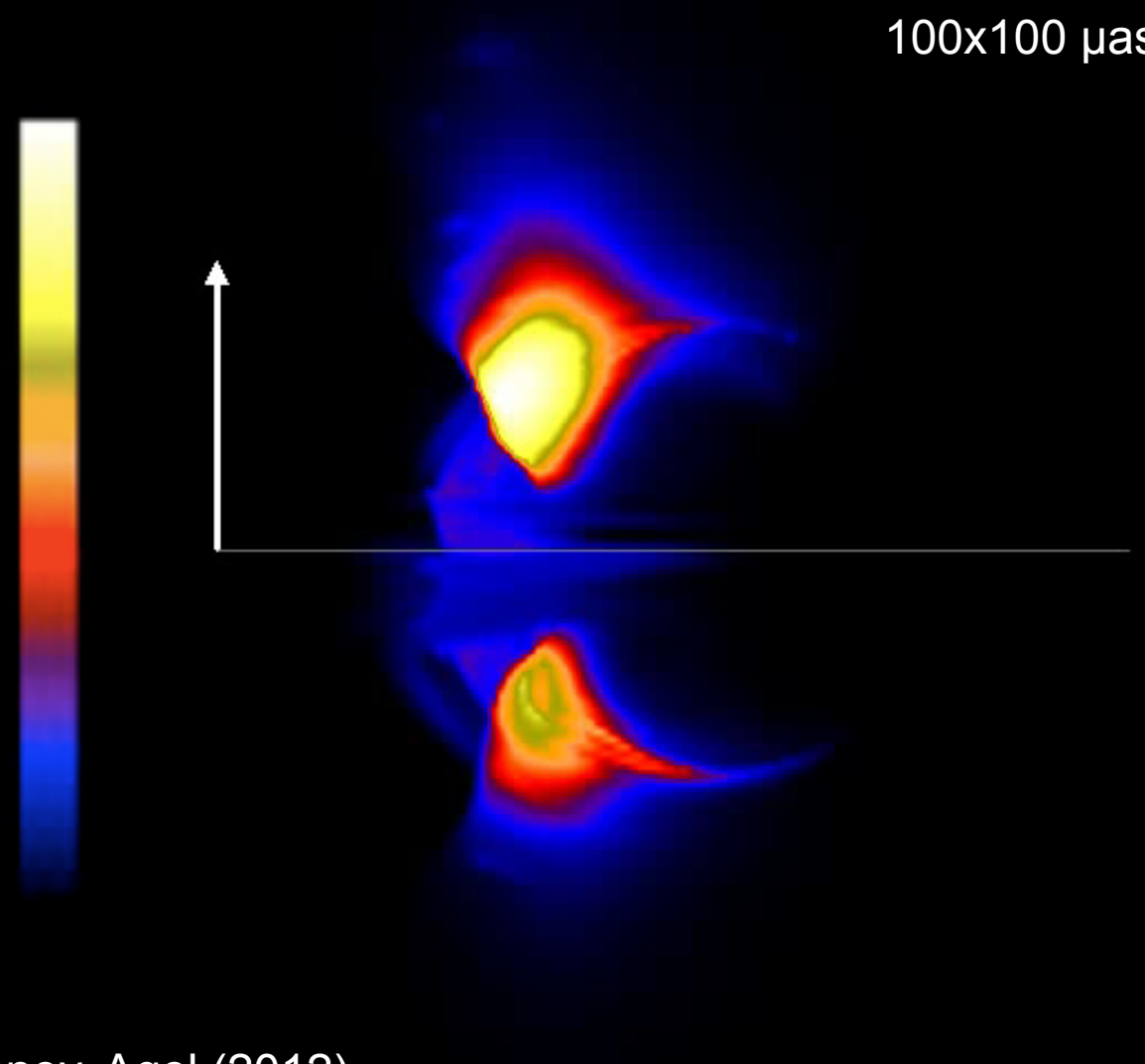
Baron & Monnier (U. Mich)

Broderick et al.

