Transient Phenomena and Physical Processes Around ***Supermassive Black Holes***

Unveiling accretion flows around our galaxy's supermassive black hole

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Recent EHTC Observations (M87 & Sgr A*)

M87*

$\dot{M} \sim (2-20) \times 10^{-4} M_{\odot} yr^{-1}$ $i \sim 163$ *degree*

$a_{\mathrm{k}} > 0.9$

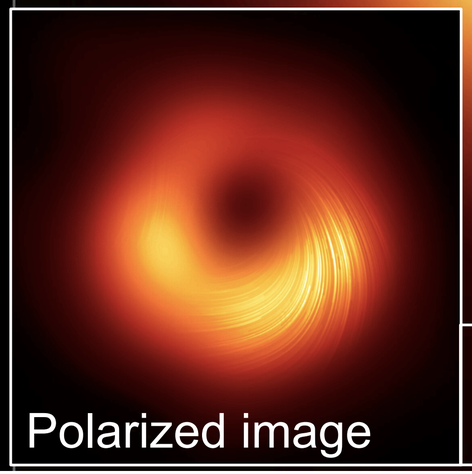
$M_{\mathrm{BH}} \sim 6.5 \times 10^{9} M_{\odot}$

Sgr A*

$\dot{M} \sim (5.2-9.5) \times 10^{-9} M_{\odot} yr^{-1}$ $i \leq 30$ *degree*

$a_{\mathrm{k}} > 0.9$

$M_{\mathrm{BH}} \sim 4 \times 10^{6} M_{\odot}$

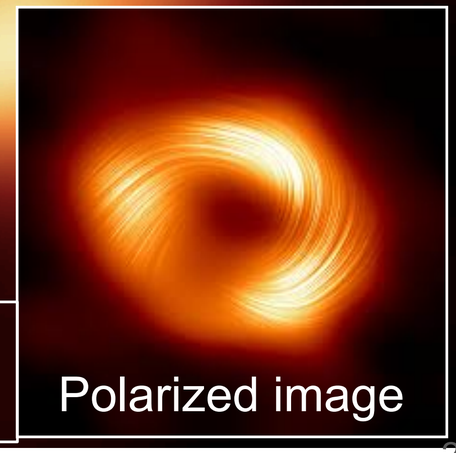


Polarized image

Significant component of poloidal (radial and/or vertical) magnetic field.

Emission from the accretion flow.

Significant component of poloidal (radial and/or vertical) magnetic field.

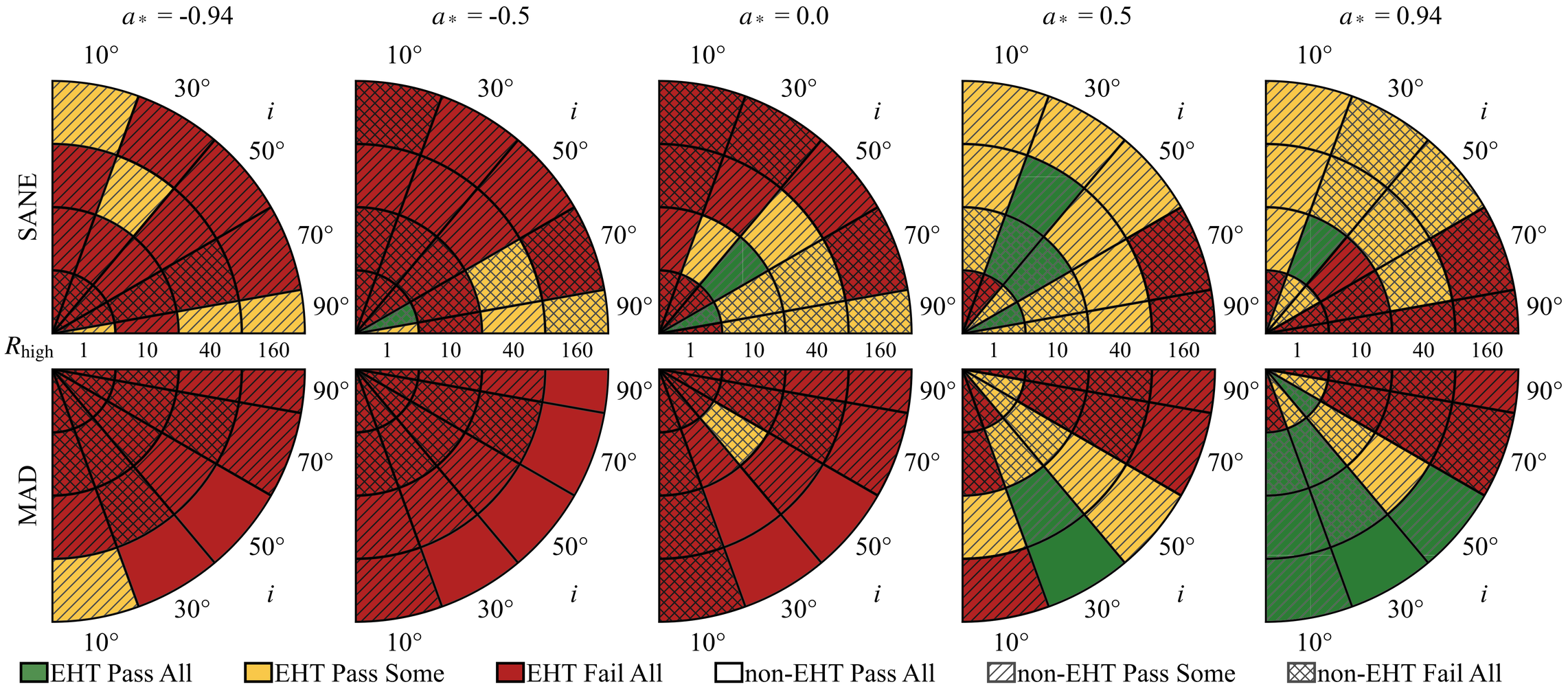


Polarized image

Dynamically important magnetic filed.

