

# Magnetic Flux Rope and the Flares in Sgr A\* from 3D Two-Temperature GRMHD Simulations

Texas Symposium on Relativistic Astrophysics 2023.12.13

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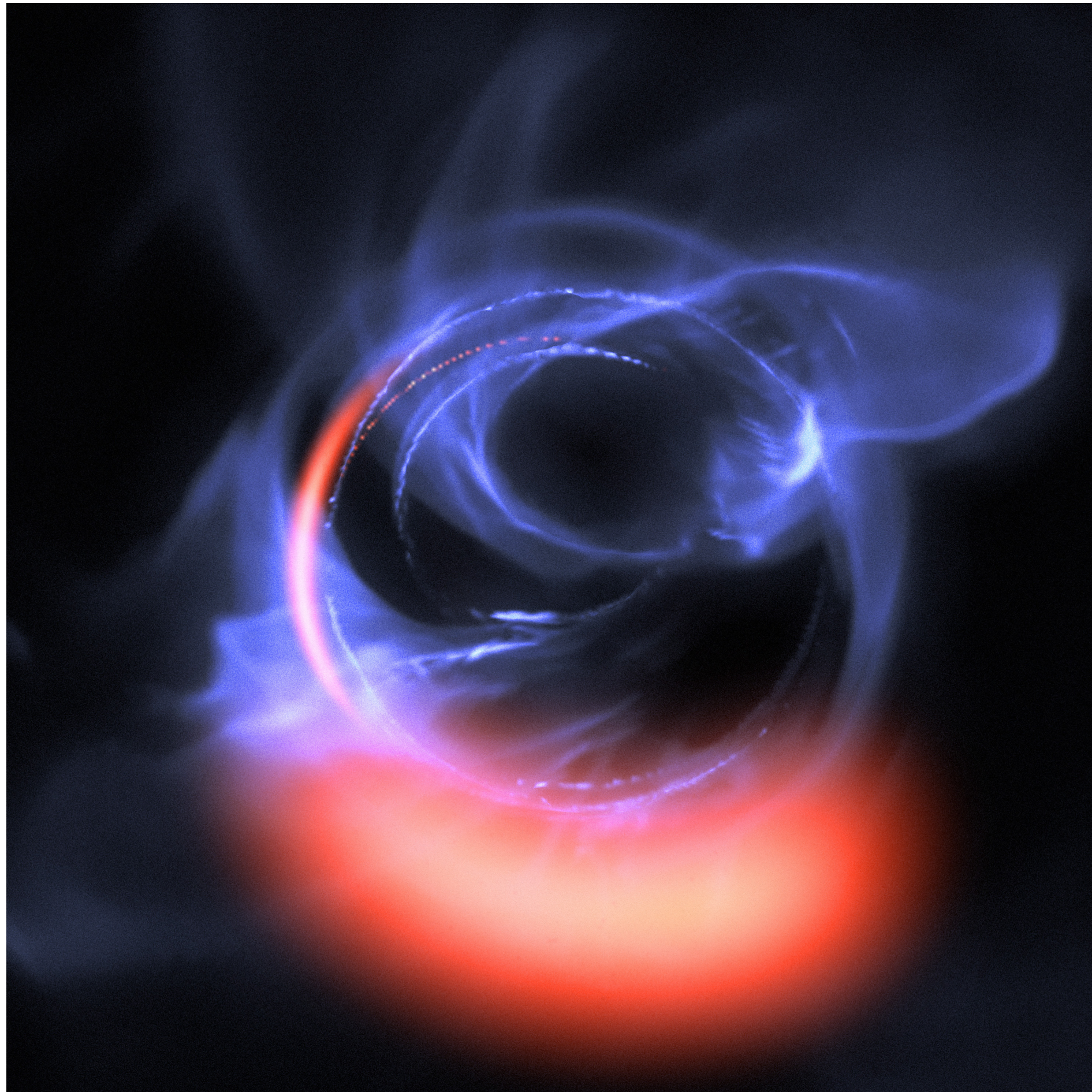
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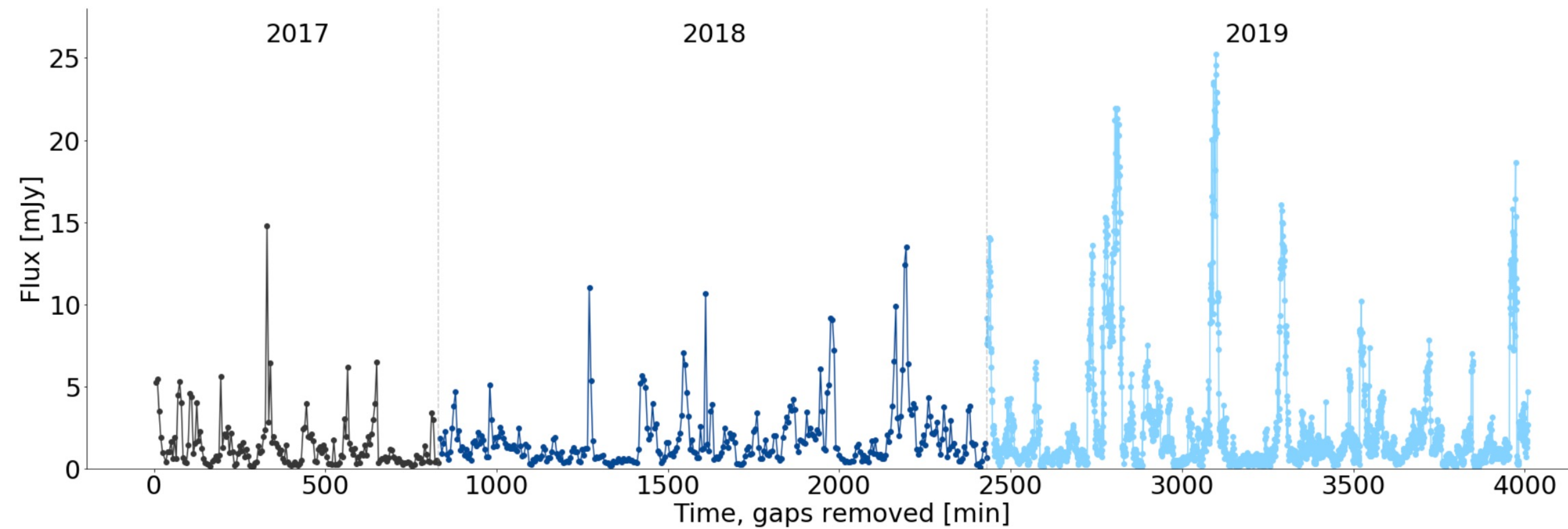


# Flares from Sgr A\*



Simulations of orbital motions of gas swirling around at about 30% of the speed of light on a circular orbit around the black hole.

