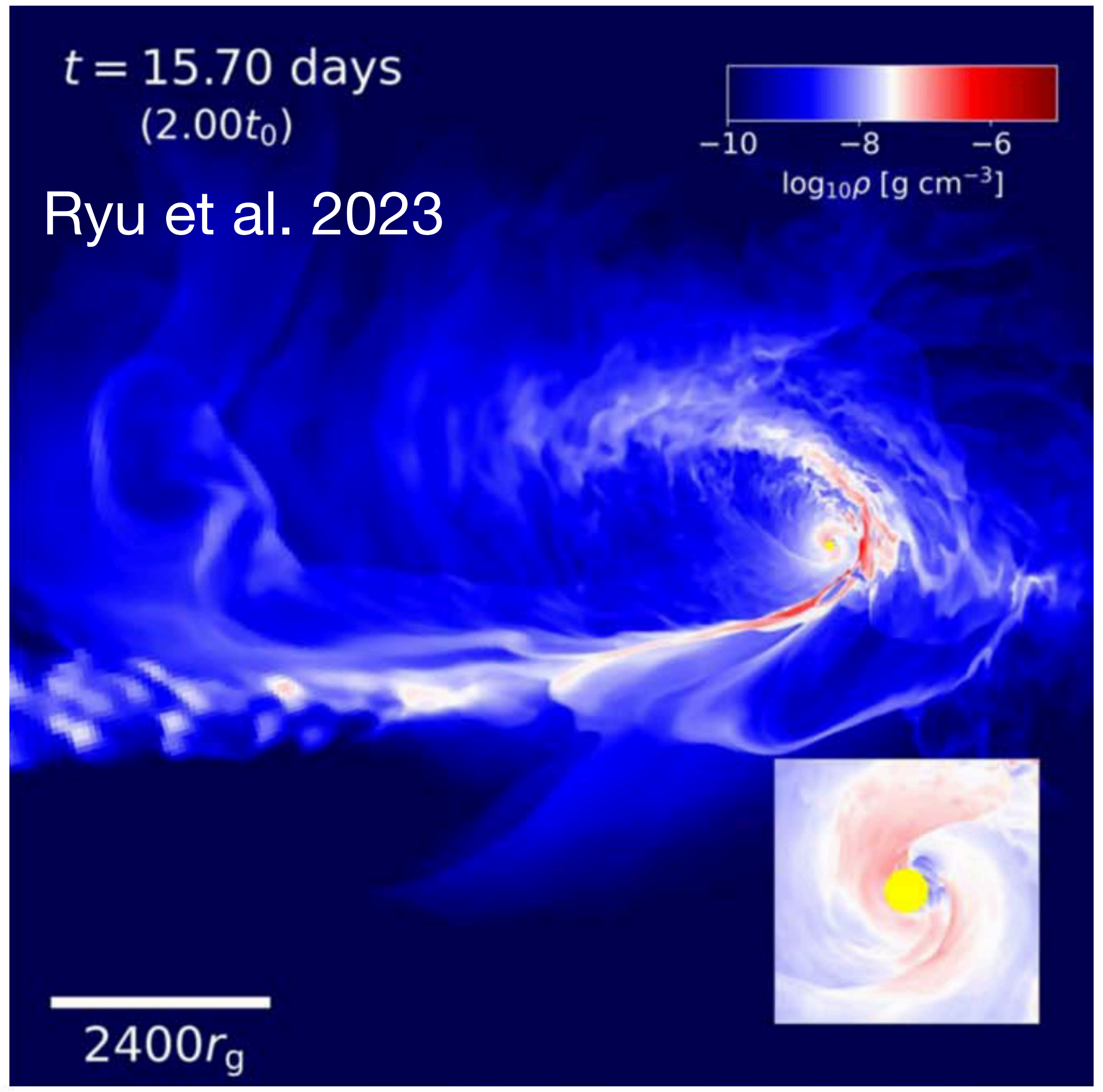
Magnetically Driven Retrograde Precession in Misaligned Black Hole Accretion Flows

The 10th East Asian Numerical Astrophysics Meeting
2025.09.16

Speaker: Hong-Xuan Jiang (蒋宏轩)
Tsung-Dao Lee Institute
Email: hongxuan_jiang@sjtu.edu.cn

Main collarborators: Yosuke Mizuno (TDLI), Dong Lai (TDLI/Cornell)

