

How to observe binary black holes?

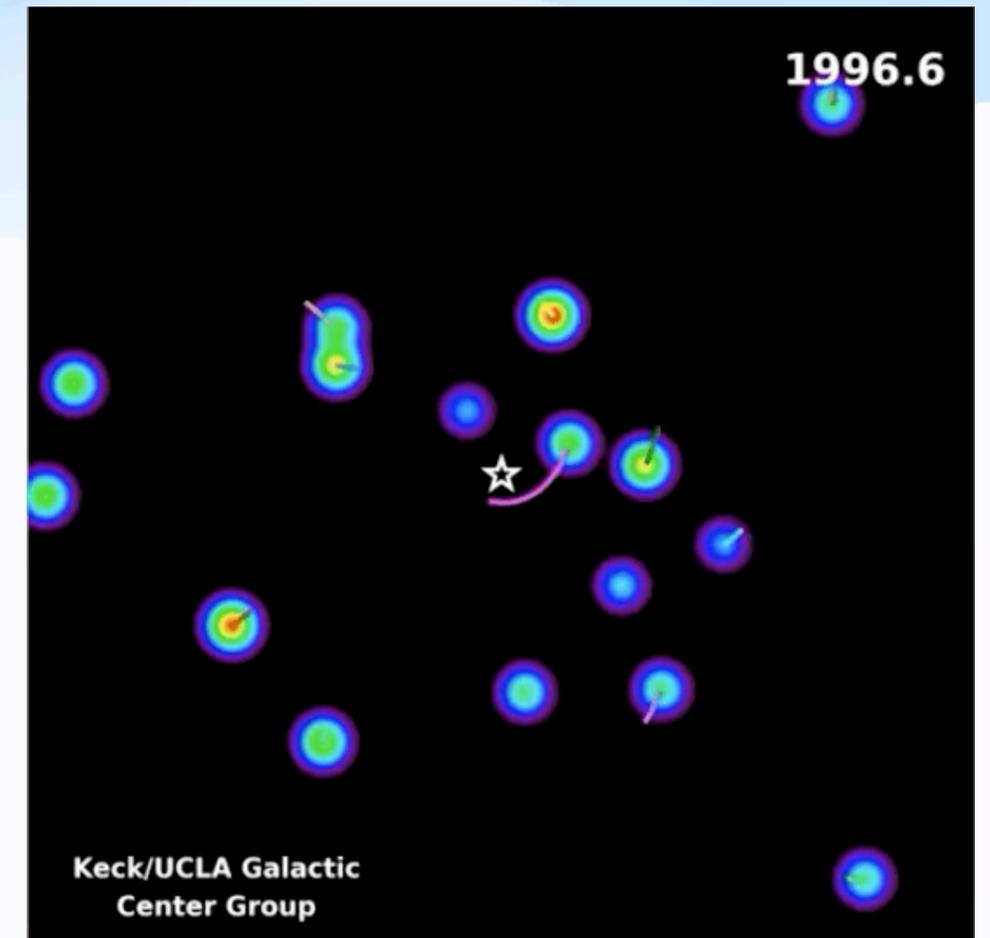
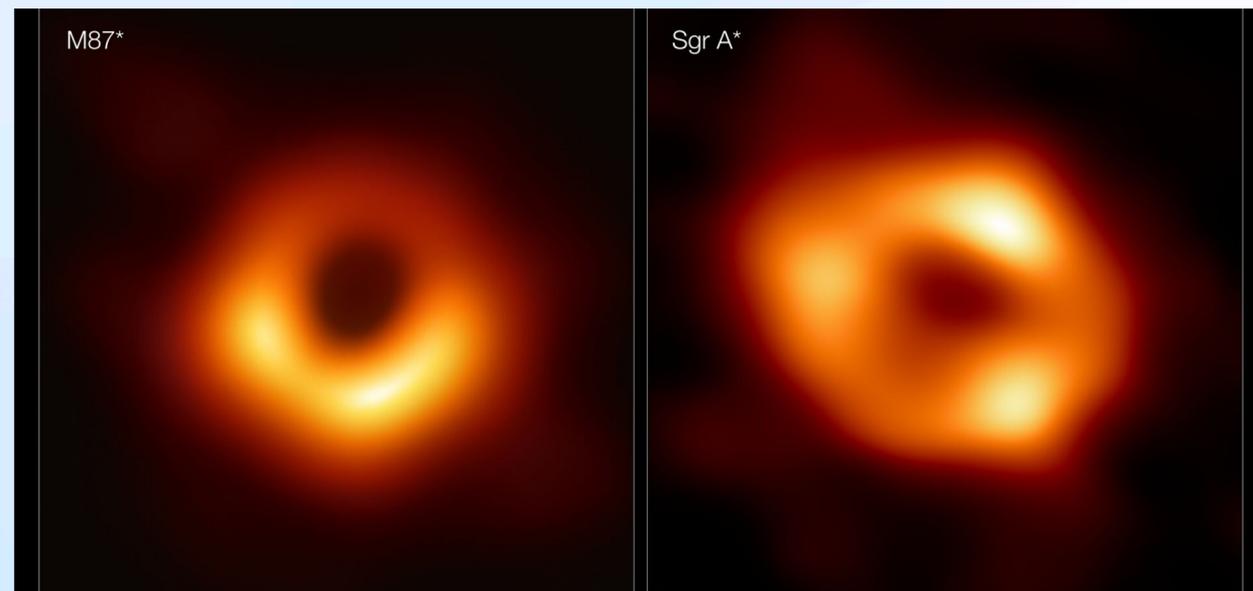
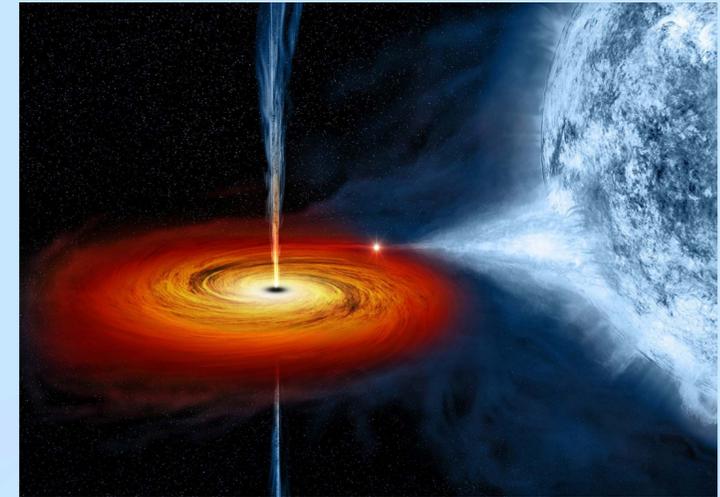
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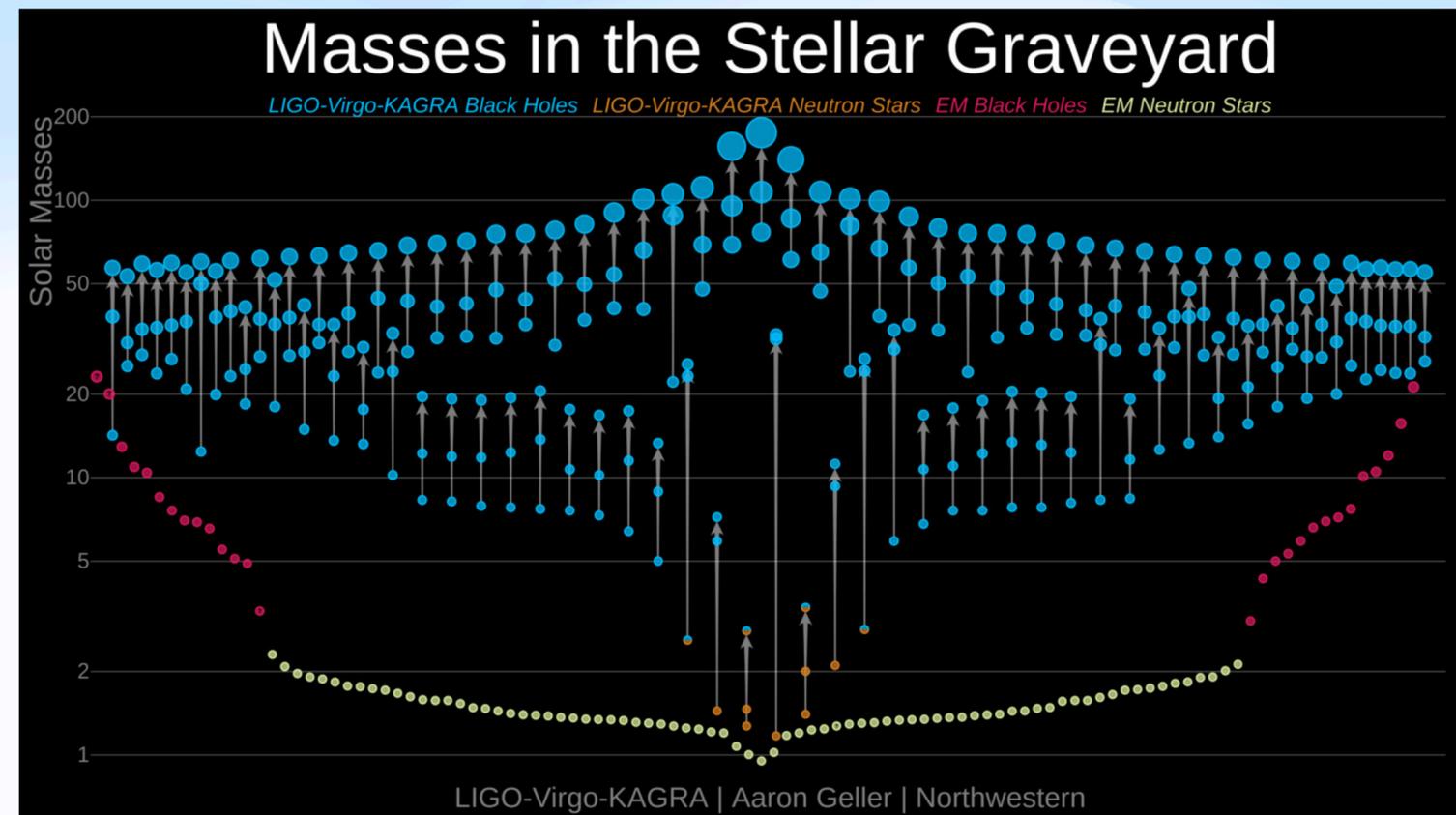
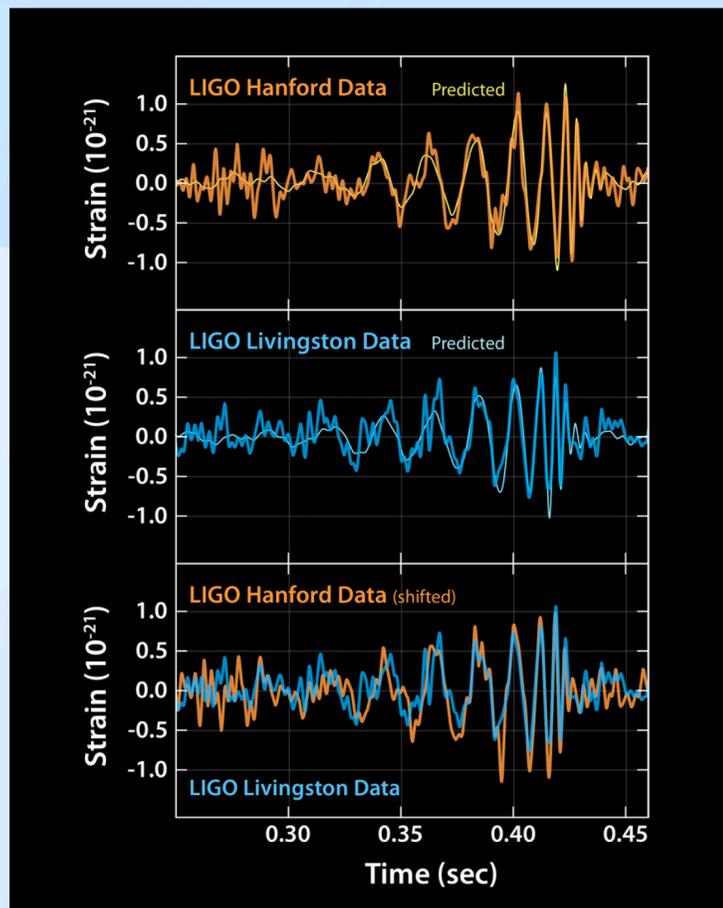
Black Holes are REAL!