Credit: ESO/Gravity Consortium/L. Calçada



Near-Infrared flux distribution from GRAVITY 2020

## Current theoretical models

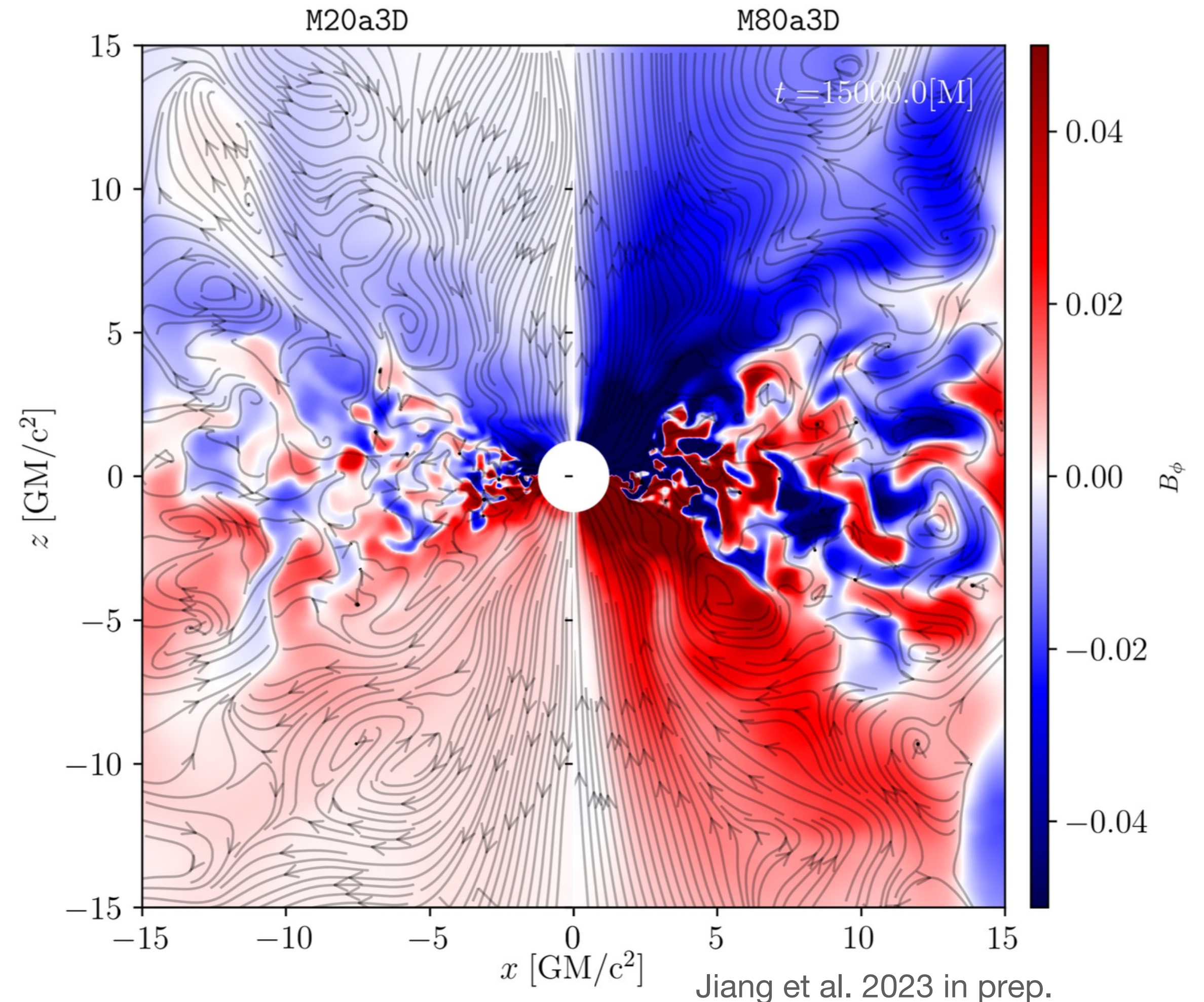
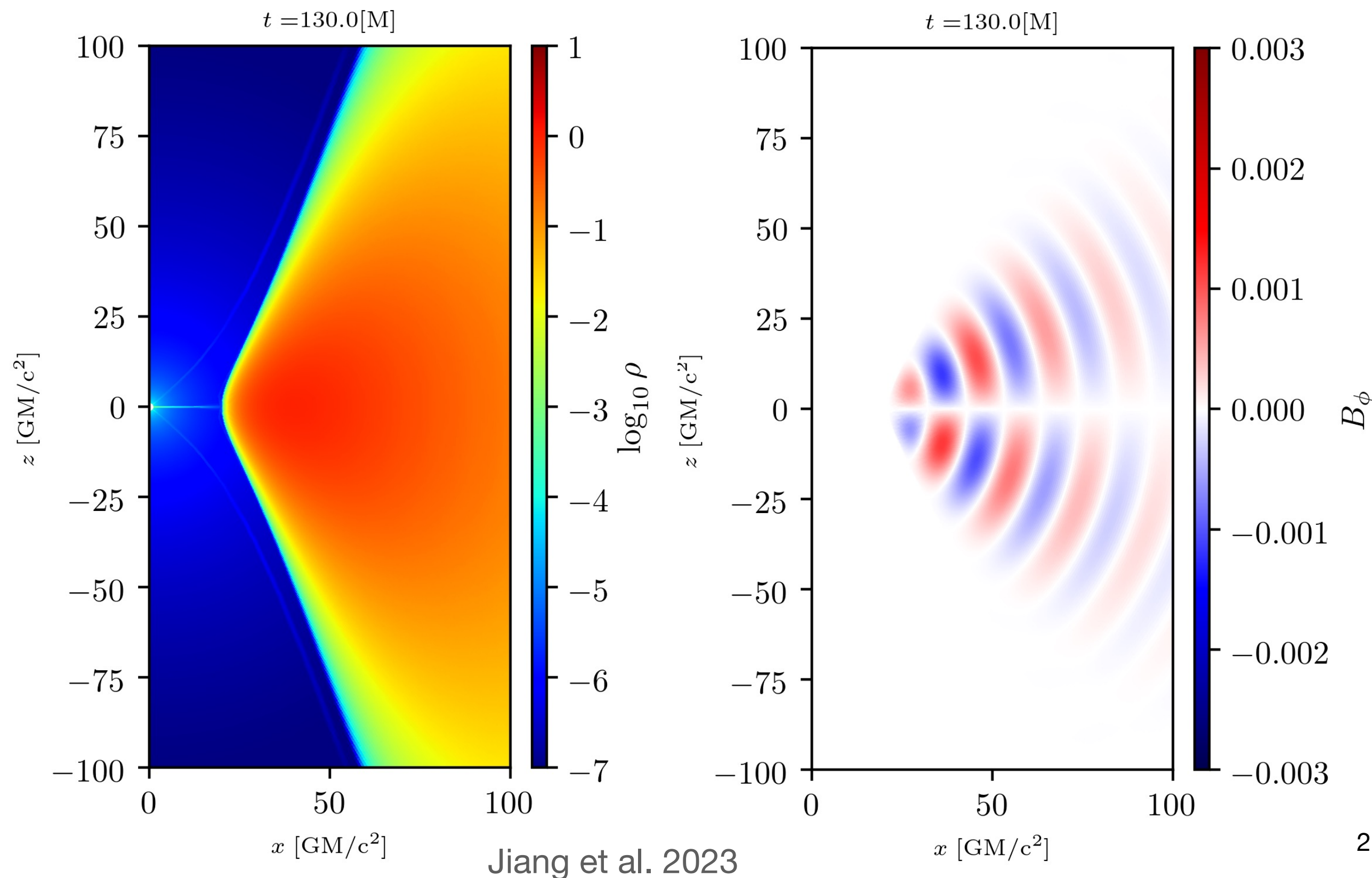
- Flux eruption of MAD
- Plasmoid chain / Flux rope
- Hotspot (toy model)