Dexter et al. (2012)

Original 4 stations 7 stations

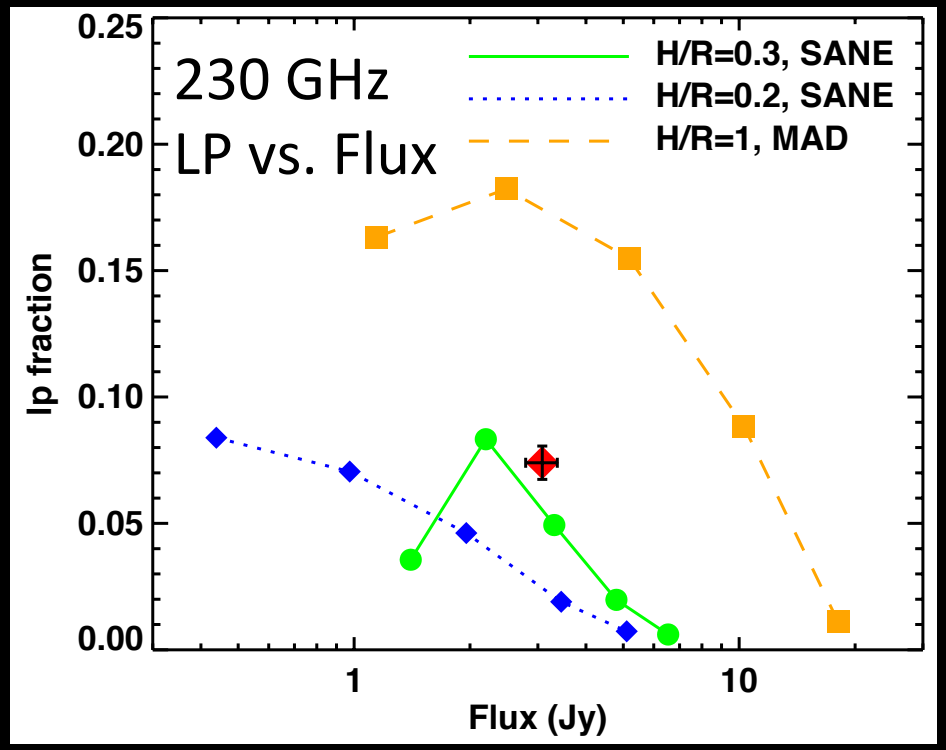
M87 (≈Sgr A*?) Jet Images

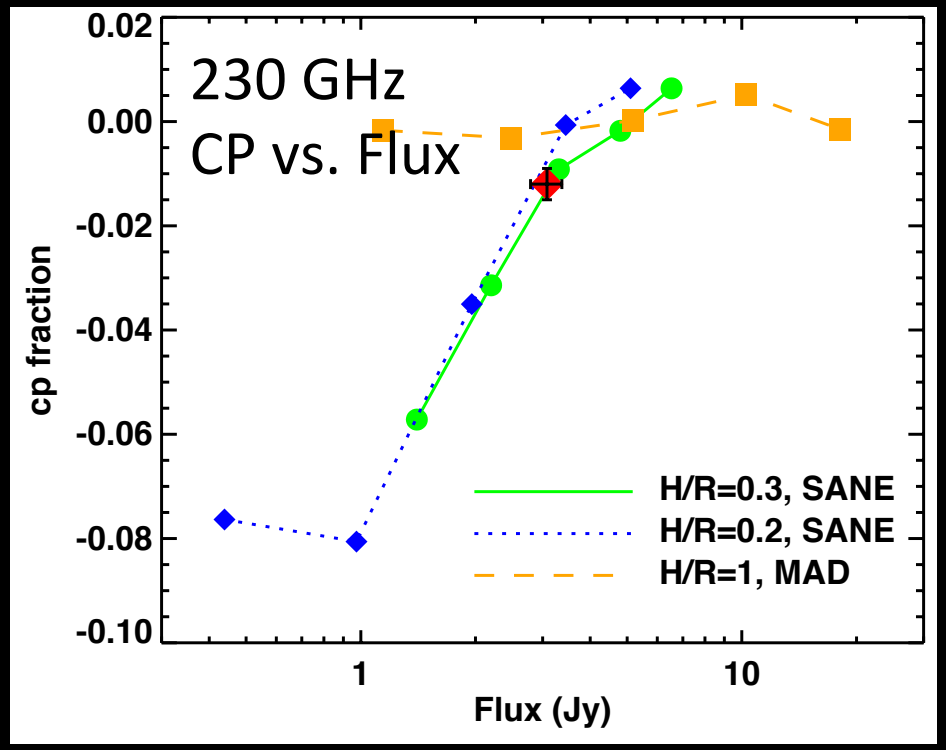


