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Dynamical properties of magnetized low-angular-momentum accretion flows onto a Kerr black hole

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Dihingia & Mizuno 2024, ApJ, 967, 4
Dihingia & Mizuno, 2025, ApJ, 982, L21

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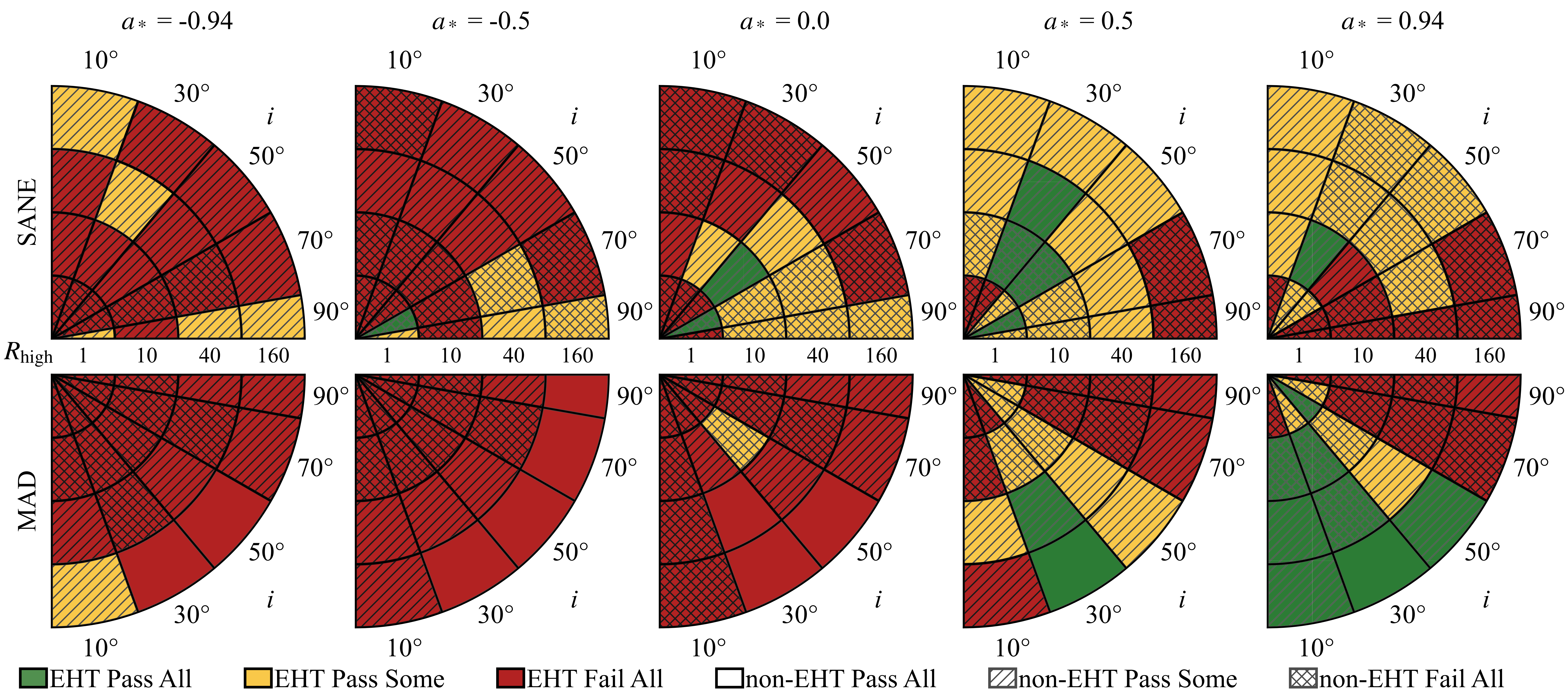
Black Hole Shadows by EHT observations

Magnetic field is dynamically important.