Flows around Sgr A*

EHTC-I,2022



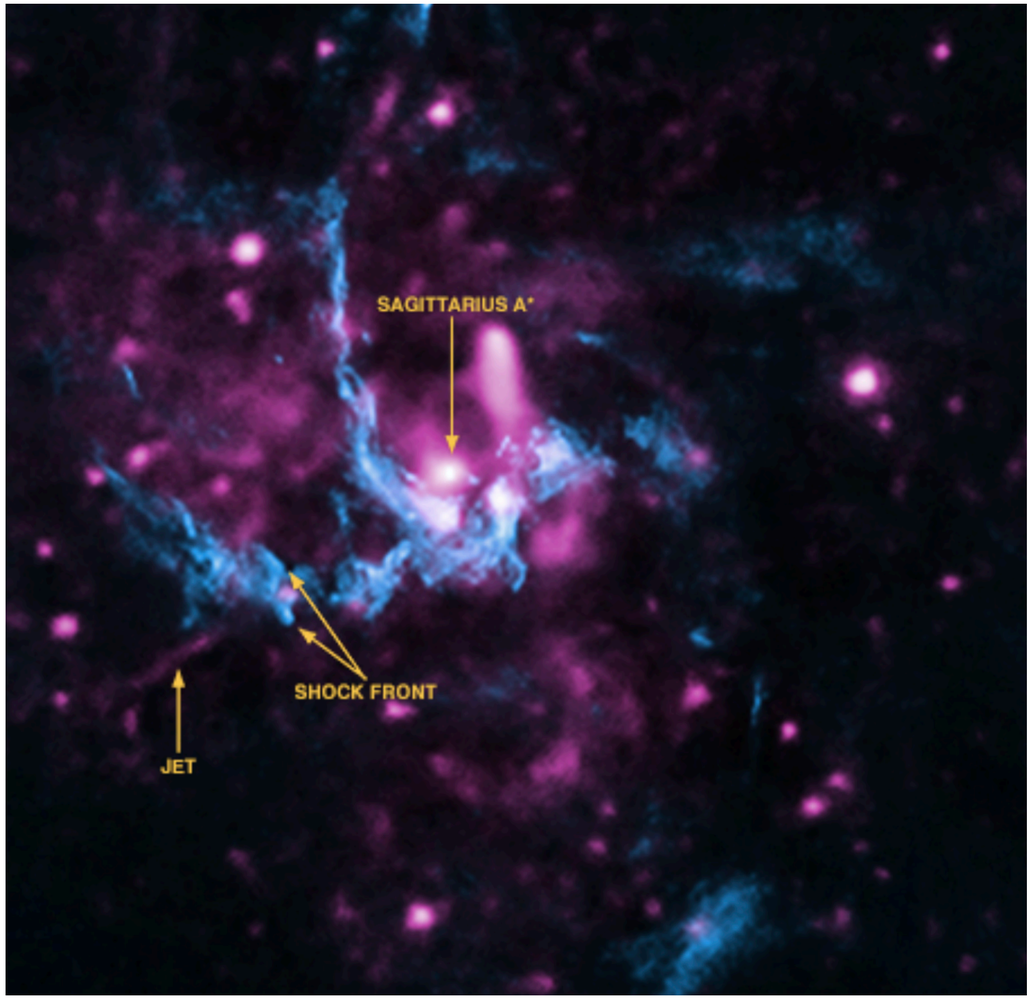
Most likely a MAD with prograde spin $a_* \geq 0.9$, 30° inclination.

MAD models show very strong jet from the black hole.

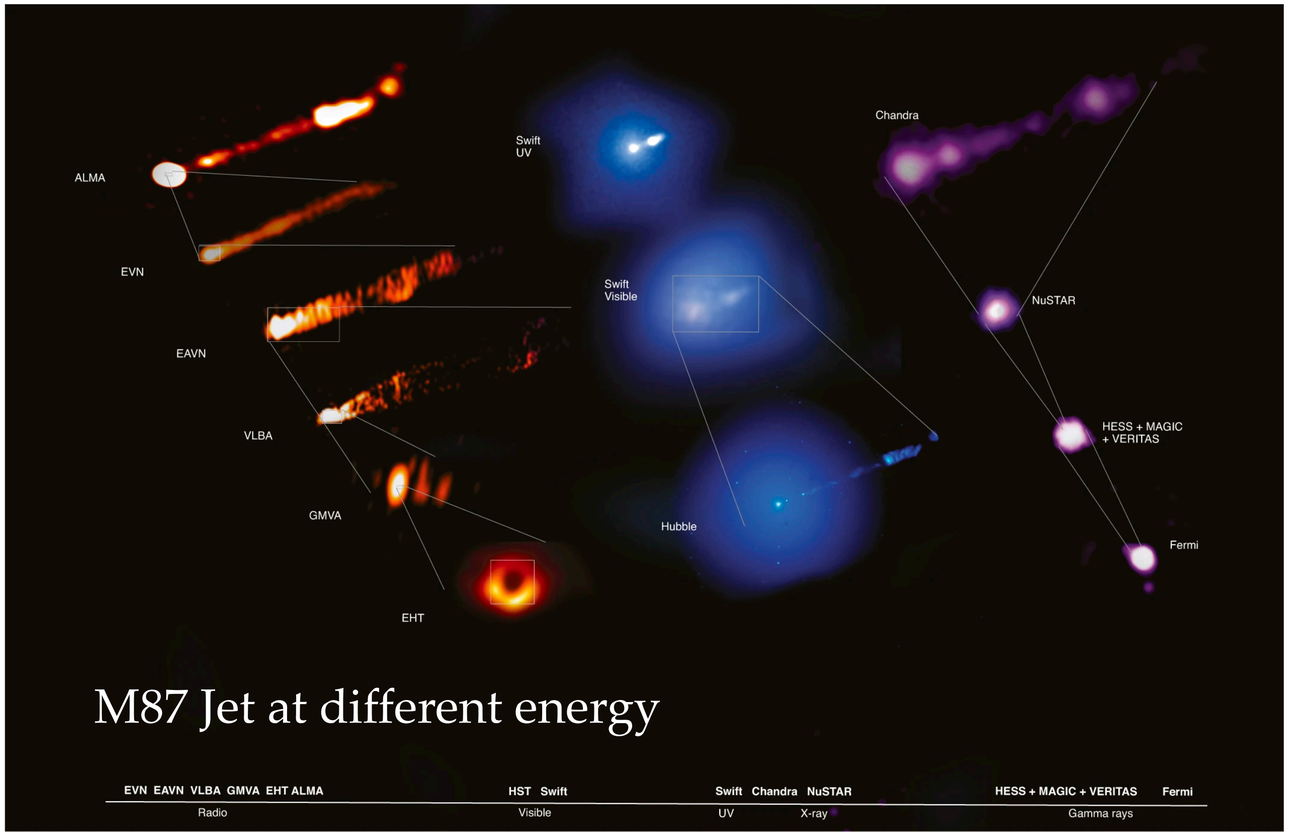
Is there a jet in Sgr A*?

