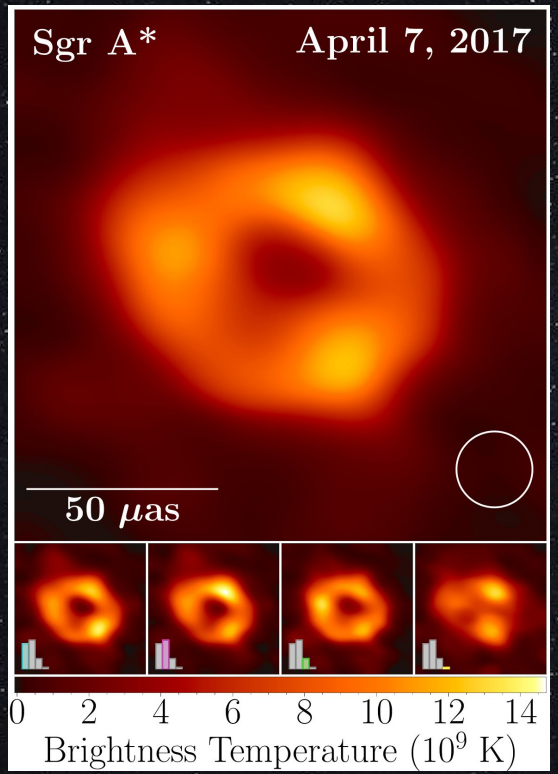
Magnetically arrested disk flux eruption events to describe SgrA* flares

Eleni Antonopoulou

National and Kapodistrian University of Athens,
Department of Astrophysics, Astronomy and Mechanics
Academy of Athens,
Research Center for Astronomy and Applied Mathematics

MAD disk flux eruption events to describe SgrA* flares



Constraint/Model	BHAC		
	Thermal	$\kappa(\sigma, \beta)$	$\kappa = 3.5$ $\varepsilon = 0.05, 0.1, 0.2$
230 GHz size	0.98	0.99	0.98, 0.98, 0.98
VA morphology	0.83	0.80	0.81, 0.81, 0.78
M-ring diameter	0.65	0.69	0.66, 0.66, 0.67
M-ring width	0.21	0.21	0.24, 0.23, 0.23
M-ring asym.	0.95	0.97	0.95, 0.95, 0.94
86 GHz flux	0.68	0.75	0.67, 0.66, 0.63
86 GHz size	0.59	0.57	0.56, 0.56, 0.55
2.2 μm flux	0.55	0.35	0.14, 0.12, 0.12
X-ray flux	0.70	...	...
Light-curve variability	0.27	0.30	0.47, 0.47, 0.46
4 Gλ variability	0.72	0.60	0.74, 0.73, 0.71
EHT constraints	0.19	0.17	0.17, 0.16, 0.15
Non-EHT constraints	0.19	0.12	0.01, 0.0, 0.0
Variability constraints	0.27	0.28	0.42, 0.42, 0.42

E.H.T. Collaboration 2022

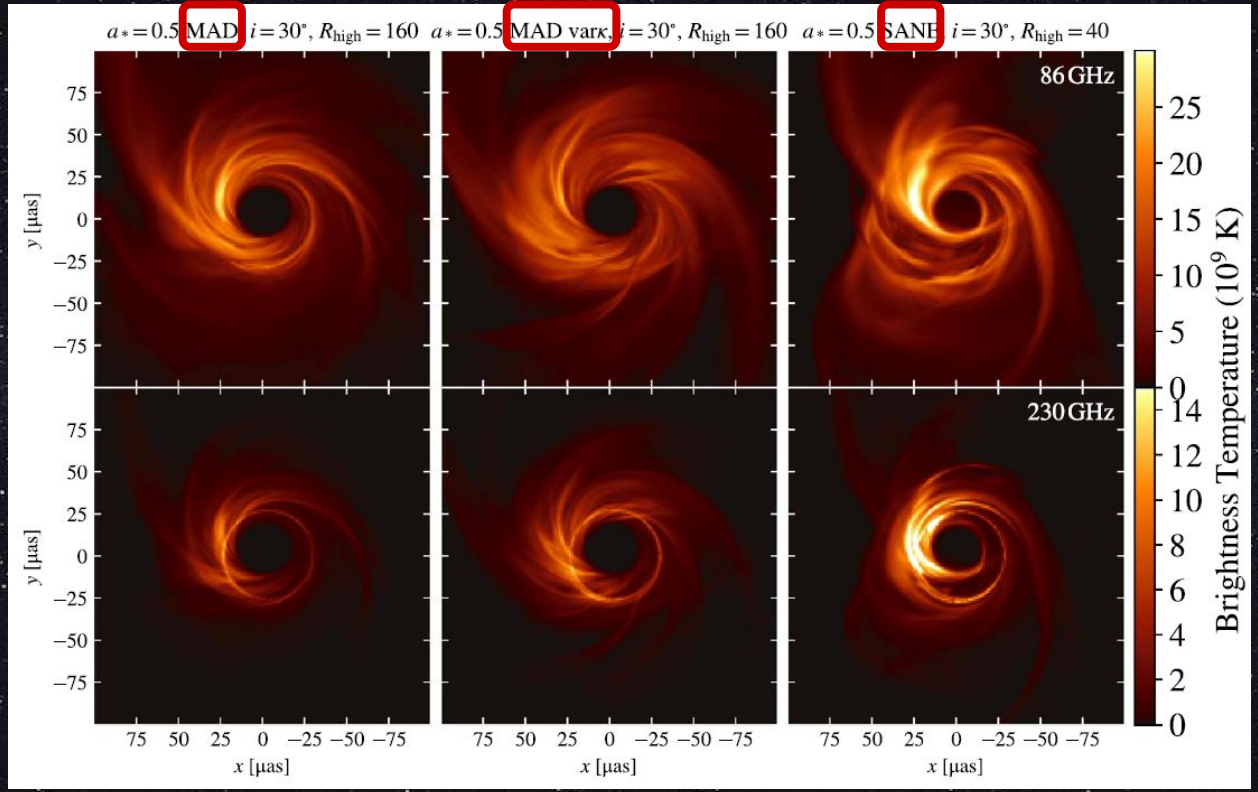
MAD disk flux eruption events to describe SgrA* flares