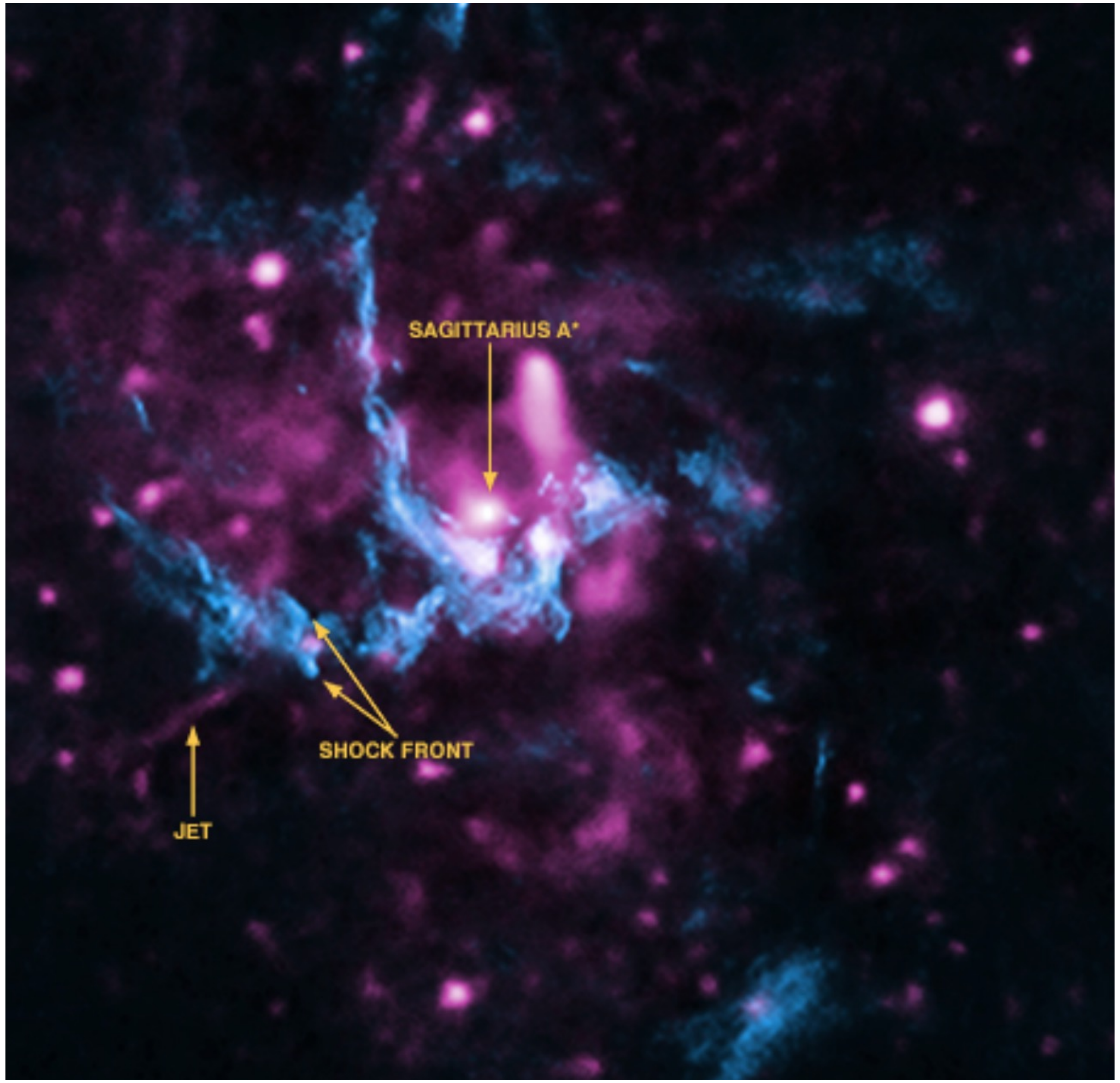
Accretion Flows around Sgr A*



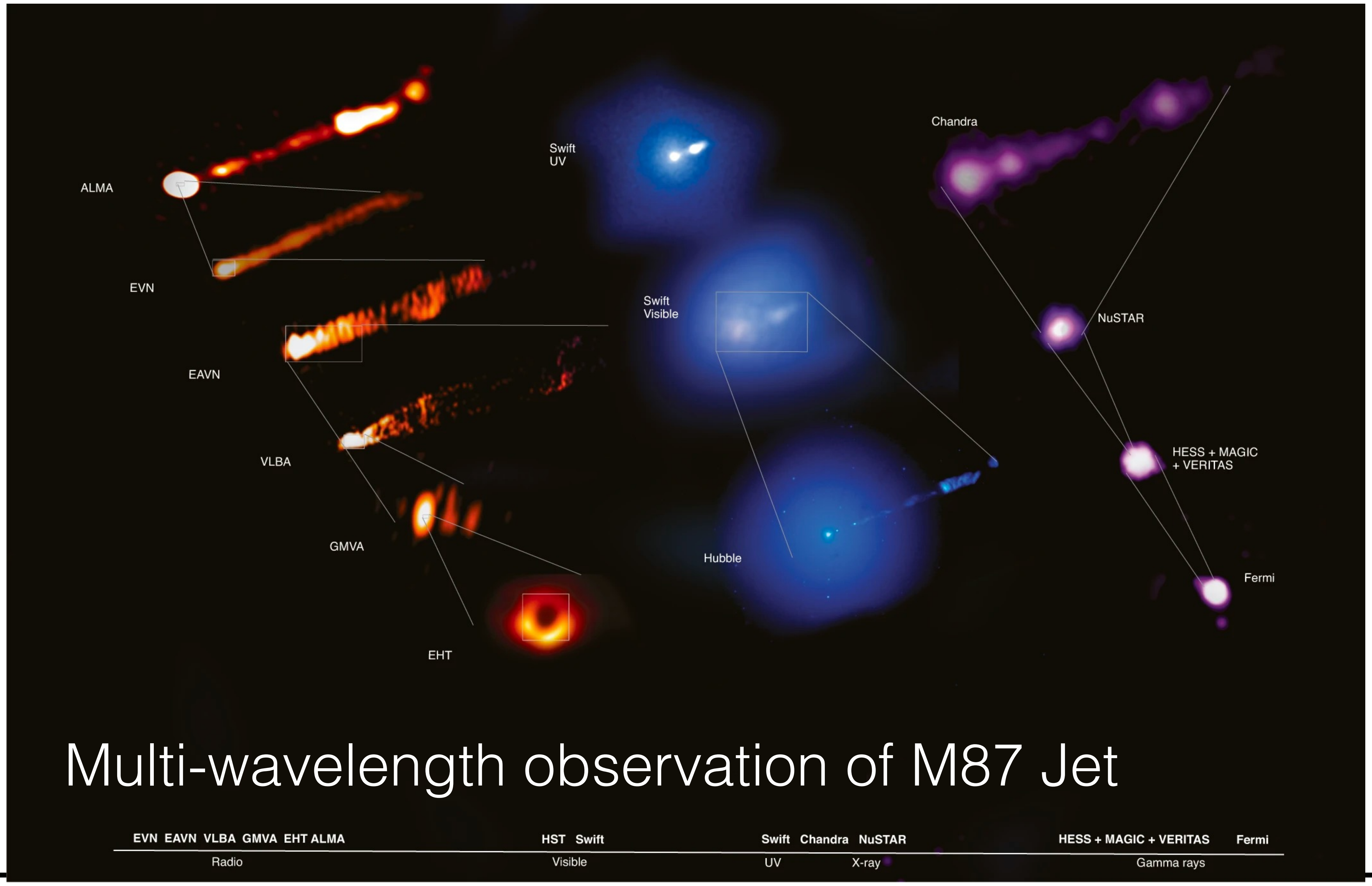
- Most likely a MAD with prograde spin, 30° inclination.
- MAD models show a strong jet from the black hole.

Is There A Jet in Sgr A*?

- MAD flows produce a strong relativistic jet, e.g., M 87* (EHTC 19, 21, 22, 24).
- There is no clear evidence of a strong jet around Sgr A*(Royster+ 19, Yusef-Zadeh+ 20).
- Flow around Sgr A* may be different from flows in M 87*



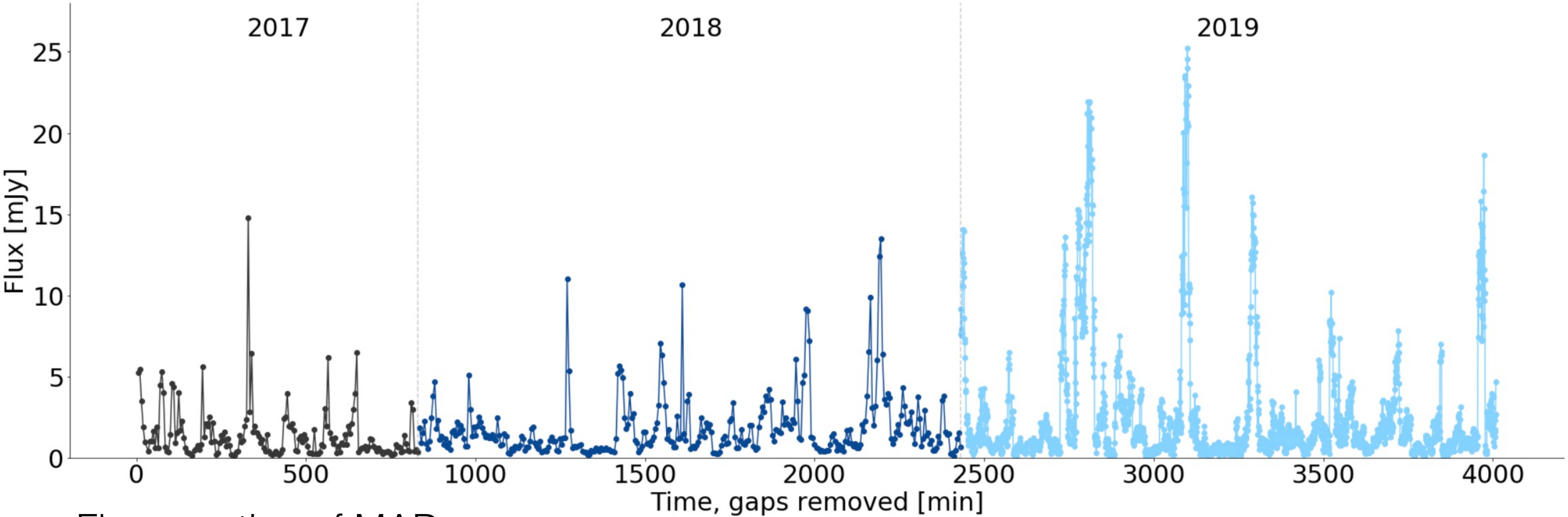
Sgr A* X-ray and radio composite image
Credit: Chandra X-ray Observatory



Multi-wavelength observation of M87 Jet

Flares from Sgr A*

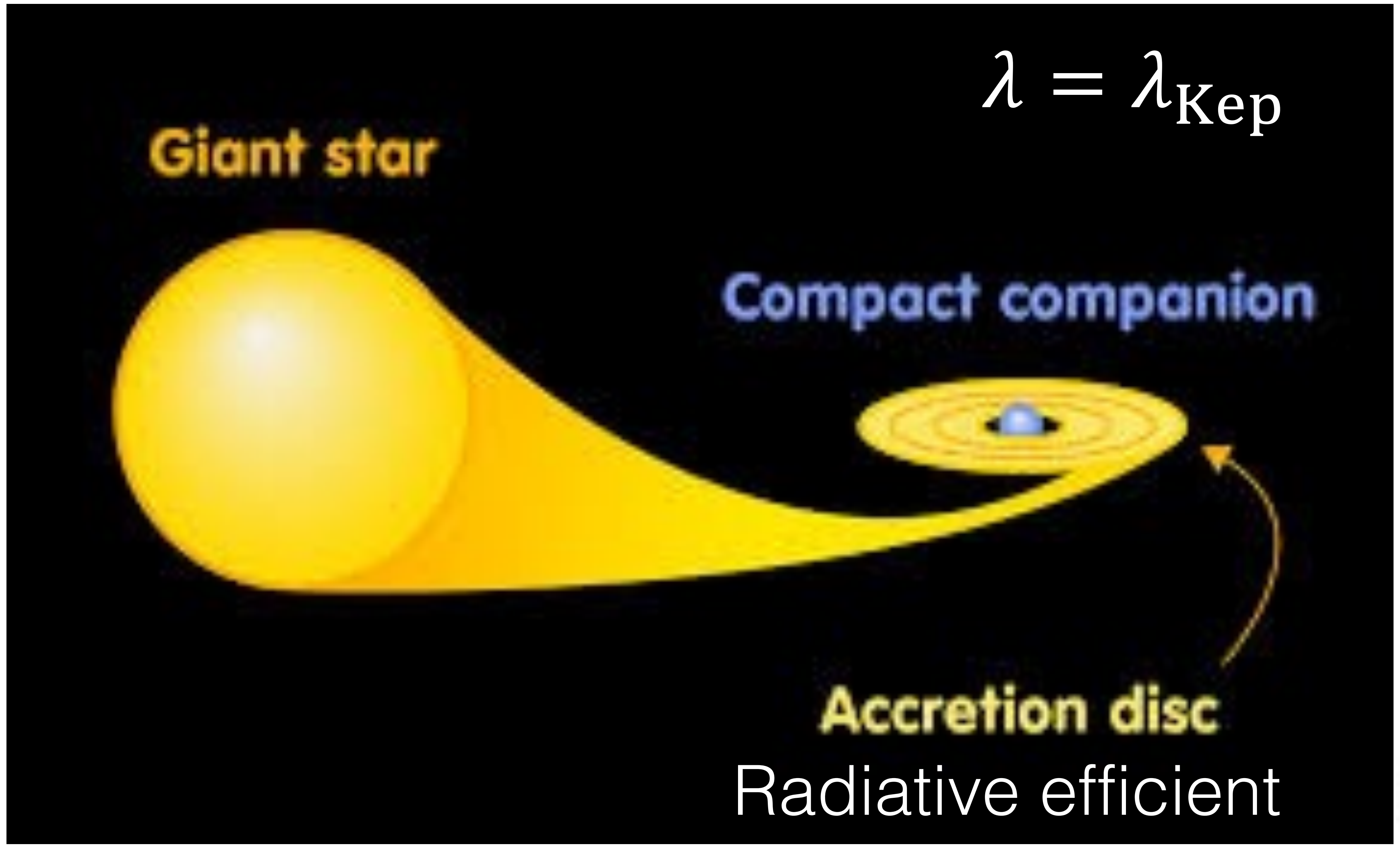
GRAVITY observations (GRAVITY Collaboration 2018, 2023)