# GRMHD model (two-temperature+multi-loop)

GRMHD simulations are initiated from an FM torus (Fishbone & Moncrief 1976) with multi-loop magnetic configurations. Two-temperature module is included to calculate electron temperature.

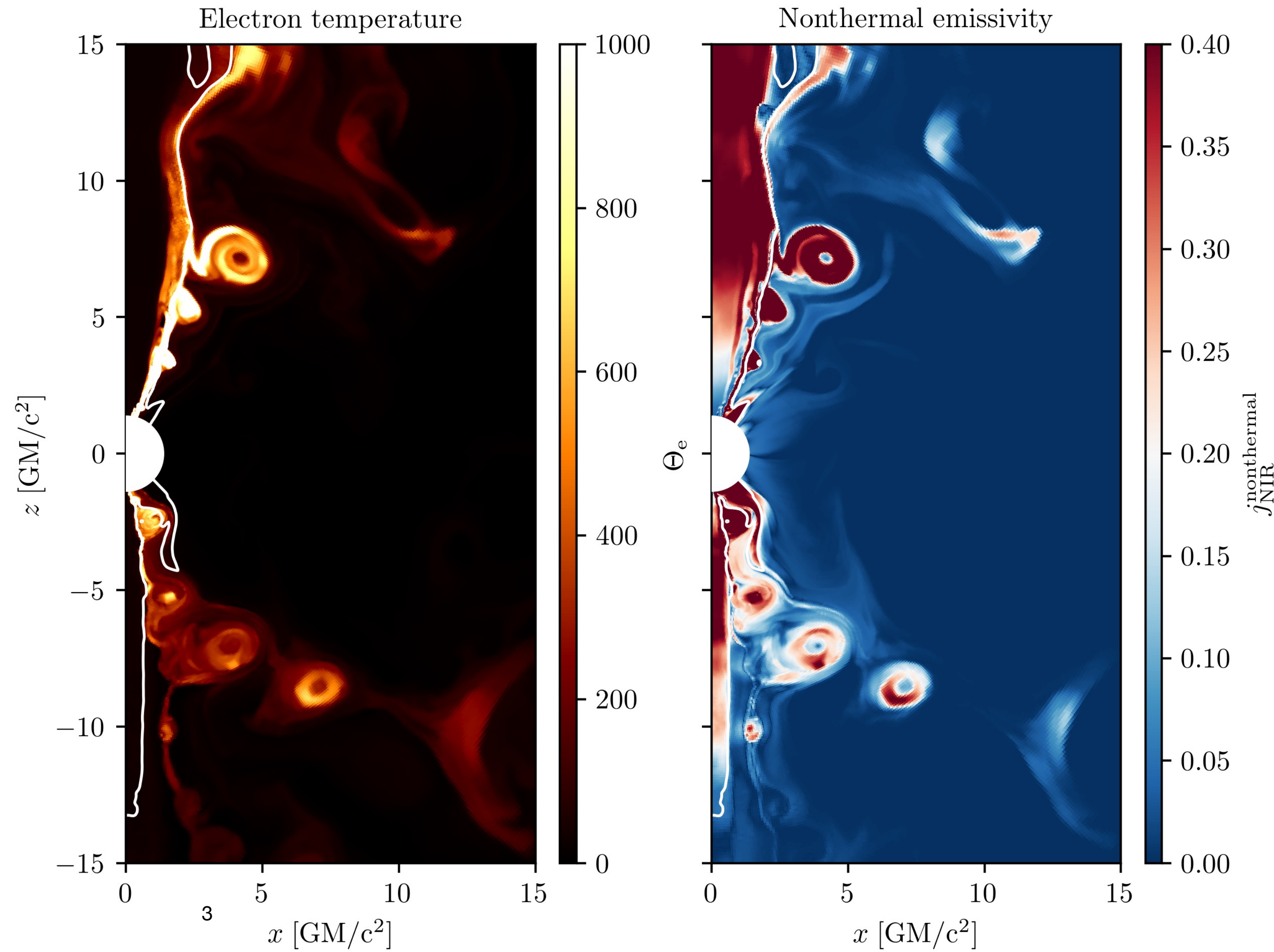
- Standard MAD setup + magnetic loop with different polarities





# Strong nonthermal emission from plasmoids in 2D GRMHD simulations

- Plasmoids and current sheet are generated via reconnection. (Jiang et al. 2023)
- Plasmoids contains high electron temperature and nonthermal Near Infrared emissivity.





# GRRT calculation from 3D GRMHD simulations

- GRRT code is using RAPTOR, and GRMHD code is BHAC.
- The inclination angle of the GRRT post-process is 30 degree.
- The accretion rate is fitted at 230GHz with a flux of 2.5 Jy.
- The  $\sigma_{\text{cut}}$  is set to be 1.
- GRRT calculation uses the GRMHD data from 10,000 M to 15,000 M, during which the accretion flow reaches a quasi-steady state.