Thermal

Critical β

Kappa

Power-law



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Rhigh

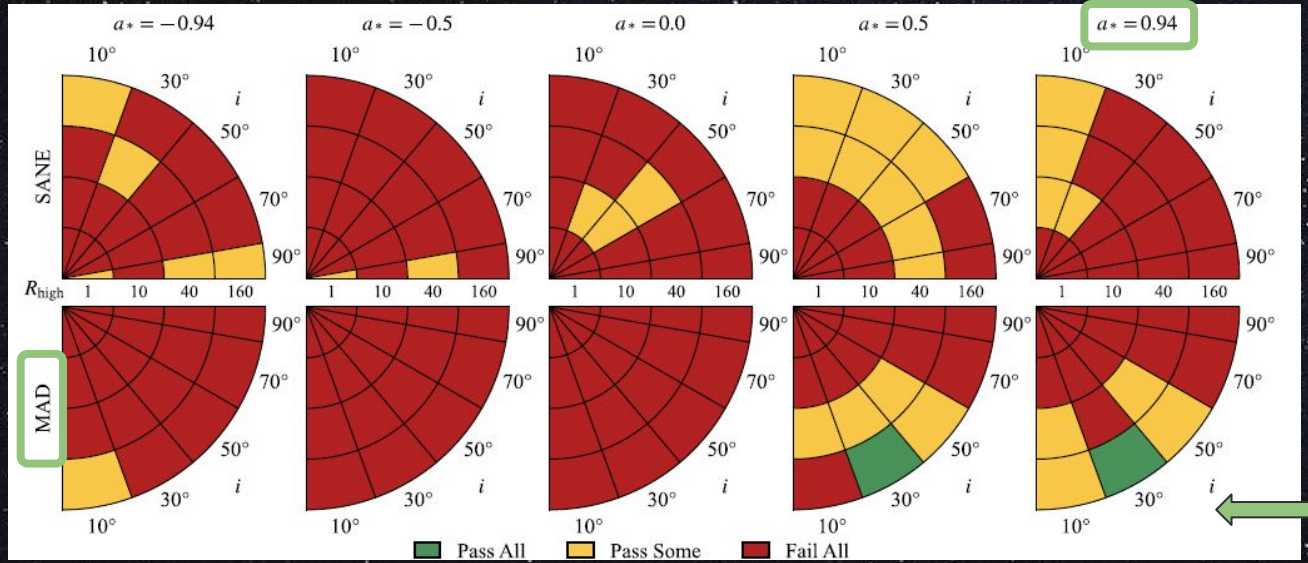
Inclination

MAD

SANE

MAD disk flux eruption events to describe SgrA* flares

Motivation: Best-bet region



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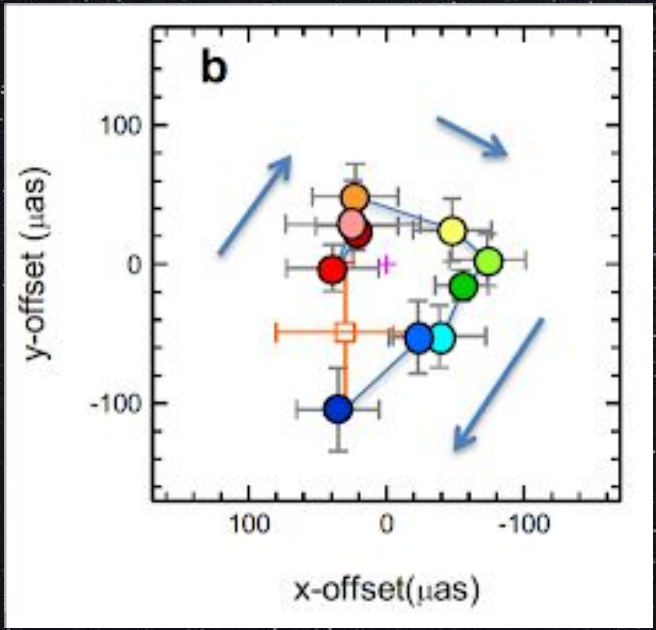
BHAC

- Kerr black hole a=0.94
- MAD model, counterclockwise rotation

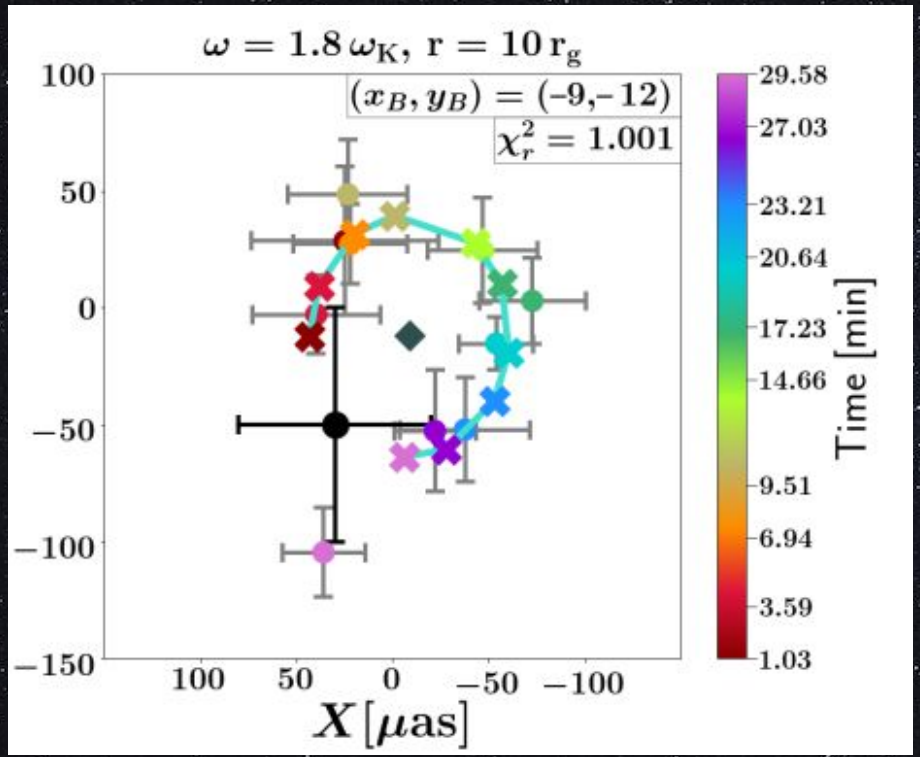
MAD disk flux eruption events to describe SgrA* flares



GRAVITY Collaboration 2018

- July 22 2018: GRAVITY observed a bright flare in the vicinity of SgrA*
- Positional changes ~120 μas in ~30 min → ~0.3c
- Maps 50–70% of a closed clockwise loop
- Approaching the flux of S2 (15 mJy)

MAD disk flux eruption events to describe SgrA* flares



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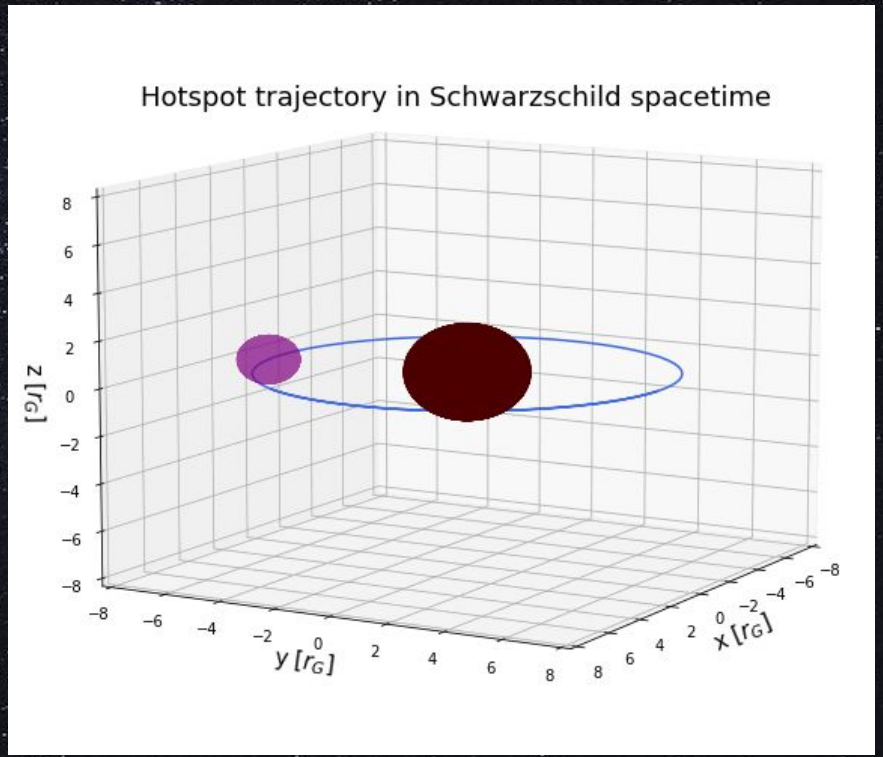