- Cyg X-1, star-stellar mass BH binary
- Dynamical evidence of Sgr A*, supermassive BH
- EHT image



Black Holes are REAL!

- GW from stellar-mass BH binaries



What about massive BH binaries?

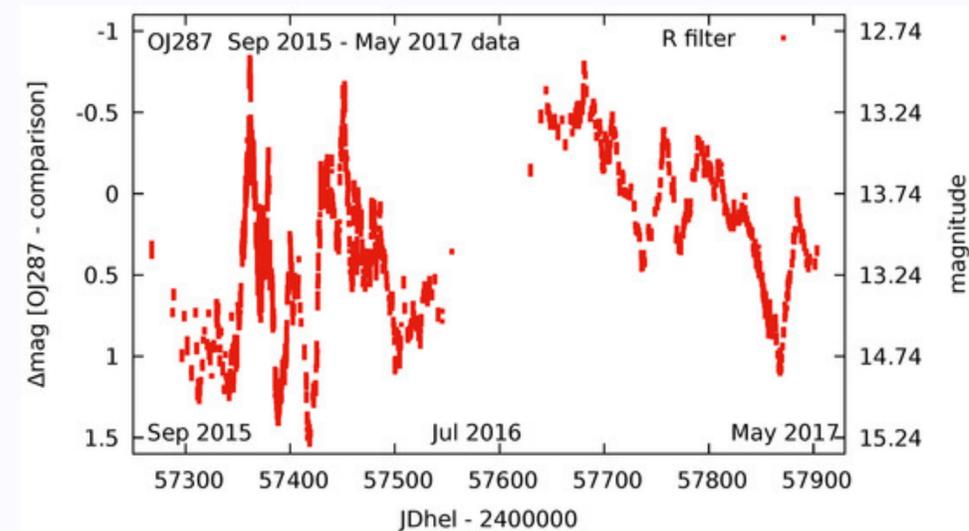
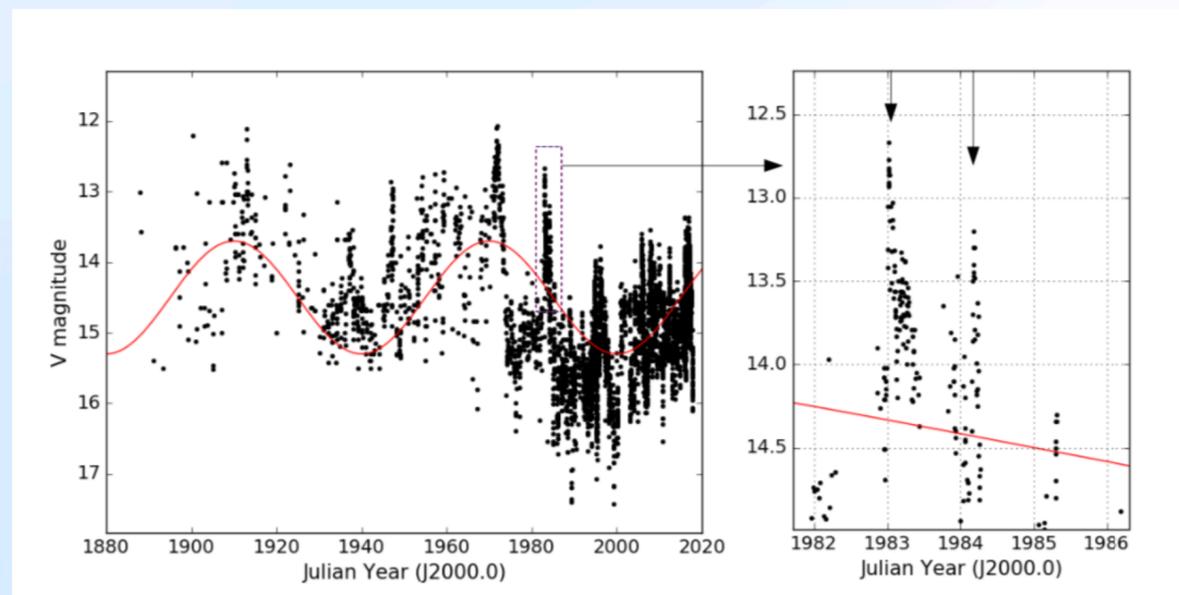
- LISA will be able to detect massive BH mergers in 2030s, hopefully.



- Can we do more before LISA's launch?

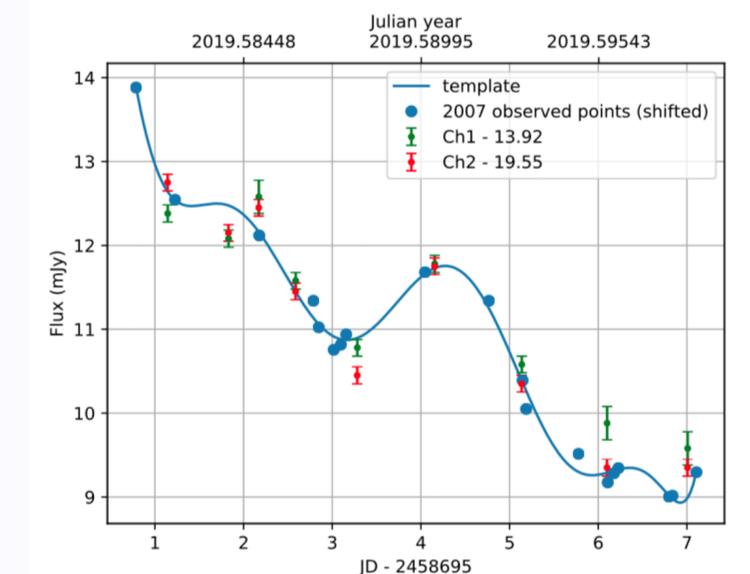
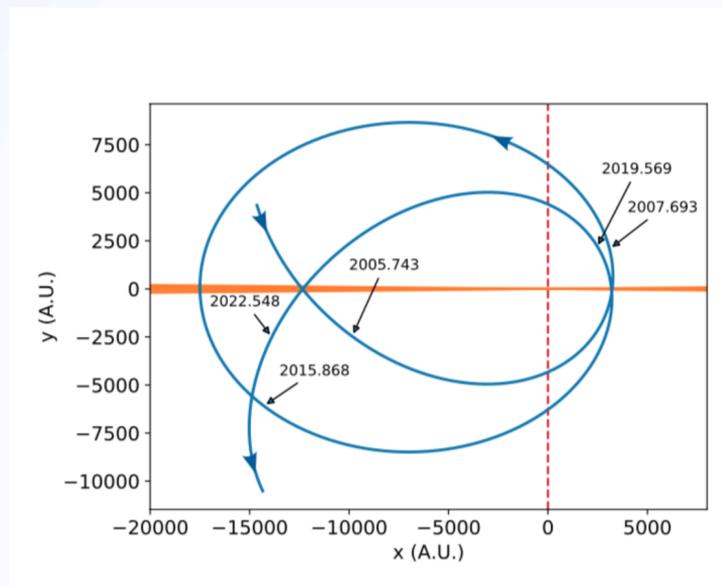
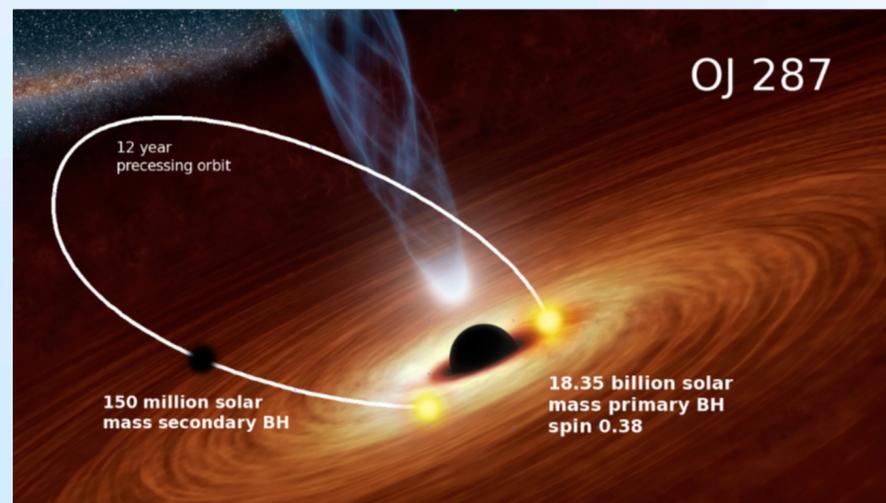
Quasi-Periodic Eruptions from OJ-287

- OJ 287 is a bright blazar at a redshift of $z \sim 0.3$.
- Its 130 years long optical light curve shows two periodic variations:
 - I. Quasi-periodic double-peaked high brightness flares with period ~ 12 years
 - II. Long term variations with 60 years period



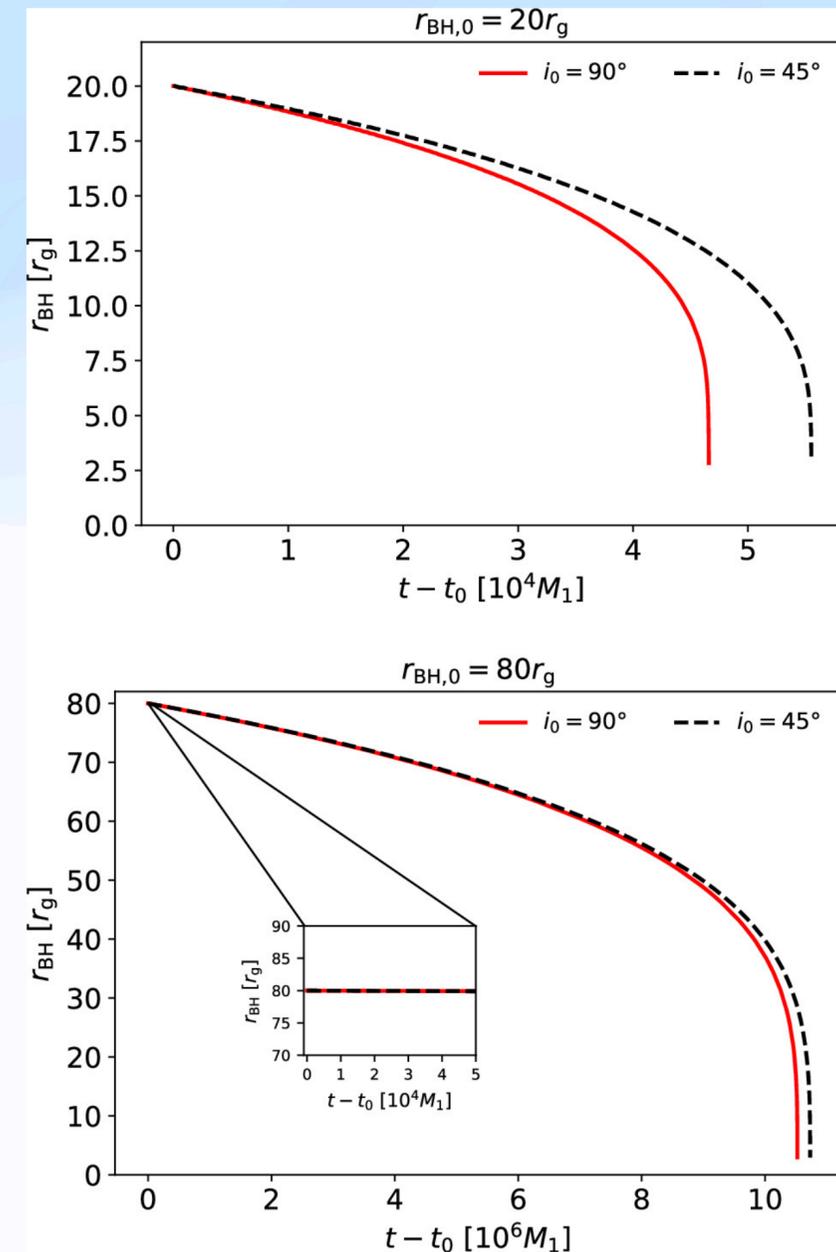
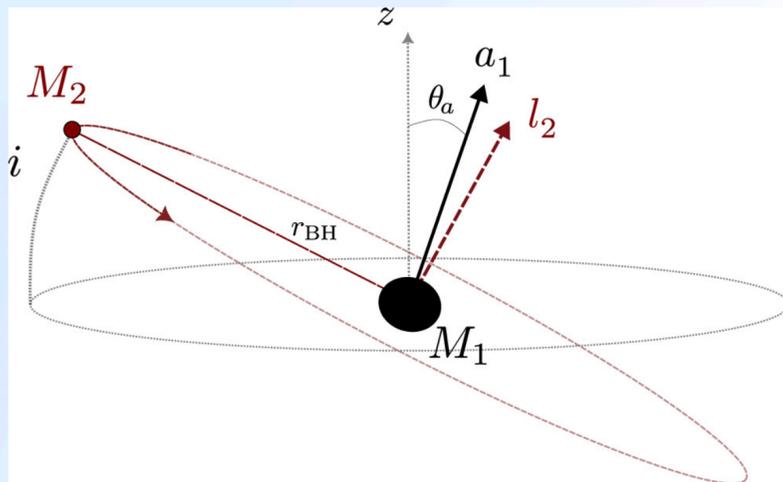
Binary BH model of OJ 287