- Flux eruption of MAD (e.g., Porth, YM, Fromm 21)
- Plasmoid chain / Flux rope (e.g., Jiang, YM et al. 24, 25)
- Hotspot (toy model)
- Low-angular momentum flow (Un. Explored)

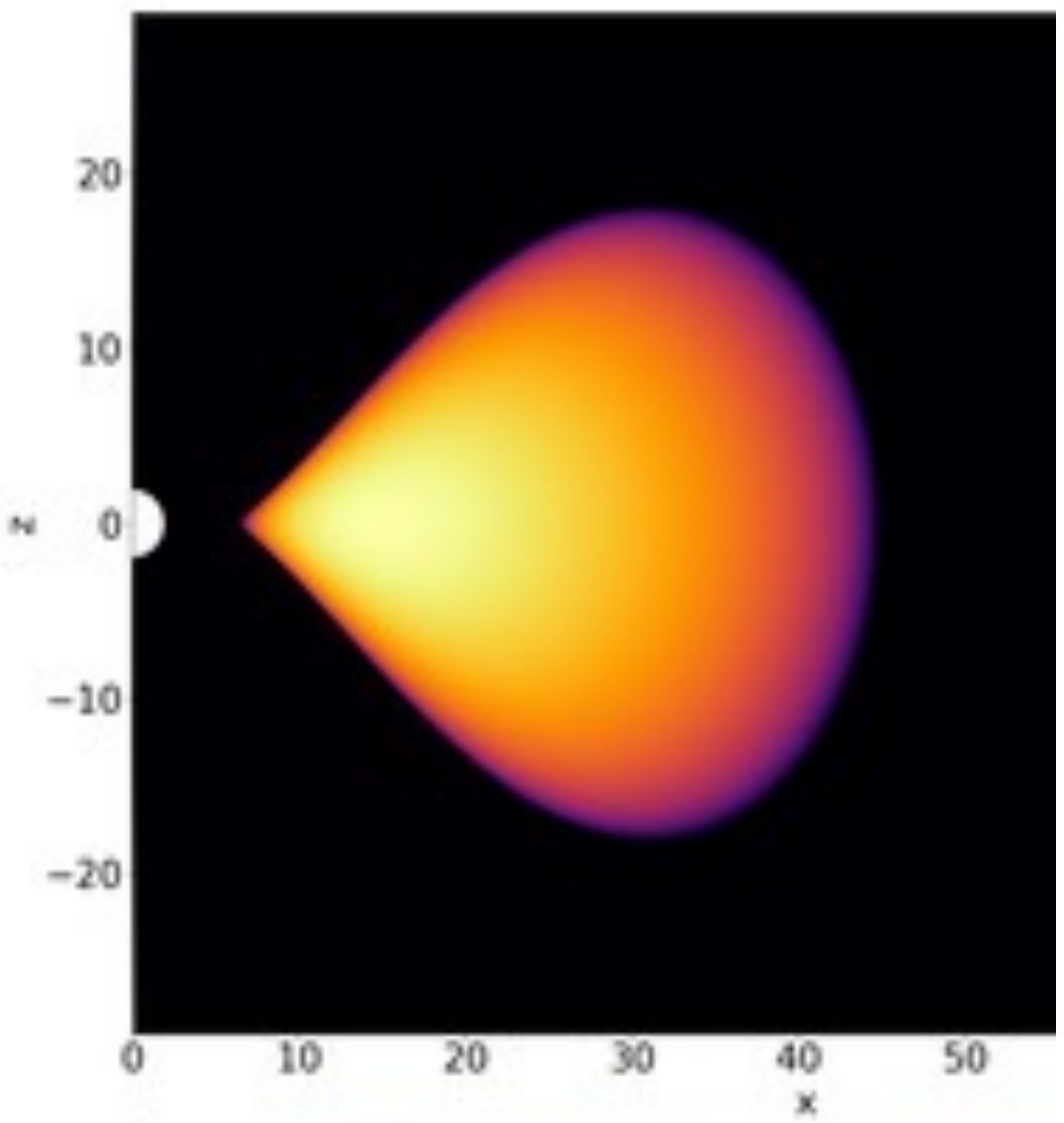
What Does Angular Momentum Do?

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



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

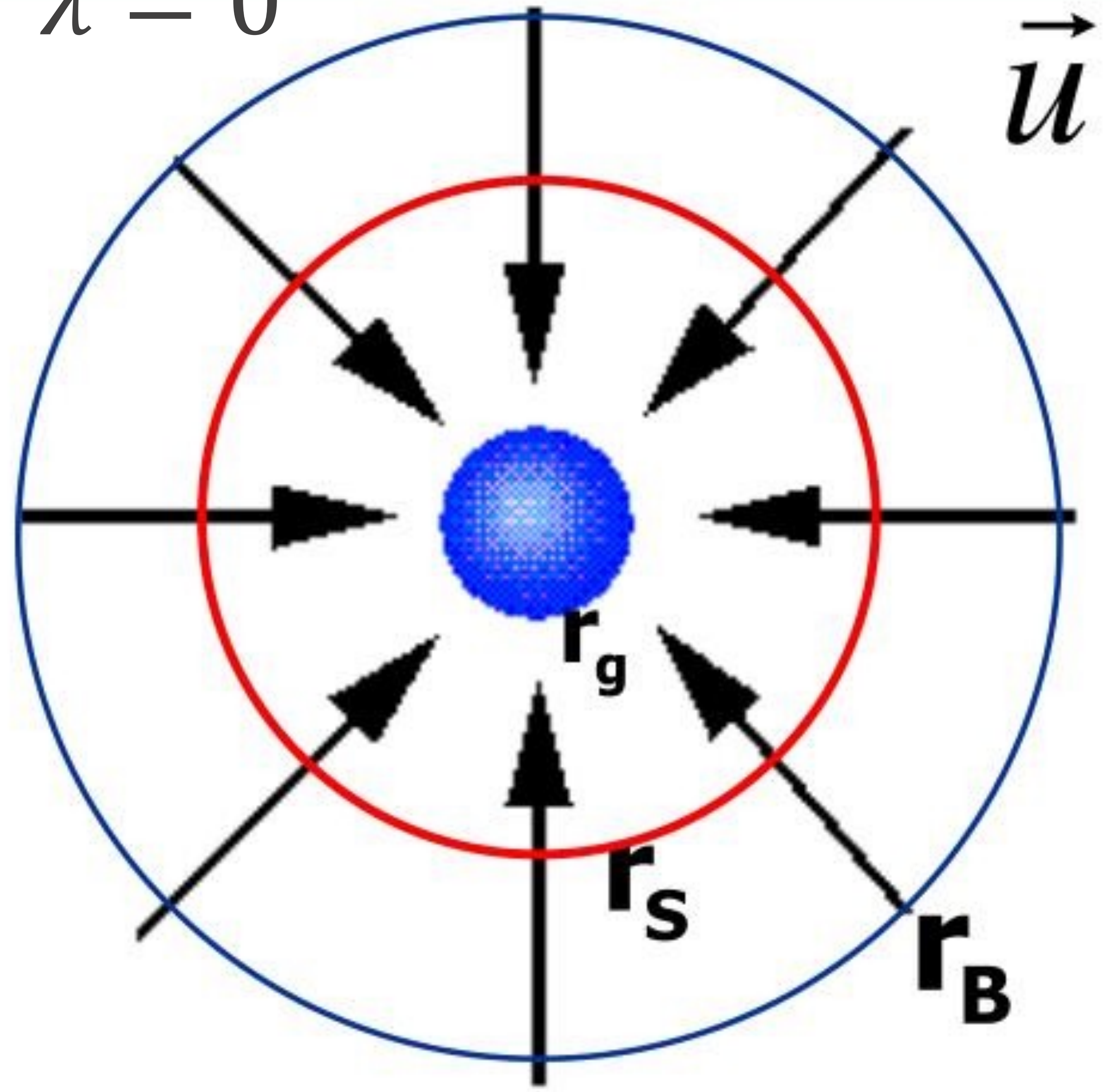
e.g., Fishbone & Moncrief (1976),
Font & Daigne (2002)



Low-angular momentum flow is one of the options to explore Sgr A* (Ressler+ 23).