Super − Keplerian Circular Trajectory

MAD flux eruption events to describe SgrA* flares

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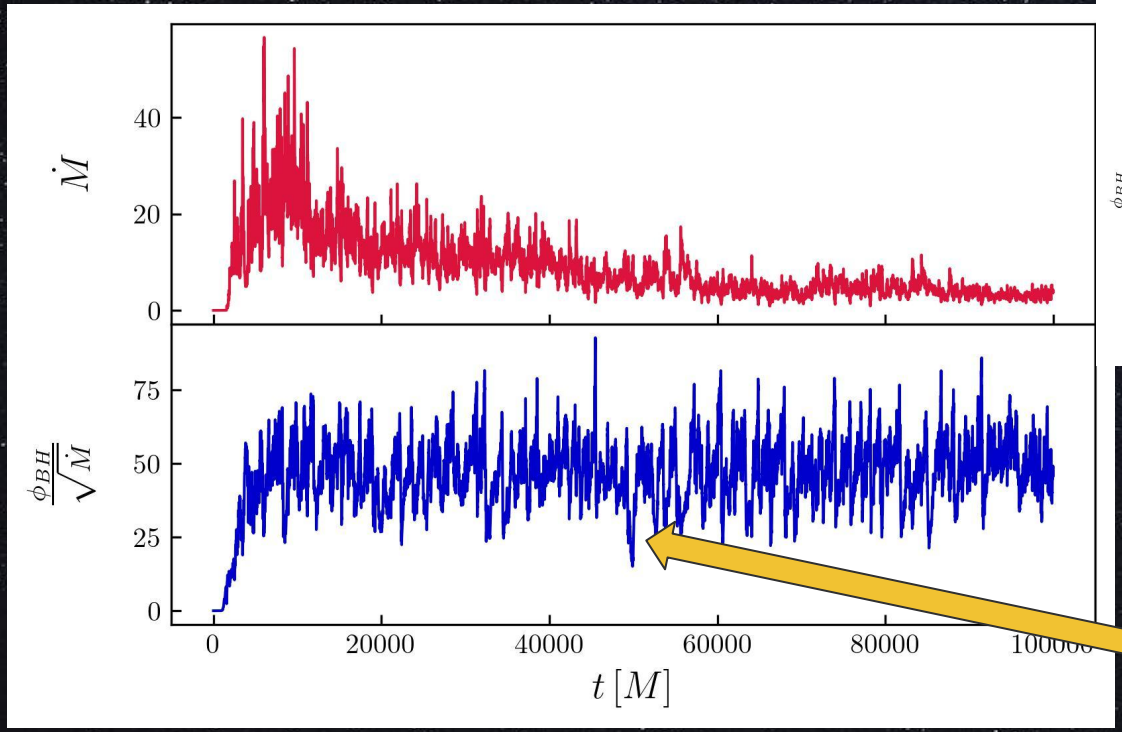
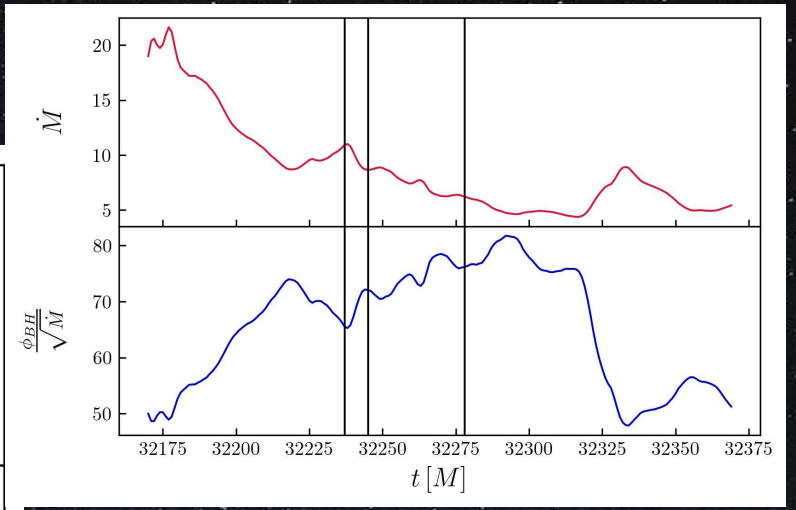
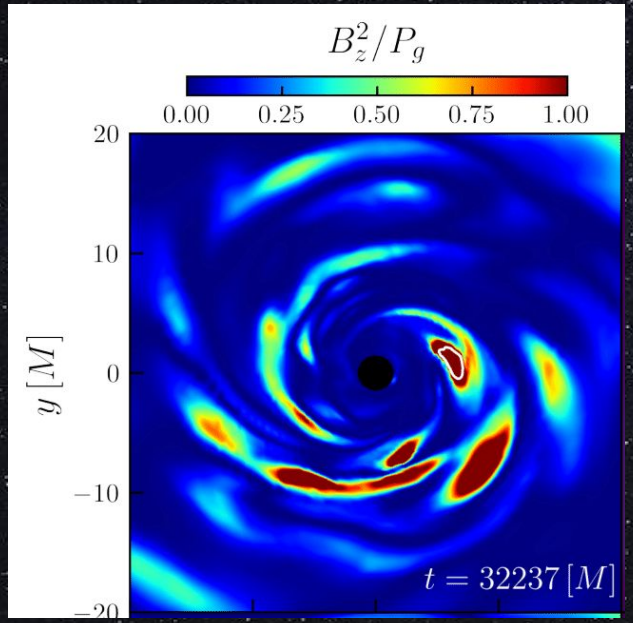




Flux eruption events in MAD simulations

MAD flux eruption events to describe SgrA* flares



How do we identify active regions?

- Significant magnetic field strength

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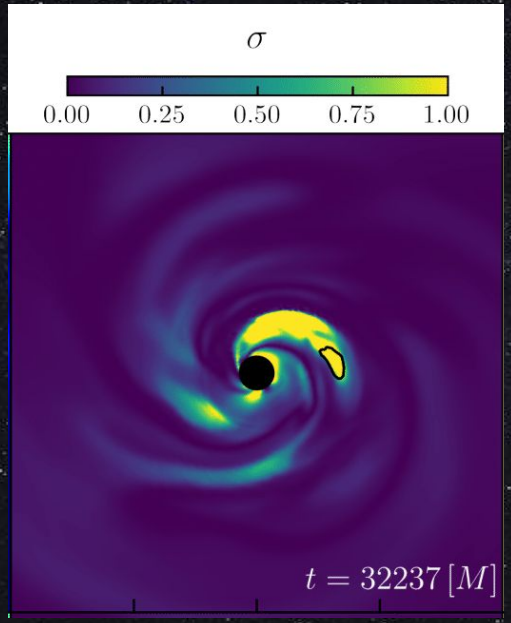
MAD flux eruption events to describe SgrA* flares



How do we identify active regions?

- Significant magnetic field strength
- High magnetization

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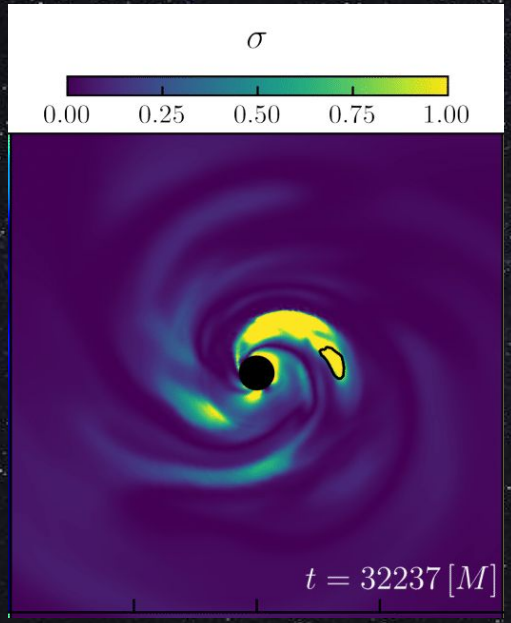
MAD flux eruption events to describe SgrA* flares



How do we identify active regions?

- Significant magnetic field strength
- High magnetization
- Equatorial plane: σ Bz**2 / Pg

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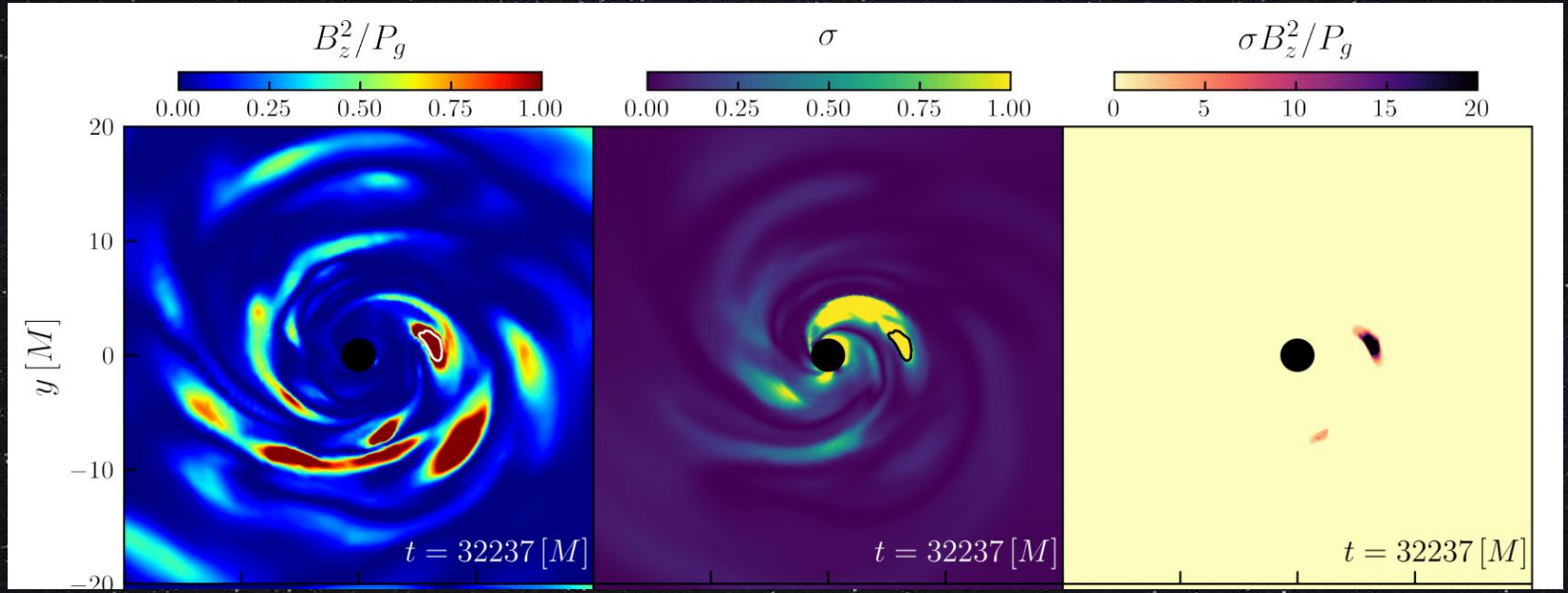