# Non-thermal emission

**Kappa electron distribution function, a combination of Maxwell and power law distribution.**

- Kappa distribution function

$$\frac{dn_e}{d\gamma} = N\gamma\sqrt{\gamma^2 - 1} \left(1 + \frac{\gamma - 1}{\kappa W}\right)^{-(\kappa+1)}$$

- Parameterized kappa function

(Meringolo et al. 2023)

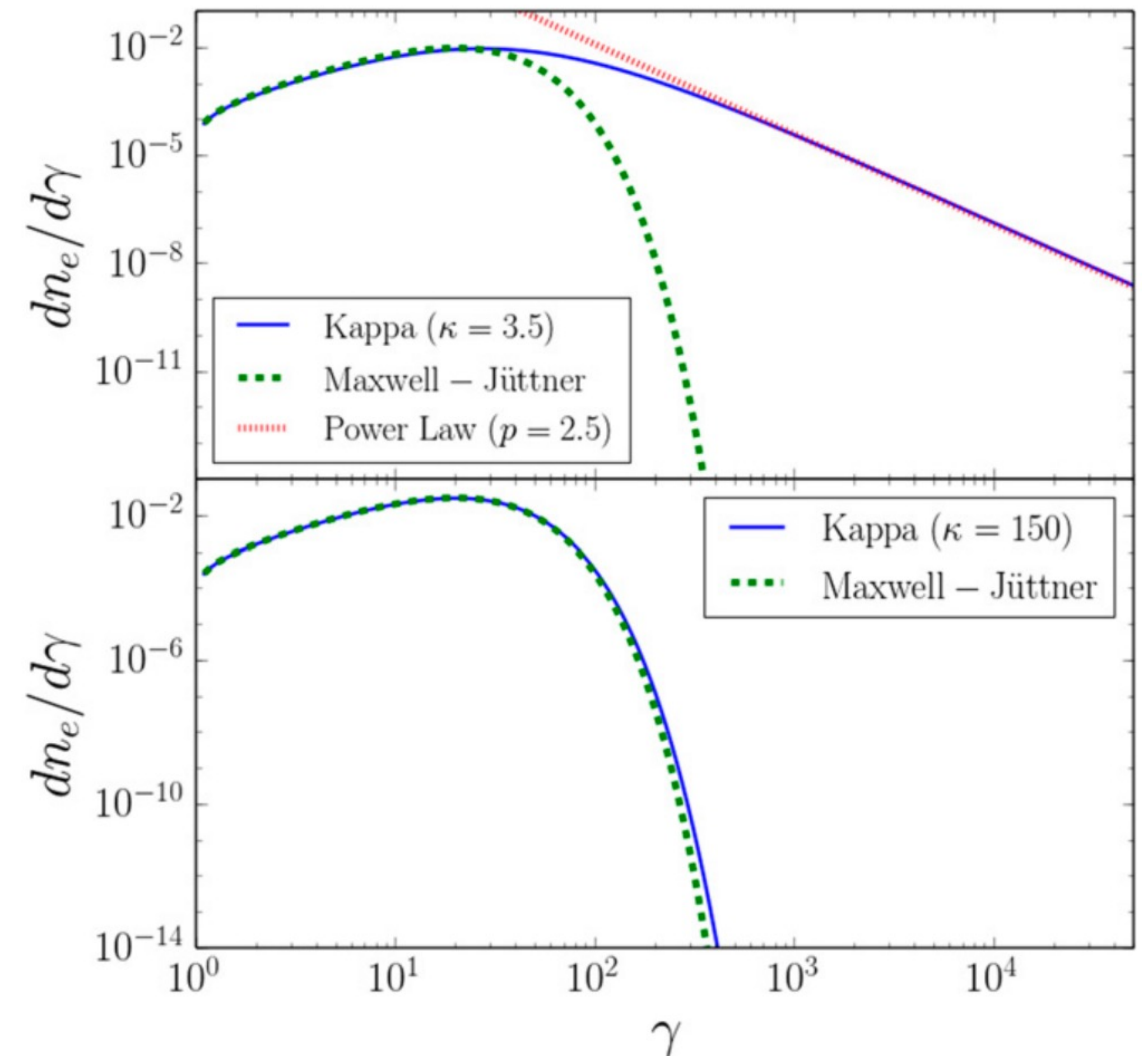
PIC simulation from turbulence plasma

$$\kappa_{\text{tur}} = 2.8 + 0.2/\sqrt{\sigma} + 1.6\sigma^{-6/10}\tanh(2.25\sigma^{1/3}\beta).$$

(Ball et al. 2016)