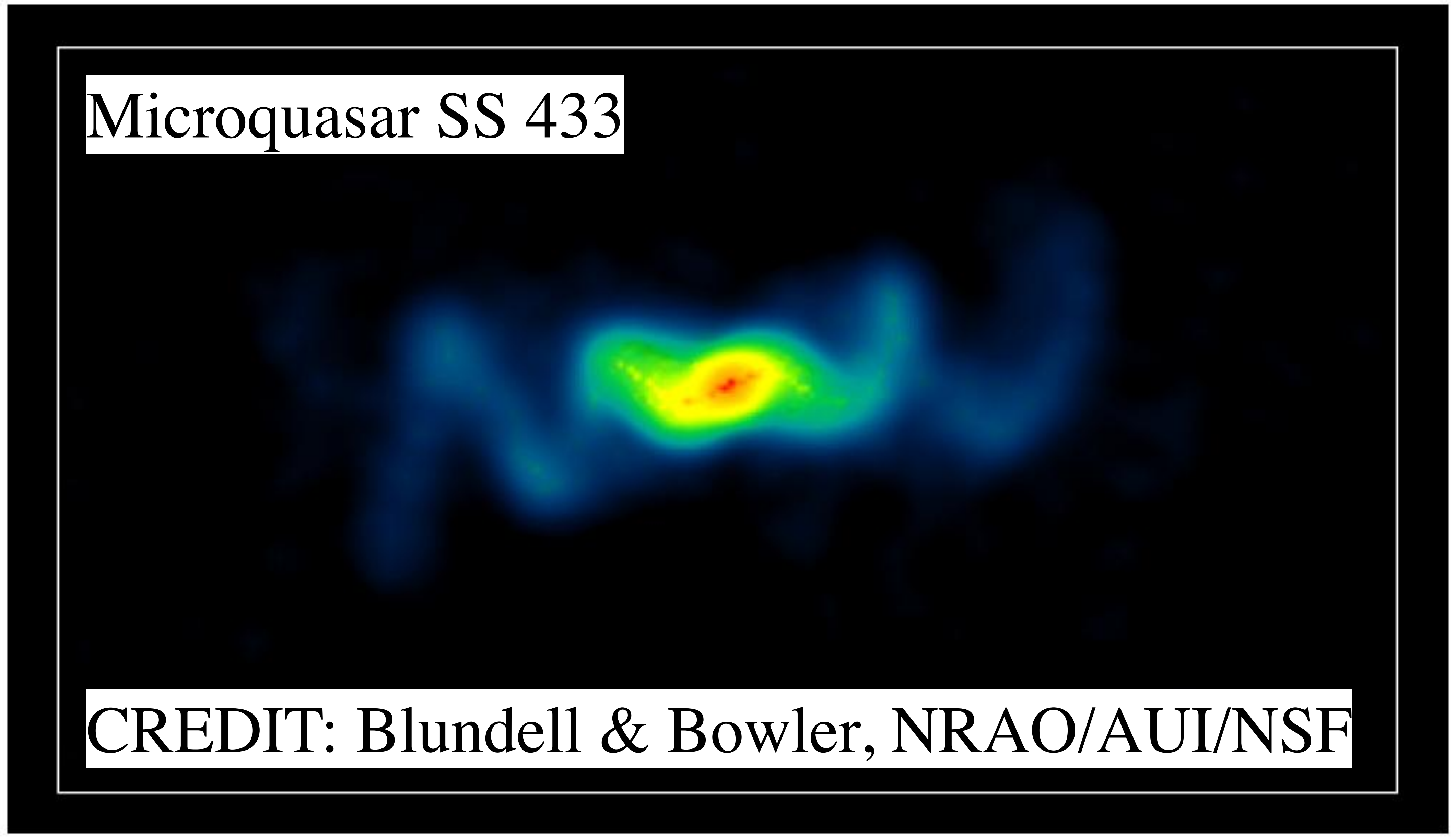
Misaligned accretion is common in the universe



Tilted disks and precessing jets are common features in various astrophysical systems, including microquasars, TDEs, and AGNs.

What's the driving mechanism of the precession?

- Lense-Thirring effect: $\tau_{\rm LT} \sim r^{-3}$
- Magnetic torque



Lense-Thirring effect

Dominates at $r \sim r_{\rm ISCO}$

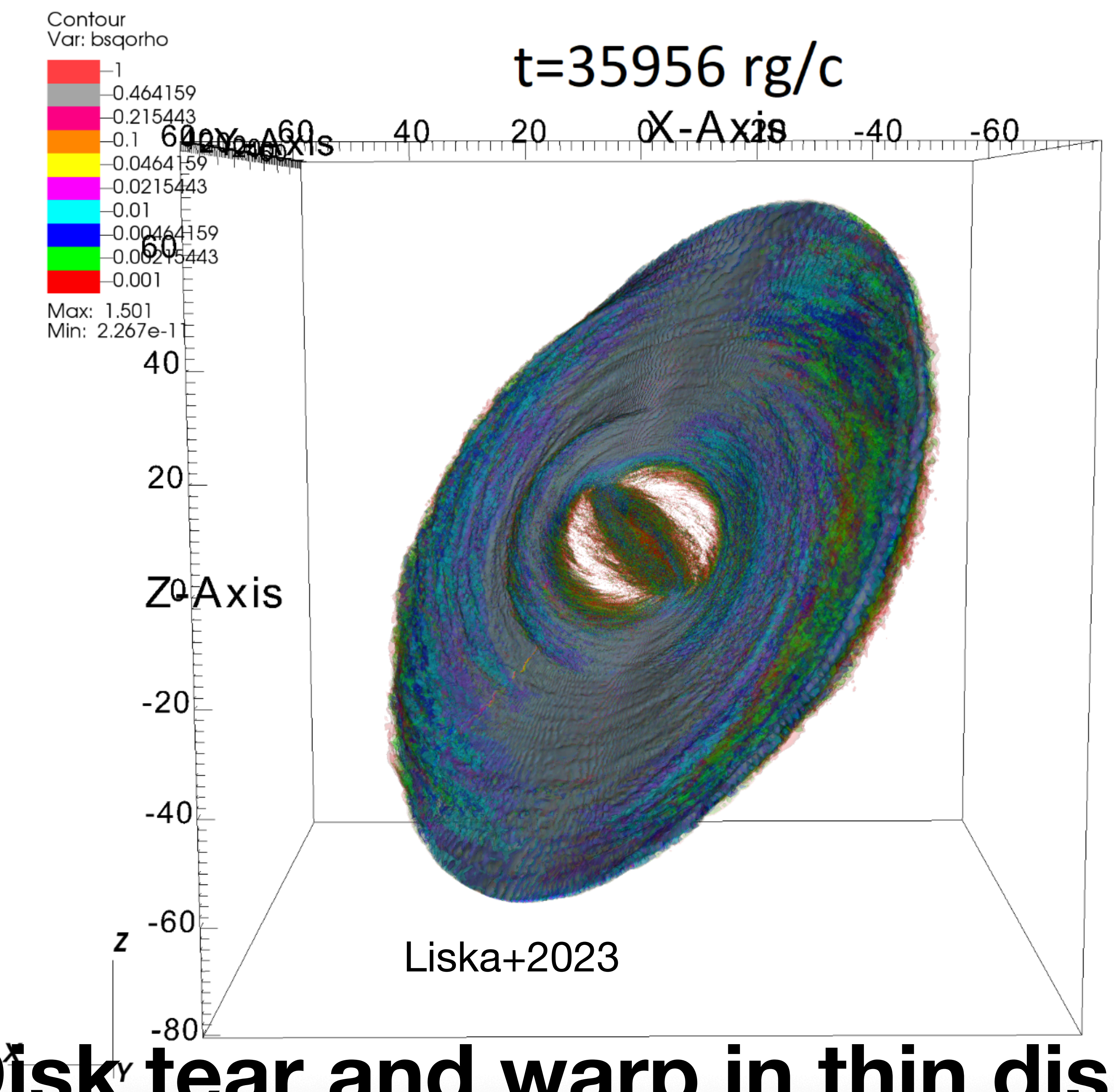
In a tilted accretion disk, the LT torque per unit area is