Dexter, McKinney, Agol (2012)

Sgr A* sub-mm polarization

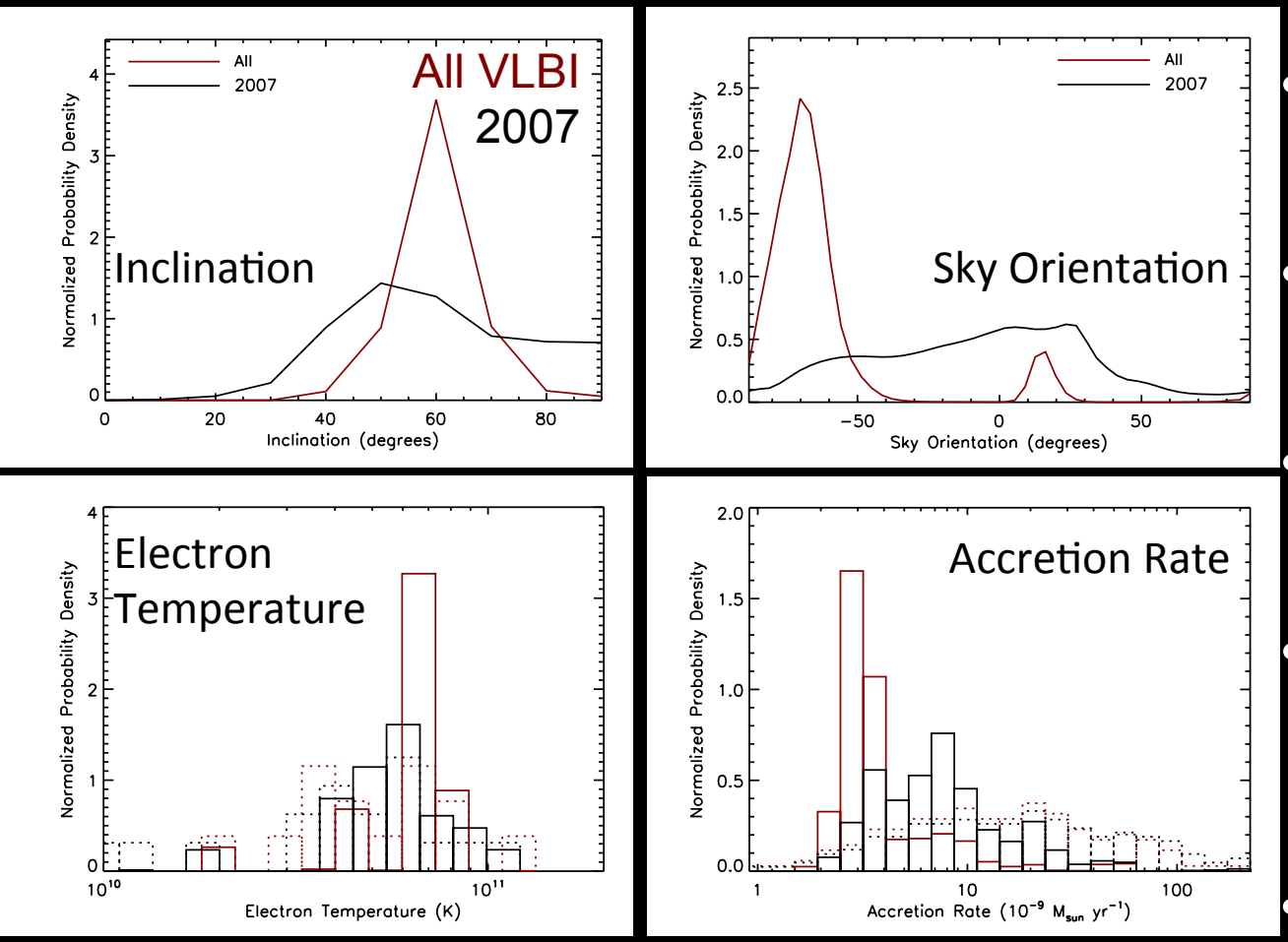
- Polarization sensitive, independent constraint (Shcherbakov et al. 2012)