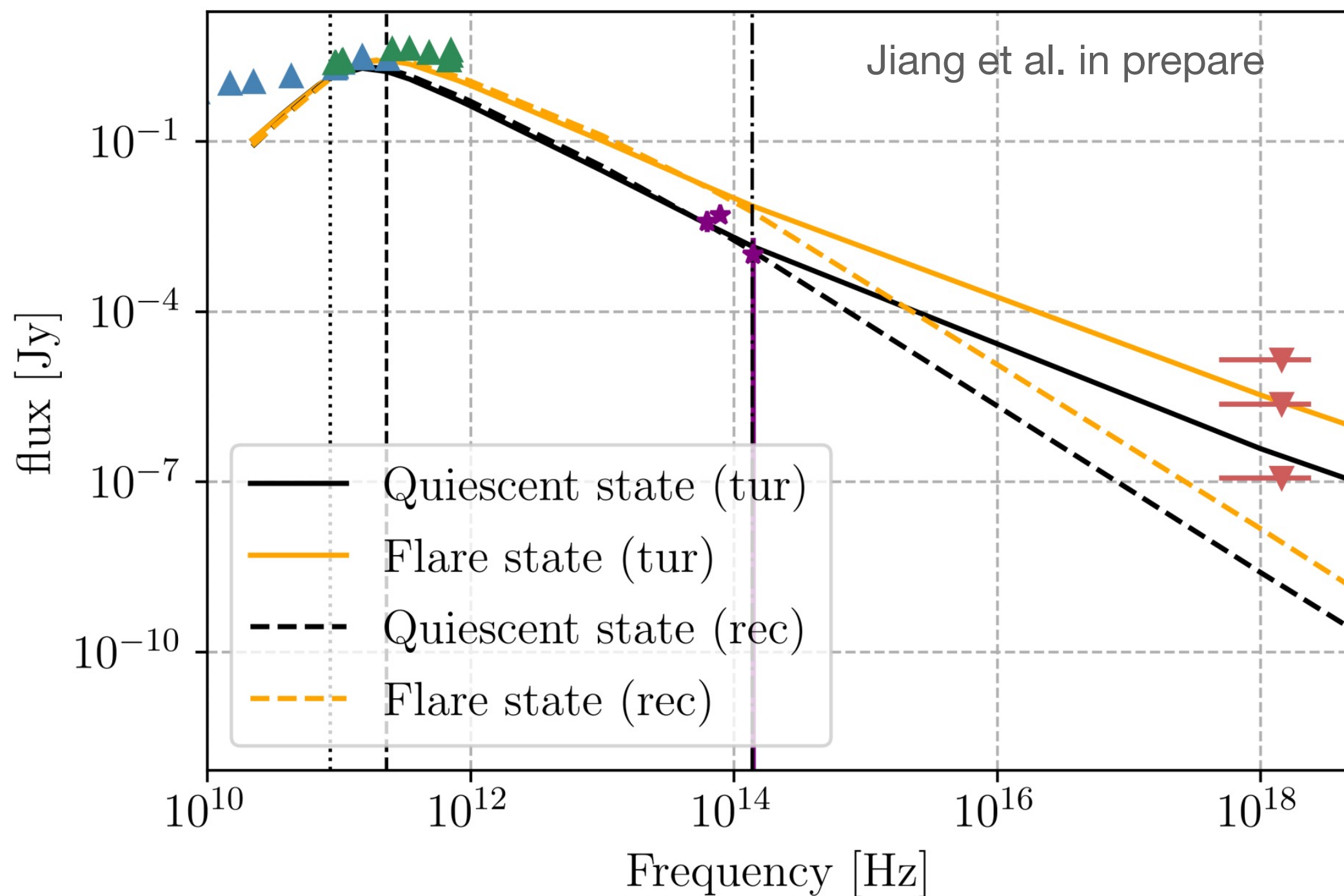
PIC simulation from reconnection plasma

$$\kappa_{\text{rec}} = 2.8 + 0.7/\sqrt{\sigma} + 3.7\sigma^{-0.19}\tanh(23.4\sigma^{0.26}\beta)$$

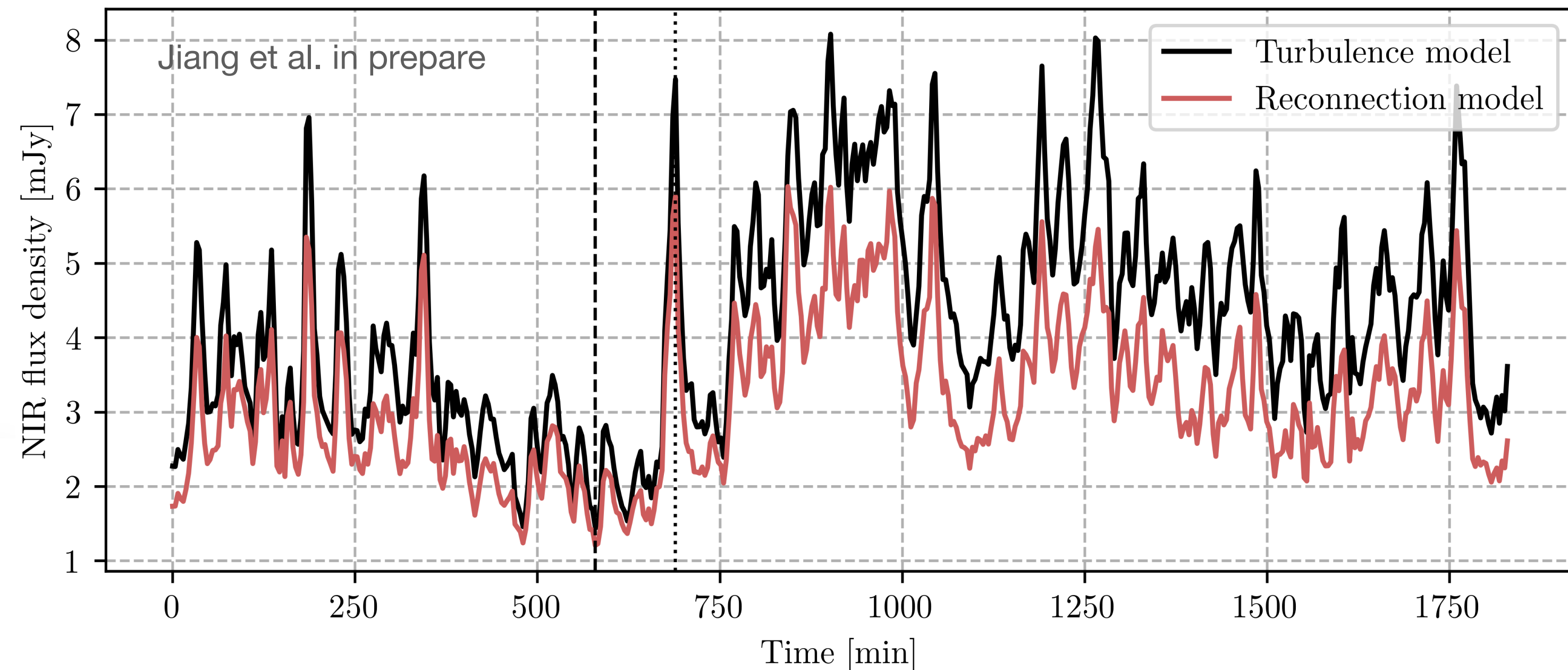




# SED from turbulent and reconnection models



- Radio data is from Flack et al. 1998. & Liu et al. (2016)
- Infrared data is from R. Schödel et al. 2011.
- X-ray data is from Mossoux et al. 2020.