$$\tau_{\rm LT} \sim \sin\beta\Omega_{\rm LT}L,$$

where LT angular frequency $\Omega_{\rm LT} \propto r^{-3}$, and L is the disk angular momentum.

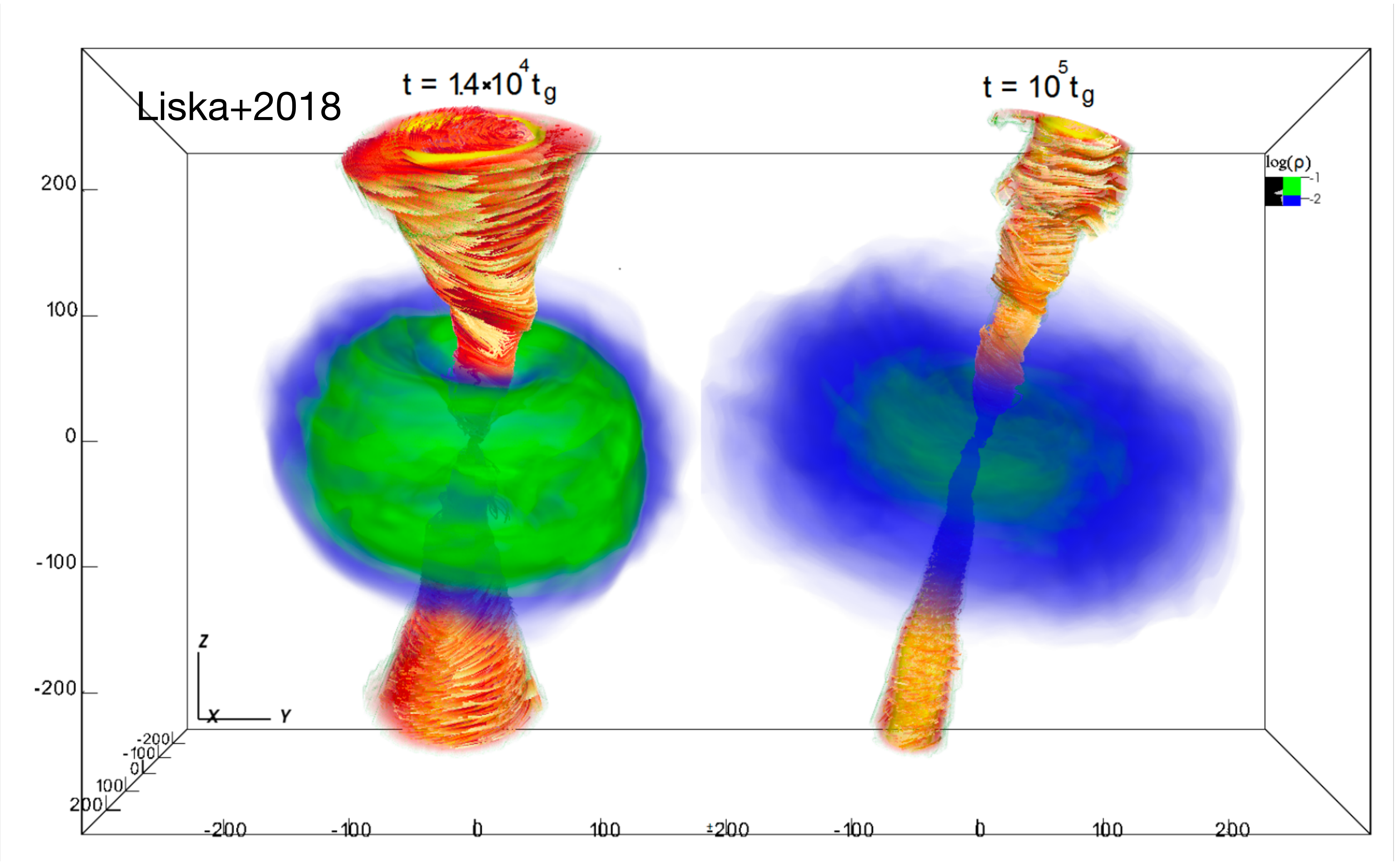
Lense-Thirring precession in GRMHD simulations