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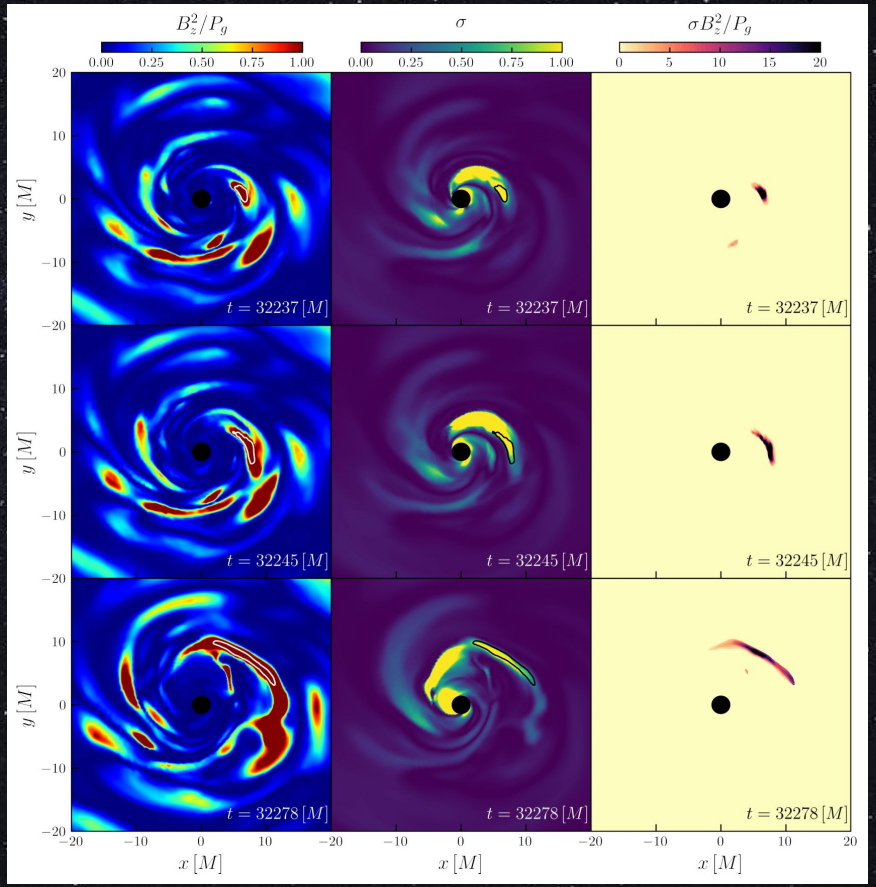
MAD flux eruption events to describe SgrA* flares

We track the evolution of the active region on the equatorial plane



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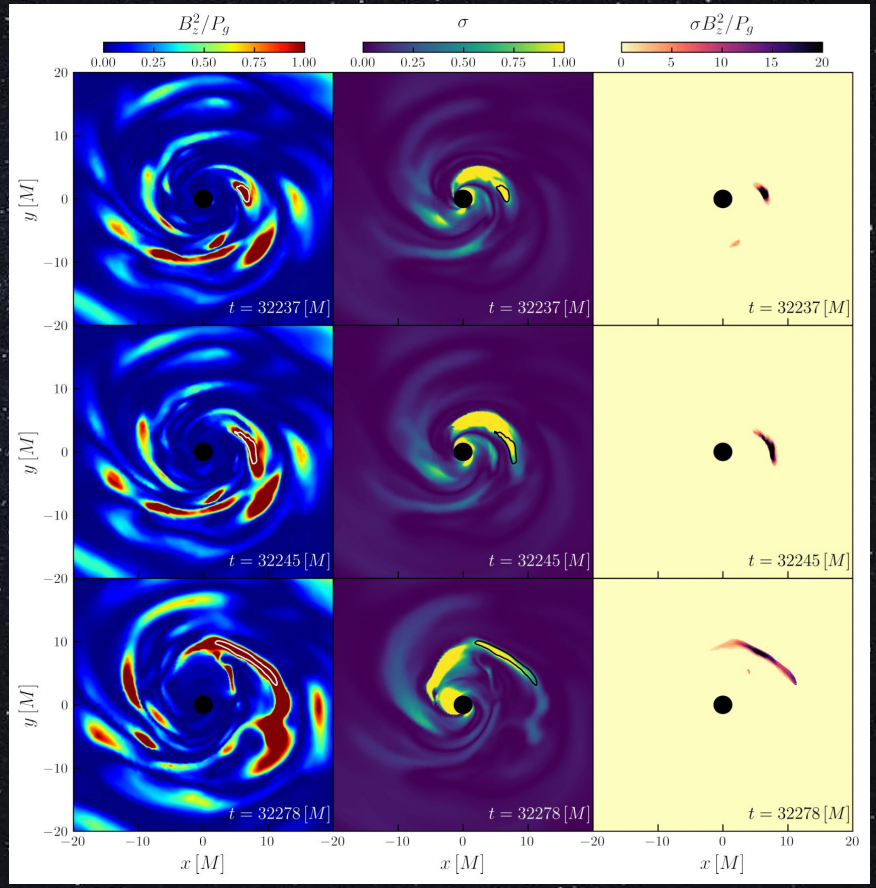
MAD flux eruption events to describe SgrA* flares

We track the evolution of the active region on the equatorial plane

1. Outward motion, toward larger orbital radii
   ur ~ 0.1c



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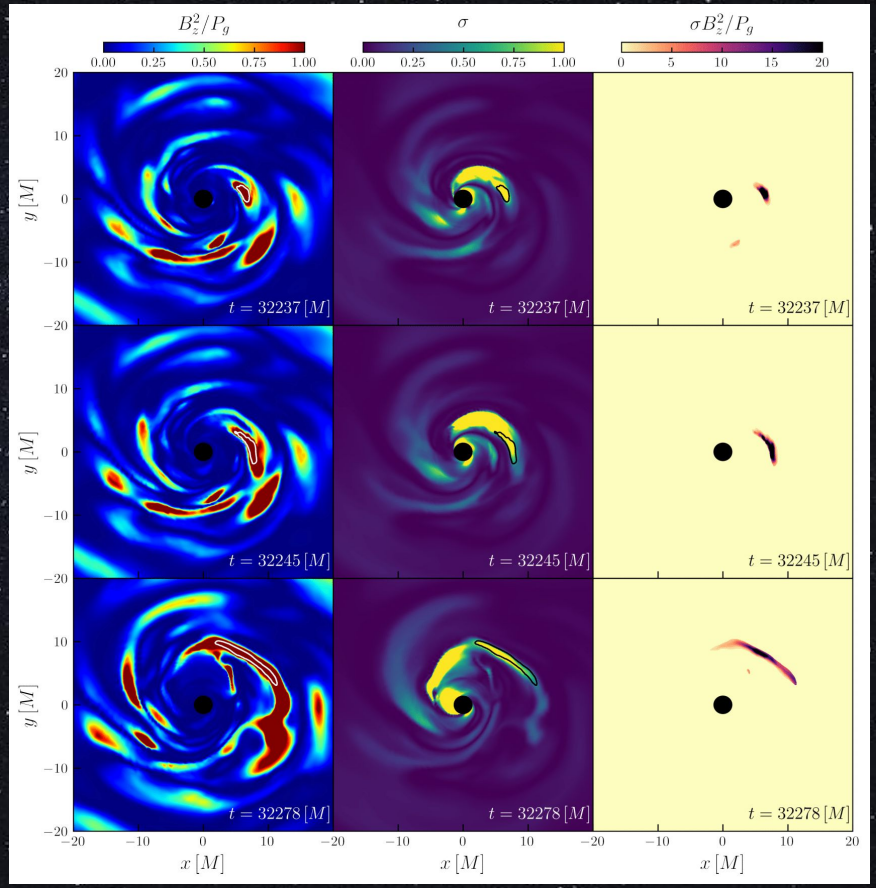
MAD flux eruption events to describe SgrA* flares