- Lehto & Valtonen (1996) model: a secondary BH impacts with the accretion disk of the primary.
- Dey et al. (2018) predicted that the next SMBH impact would occur in July 31, 2019.
- Spitzer observations strongly supports the arrival of the predicted flare.
- The predicted July 2022 impact flare could NOT be monitored due to OJ 287's solar elongation!! (& the demise of Spitzer) arXiv:2308.03017



GRMHD simulations of BH-Disk interactions

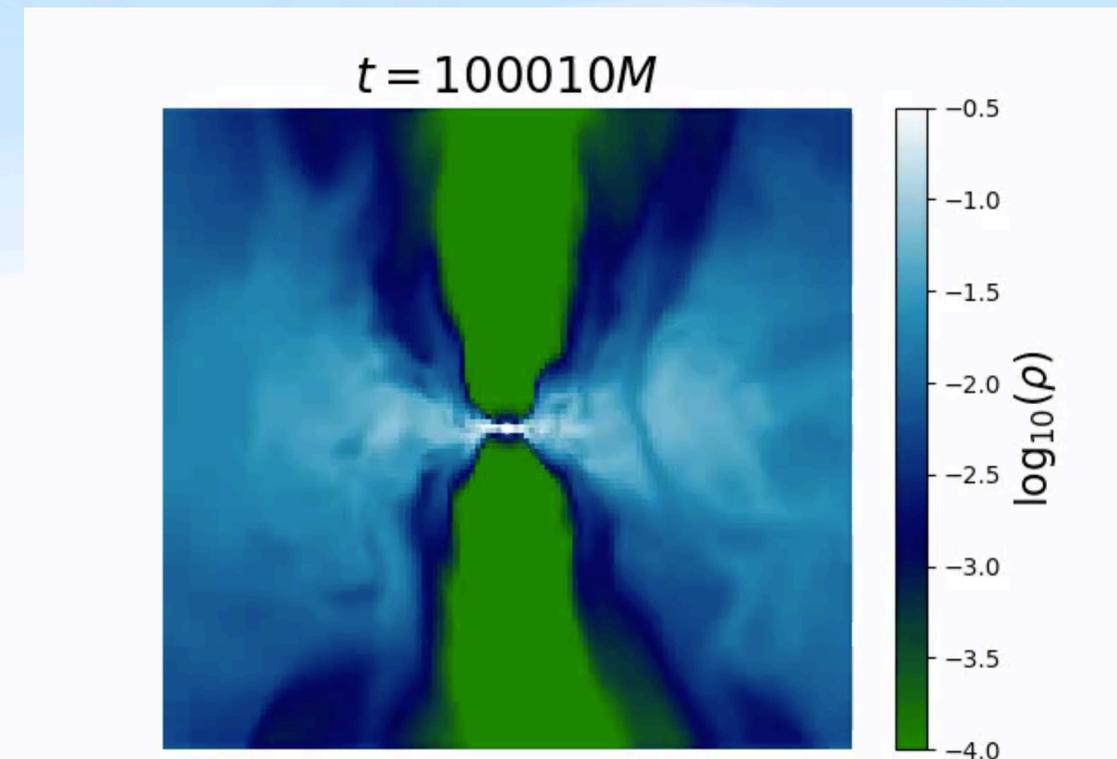
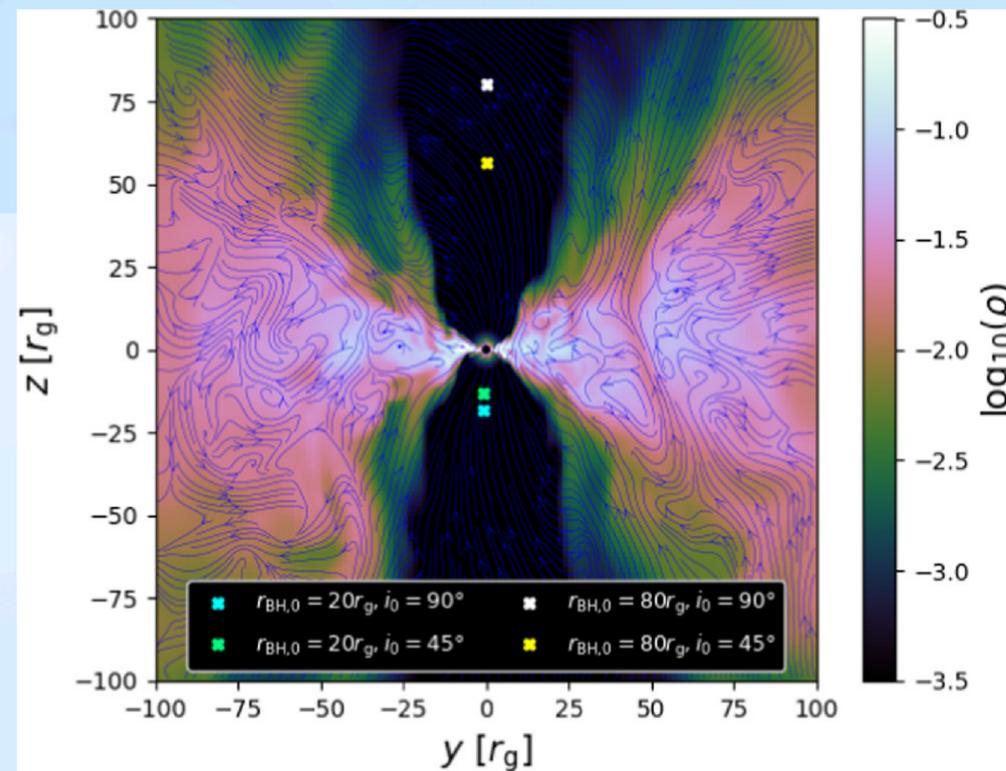
- 3D GRMHD with Athena++
- Approximate metric as in Combi et al. (2021) + PN trajectories
- The central BH is assumed to be static.
- Start with a Fishbone & Moncrief torus,
- Relax the disk before introducing the perturber



Thick MAD Disk

Sean M. Ressler, Luciano Combi, Xinyu Li, Bart Ripperda, and Huan Yang (2404.02193)

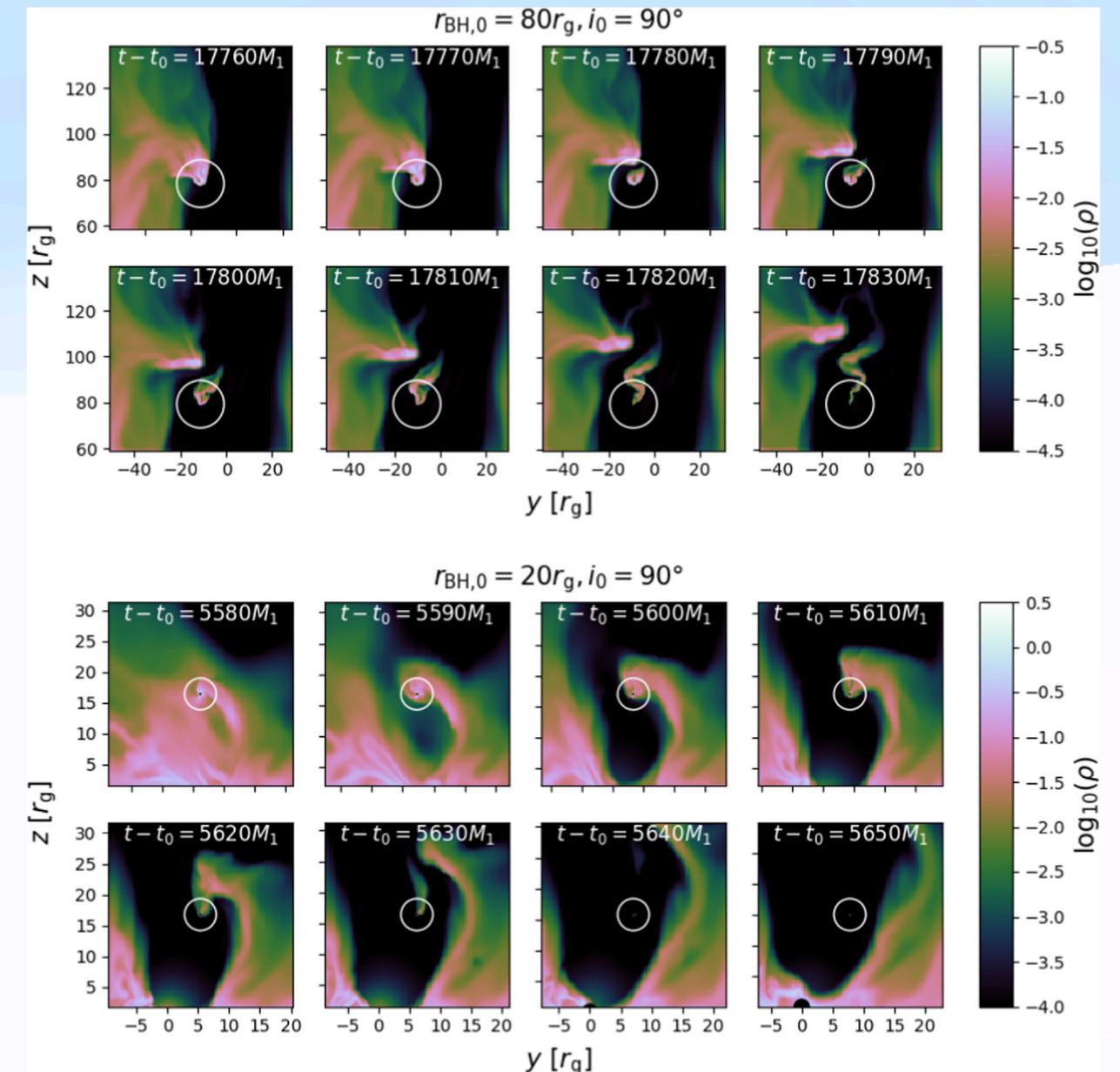
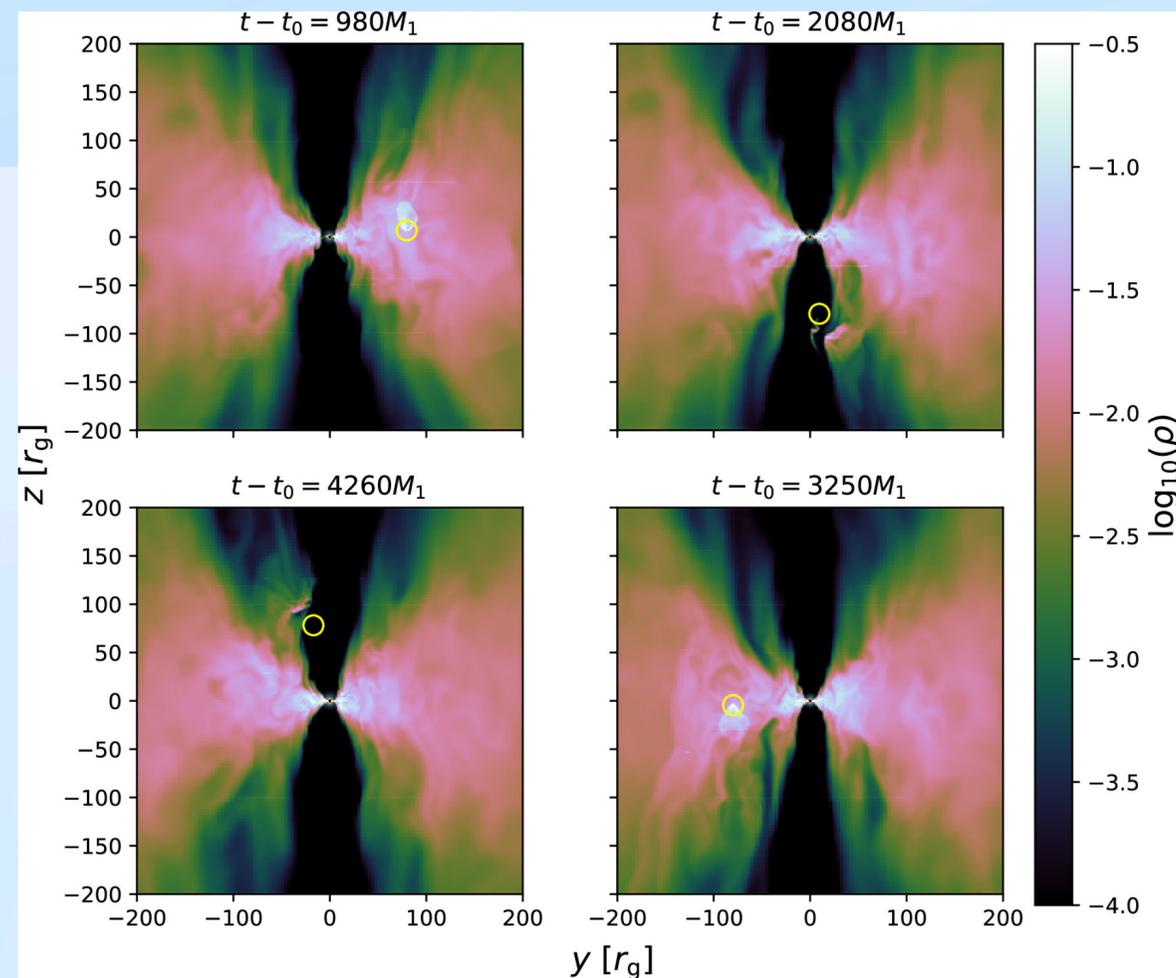
- $q=0.1$ fixed.