Geometrically thin and thick disks



Disk tear and warp in thin disks

$\sim 10\, r_g$

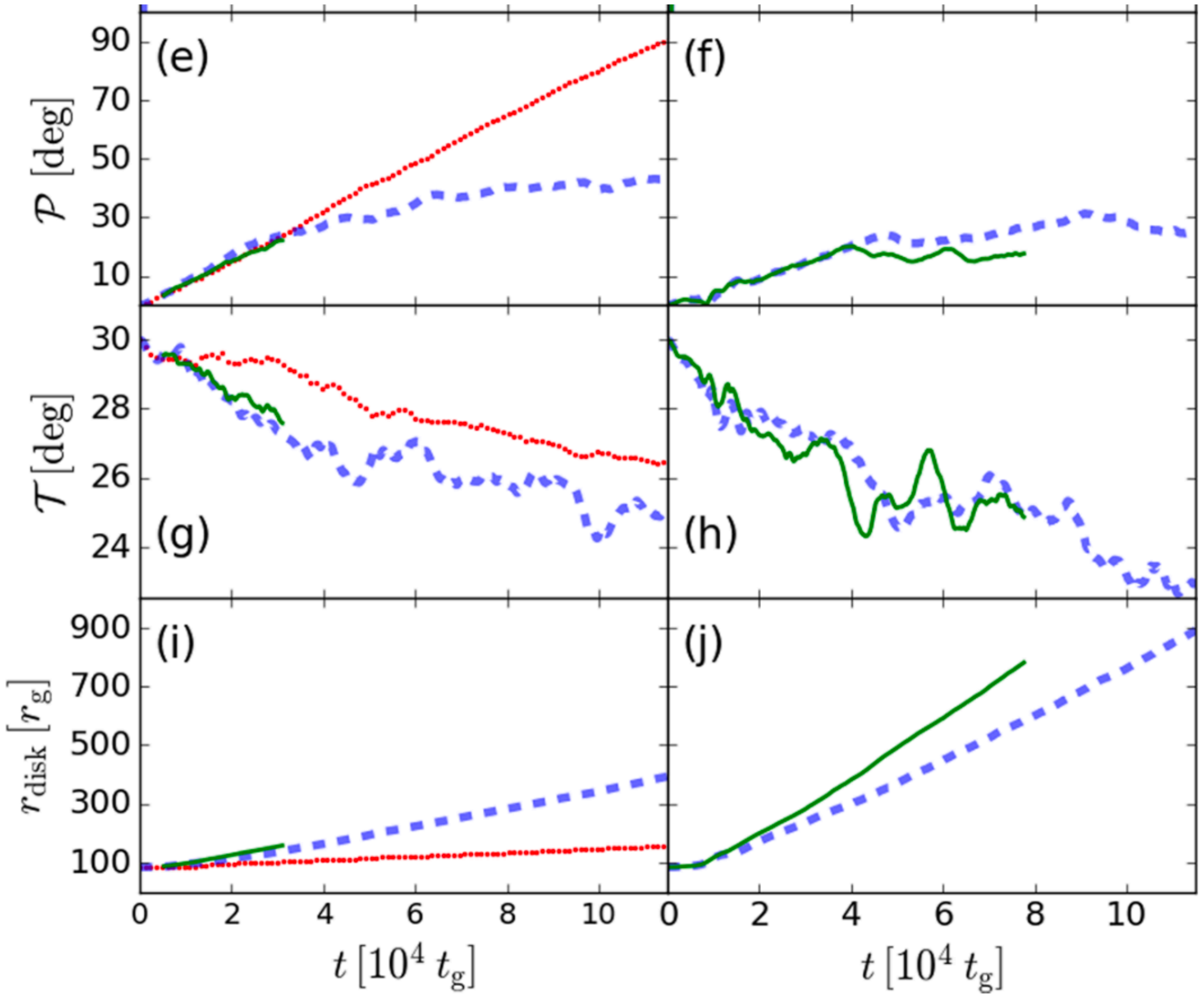


- In thick disks, viscosity and pressure propagate misalignment as a bending wave.
- Bending Wave propagates through disk on timescale ~ sound-crossing time, allowing coherent precession despite LT effect's limited radial range.