We track the evolution of the active region on the equatorial plane

1. Outward motion, toward larger orbital radii
   ur ~ 0.1c

2. Counterclockwise orbital rotation, due the accretion disk's rotation
   uφ ~ 0.1uK − 0.4uK



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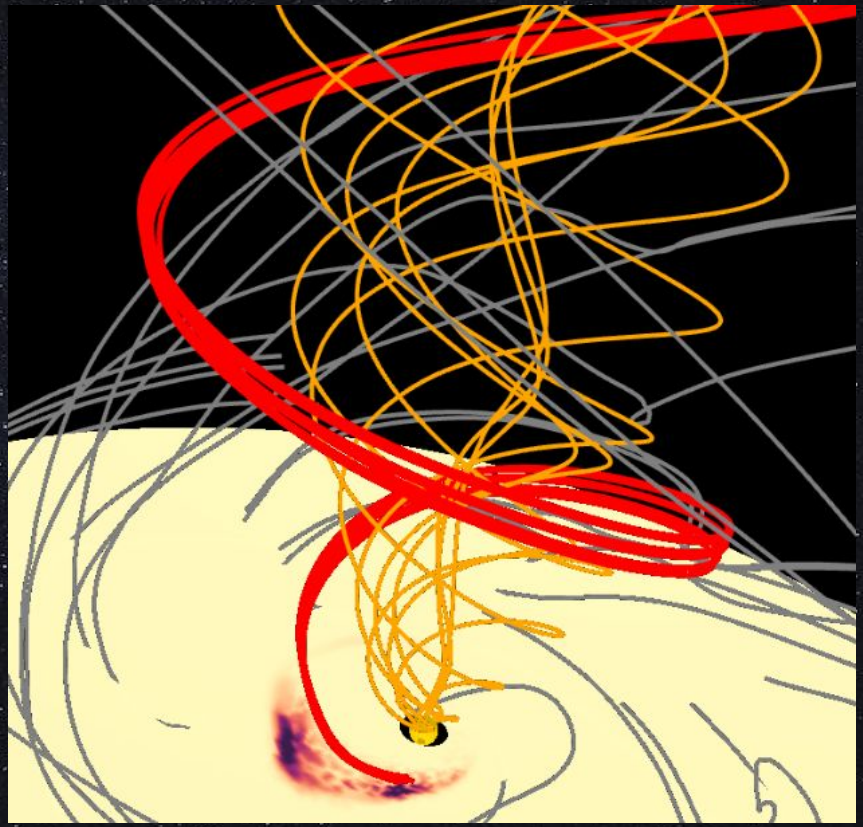
MAD flux eruption events to describe SgrA* flares

We examine the 3D morphology of the energetic flux tubes generated during the flux eruption event

Newly generated flux bundles

Disk's magnetic field lines

Magnetized funnel field lines



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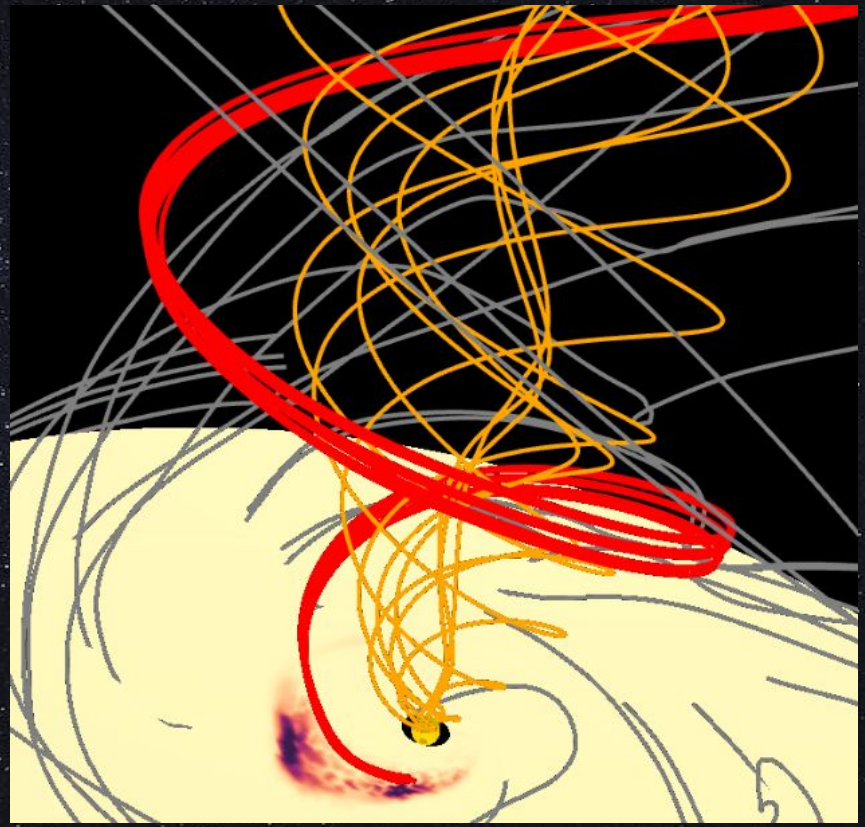
MAD flux eruption events to describe SgrA* flares

Basic assumptions:

- During magnetic reconnection, the released magnetic energy generates energetic particles,
- Forming hot spots on the equatorial plane of the disk,
- These hot spots are ejected outward and travel along highly magnetized flux tubes at a fraction of the speed of light



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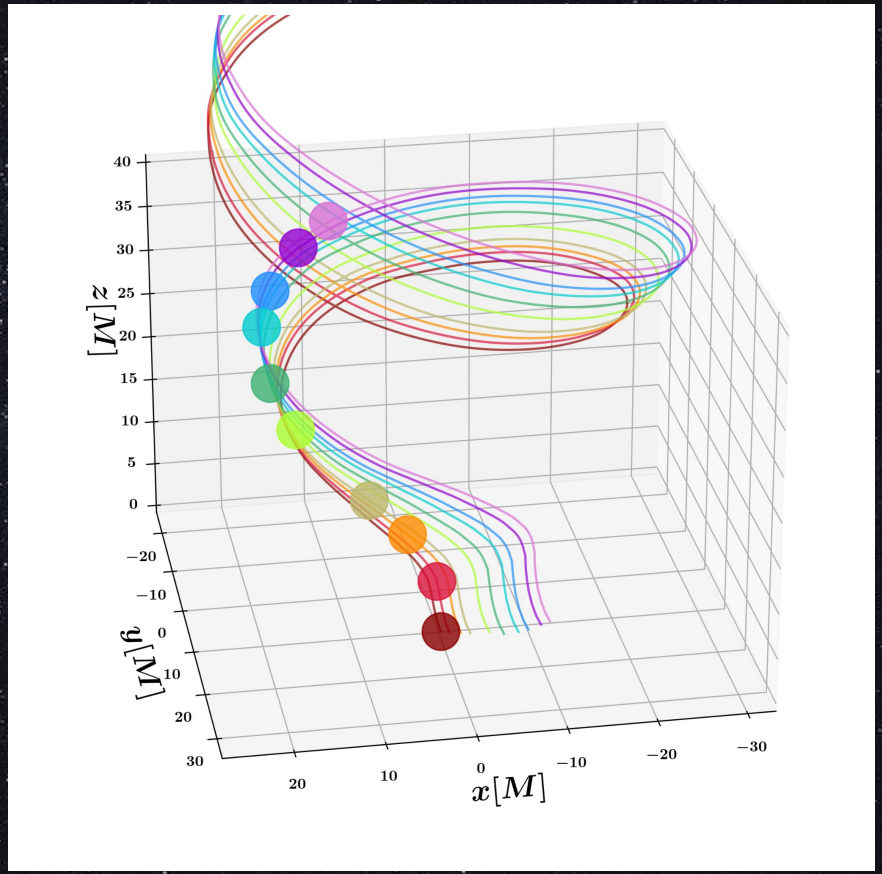
MAD flux eruption events to describe SgrA* flares

Flare Models

- Spherical hot spots of r = 1M
- Generated at the equatorial plane and propagate along the flux tube with a constant ejection velocity between 0.5c - 0.8c
- Flux tube foot-point: outward motion & sub-Keplerian orbital rotation between 0.1uK - 0.4uK