Thick MAD Disk: Morphology

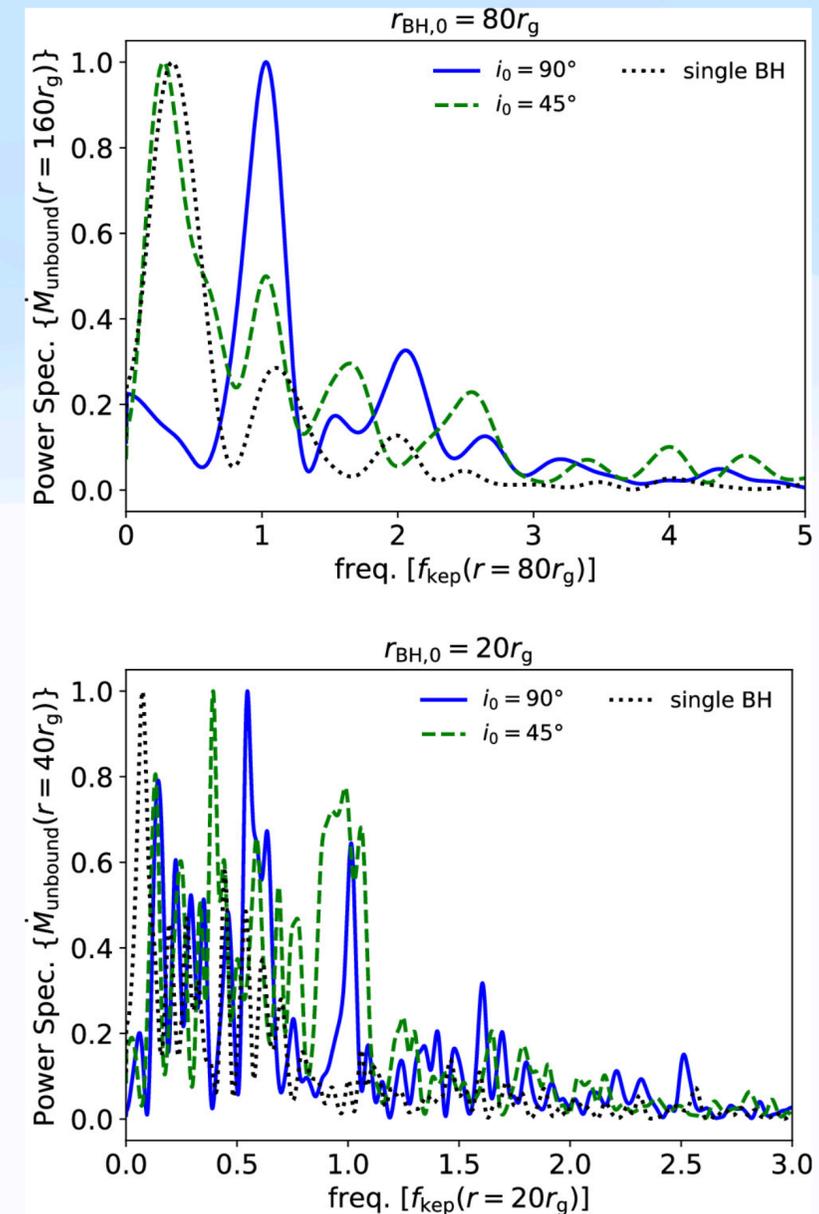
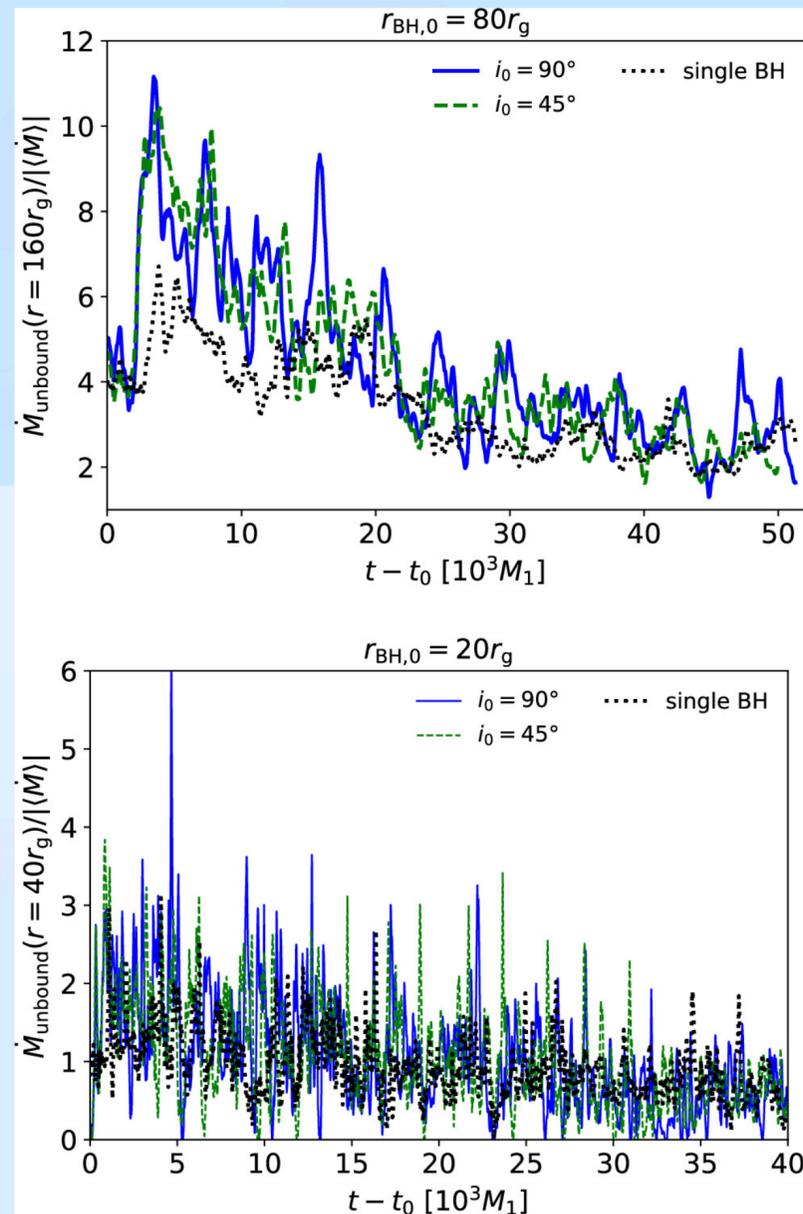
Sean M. Ressler, Luciano Combi, Xinyu Li, Bart Ripperda, and Huan Yang (2404.02193)