Precession stops when disk expands

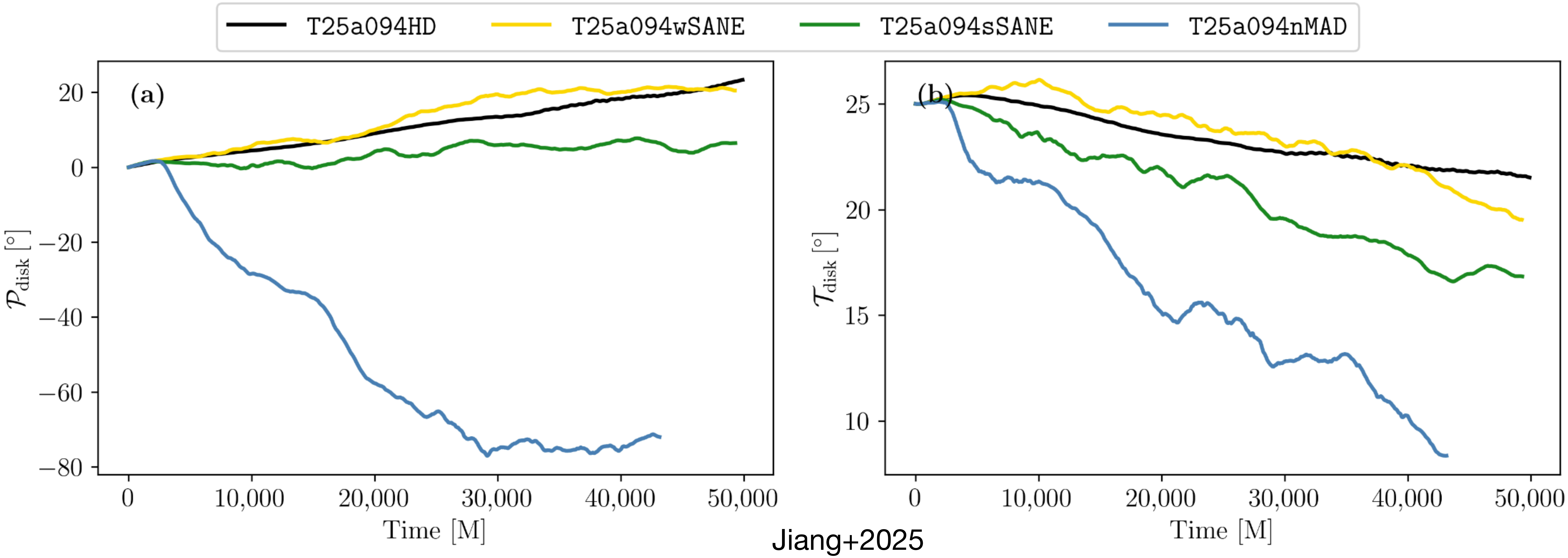
- MRI drives angular momentum transport and enables **disk expansion**.
- As disk size increases, the **travel time** for bending waves to cross the disk increases.
- As the disk size grows, bending waves can't effectively "communicate" across the full disk anymore, and precession becomes desynchronized. Global precession stops.

Liska+2018



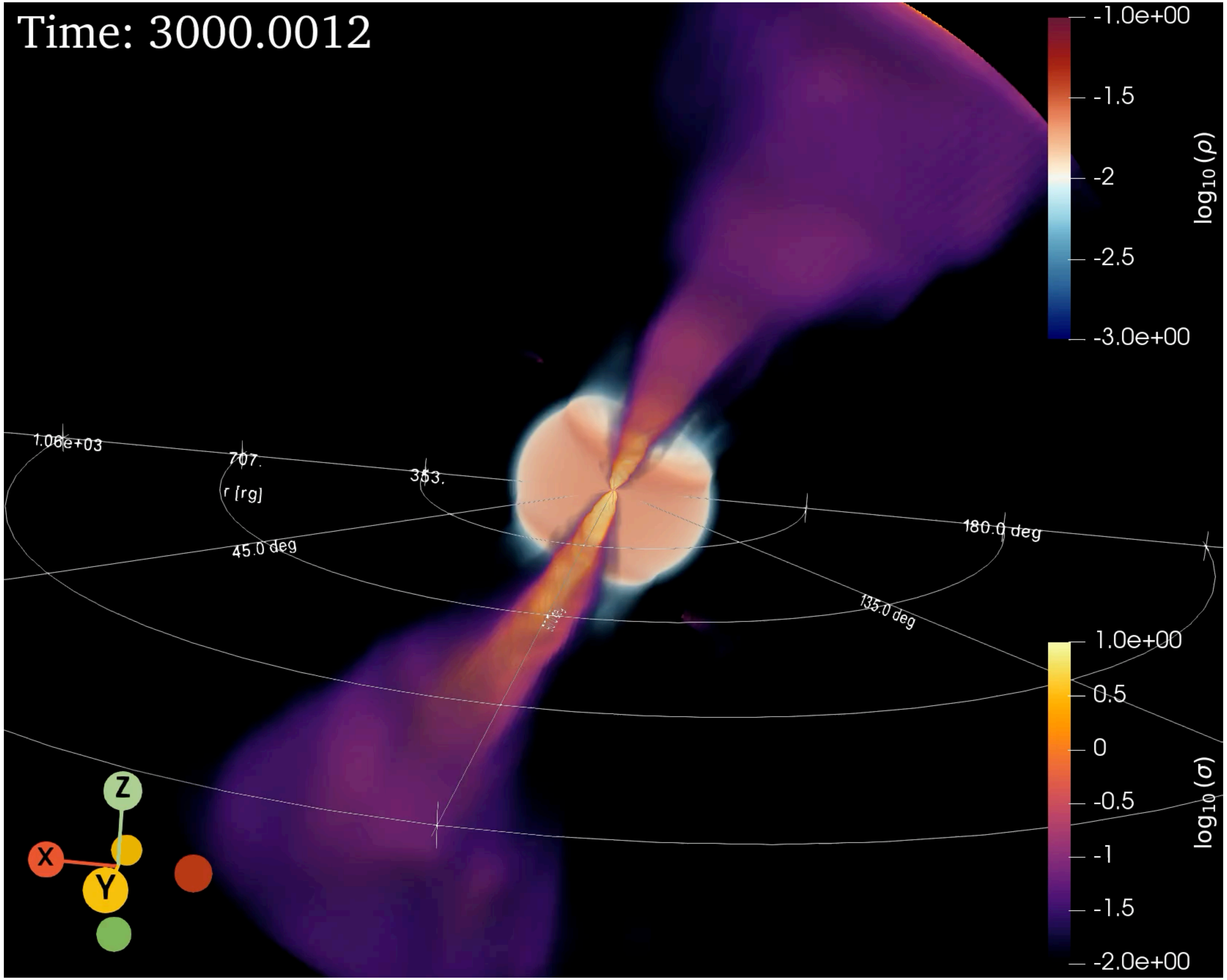
Magnetically driven retrograde precession

Retrograde precession appears when magnetic field is strong enough.