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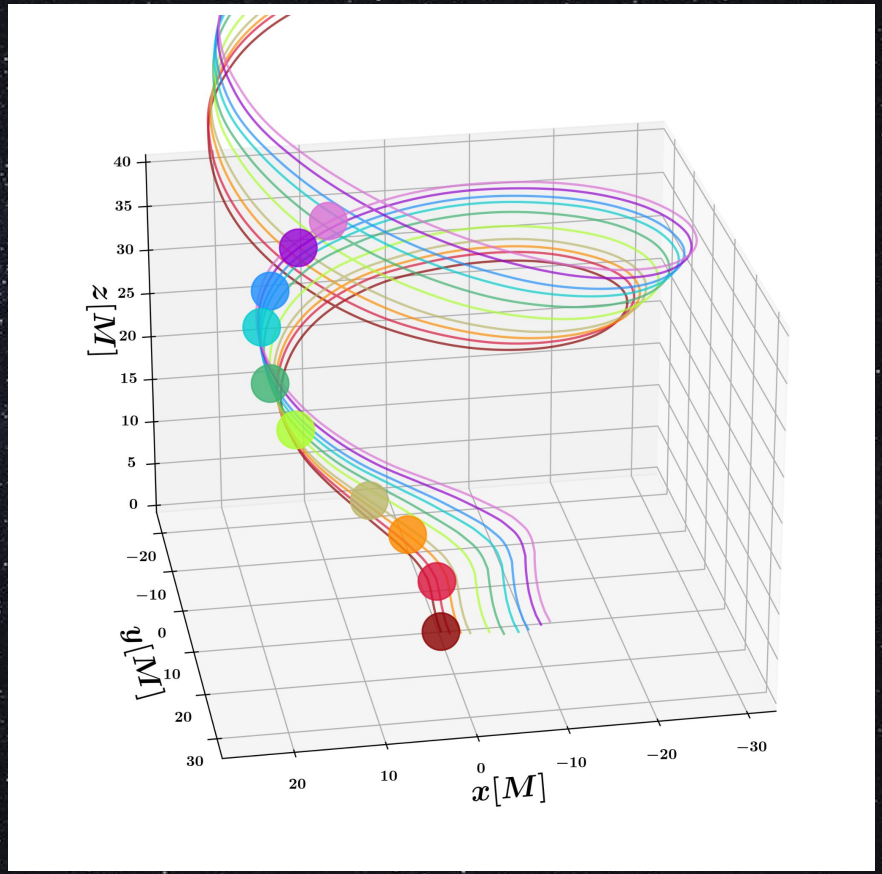
MAD flux eruption events to describe SgrA* flares

Flare Models

- Black Hole Imaging
- Each flare model corresponds to a fixed flux tube structure captured at a specific time during the flux eruption event
- Different models represent the overall evolution of the flux tube's shape throughout the event



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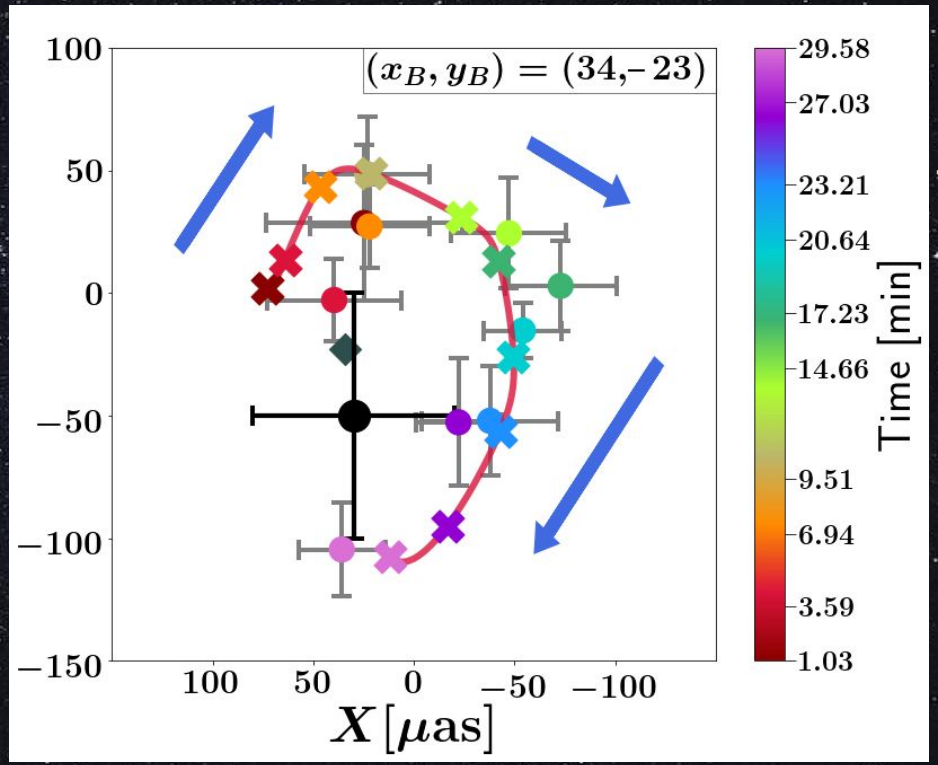
MAD flux eruption events to describe SgrA* flares

- Flux tube: counterclockwise motion, counterclockwise field lines & upward trend
- Hot spot: moves along the clockwise field lines & continuously gains height
- Hot spots with a relativistic ejection velocity balance out the drag of the accretion flow and move clockwise in the sky



u_disk : 0.1 uK
u_spot : 0.8 c

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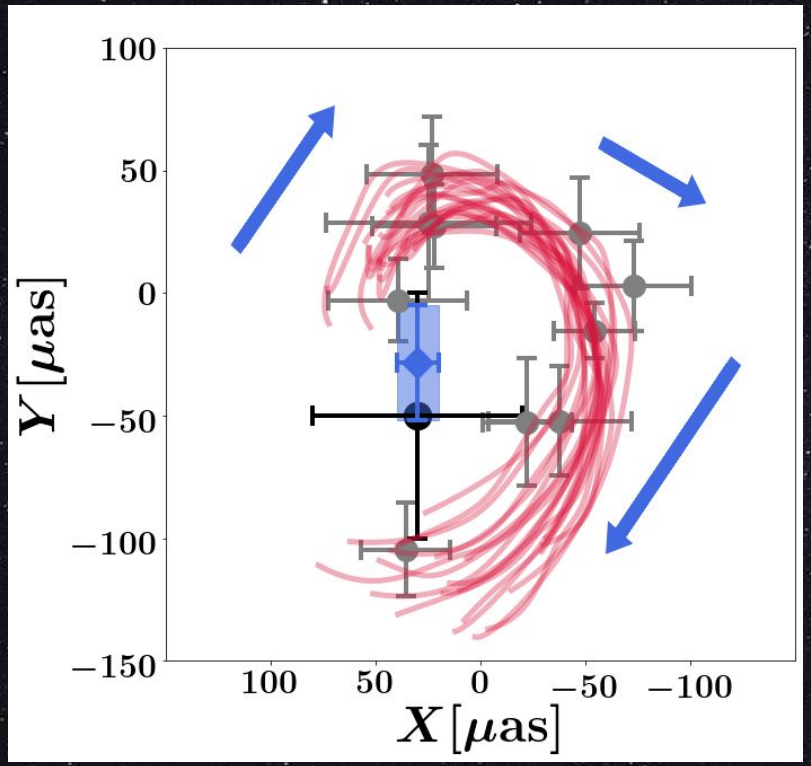
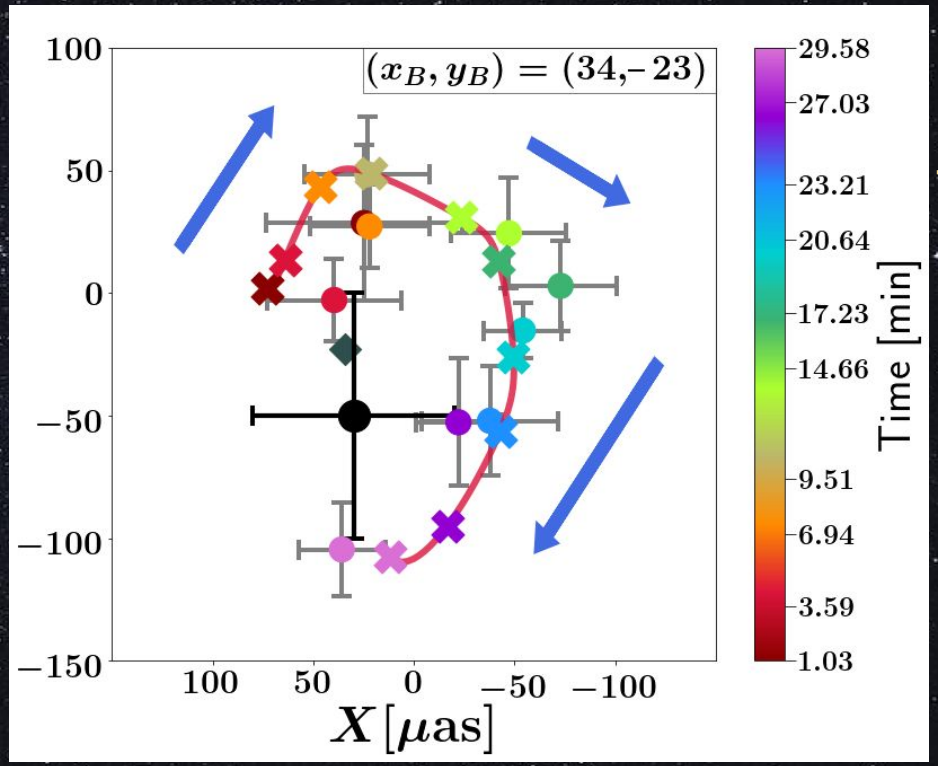
MAD flux eruption events to describe SgrA* flares