Dexter & McKinney (2013)

Parameter Estimates



Dexter et al. (2010, 2011)

- $i = 60^{+15}_{-15}$ degrees
- $\xi = -70^{+86}_{-15}$ degrees
- $T_e/10^{10}$ K = 6 ± 2
- $dM/dt = 3^{+7}_{-1} \times 10^{-9}$ M_{sun} yr^{-1}
- All to 90% confidence

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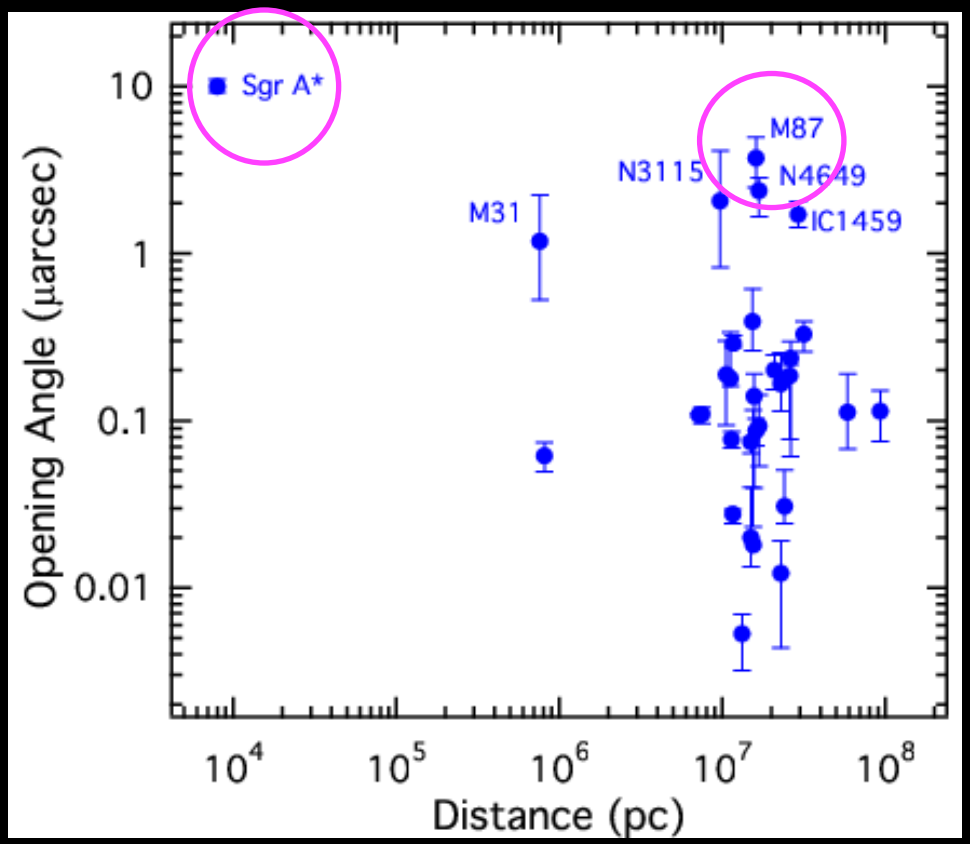
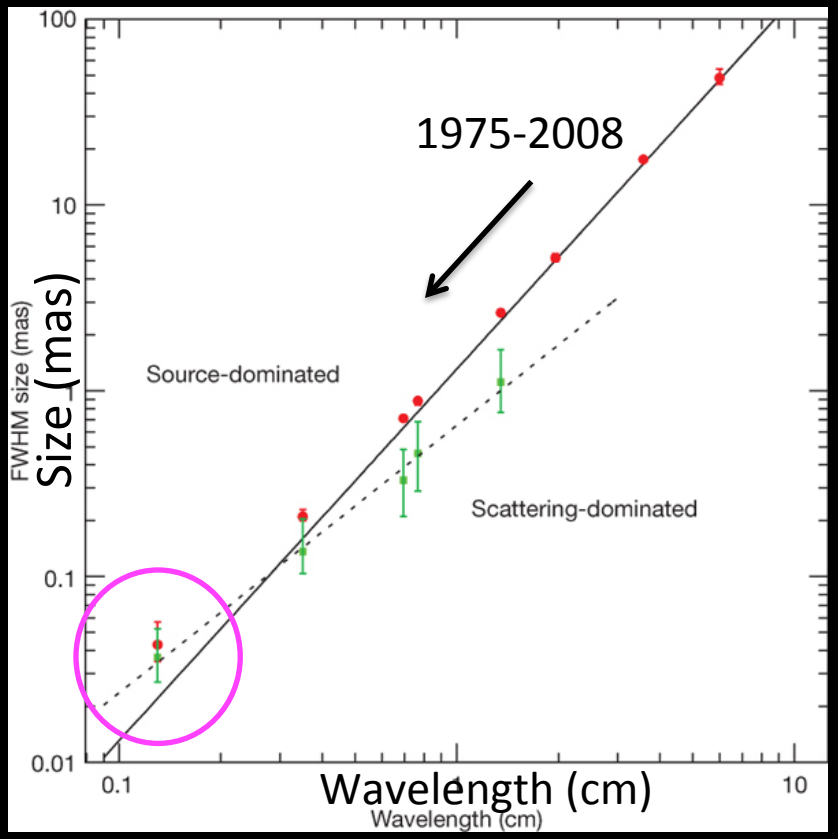
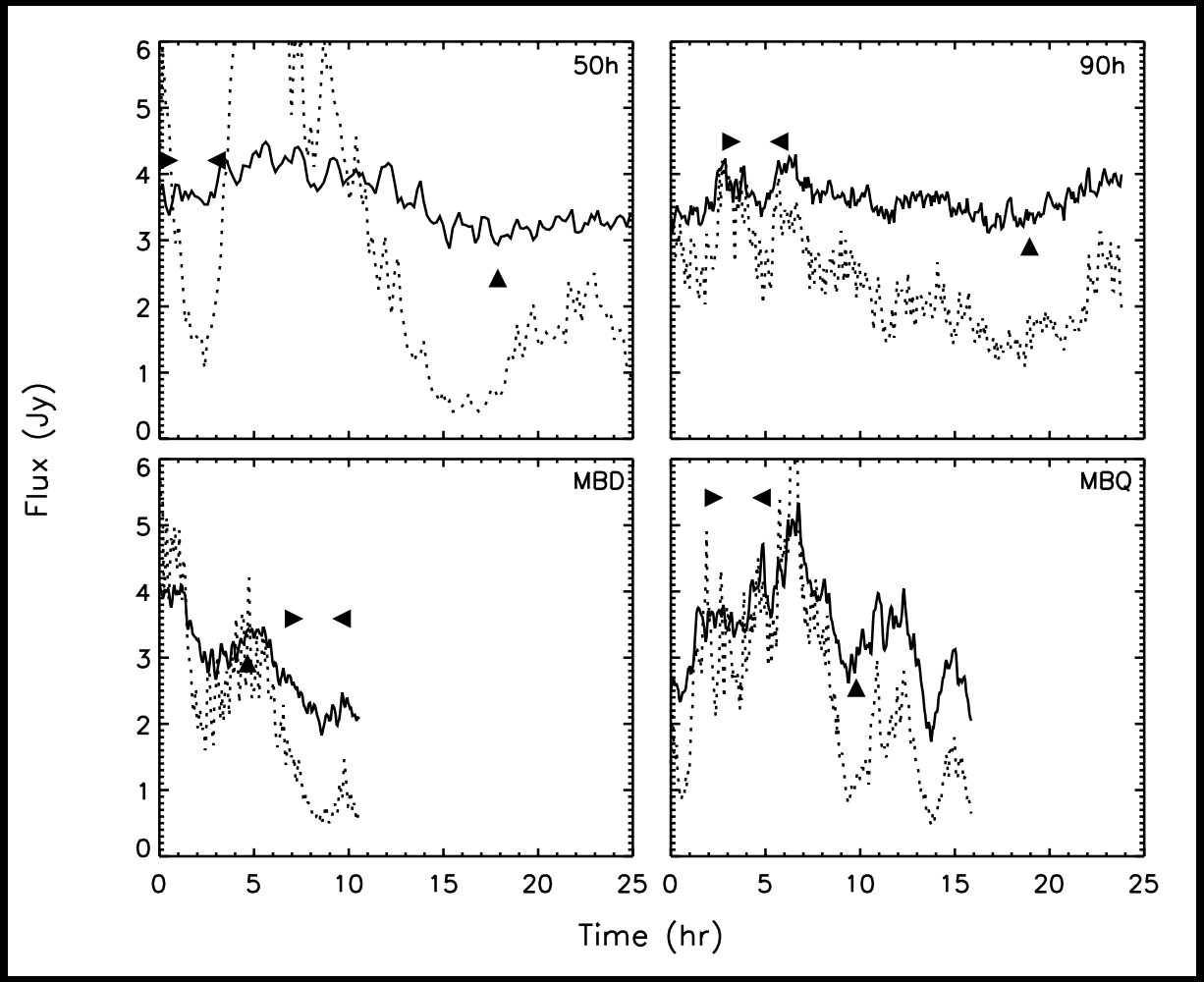


