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
Black Hole Images & Shadows

- Sensitive to viewing geometry & details of emission region

Bardeen (1973); Dexter & Agol (2009)
Broderick & Loeb (2009)
Falcke, Melia & Agol (2000)
Bromley, Melia & Liu (2001)
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)

Ray Tracing à®® Schnittman et al. (2006)
Sgr A* Disk Images

100x100 µas

Dexter et al. (2009, 2010)

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.

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Ricarte & Dexter, in prep.

![Graph showing False Negative Probability vs. Fraction of flux in ring for different frequencies and phases.](image)
Sgr A* Flares from Tilted Disks

Dexter & Fragile (2013)

Spectral index = -0.5 +/- 0.1
(cf. Witzel talk)
Predictions for GRAVITY

Hamaus et al. (2009)

\[ y(t) \ (\mu\text{as}) \]
\[ i=50^\circ \]

Dexter & Fragile (2013)

\[ x(t) \ (\mu\text{as}) \]
Results so far

• **Sgr A*** (Dexter et al. 2009, 2010, Dexter & Fragile 2013)
  – GRMHD can explain mm data
  – Estimate $M_{\text{dot}}$, $T_e$, 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: \( \tau = 8-4+7 \text{ hr (3\(\sigma\))} \)
- \( \tau \gg t_{\text{orb}}, \approx t_{\text{visc}} \)
- 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

Broderick et al.

Dexter et al. (2012)

Original

4 stations

7 stations

Baron & Monnier (U. Mich)
M87 (≈Sgr A*?) Jet Images

100x100 µas

Dexter, McKinney, Agol (2012)
Sgr A* sub-mm polarization

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

Dexter & McKinney (2013)
Parameter Estimates

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

Dexter et al. (2010, 2011)
The Sgr A* Black Hole Laboratory

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Millimeter Flares

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

Solid – 230 GHz (1.3mm)  Dotted – 690 GHz (0.4mm)
Crescent Images & Shadows

Shadow may be detected on Chile-Mexico baseline (in closure phase too)
Modeling M87

• GRMHD starting to do relativistic magnetized jets

• Electrons: disk/jet, emission: synchrotron
  – Magnetic jet, let $u_{\text{jet}} = \eta B^2$
  – $n(\gamma) = A\gamma^{-p}$, $\gamma > \gamma_{\text{min}}$
  – Inner radii only
The Size of M87

Size = 33-44 μas

Doeleman et al. (2012)

Size = 40 μas