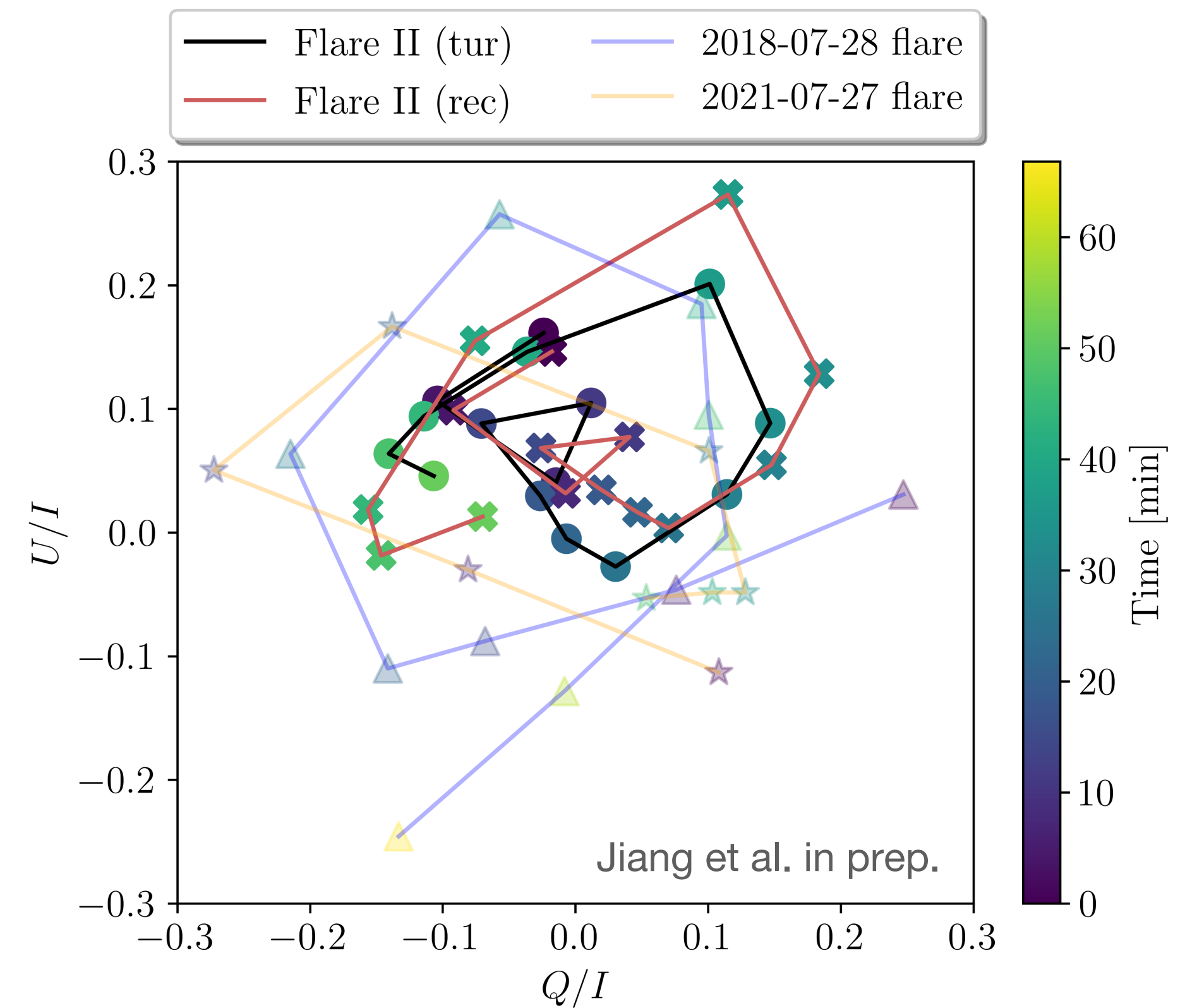
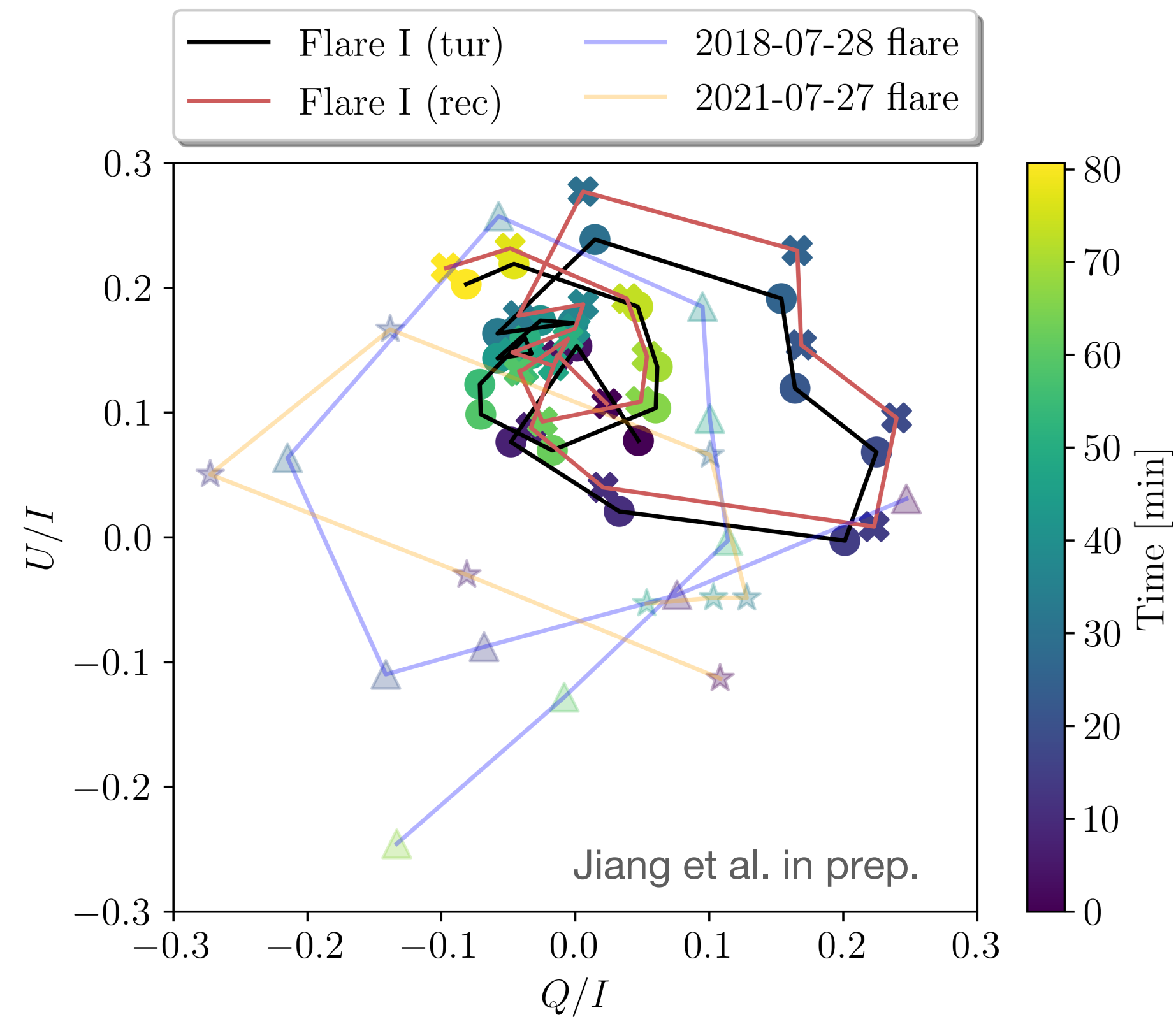




# QU loop at NIR

## Circular motion of the flares

- As the flare rotates around the Black Hole, the polarization vector rotates by one full loop at the same time with it.