u_disk : 0.1 - 0.4 uK
u_spot : 0.5 - 0.8 c



u_disk : 0.1 uK
u_spot : 0.8 c

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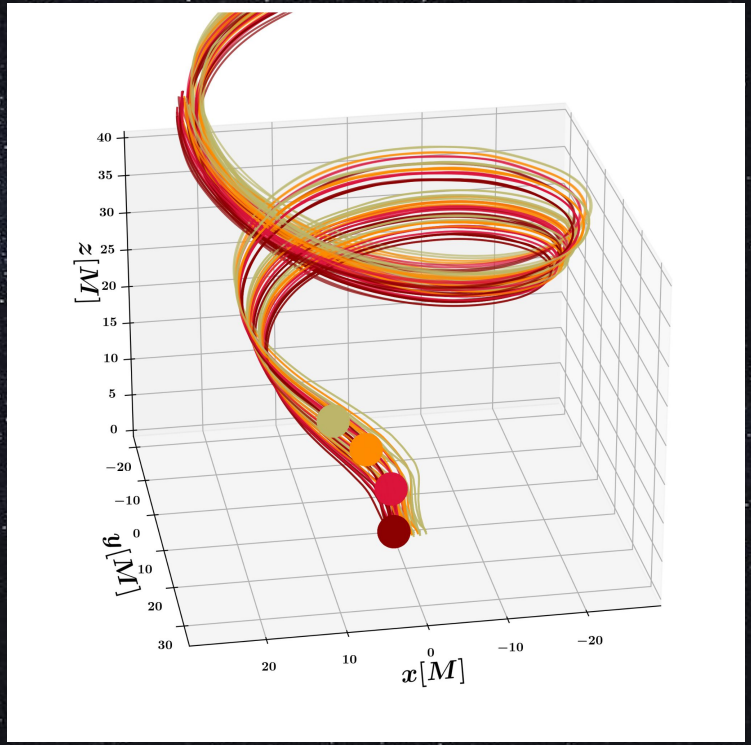
MAD flux eruption events to describe SgrA* flares

- July 22 2018: Very tricky to reproduce first data points
- Flux tube: distinct counterclockwise motion, continuous clockwise loop & upward trend
- Hot spot: continuously gaining height & appears to be passing very close to its initial position
- Projection of the flux tube's shape on the sky plane...



u_disk : 0.4 uK
u_spot : 0.8 c

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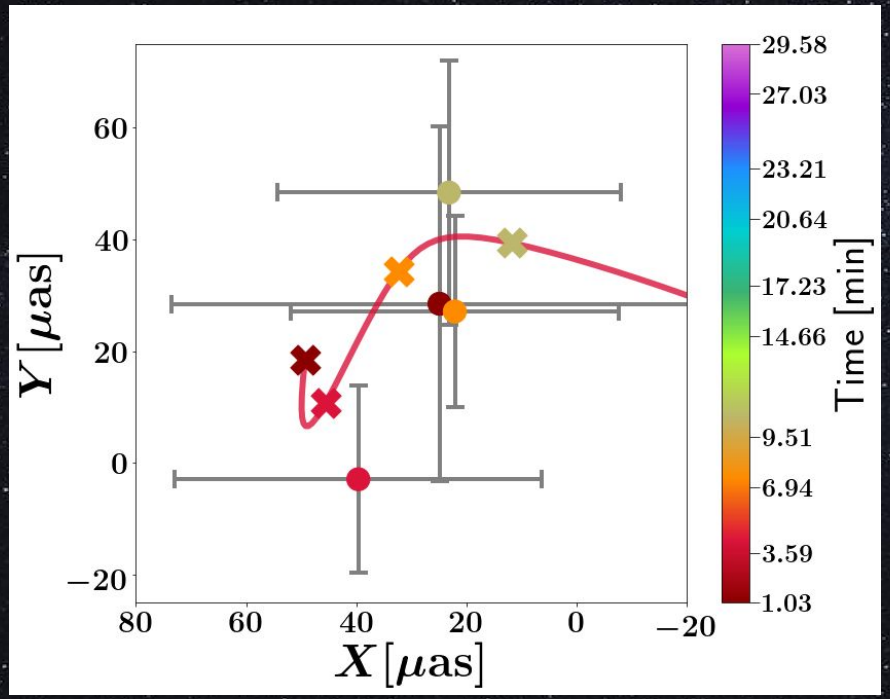
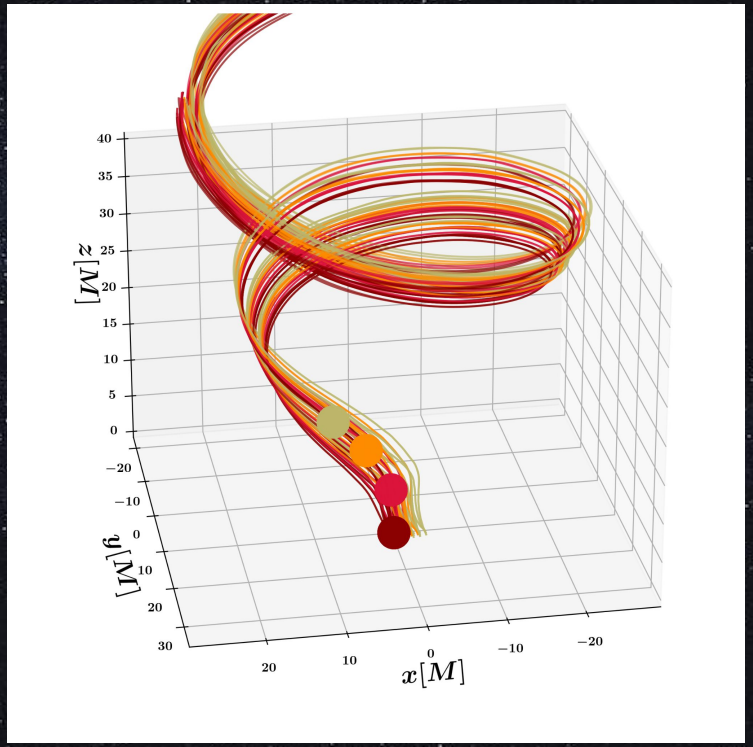
MAD flux eruption events to describe SgrA* flares





u_disk : 0.4 uK
u_spot : 0.8 c

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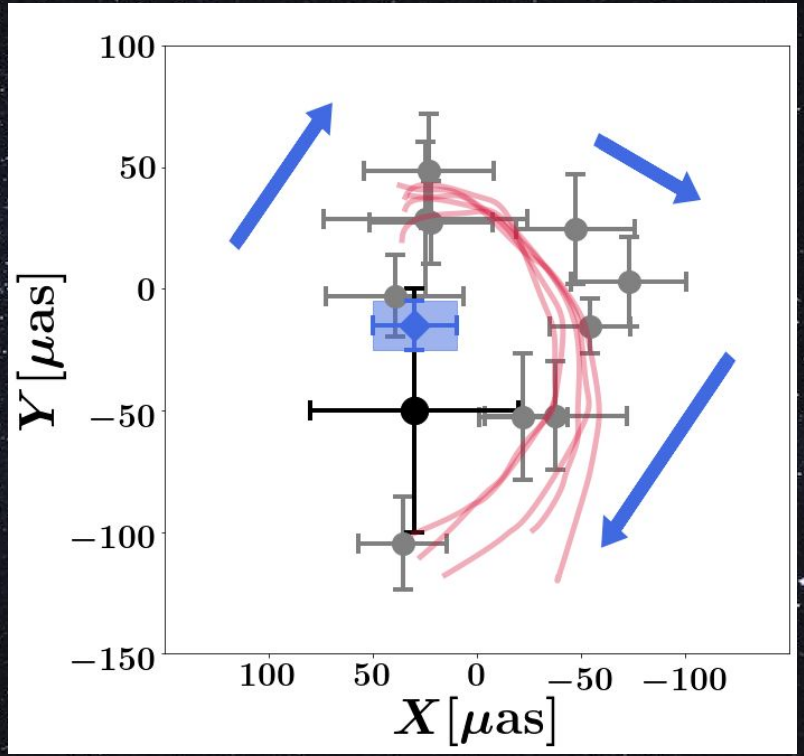
MAD flux eruption events to describe SgrA* flares