Psaltis (2008)



Doeleman et al. (2008)

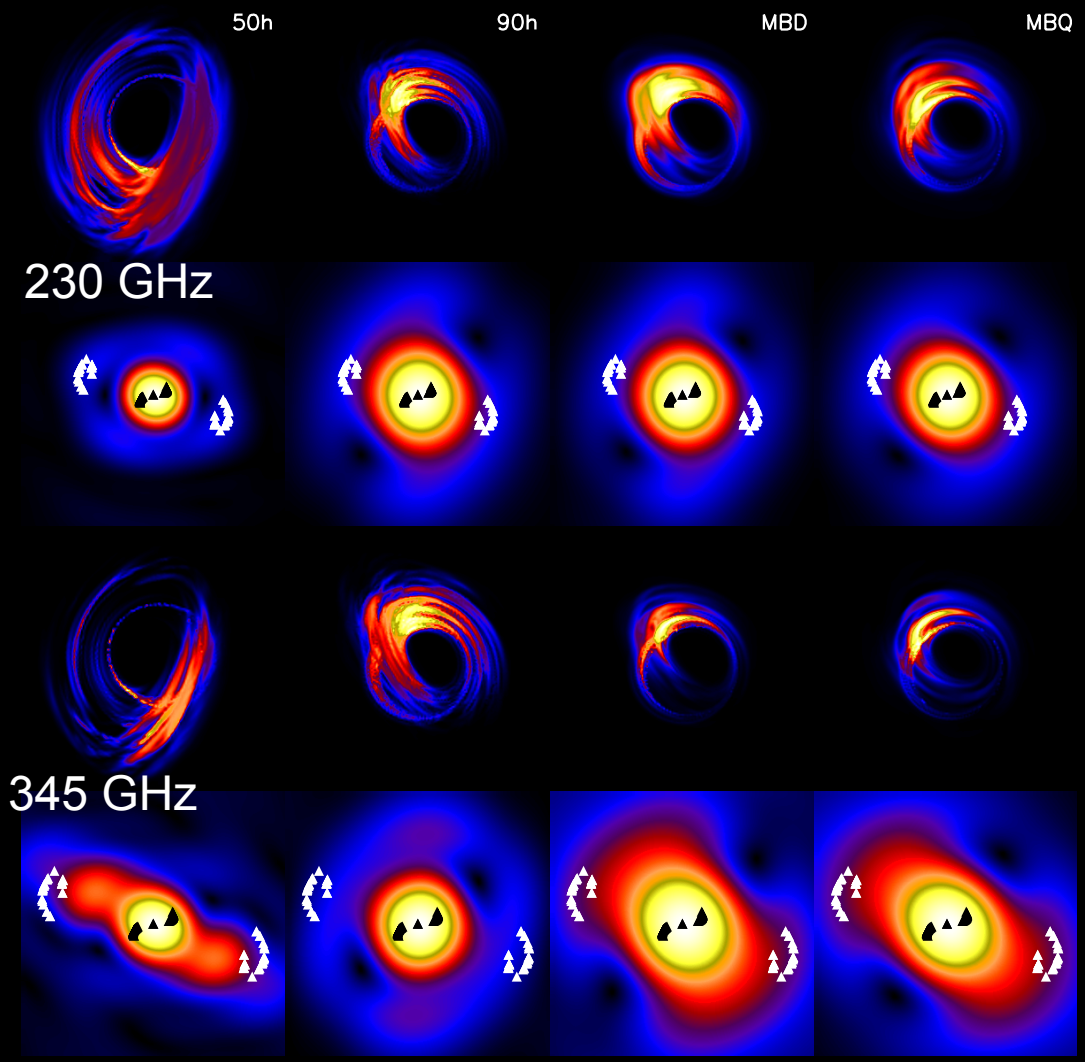
Millimeter Flares

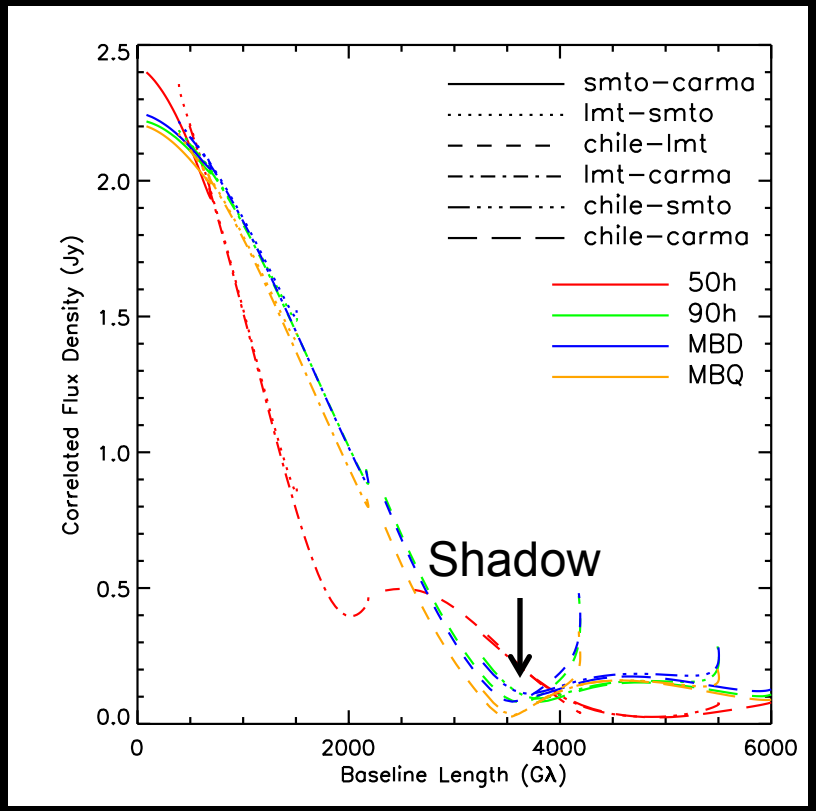


Solid – 230 GHz (1.3mm) Dotted – 690 GHz (0.4mm)

- Correlation with accretion rate
- Driven by magnetic turbulence
- Models reproduce observed mm flares
- IR/X-ray?

Crescent Images & Shadows

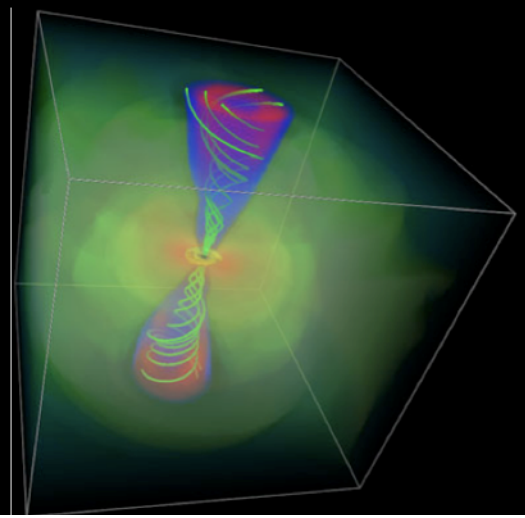