Hoyle & Lyttleton (1941),
Bondi (1952)

$\lambda = 0$



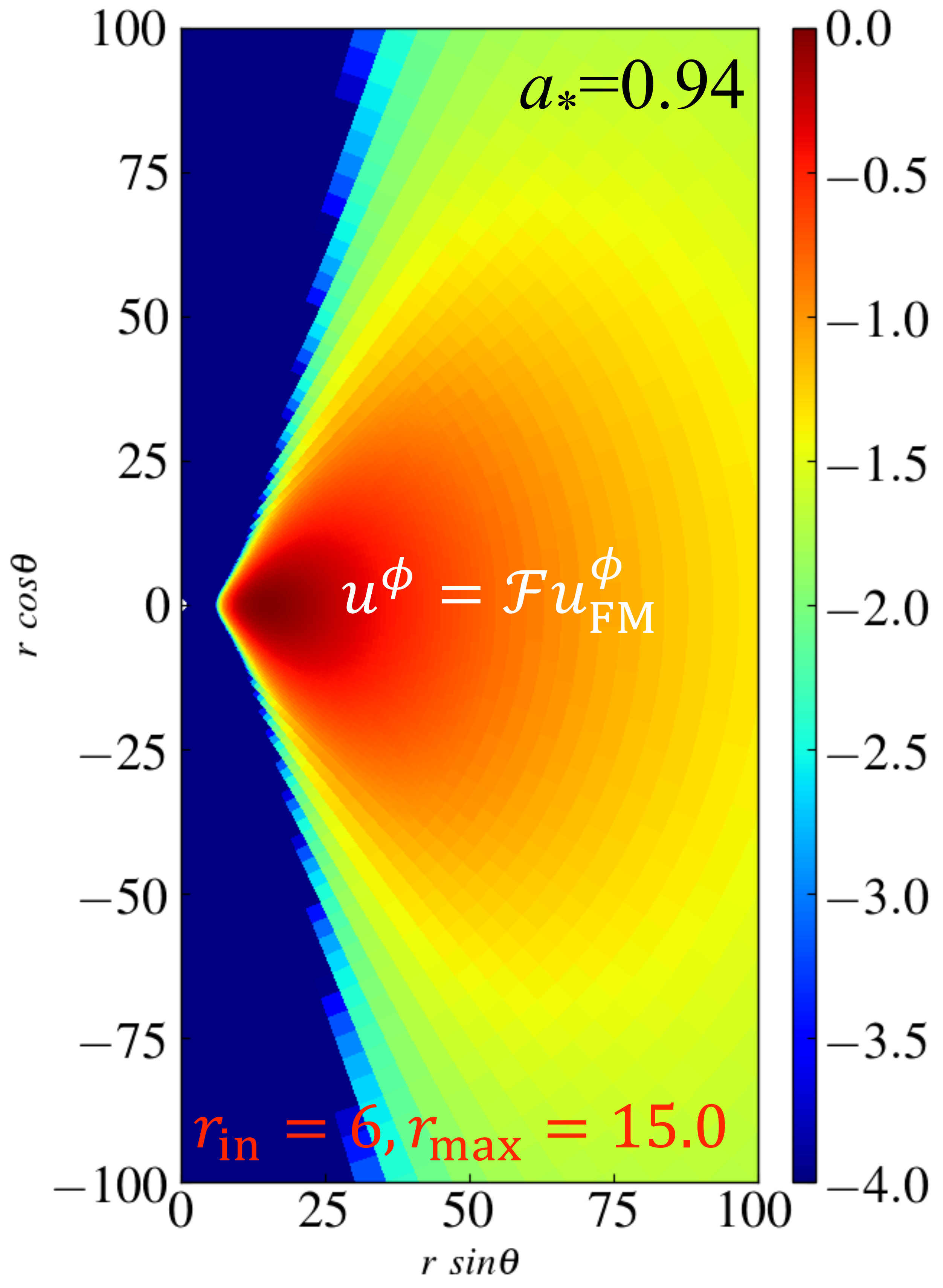
Radiative (very) inefficient

What Does Angular Momentum Do?

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

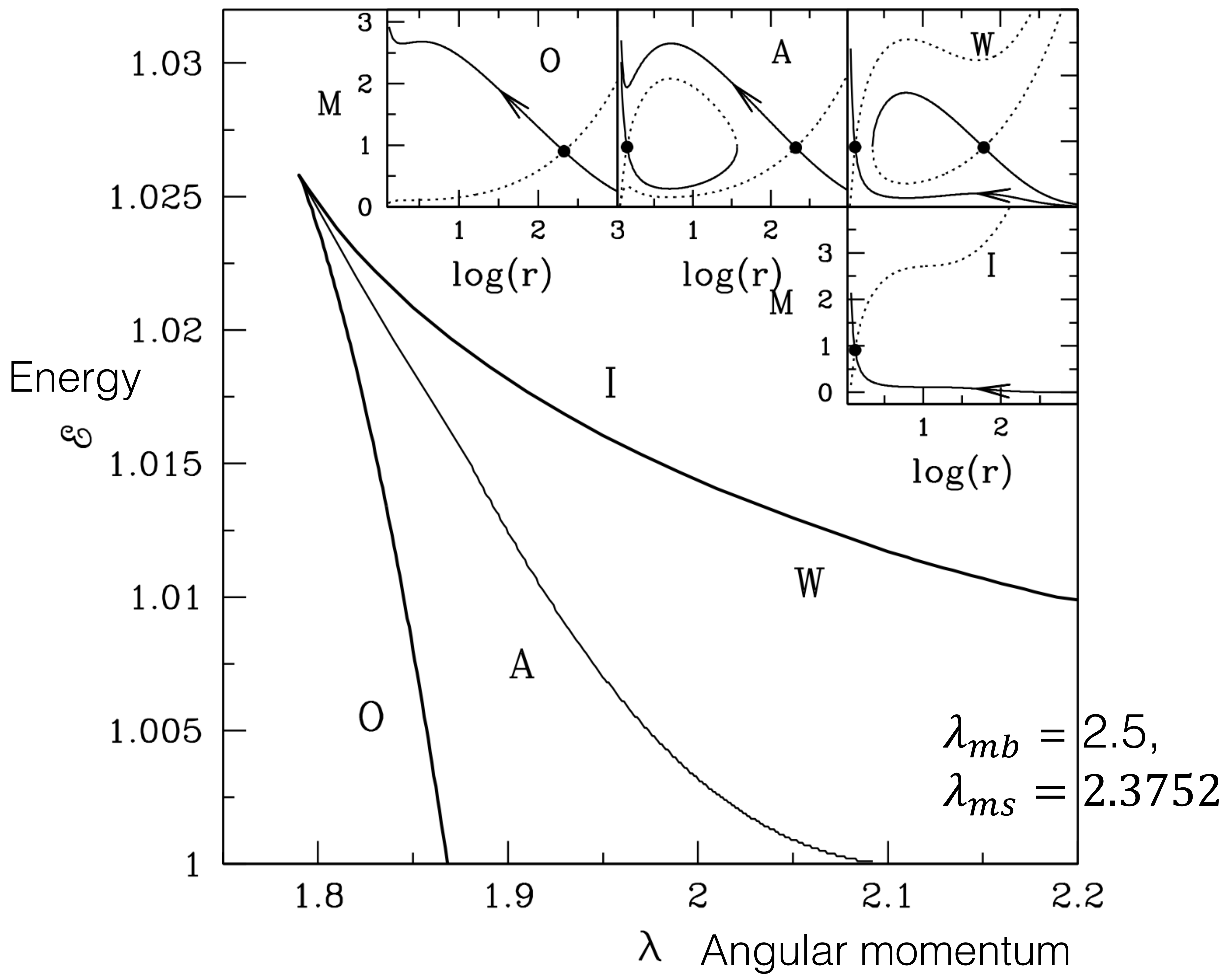
2. We modify Fishbone & Moncrief (1976) torus to accommodate low-angular momentum flow.

3. Perform GRMHD simulations.



Initial setup for our study (Dihingia & YM 2024)

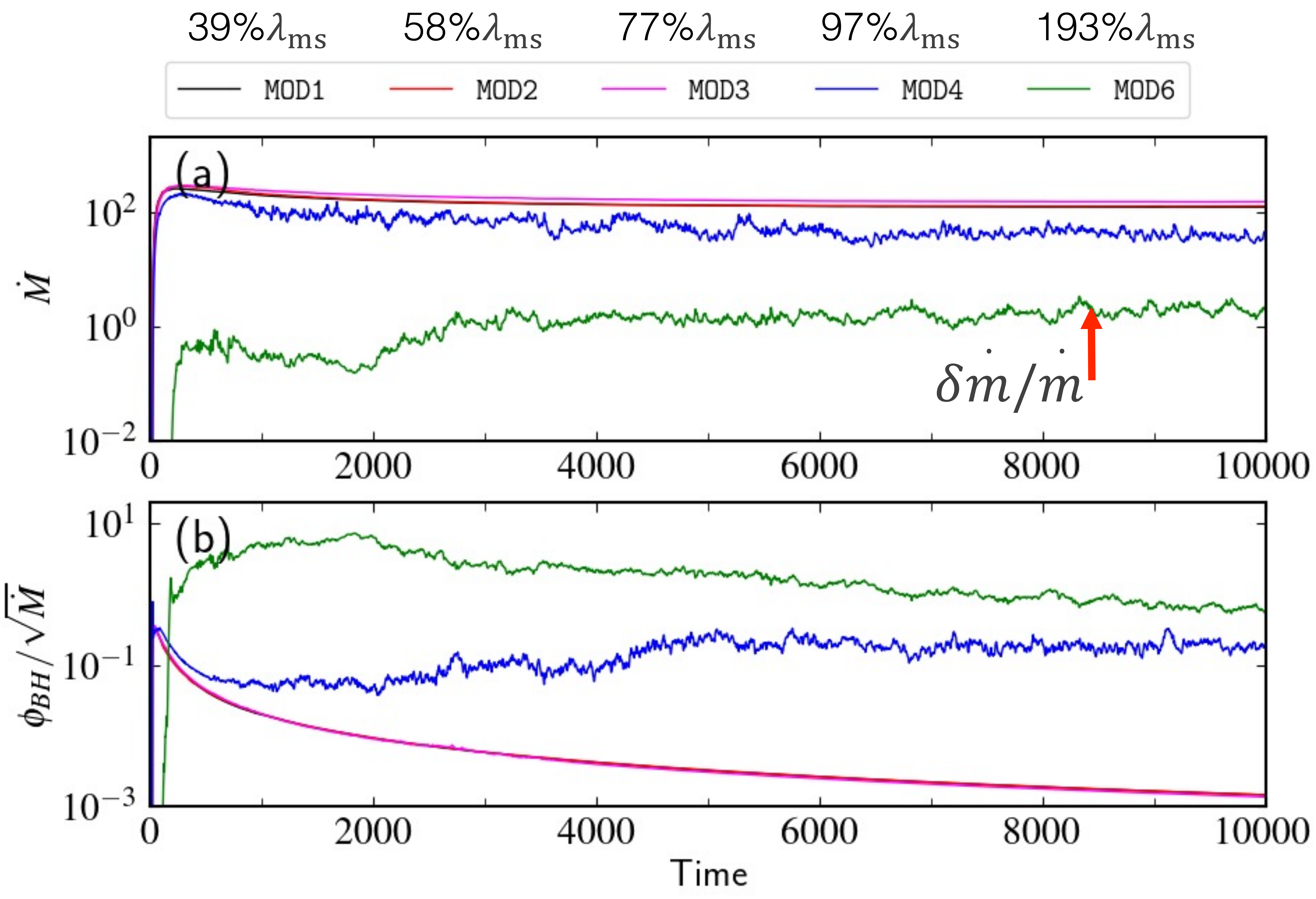
Intermediate $\lambda < \lambda_{mb}$; $\lambda < \lambda_{\rm ms}$