MAD flow is prone to strong relativistic jet, e.g., M 87* (EHTC 2019, 2021, 2022, 2024).

There is no clear evidences of strong jet around Sgr A*(Royster et al. 2019; Yusef-Zadeh et al. 2020). Flow around it may not be like the flow around M 87*

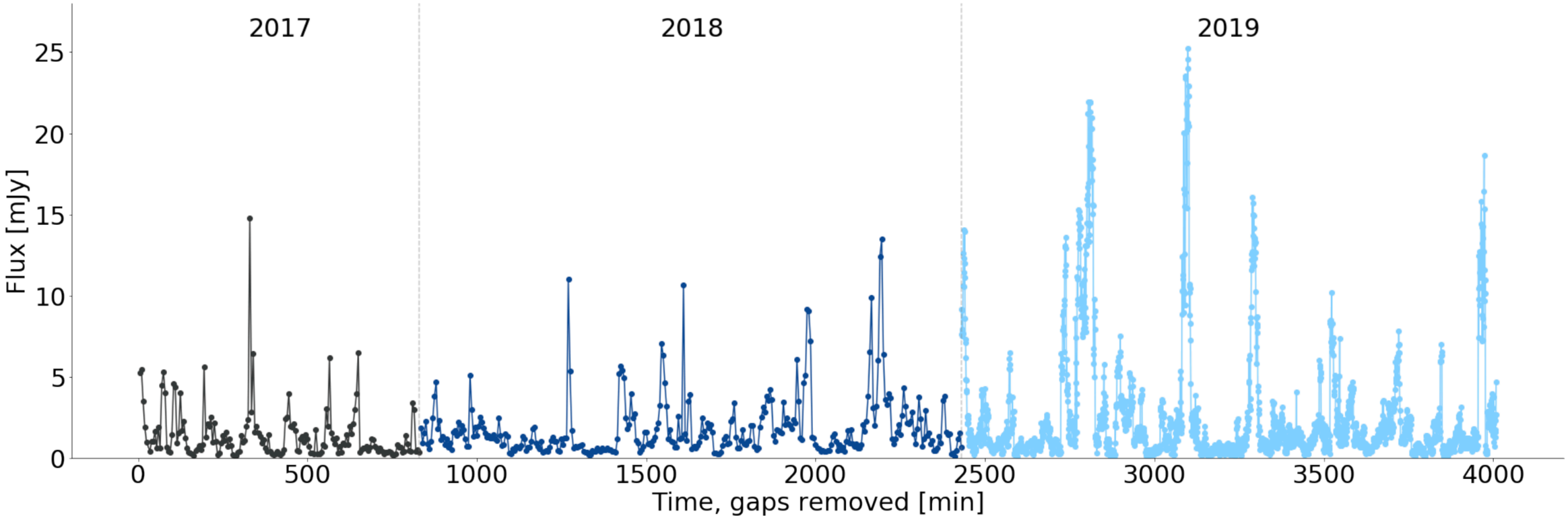


Sgr A* X-ray and radio composite image
Credit: Chandra X-ray Observatory



Polarimetric features of the flares from Sgr A*

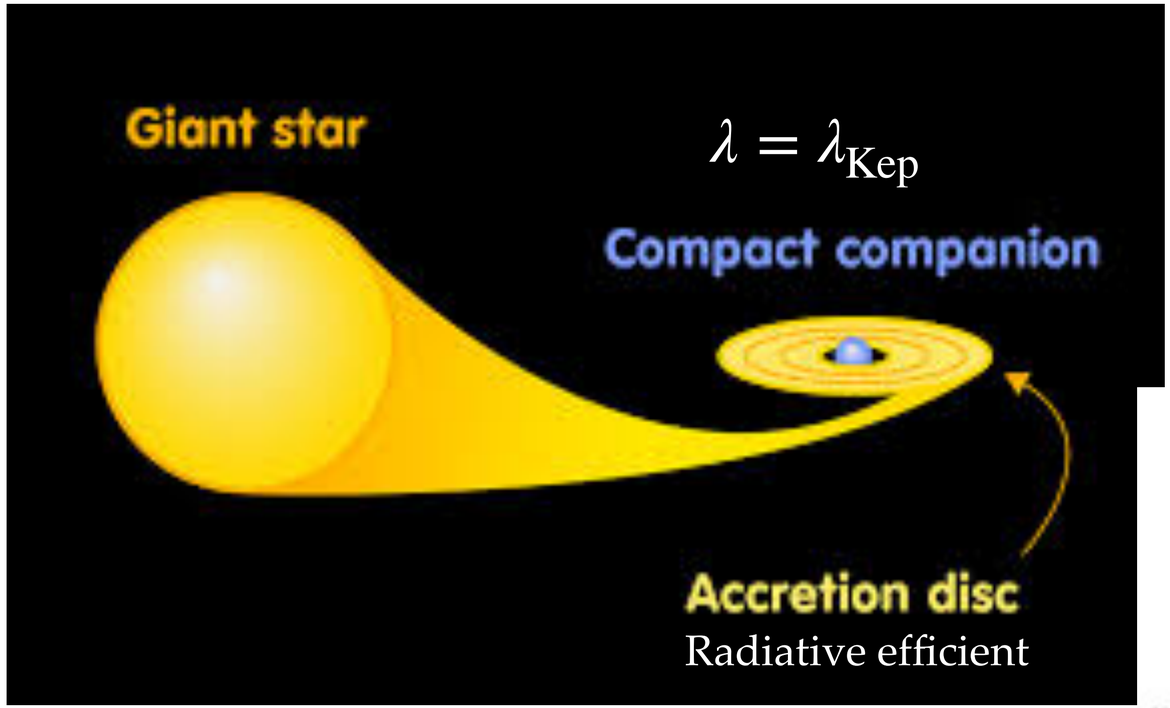
GRAVITY observations (GRAVITY Collaboration 2018, 2023)