- Bow shock from BHL accretion
- Mass is dragged out by the secondary



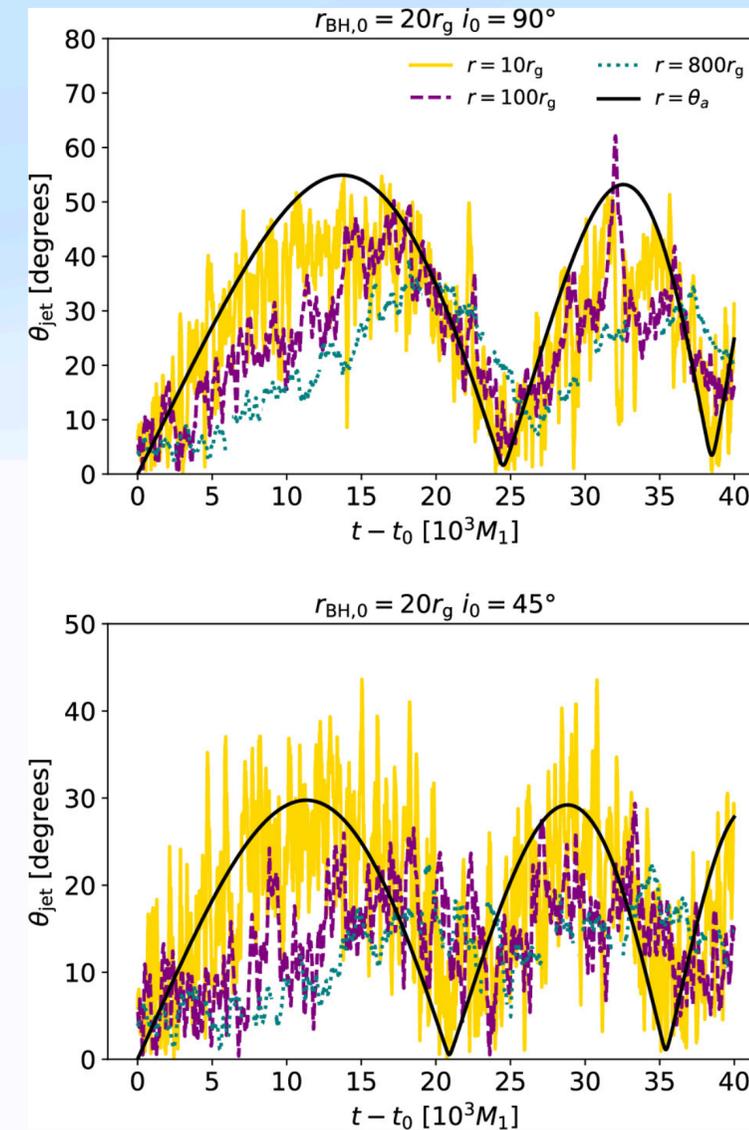
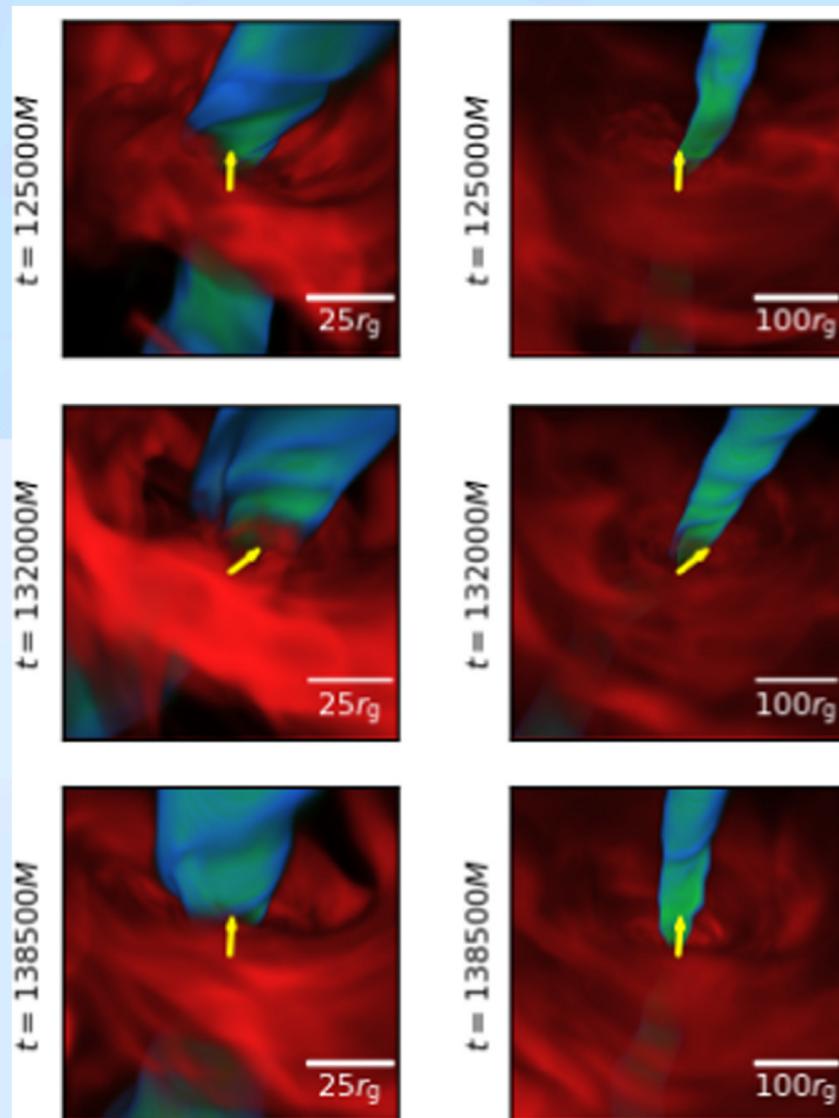
Thick MAD Disk: mass outflow rate

Sean M. Ressler, Luciano Combi, Xinyu Li, Bart Ripperda, and Huan Yang (2404.02193)



Thick MAD Disk: spin-orbit coupling

Sean M. Ressler, Luciano Combi, Xinyu Li, Bart Ripperda, and Huan Yang (2404.02193)



Thick MAD Disk: summary

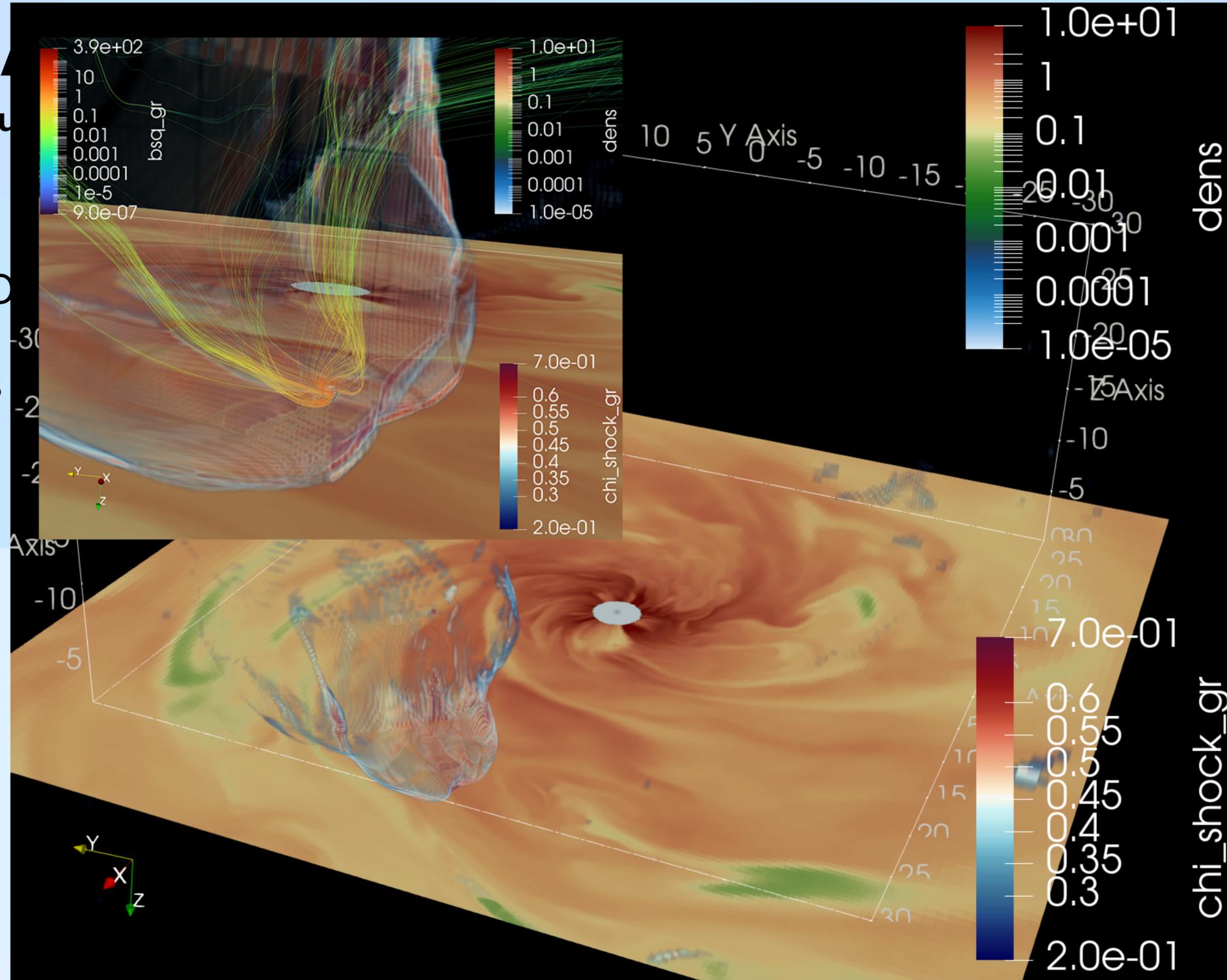
Sean M. Ressler, Luciano Combi, Xinyu Li, Bart Ripperda, and Huan Yang (2404.02193)

- the overall effects of the secondary on the primary accretion flow are small
- hard to confirm the secondary from EM light curve
- the spin-orbit coupling can cause the spin direction of the primary to significantly change
- observations of precession in thick AGN disks would be strong evidence for the presence of a secondary black hole companion

Thick M

Hongxuan Jiang, Yos

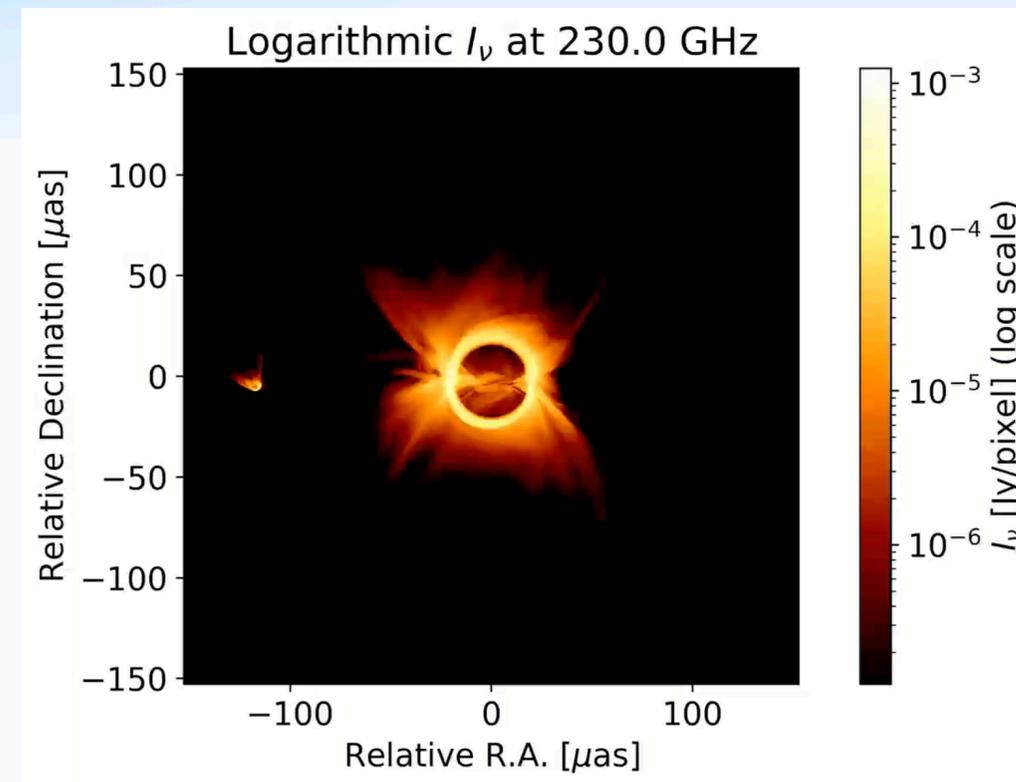
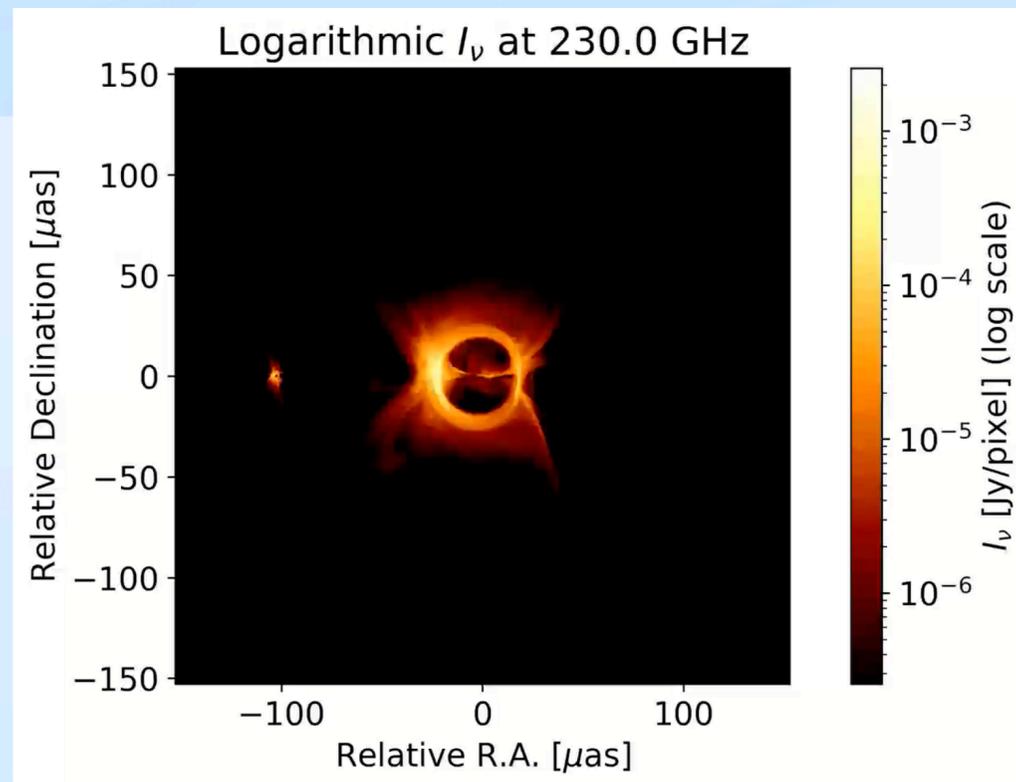
- GRRT code BHO
- Shock produces



Thick MAD Disk: lensing flares

Hongxuan Jiang, Yosuke Mizuno, Xinyu Li (in prep.)