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.



Mass accretion rate

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

Magnetic flux rate

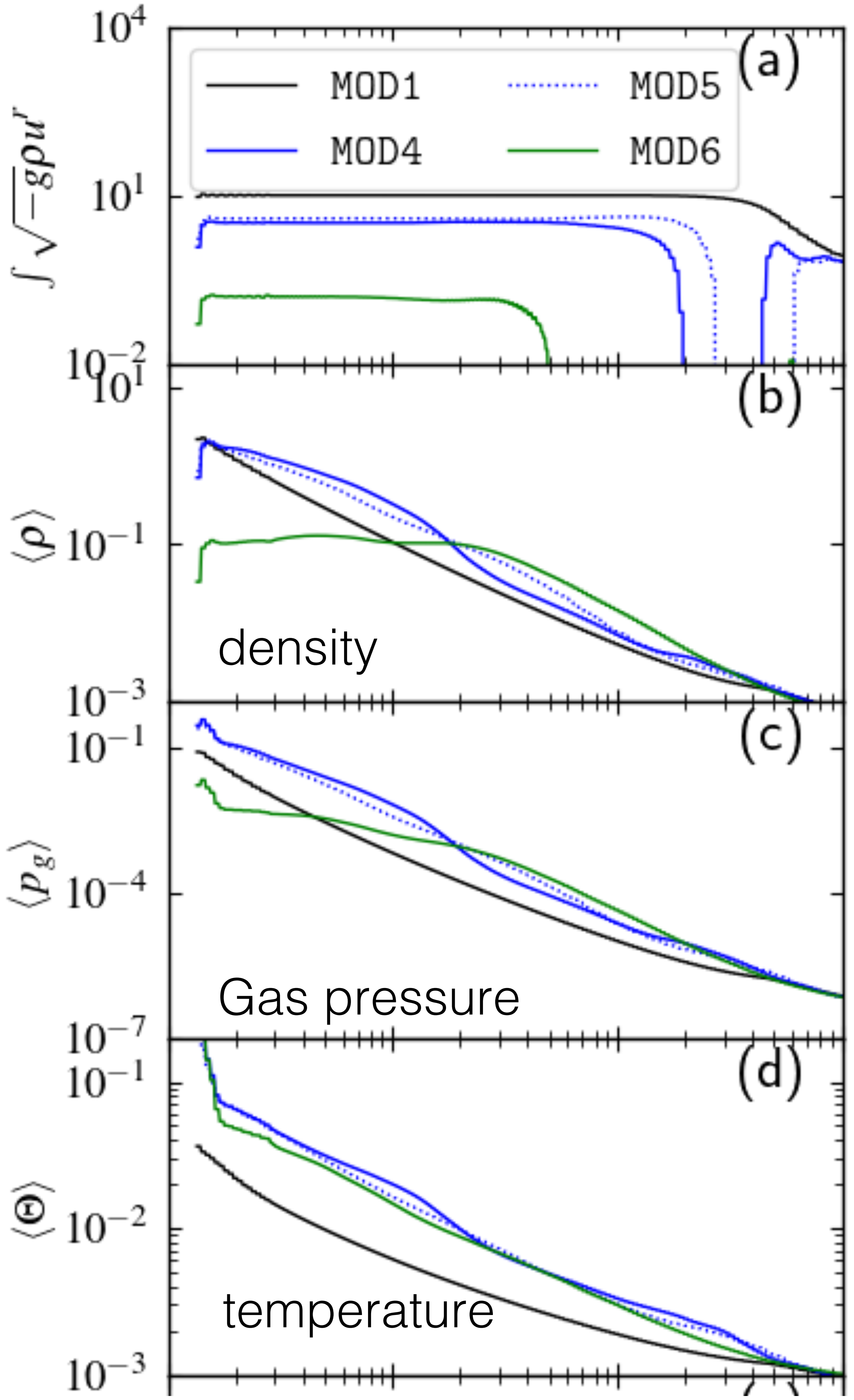
$$\Phi_{\rm B} = \frac{1}{2} \int_0^{2\pi} \int_0^{\pi} |B^r| \sqrt{-g} d\theta d\phi.$$

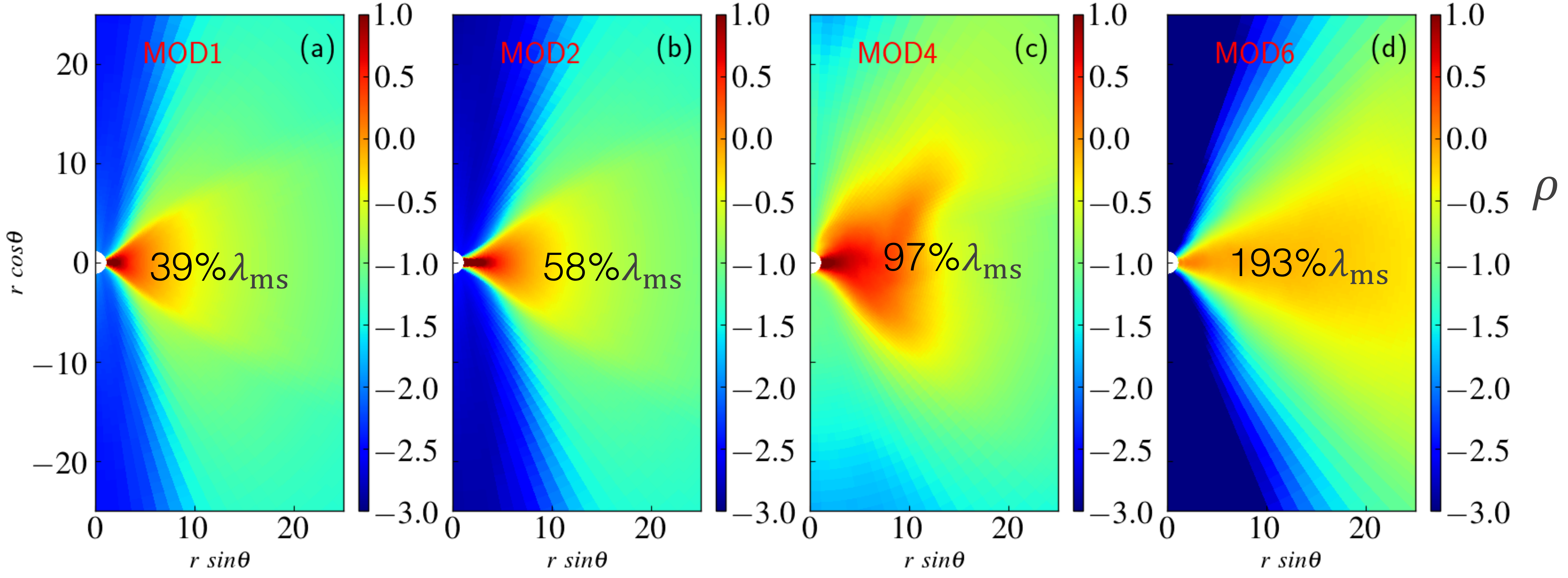
Measured at horizon

Dihingia & YM (2024)