Shadow may be detected on Chile-Mexico baseline (in closure phase too)

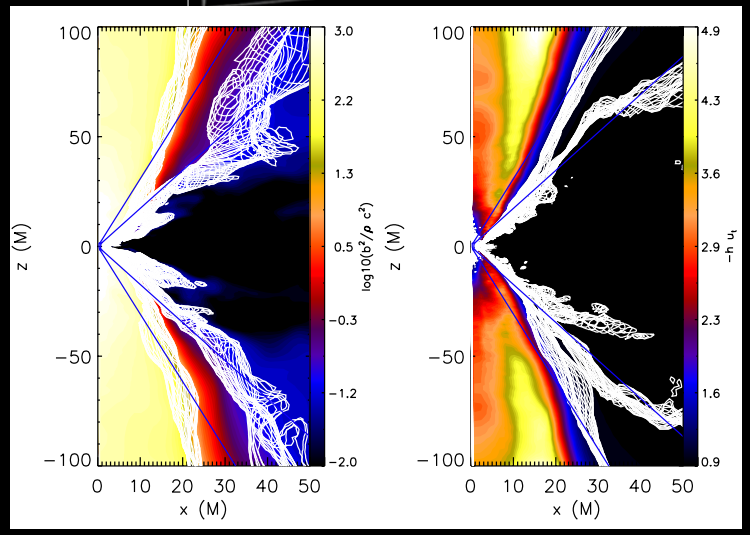
Modeling M87

McKinney & Blandford (2009)



- GRMHD starting to do relativistic magnetized jets

- Electrons: disk/jet, emission: synchrotron
  - Magnetic jet, let $u_{jet}=\eta B^2$
  - $n(\gamma)=A\gamma^{-p}$, $\gamma > \gamma_{min}$
  - Inner radii only



The Size of M87