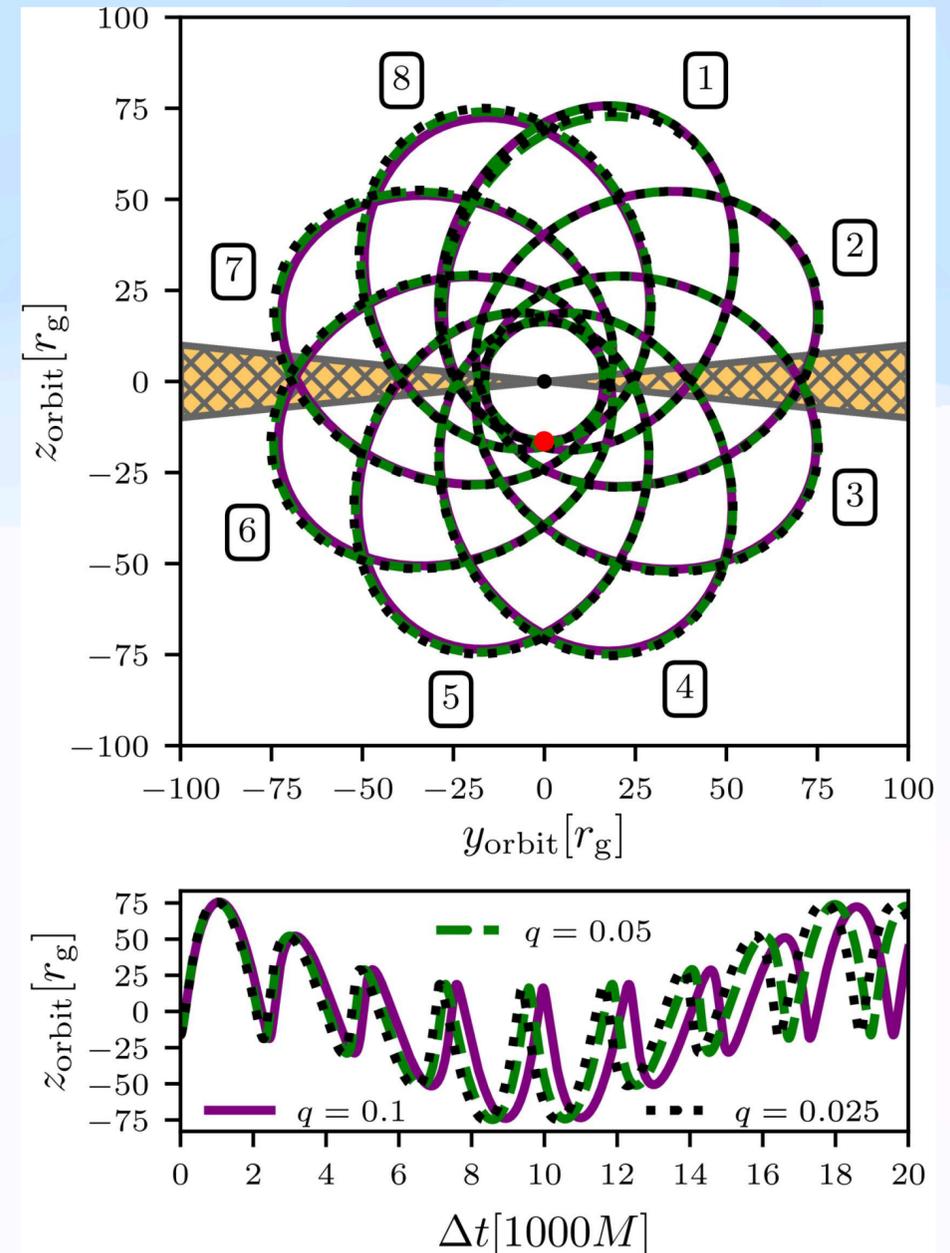
- GRRT code BHOSS for post-processing
- Shock produces non-thermal electrons



Thin Disk: OJ-287 like system

Sean M. Ressler, Luciano Combi, Bart Ripperda, Xinyu Li (2509.18241)

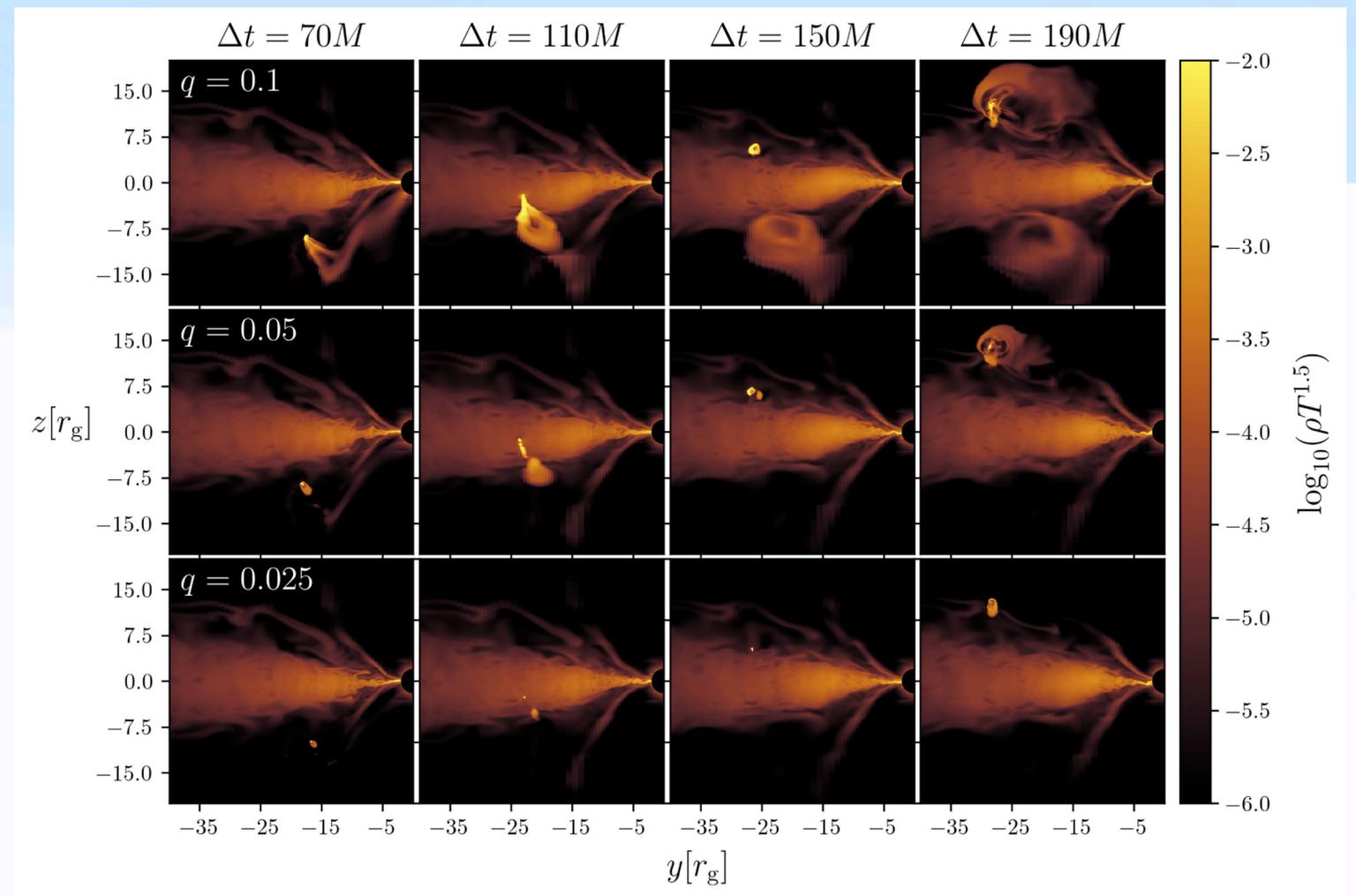
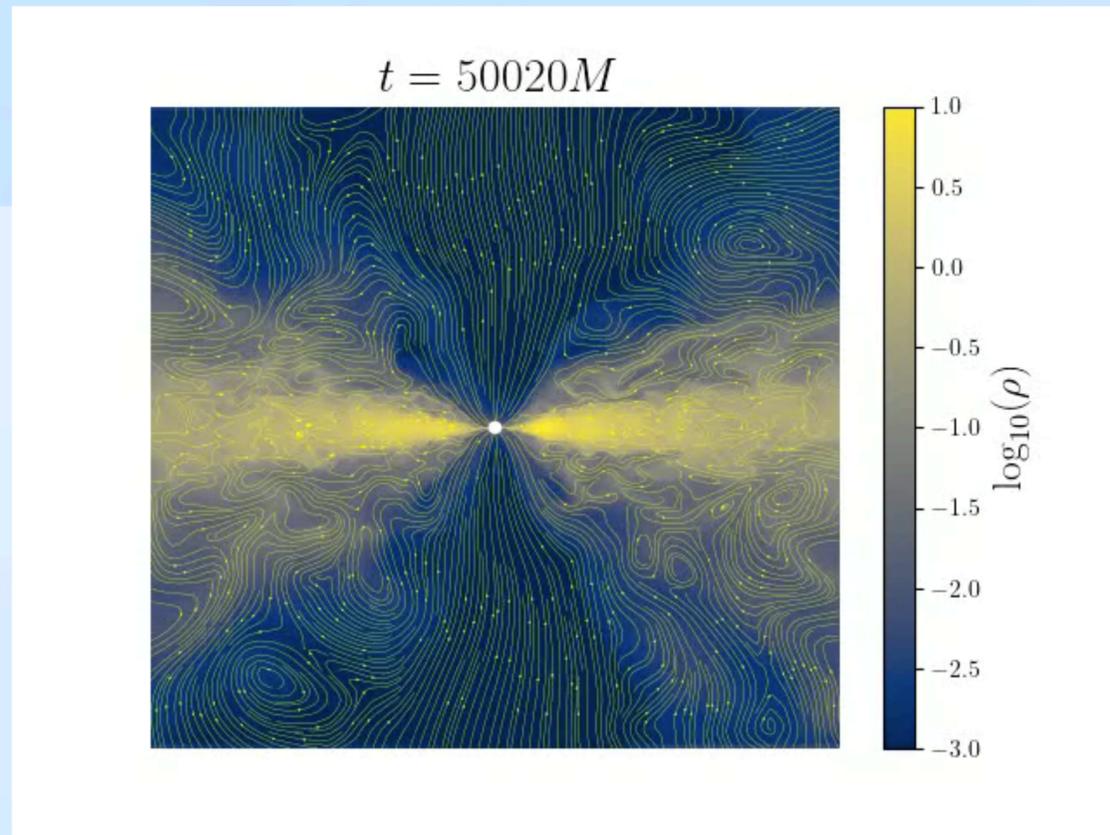
- Adding a cooling term to keep the disk thin
- $H/R=0.1$, $q=0.1, 0.05, 0.025$