Flow Properties

Radial distr. averaged quantities

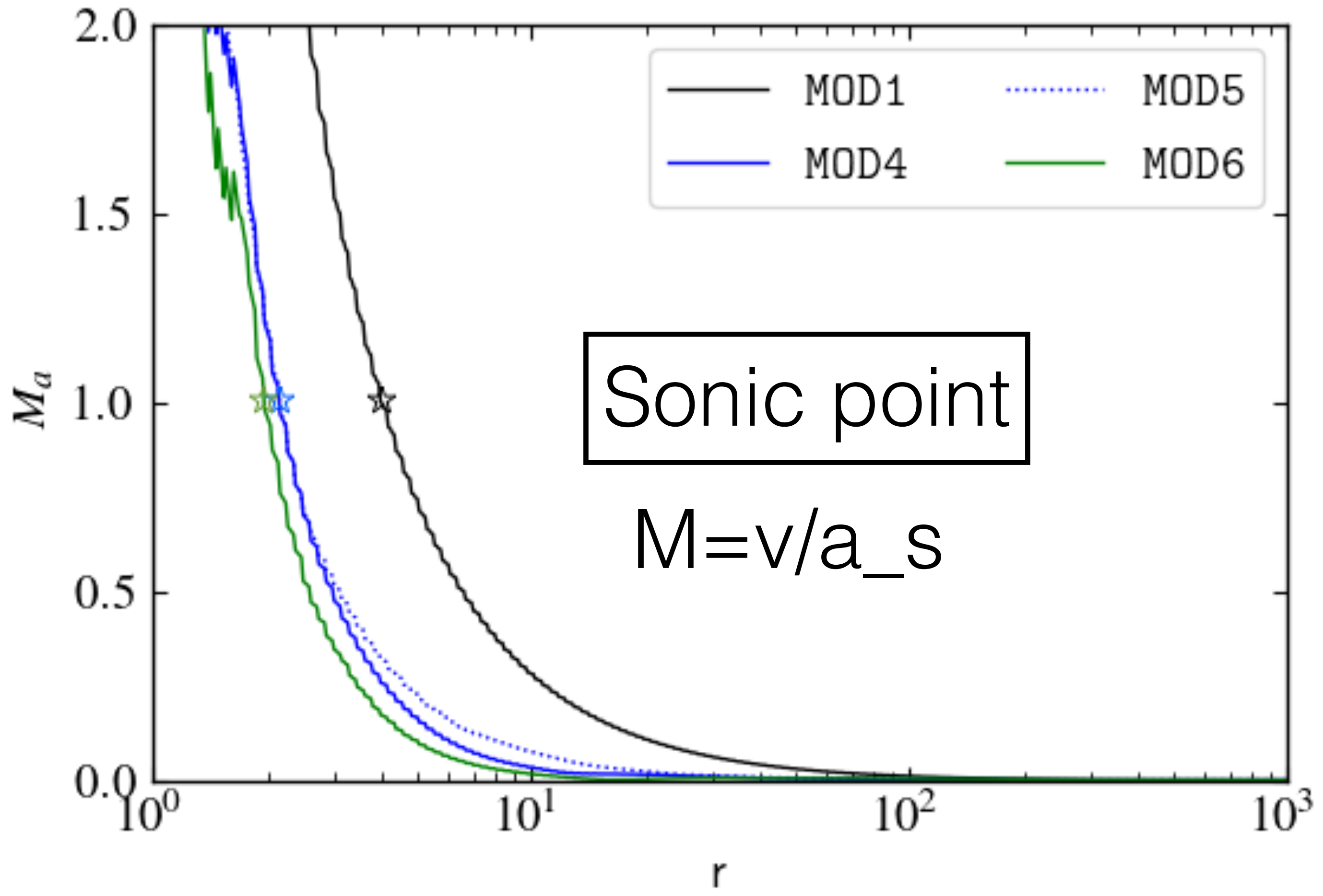




Very low-angular momentum:
$\rho \propto r^{-3/2}$ and $p_g \propto r^{-5/3}$

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

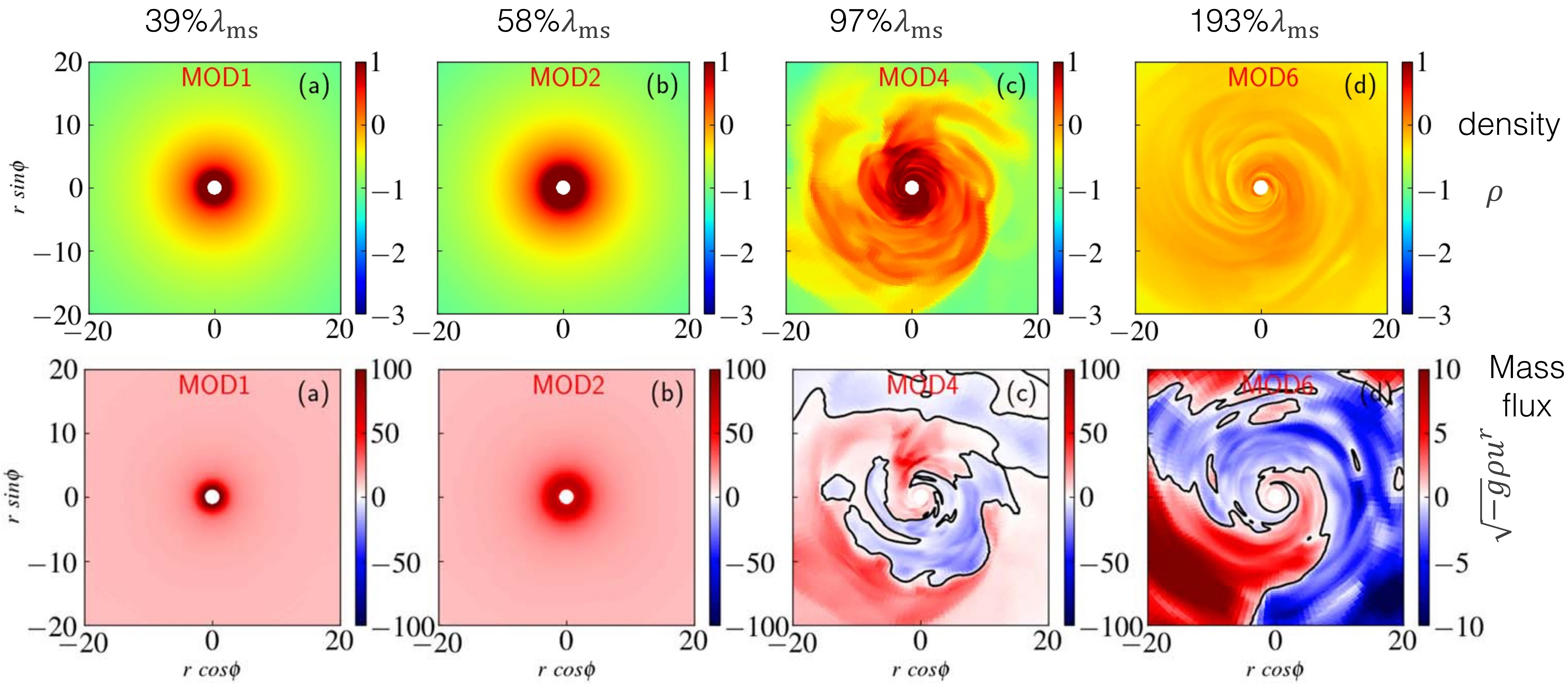
High angular momentum:
$\rho \propto r^{0}$ and $p_g \propto r^{-3/4}$



Dihingia & YM (2024)

Flow Properties

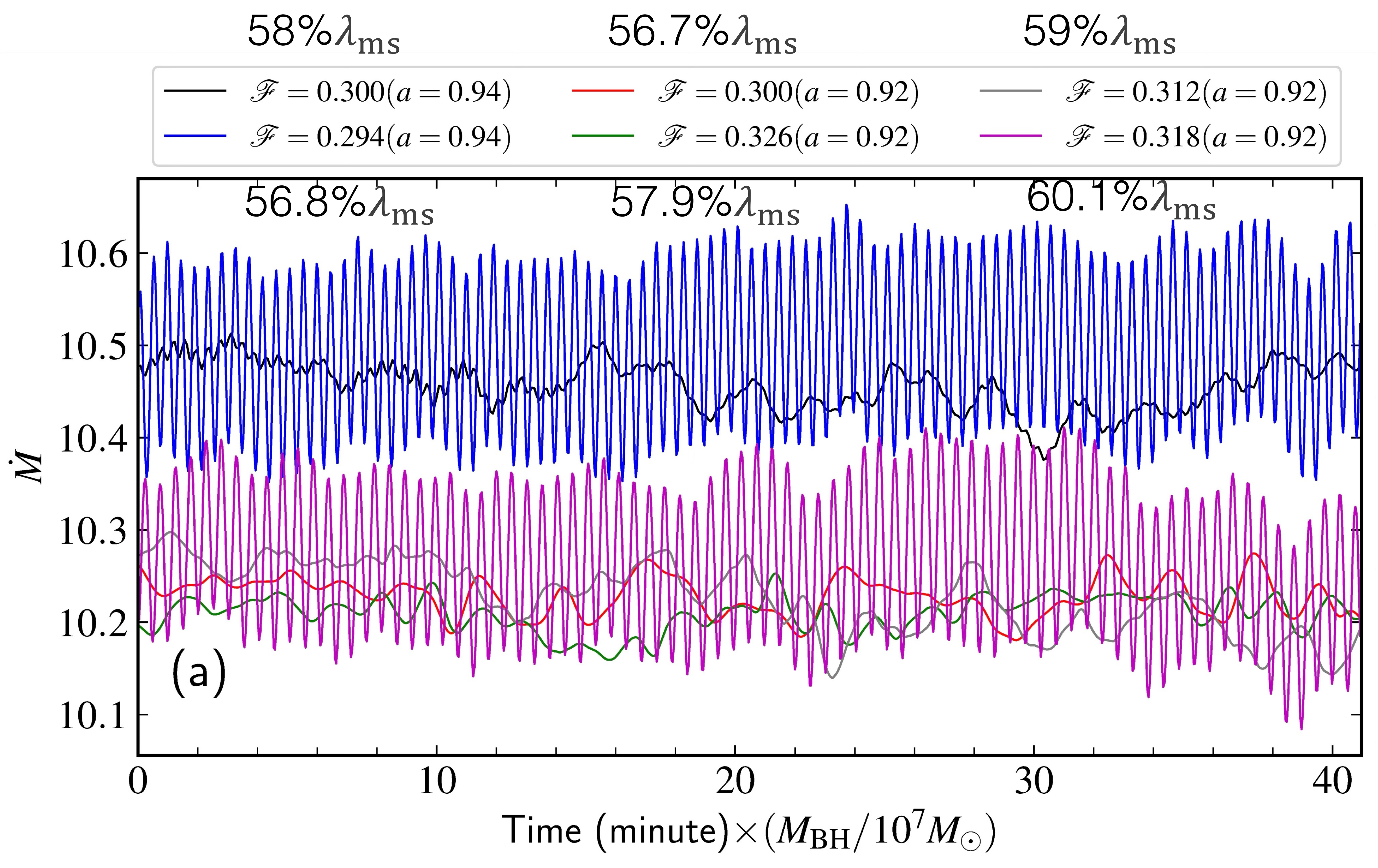
Spiral arm in the intermediate angular momentum range could be possible source of the flares.