Jiang+2025

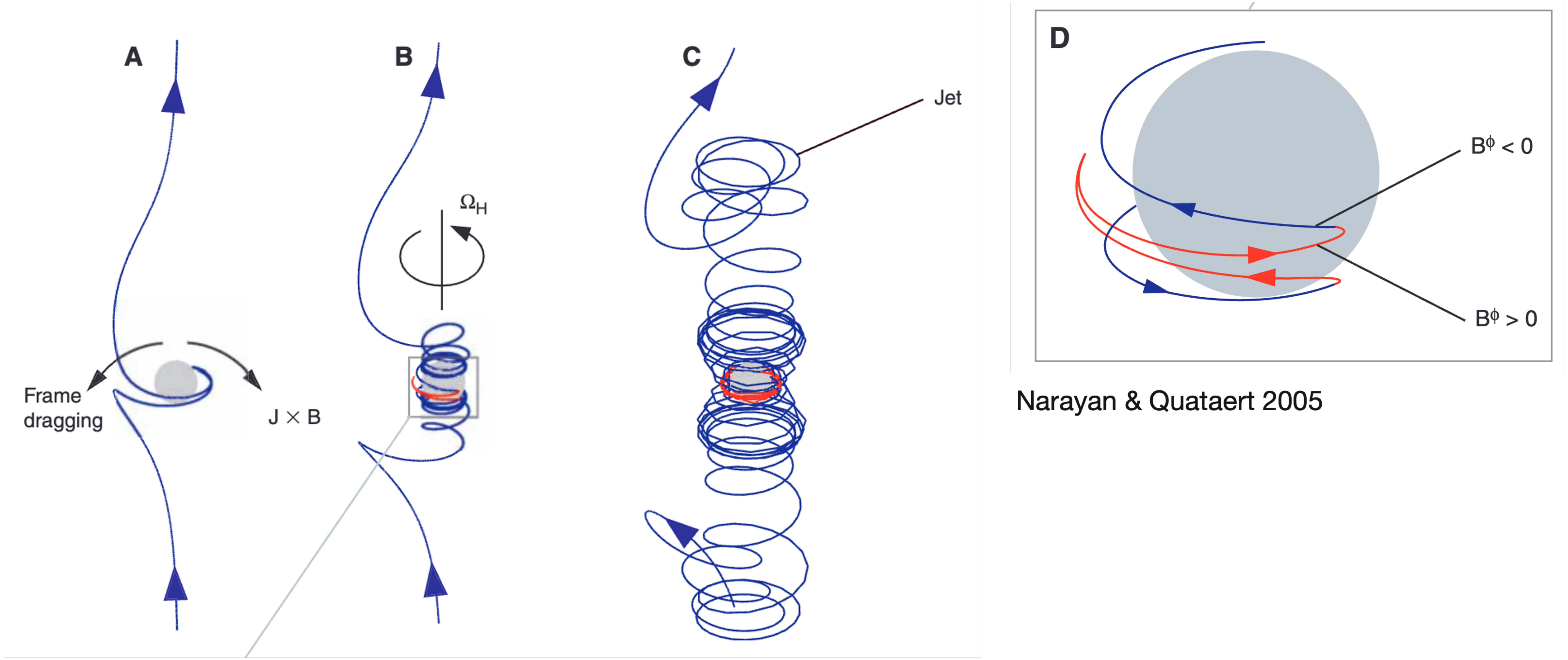
Jiang+2025



Time: 3000.0012
-1.0e+00
-1.5
-2
-2.5
-3.0e+00
$\log_{10}(\rho)$
1.06e+03
707.
353.
r [rg]
45.0 deg
180.0 deg
135.0 deg
1.0e+00
0.5
0
-0.5
-1
-1.5
-2.0e+00
$\log_{10}(\sigma)$
Z
X
Y

How does the magnetic field drives retrograde precession?