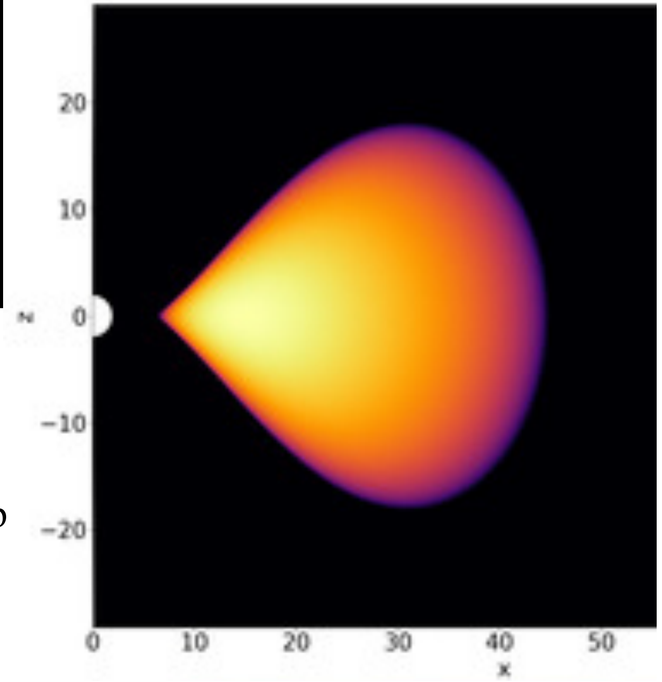
- Flux eruption of MAD
- Plasmoid chain / Flux rope
- Hotspot (toy model)
- Low-angular momentum flow (Un. Explored)

What does angular momentum do?

Shakura & Sunyaev (1973), Novikov & Thorne (1973)



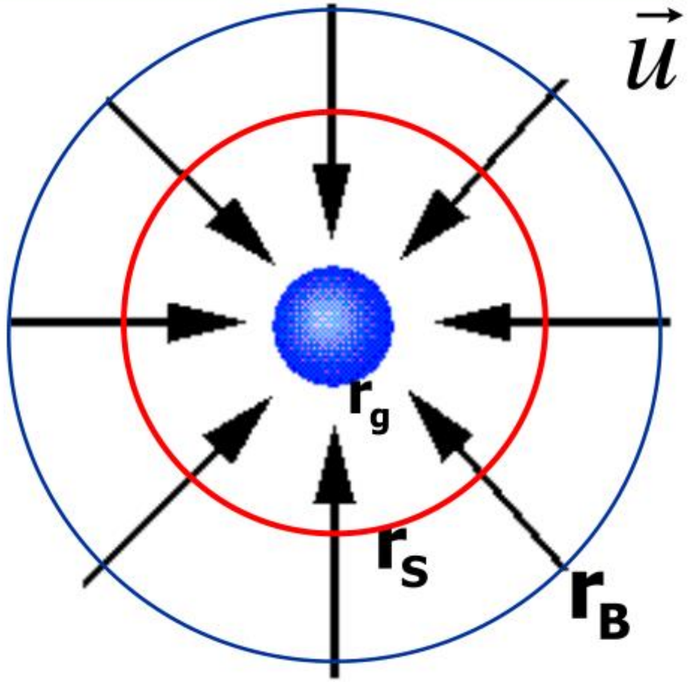
Low-angular momentum flow is one of the option to explore Sgr A* (Ressler et al. 2023).



Intermediate $\lambda > \lambda_{mb}$ but $\lambda < \lambda_{\rm Kep}$

e.g., Fishbone & Moncrief (1976), Font & Daigne (2002)

Hoyle & Lyttleton (1941), Bondi (1952)



$\lambda = 0$

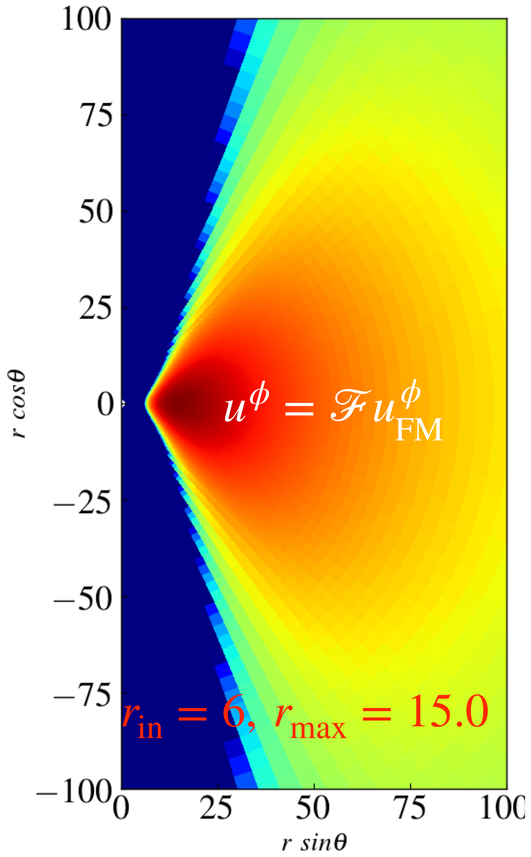
Radiative (very) inefficient

What does angular momentum do?