Clockwise disk rotation

- Flux tube: clockwise motion, counterclockwise field lines & upward trend
- Hot spot: moves along the counterclockwise field lines & continuously gains height
- Nearly Keplerian disk rotation balances out hot spot motion, too high for typical MAD models



u_disk : 0.8 - 0.9 uK
u_spot : 0.1 c

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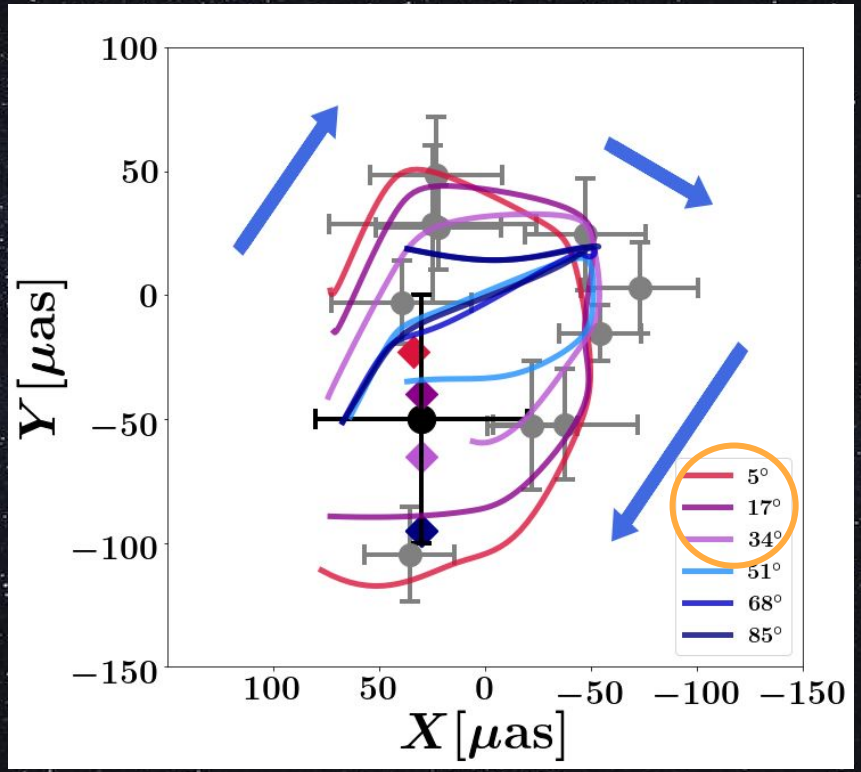
MAD flux eruption events to describe SgrA* flares

- Best flare model for an evenly spaced range of observation angles
- Larger observation angles produce increasingly deformed hot spot orbits
- The GRAVITY observations demonstrate a strong preference for face-on inclinations



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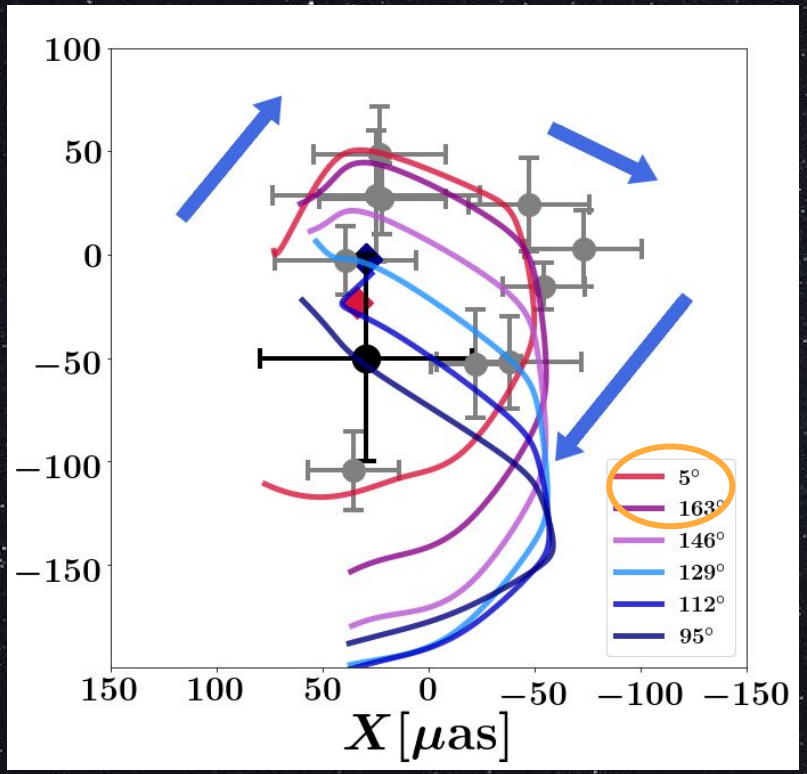
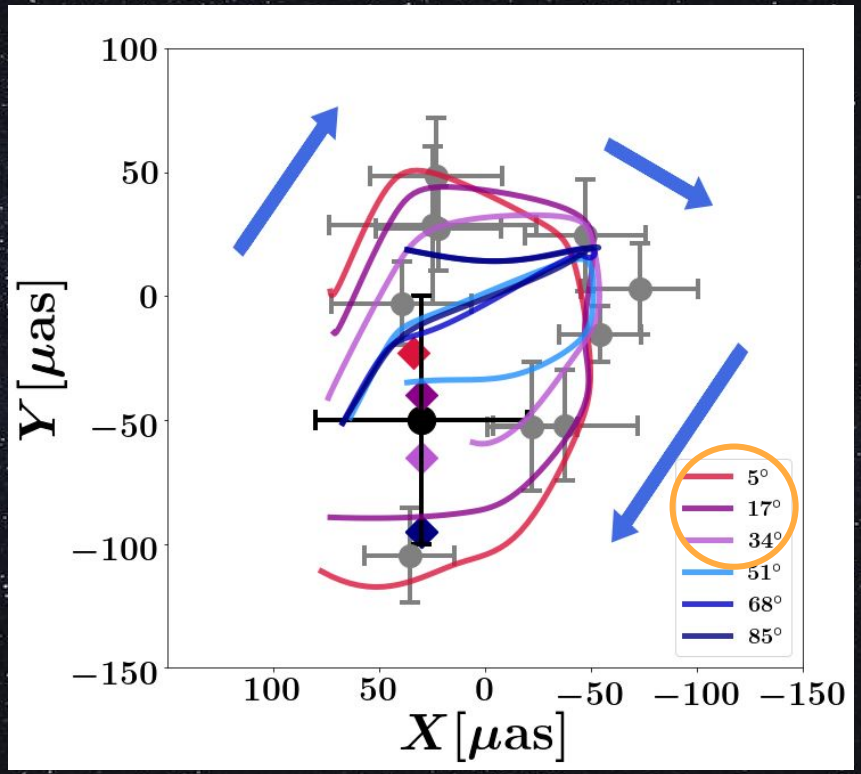
MAD flux eruption events to describe SgrA* flares





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MAD flux eruption events to describe SgrA* flares

- ★ The flux eruption events that naturally arise in the MAD accretion state provide a promising framework for reproducing the observed flaring behavior in the vicinity of SgrA*
- ★ Hot spots with a relativistic ejection velocity are able to balance out the counter-clockwise dragging of the flux tube's foot-point on the disk and demonstrate a clockwise motion in the sky
- ★ Our flare models favor face-on inclinations in the range [0, 34] and [163, 180] for SgrA*