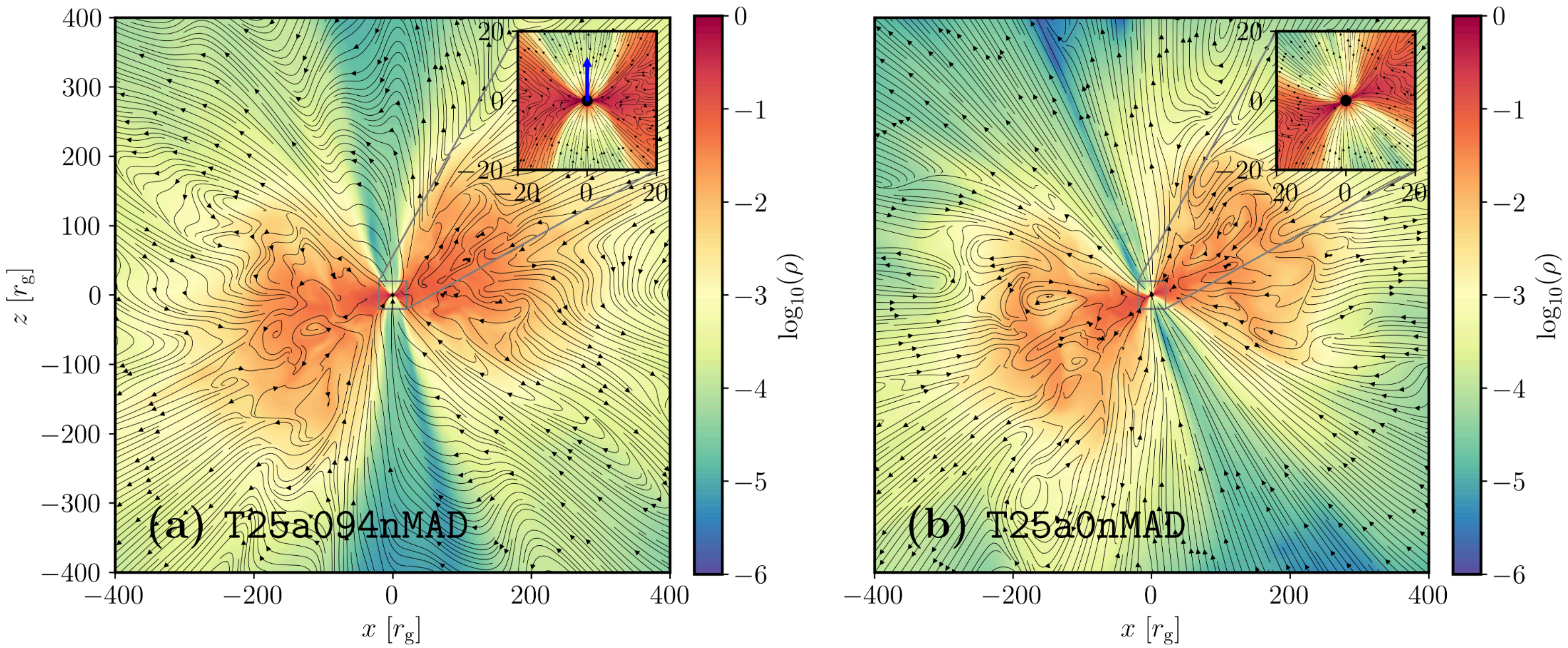
Magnetic field twisting from frame-dragging



Narayan & Quataert 2005

Magnetic precession torque

- The rotation of the BH aligns the poloidal magnetic field to the spin direction $\hat{z}$, while the torus remains misaligned.
- The misaligned magnetic projects a radial magnetic field in the disk, whose interaction with the poloidal current K_ϕ in the torus leading to a force perpendicular to the disk.



Jiang+2025

The force is $\phi-$dependent, leading to a magnetic torque (per unit area) on the disk

$$\mathbf{T}_{\text{mag}} = -\frac{1}{4\pi} r B_z^2 \tan\theta \hat{z} \times \hat{l}$$

Comparison between magnetic and LT torque

- The magnetic torque induces a **retrograde** precession with a local frequency of