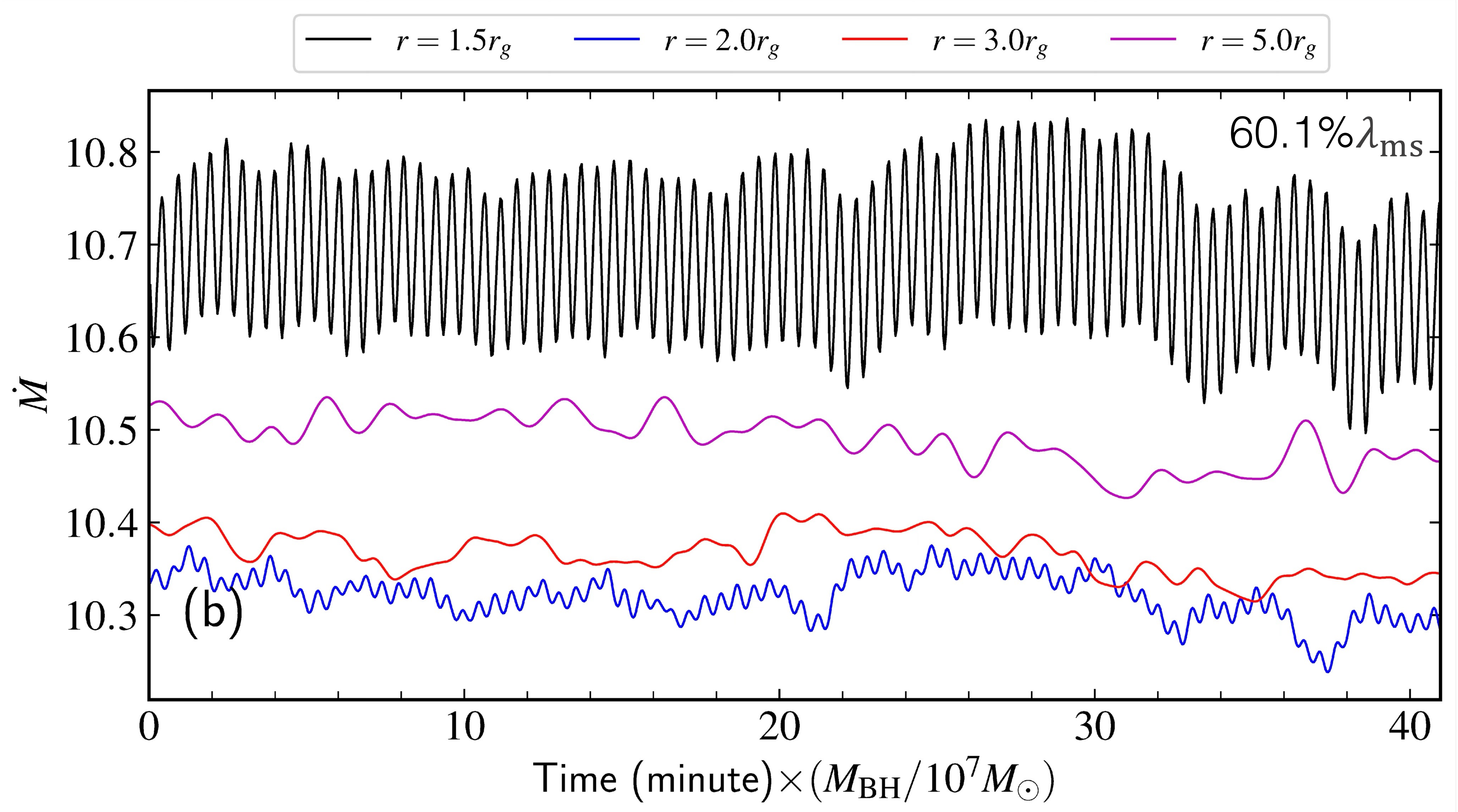
Tune the Angular Momentum

- In some cases, coherent oscillations can be seen in the accretion rate at the event horizon.

For coherent oscillations, we need to tune the angular momentum very precisely.



Oscillations die out quickly as the radii is shifted outwards.



F: fraction of Keplerian angular momentum

Dihingia & YM (2025)

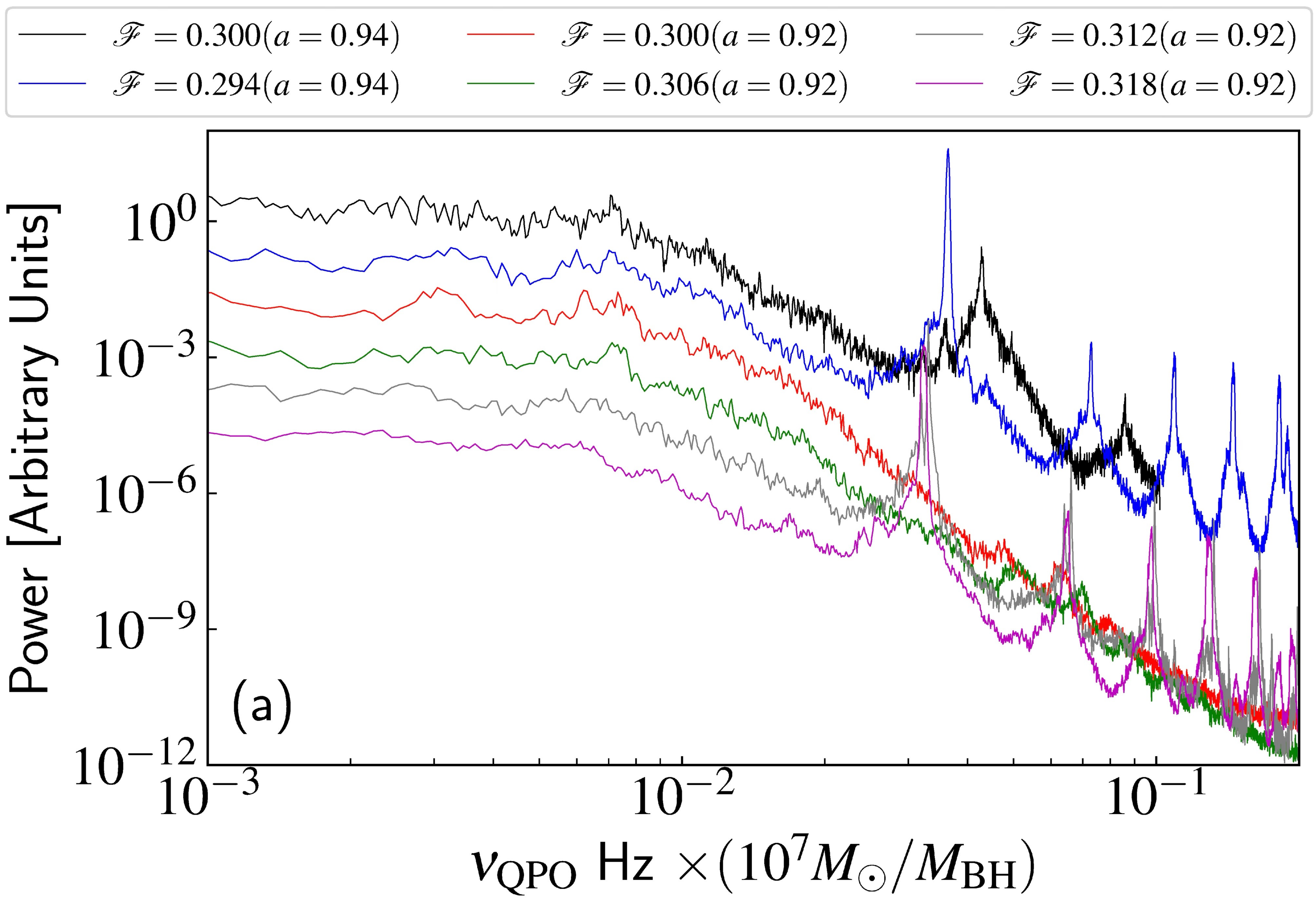
Inner Flow Changes from Angular Momentum