Thin Disk: morphology

Sean M. Ressler, Luciano Combi, Bart Ripperda, Xinyu Li (2509.18241)

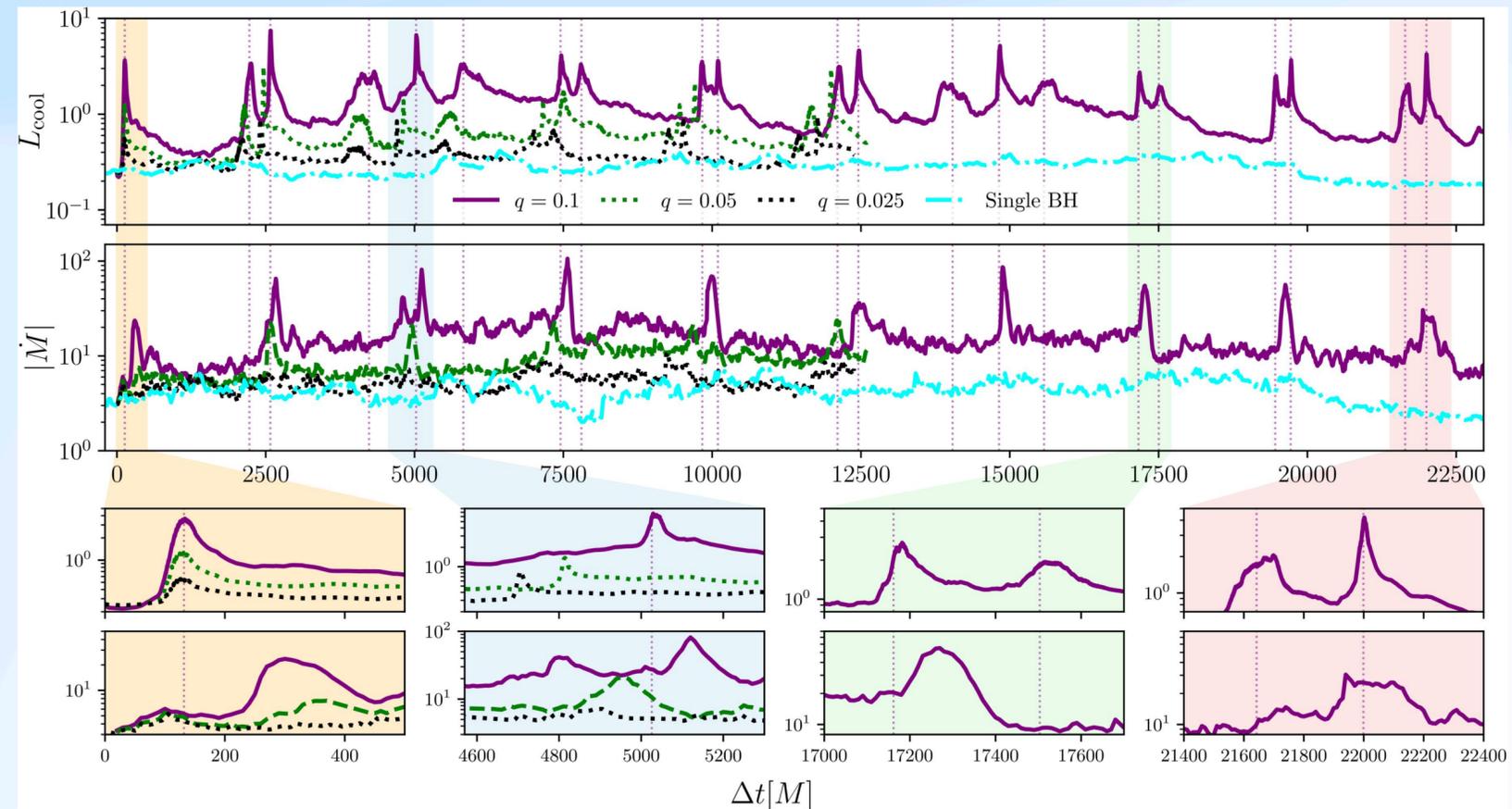
- Jets from the boosted secondary



Thin Disk: light curve

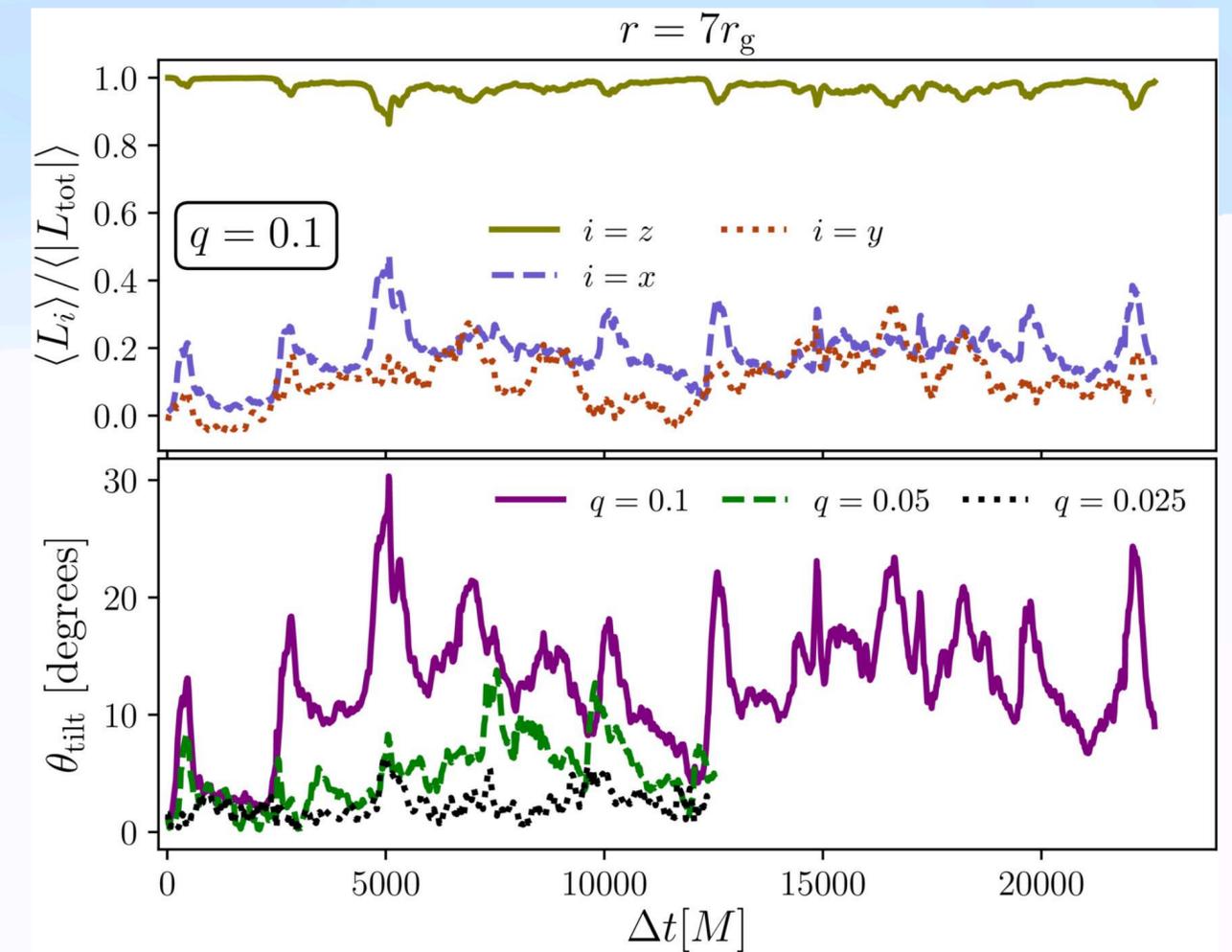
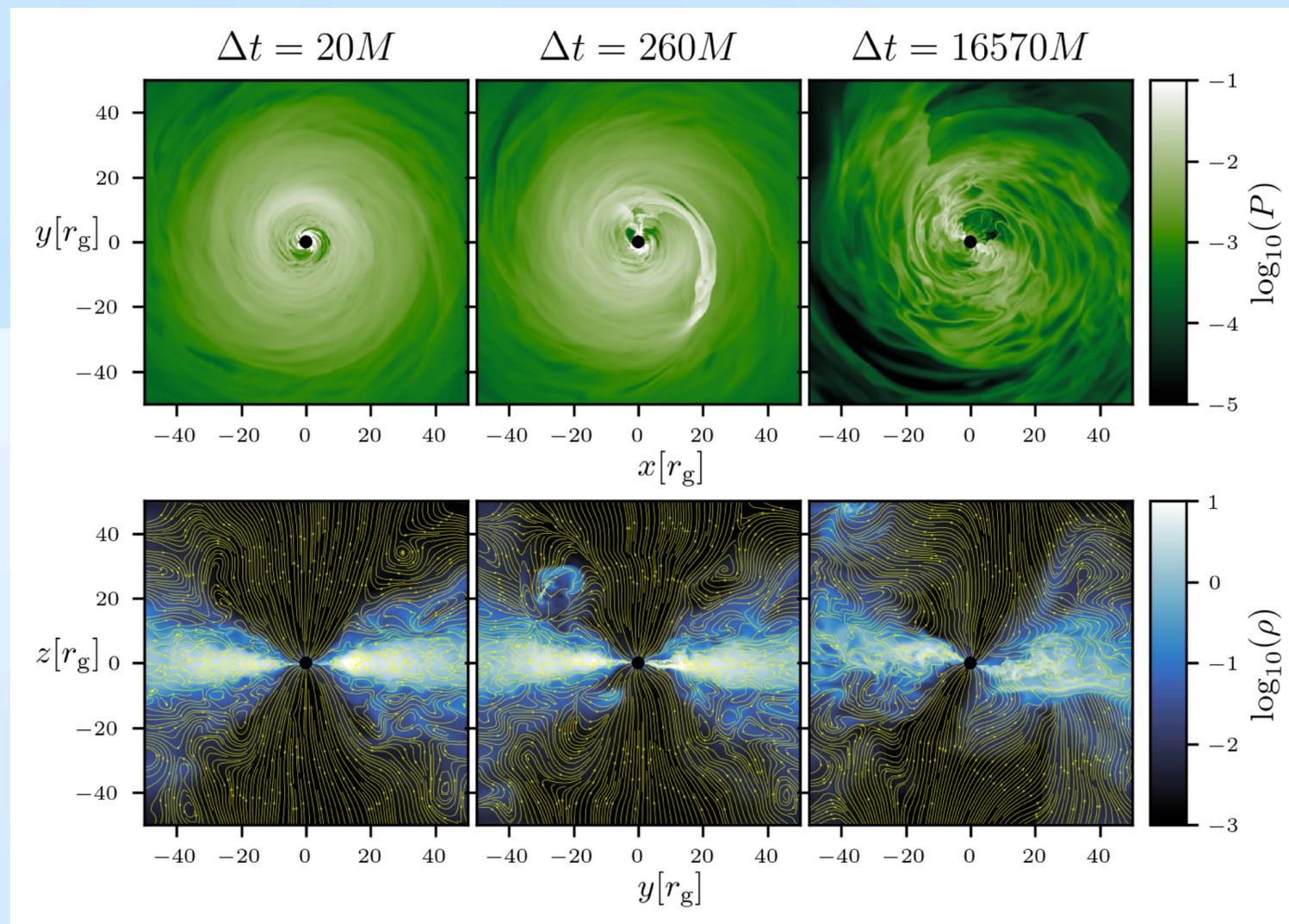
Sean M. Ressler, Luciano Combi, Bart Ripperda, Xinyu Li (2509.18241)

- Each impact of the secondary with the disk results in a spike.
- Short timescale variabilities exhibit observed features.