$$\Omega_{\rm mag}(r) = -\frac{B_z^2 \tan\theta}{4\pi\Sigma r\Omega(r)}$$

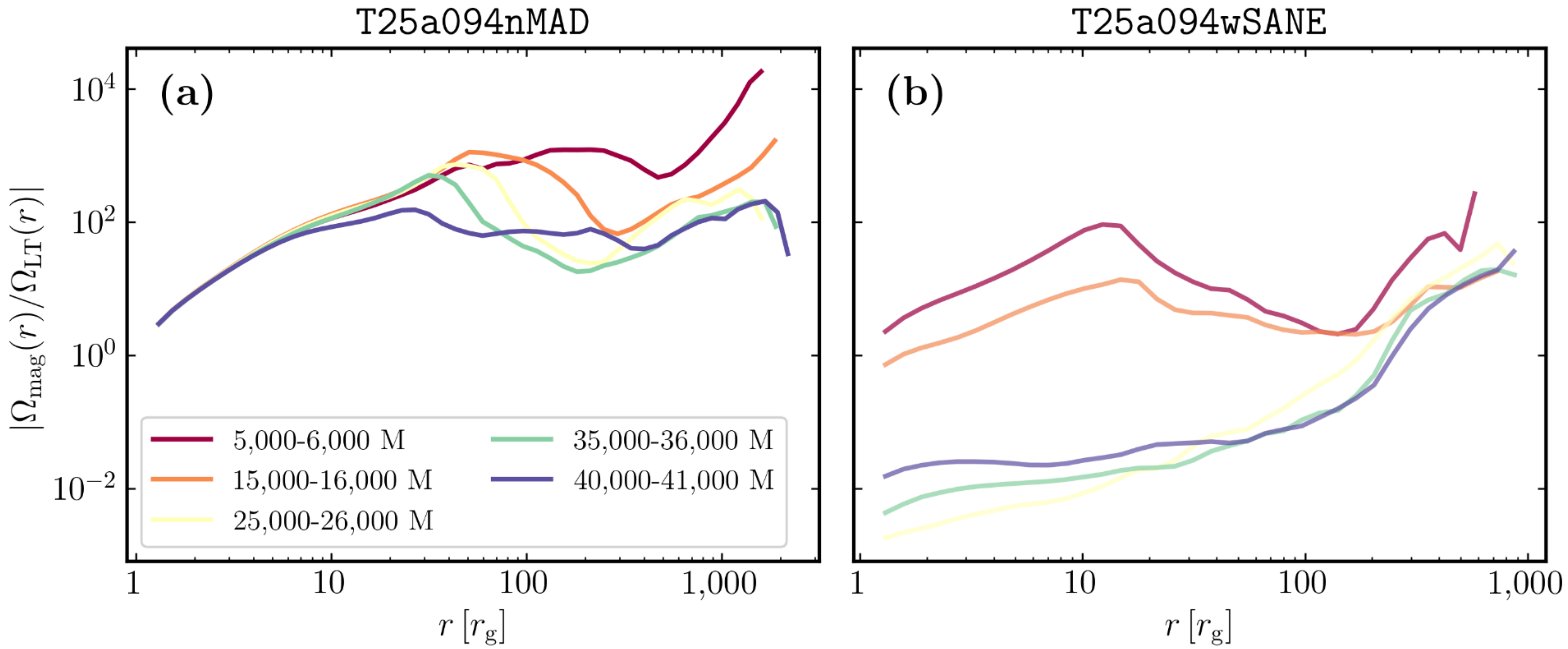
- Lense-Thirring Precession Frequency

$$\Omega_{\rm LT}(r) = \frac{2S}{r^3} = \frac{2M^2 a}{r^3}$$

- The ratio of the magnetic to LT precession frequency is given by

$$\frac{\Omega_{\rm mag}(r)}{\Omega_{\rm LT}(r)} \simeq -\frac{B_z^2 \tan\theta/8\pi}{a\rho c c_{\rm s}(r_{\rm g}/r)^2}$$

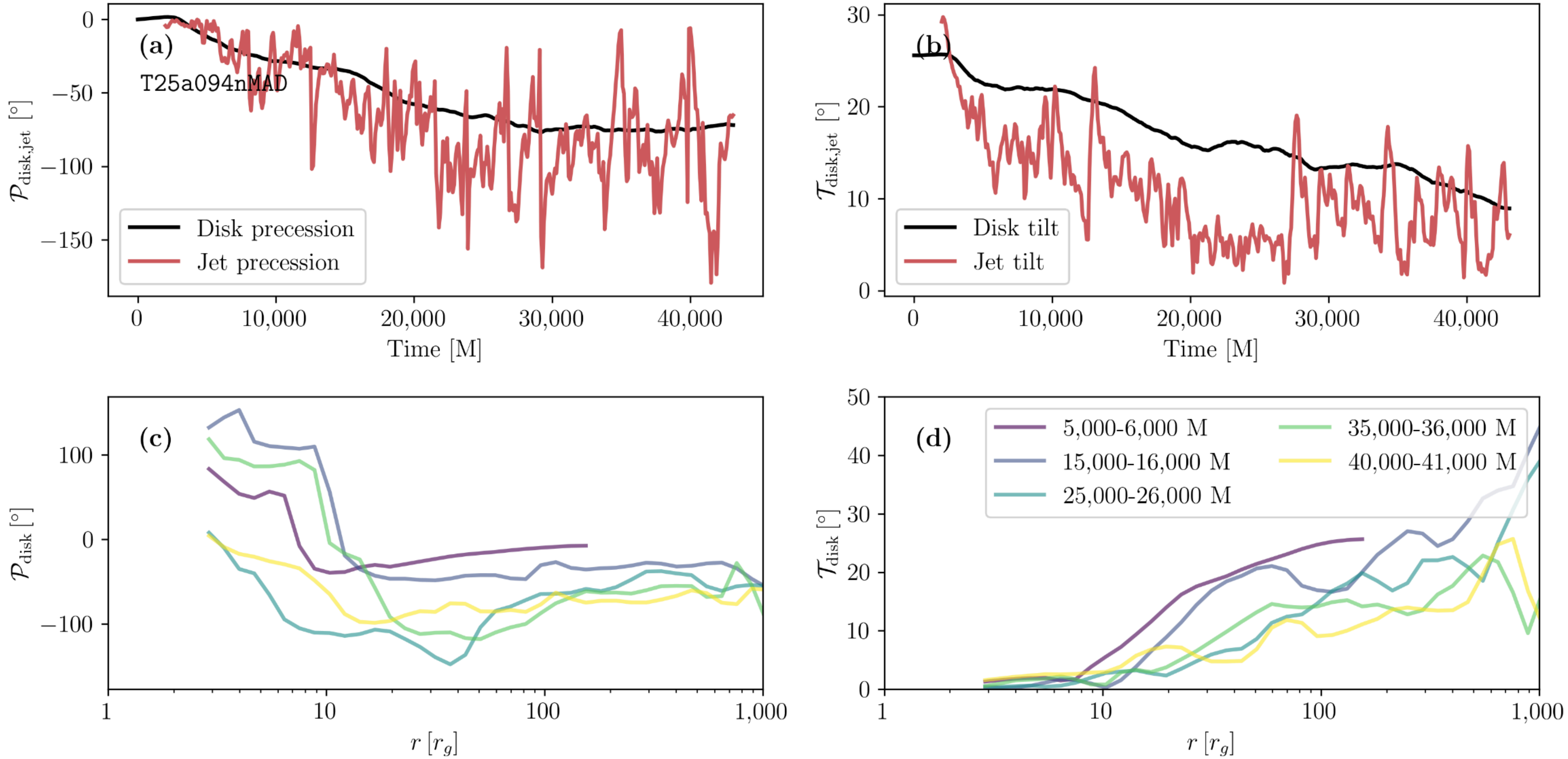
Jiang+2025



The magnetic torque is significantly stronger than the LT torque!

Jet/disk interaction and alignment

Jiang+2025



- LT effect strongly twists the innermost region of the disk
- Jet aligns the disk orientation to the BH spin direction (magneto-spin alignment)

Conclusions

- Lense-Thirring effect cannot effectively precess the whole disk.
- Magnetic field effectively drives retrograde precession in an opposite direction of the BH spin and disk.
- The observed retrograde precession arises from the alignment of the black hole spin with the magnetic field, which decouples the field from the accretion disk.
- None of the models SANE/MAD shows persistent precession, suggesting incompleteness on the current disk model.

Thanks for your listening!