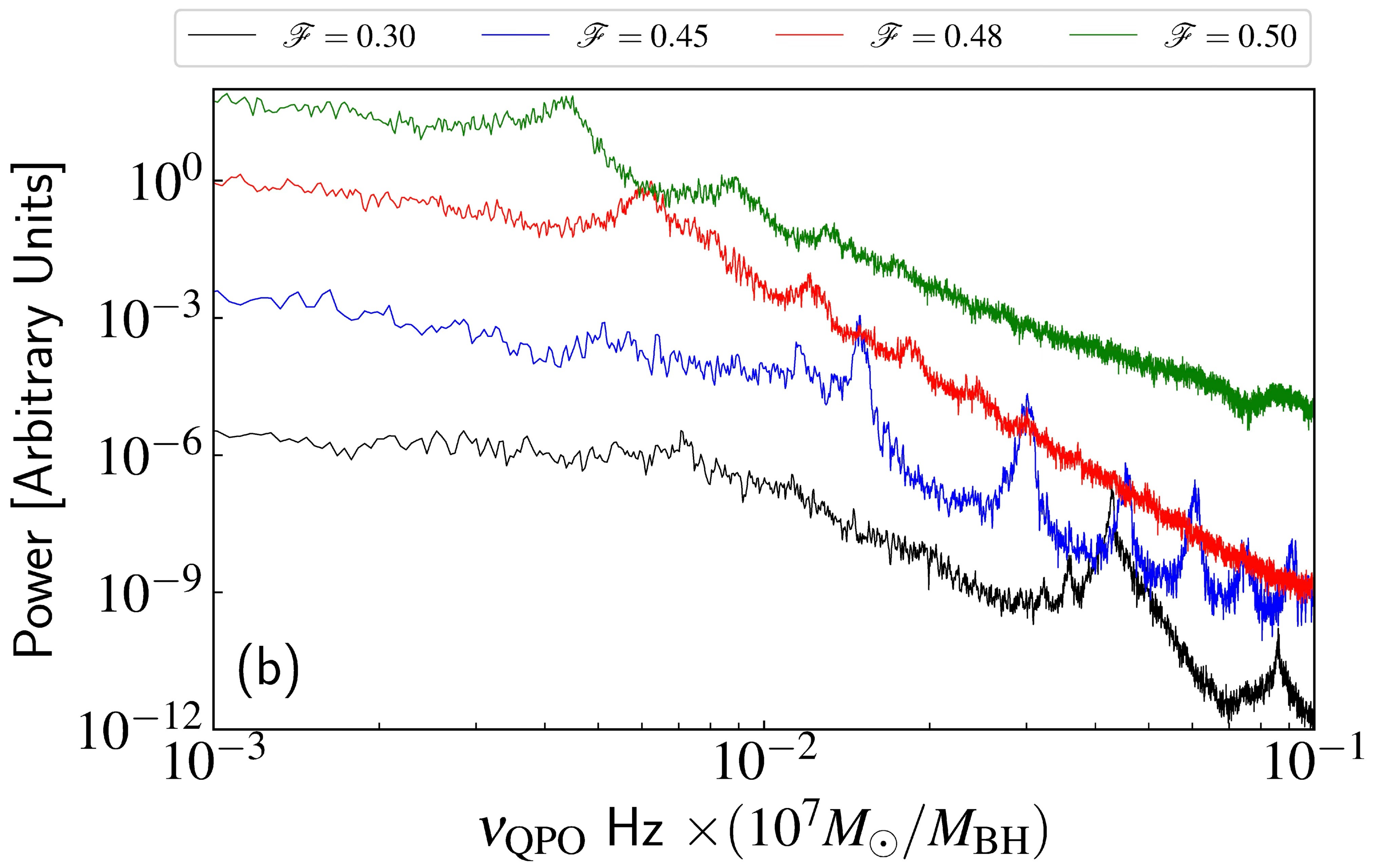
- The inner accretion structure changes drastically with angular momentum. We observe the formation of a pseudo-surface (PS) for a certain range of angular momentum.
- PS oscillates when the resonance condition is satisfied. For certain angular momentum, we observe formation of shocks.

Dihingia & YM (2025)

cHz QPOs in SMBHs

- We see very high-quality peaks in the power density spectra of mass accretion rate, i.e., QPOs can be seen.
- The range can be in centi-Hertz (cHz) and beyond (for SMBH).





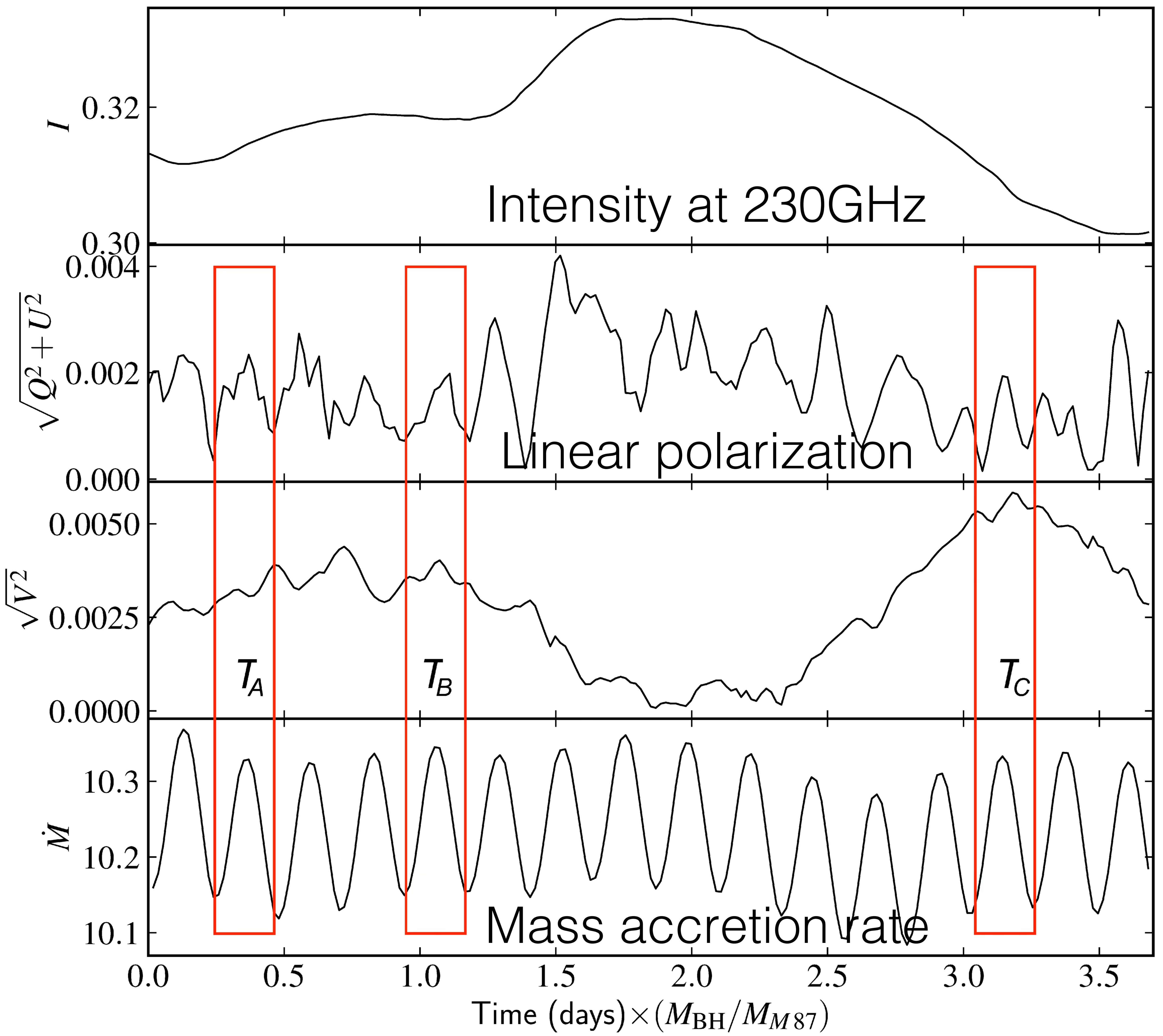
- The same resonance condition can be seen for different spin parameters.
- Peak frequency changes for different angular momentum.

F: fraction of Keplerian angular momentum

Dihingia & YM (2025)

Detectability of cHz QPOs

- Perform GRRT calculation
- We can not see the oscillations in the intensity
- But linear polarisation shows correlations with the oscillations.
- Future high-resolution polarisation survey will be a game changer for the detection of cHz QPOs from supermassive black holes.
- For BH-XRBs, we can see them in kHz in X-rays.
- e.g., IXPE (US), PolSat (India), eXTP (China)



Dihingia & YM (2025)

Summary

- Although it generates the flaring events, MAD flows produce a strong jet that may not be the actual behaviour of Sgr A*
- Our setup was able to simulate low-angular momentum GRMHD flow without a very complex setup (Ressler+18, Olivares+23).
- Accretion flow with an intermediate range of angular momentum has similar properties to 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.
- Low angular momentum accretion flow can produce stable, centi-Hertz QPOs with clear 2:1 harmonics.
- While intensity variations are redshifted away, the QPOs imprint on linear polarization at 230 GHz