1. Semi-analytic investigations show different types of accretion solutions around black holes.

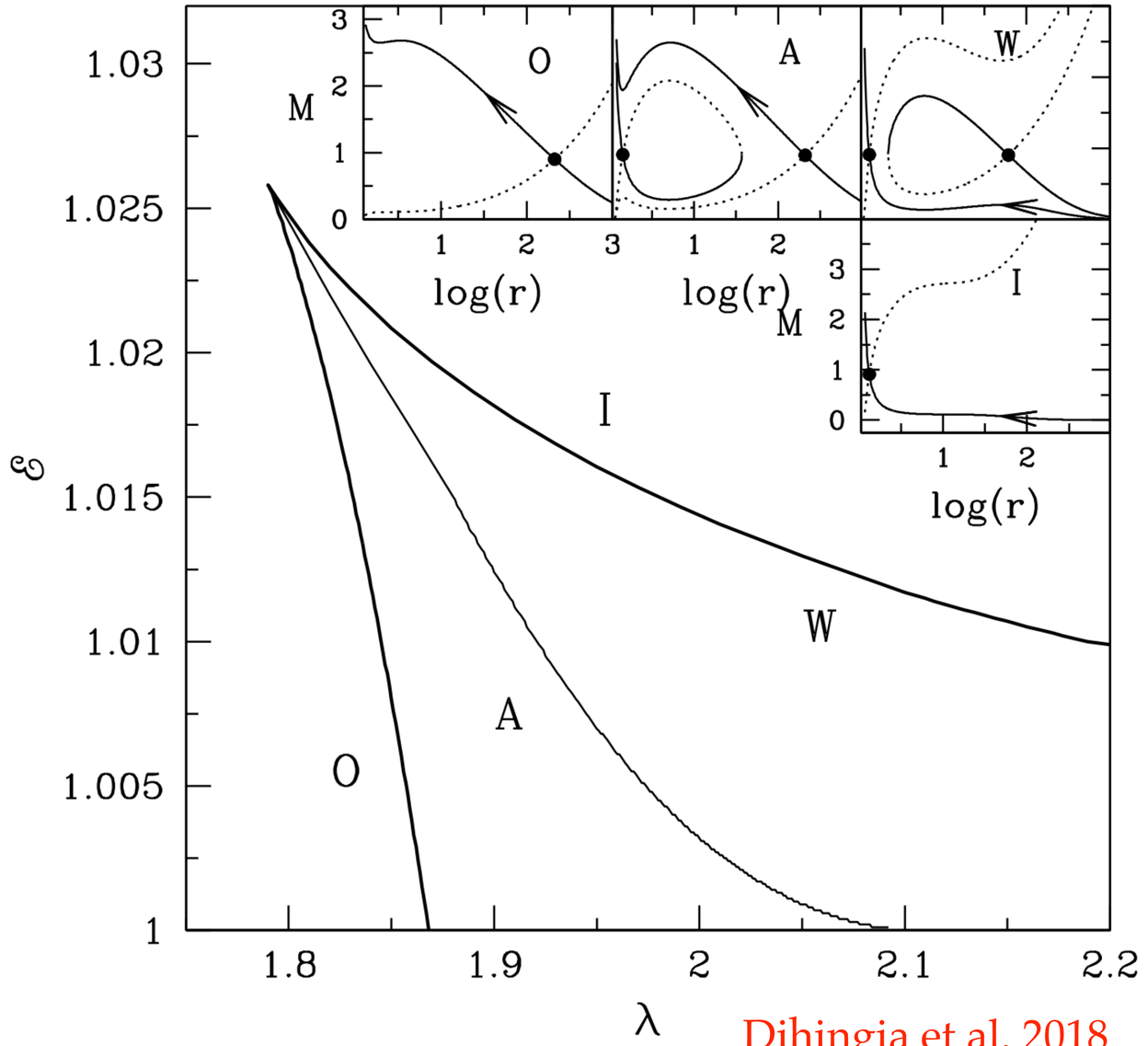
2. We modify Fishbone & Moncrief (1976) torus to accommodate low-angular momentum flow.

3. Perform GRMHD simulations.



Initial setup for our study (Dihingia et al. 2024)