Thin Disk: disk tilt

Sean M. Ressler, Luciano Combi, Bart Ripperda, Xinyu Li (2509.18241)



Thin Disk: takeaway

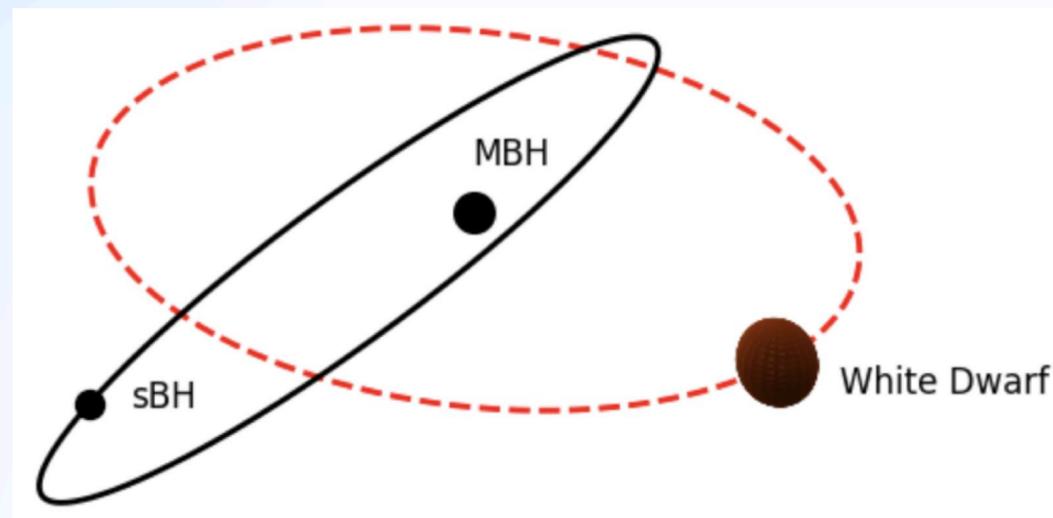
Sean M. Ressler, Luciano Combi, Bart Ripperda, Xinyu Li (2509.18241)

- We confirm the basic paradigm that impacts of the secondary on the disk can generate enough power to outshine the quiescent emission.
- The secondary also causes spiral shocks to form in the disk, enhanced accretion events, overall heating of the flow, and stochastic tilting of the disk.

Micro-TDE between EMRI and WD

Xinyu Li, Houyi Sun, Yuan-Chuan Zou, Huan Yang (2501.13702)

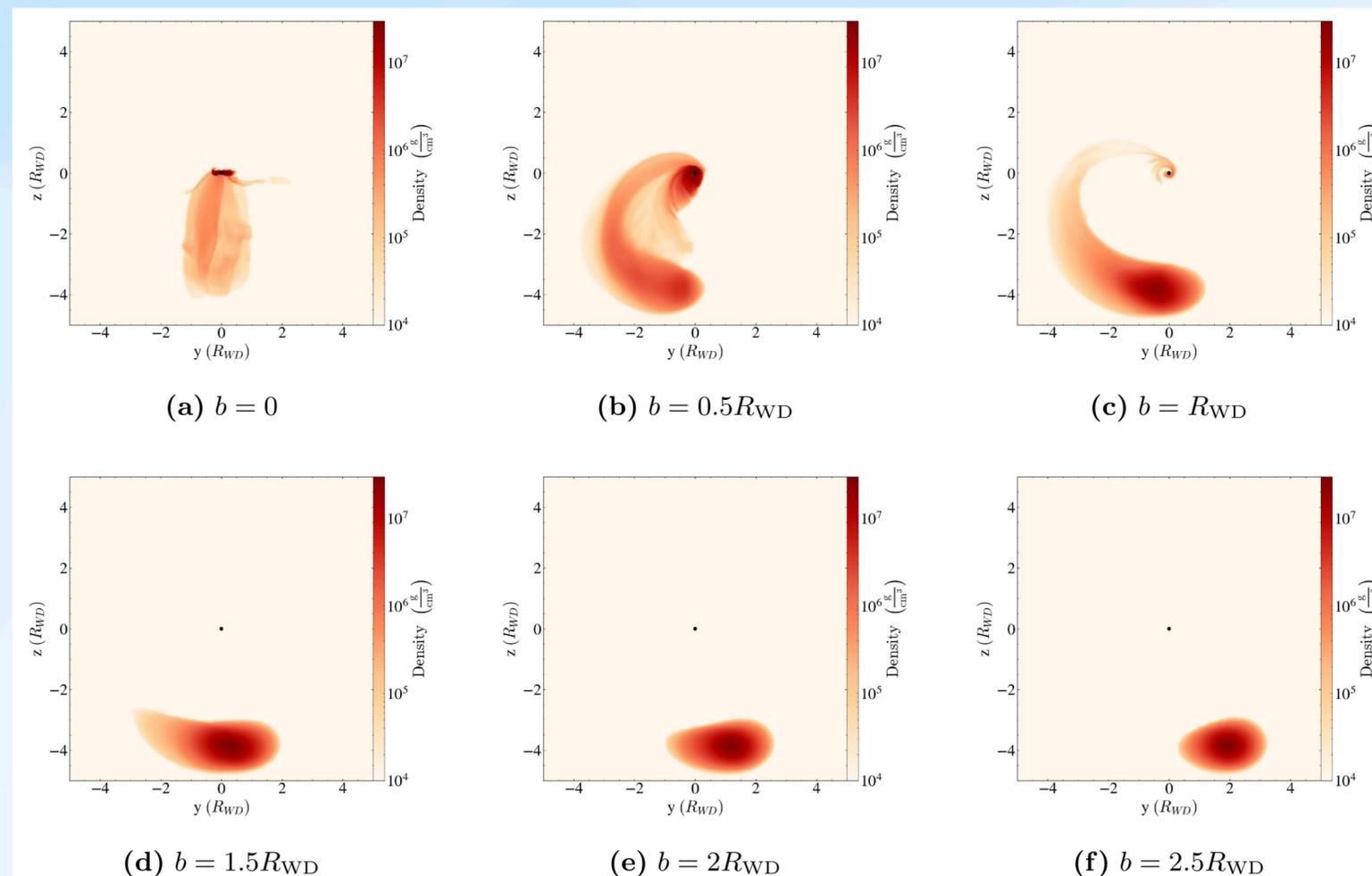
- A stellar-mass BH on highly eccentric orbit around a massive BH within 100 gravitational radius.
- A WD around the MBH may closely encounter with the sBH, $v \sim 0.1c$.
- The event rate is calculated a few times per year within $z \leq 3$.



Micro-TDE between EMRI and WD

Xinyu Li, Houyi Sun, Yuan-Chuan Zou, Huan Yang (2501.13702)

- The WD will be tidally disrupted by the sBH.
- Hydrodynamical simulations.

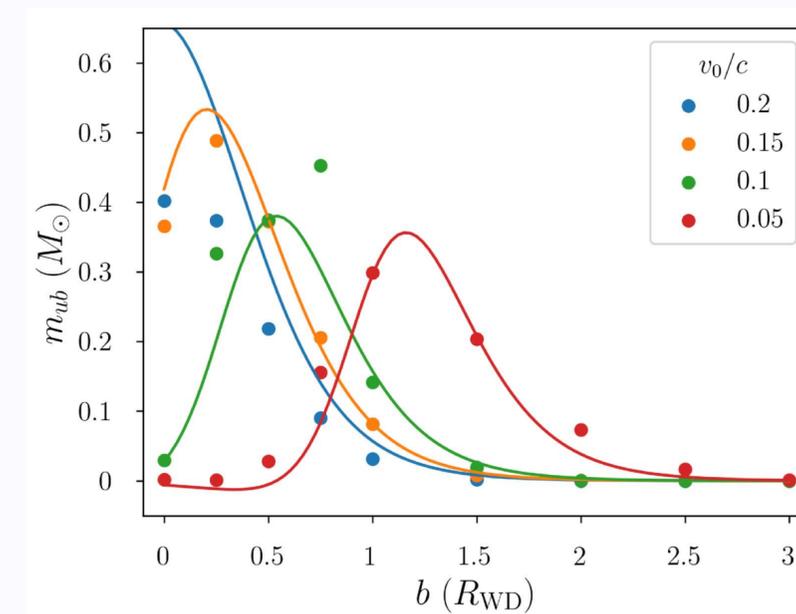
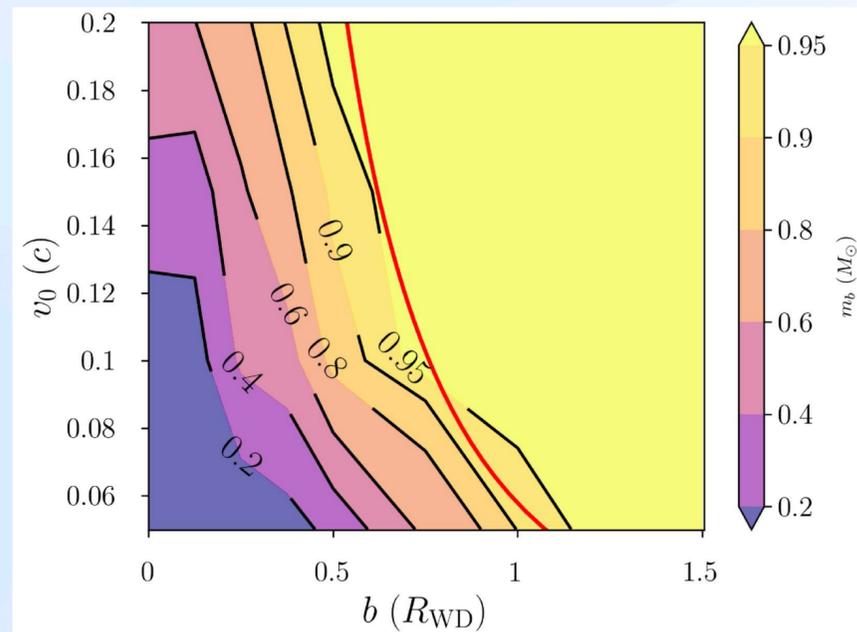


Micro-TDE between EMRI and WD

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Fate of the WD material:

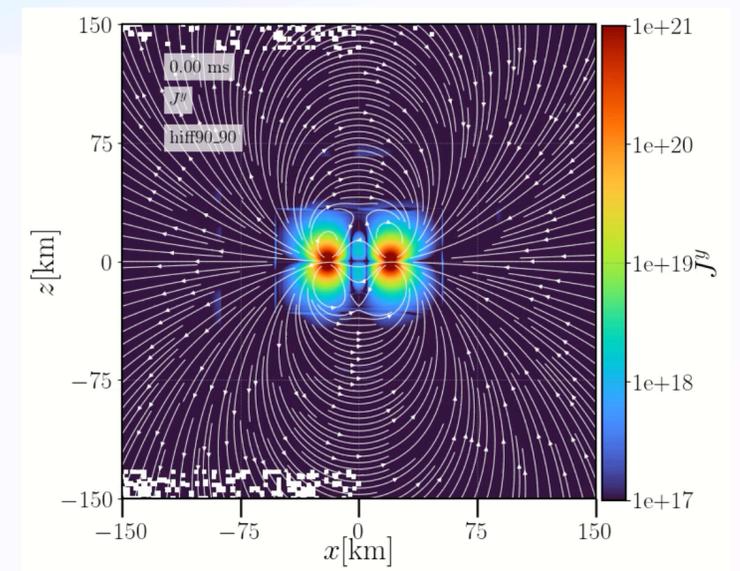
- Accreted onto the sBH \rightarrow X-ray burst
- Remain bound
- Unbound from the sBH-WD system, may accrete onto the MBH \rightarrow late optical flare



Summary

How to observe black hole binaries?

- BH-disk interactions
 - thick disk: jet precession from spin-orbit coupling, lensing flares
 - thin disk: reproduce OJ-287 observed features
- Micro-TDE between EMRI and WD
 - X-ray burst + late optical flare



Ask Dhruv Desai on our latest BNS mergers