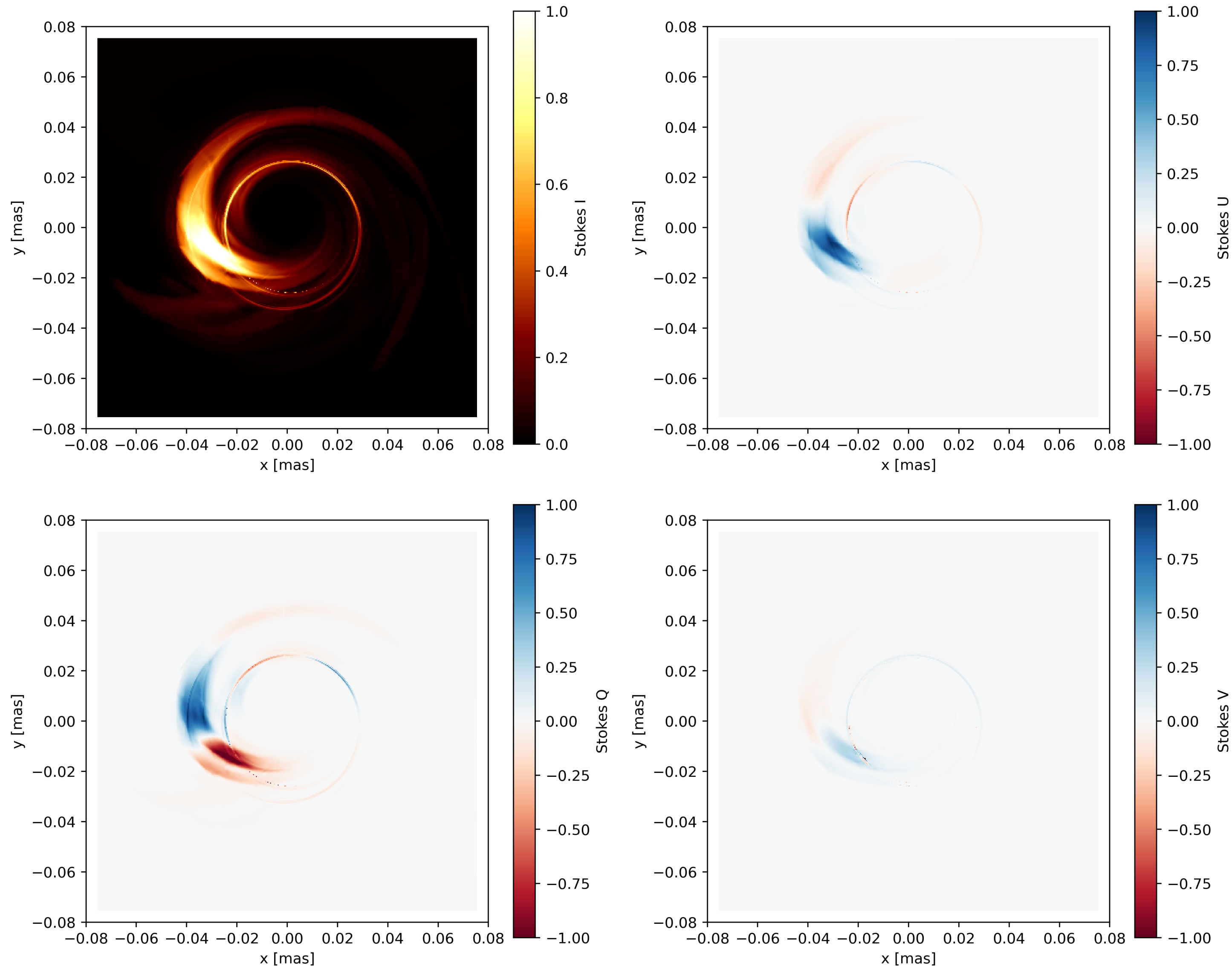




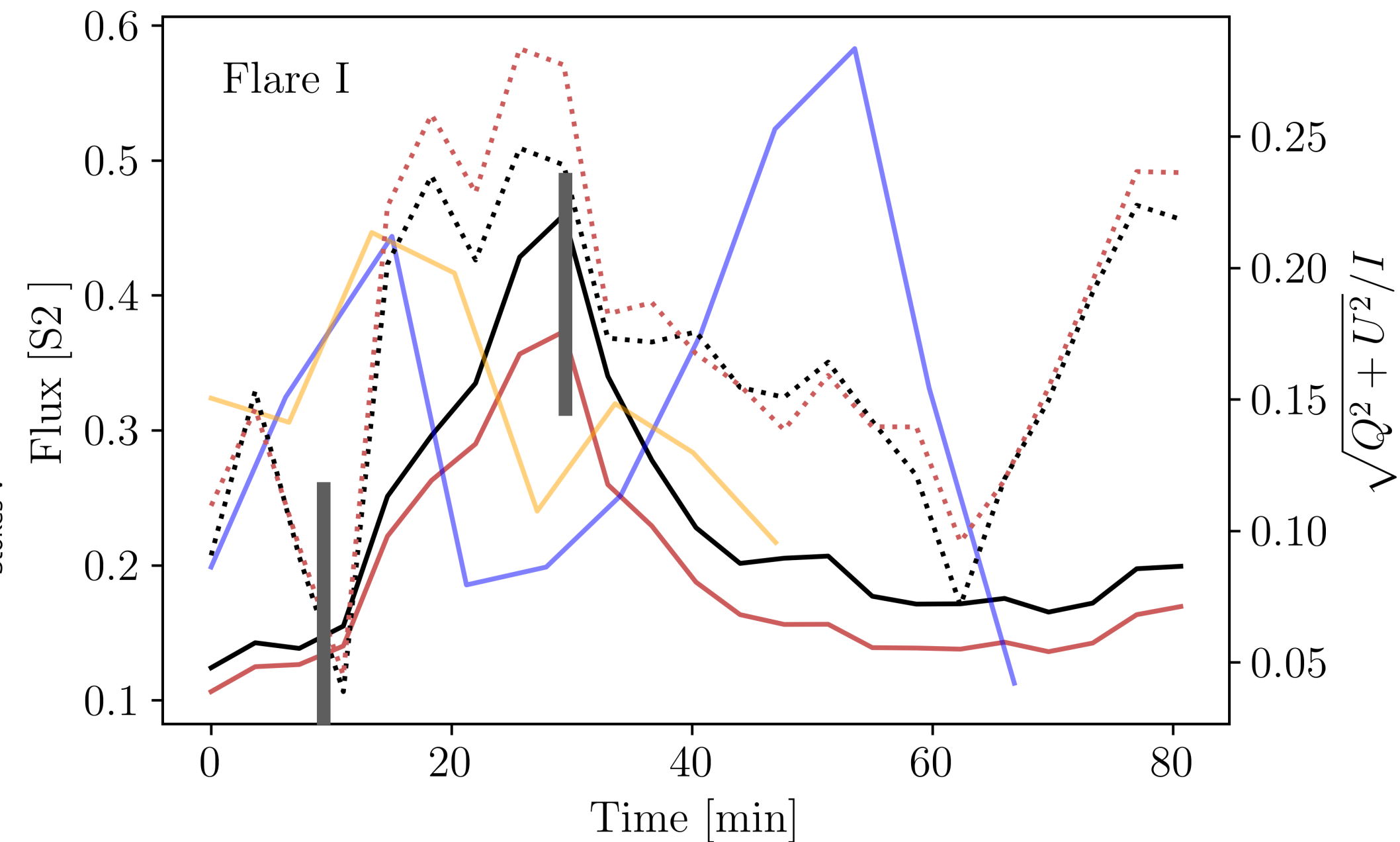
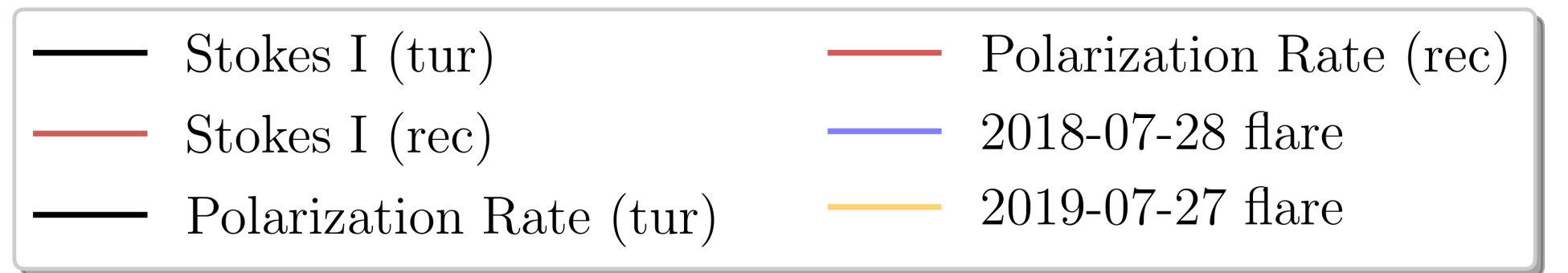
# NIR Black Hole image during flare:

t=242294.1 [days]

Jiang et al. in prep.



Flare has a relatively higher polarization rate than quiescent state.

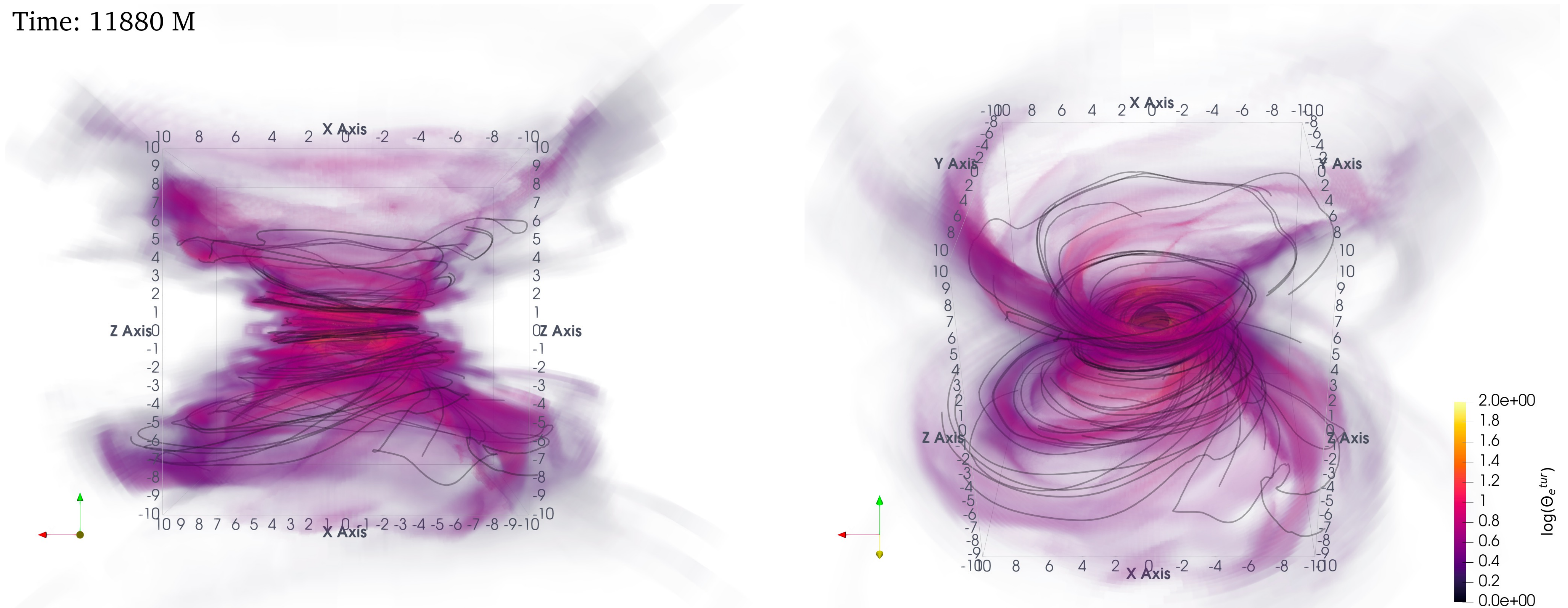




# Magnetic flux ropes in 3D GRMHD simulation

(Jiang et al. in prep.)

Time: 11880 M





# Conclusions

- Multi-loop magnetic configuration generates multiple flux ropes which is a potential model for the flaring activity of Sgr A\*.
- Based on the 2D result, we speculate the observed flux ropes are unresolved plasmoid chains.
- Our subgrid models based on turbulent and reconnection plasma can generate correct SED and flaring light curves. But the reconnection model fails to match observation at X-ray band.
- Relatively higher polarized emission is seen during flares, which agrees with the current observation.



**Thanks for your listening!**