Intermediate $\lambda < \lambda_{mb}$; $\lambda < \lambda_{\rm ms}$

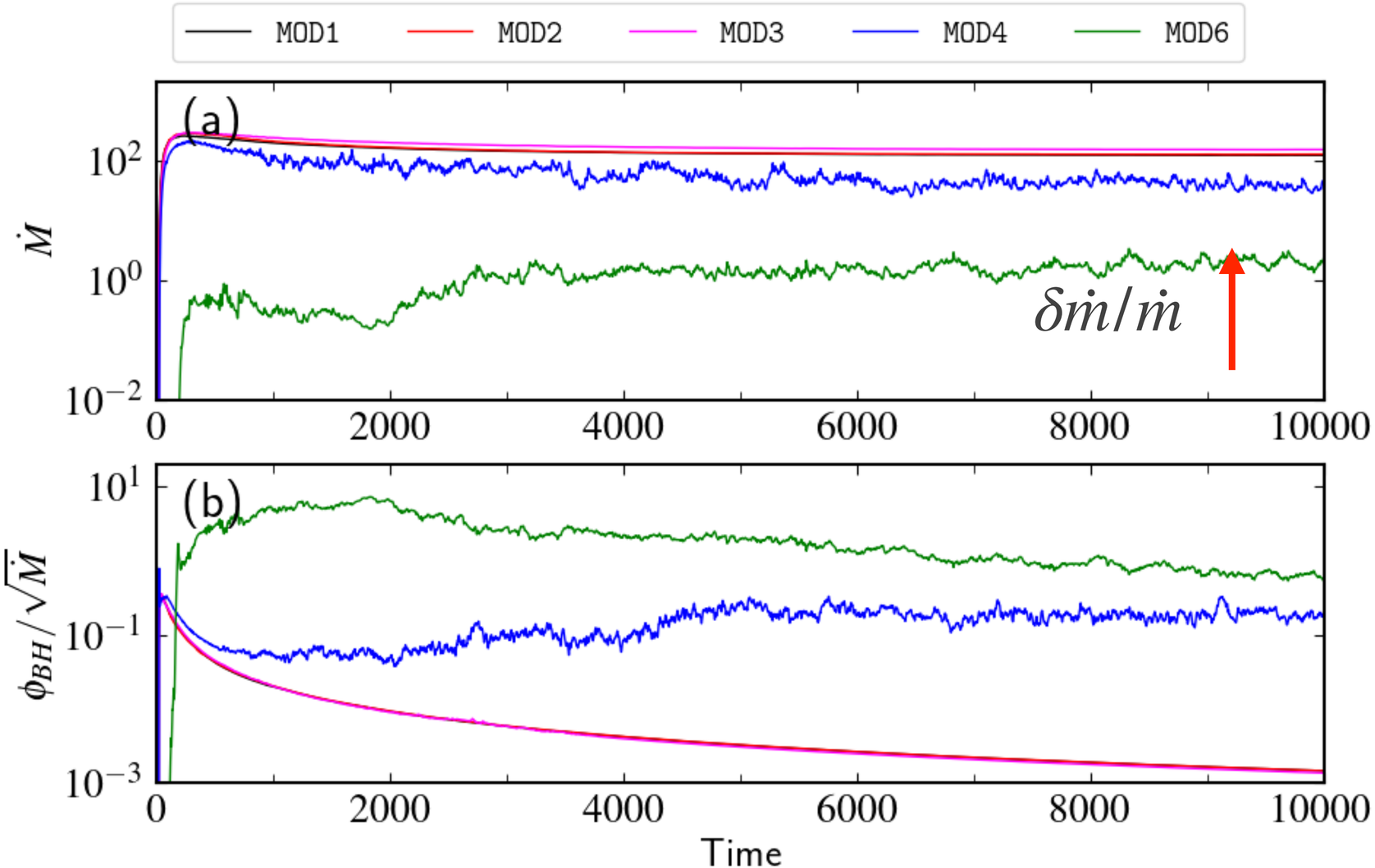


Dihingia et al. 2018

Results: Timing properties

1. We find quasi-steady accretion solutions for low-angular momentum flow.

2. The accretion flow changes drastically with the increase in angular momentum.

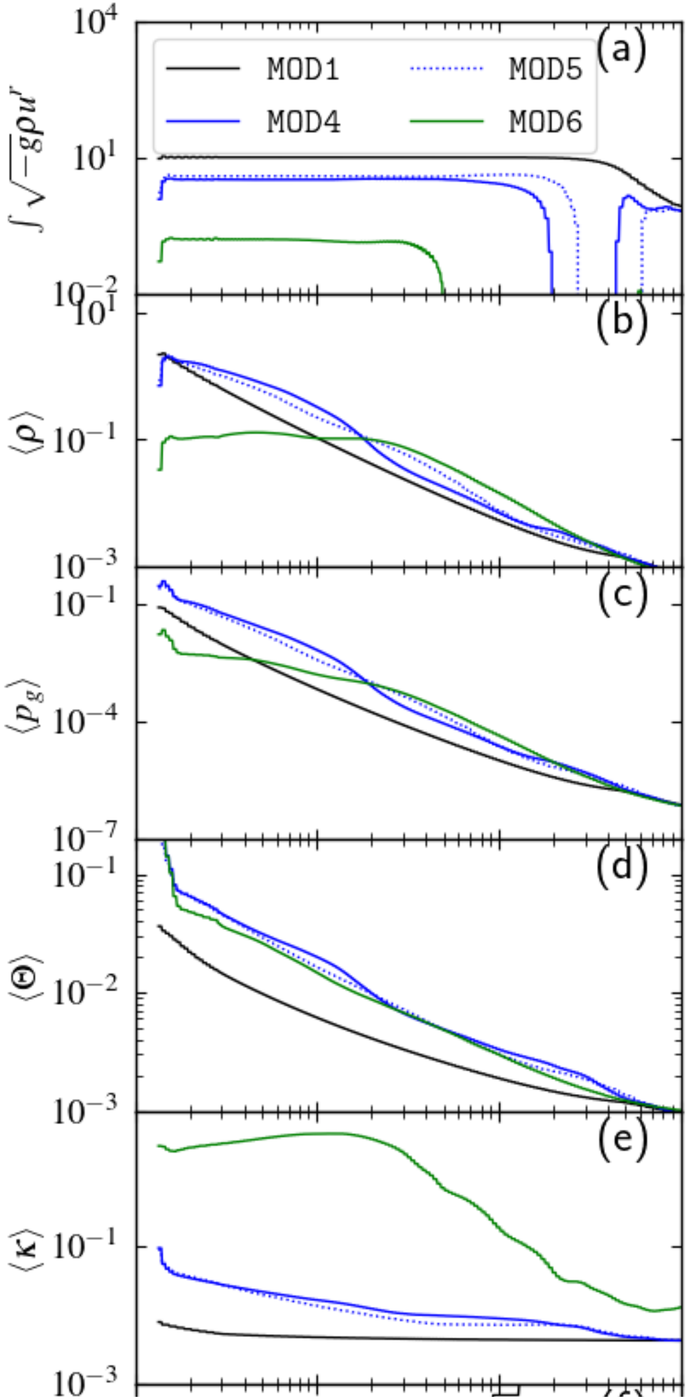


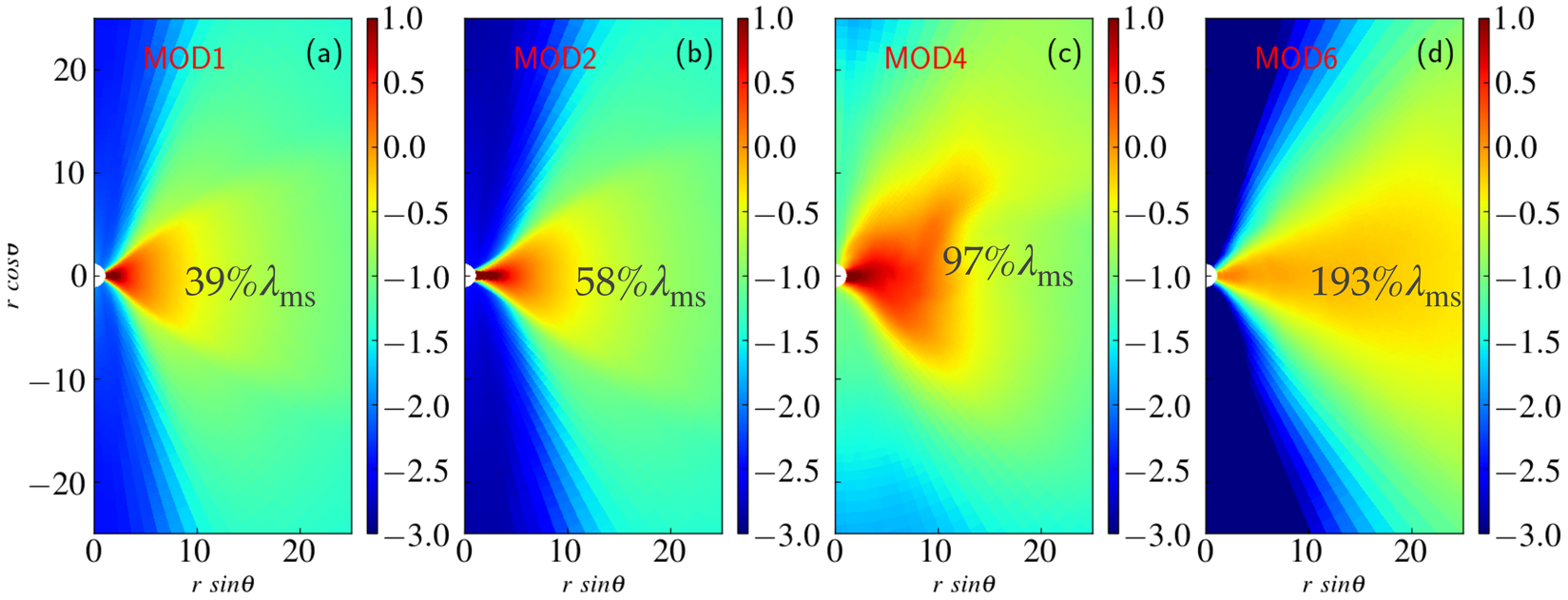
$$\dot{M} = \int_0^{2\pi} \int_0^{\pi} \rho u^r \sqrt{-g} d\theta d\phi,$$

$$\Phi_{\rm B} = \frac{1}{2} \int_0^{2\pi} \int_0^{\pi} |B^r| \sqrt{-g} d\theta d\phi.$$

Dihingia et al. 2024

Flow properties

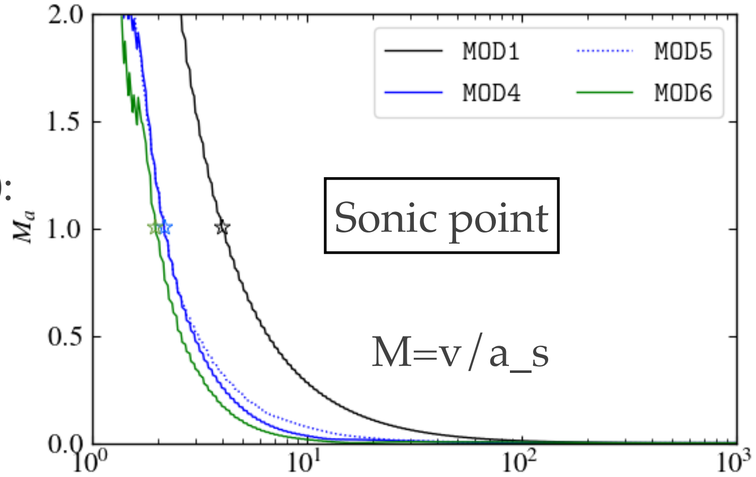




Very low-angular momentum:
$\rho \propto r^{-3/2}$ and $p_g \propto r^{-5/3}$

Intermediate angular momentum (MAD Like):
$\rho \propto r^{-1}$ and $p_g \propto r^{-7/4}$

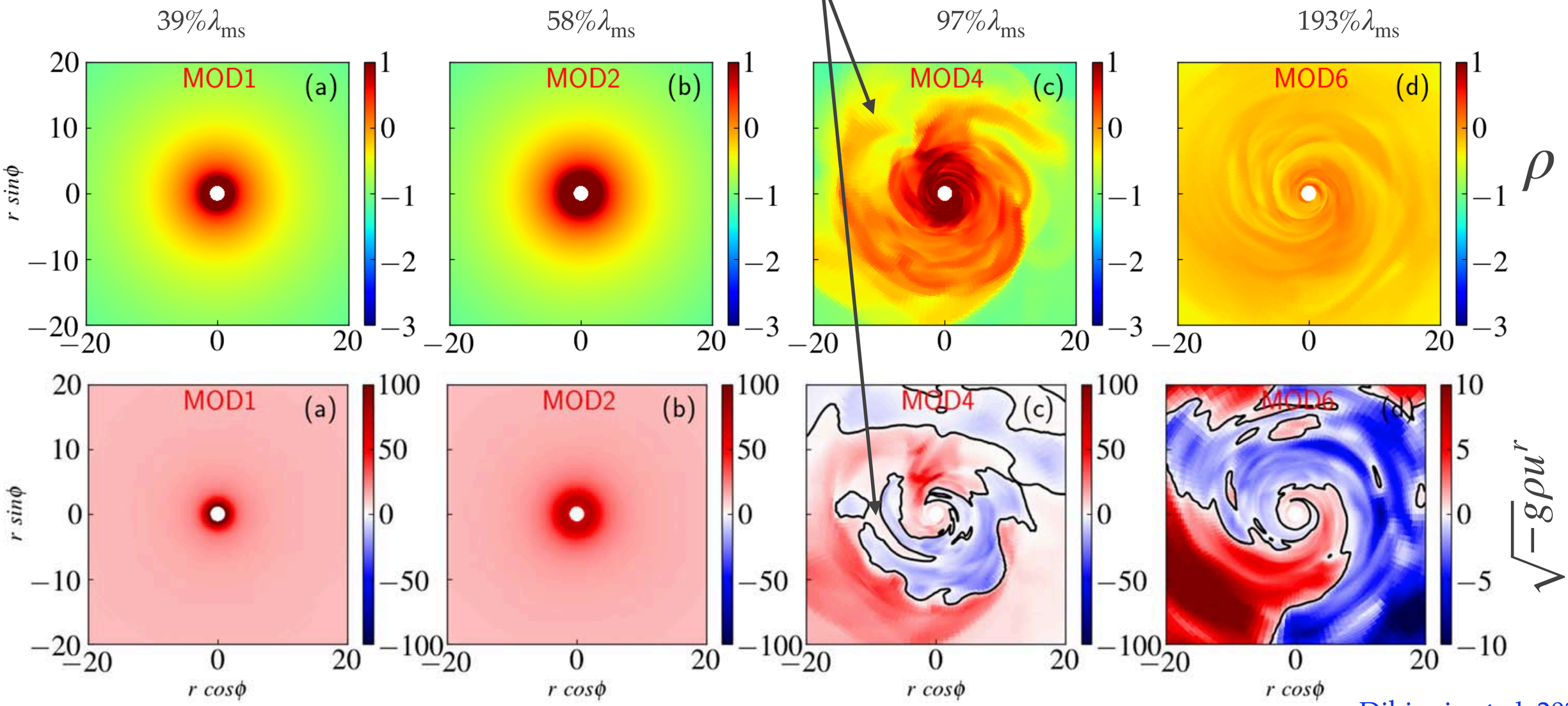
High angular momentum:
$\rho \propto r^{0}$ and $p_g \propto r^{-3/4}$



Dihingia et al. 2024

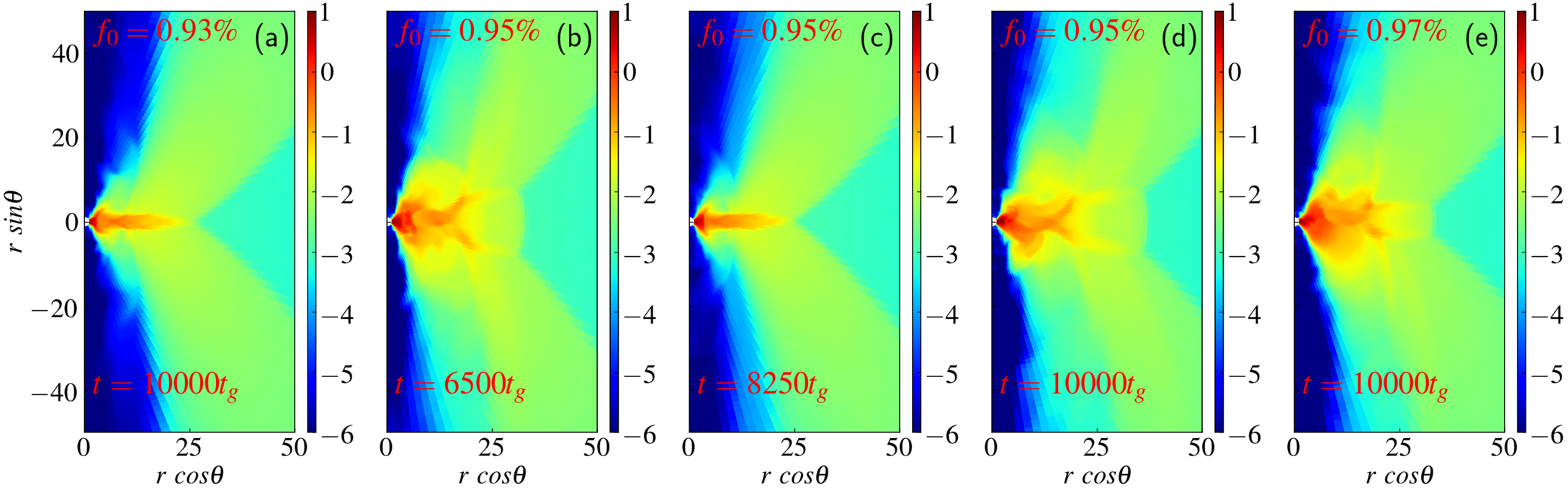
Flow properties with angular momentum

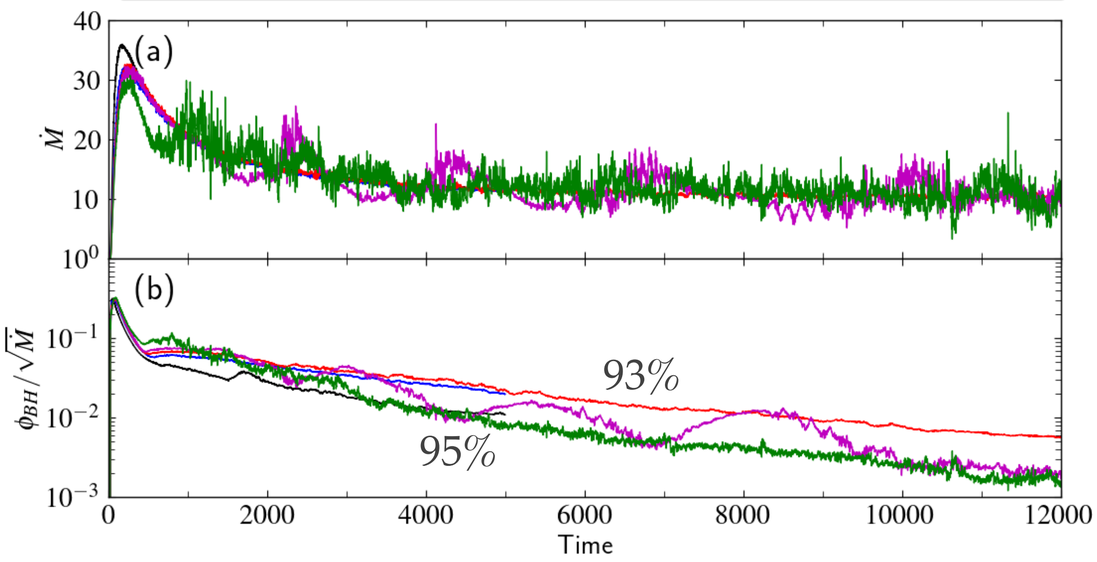
Spiral arm in the intermediate angular momentum range could be possible source of the flares.



Dihingia et al. 2024

Shocks in low-angular momentum flow





For a limited range of parameters flow experienced standing/oscillating shocks.

They can be potential source of particle acceleration.

Summary

MAD flow although generates the flaring events, however they have strong jet that may not be the actual behaviour of Sgr A*.

Our setup could able to simulate low-angular momentum GRMHD flow without very complex setup such as Ressler et al. 2018, Olivares et al. 2023 (GRHD).

Accretion flow with an intermediate range of angular momentum has similar properties as MAD but without a jet.

Intermediate angular momentum flow could provide a possible solution to explain the complex observation features of the supermassive black hole Sgr A* at our galactic center.

Thanks(谢谢)