How to observe binary black holes?

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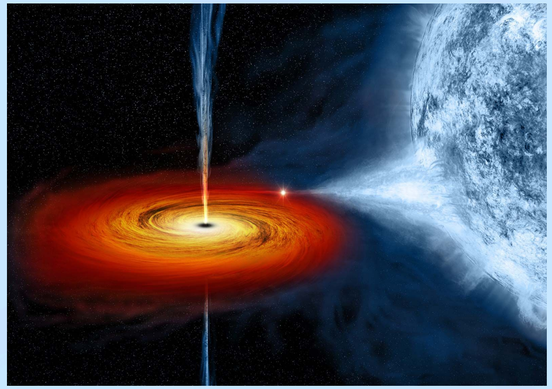
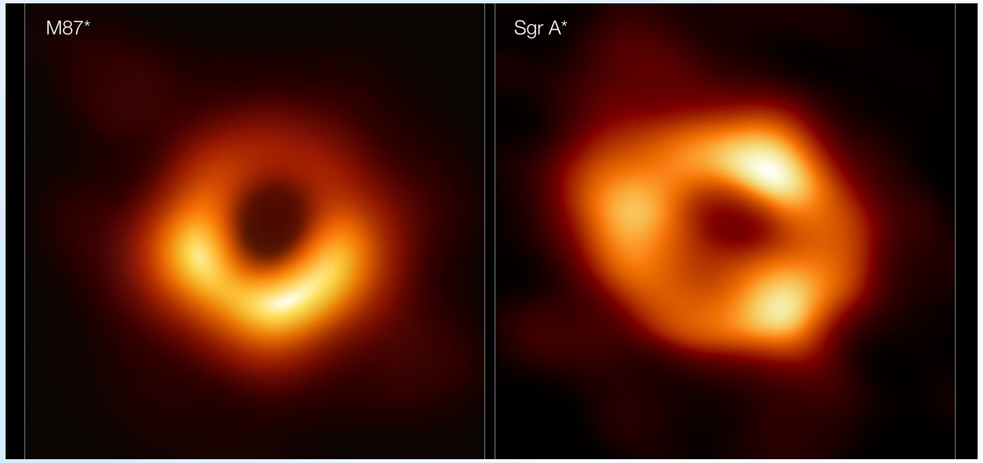
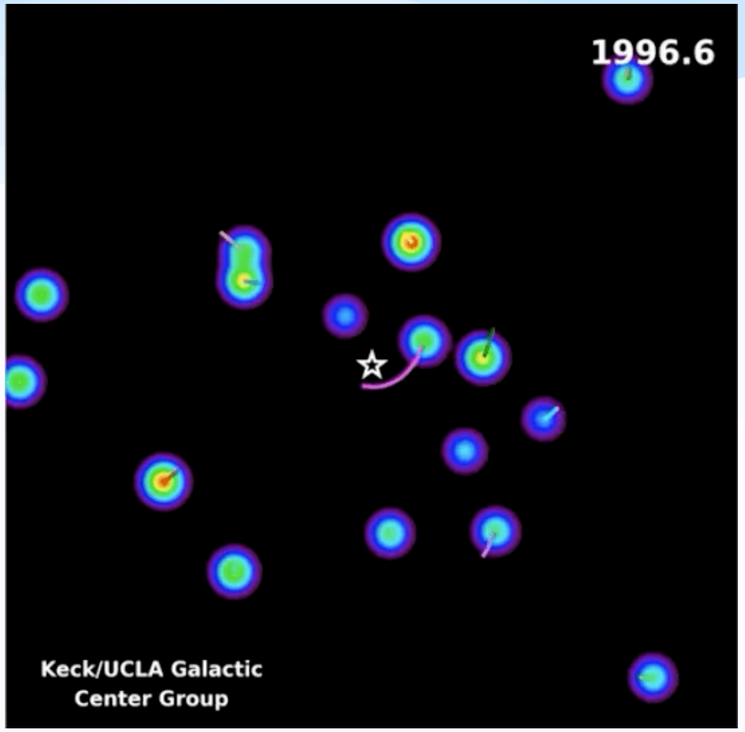
Black Holes are REAL!



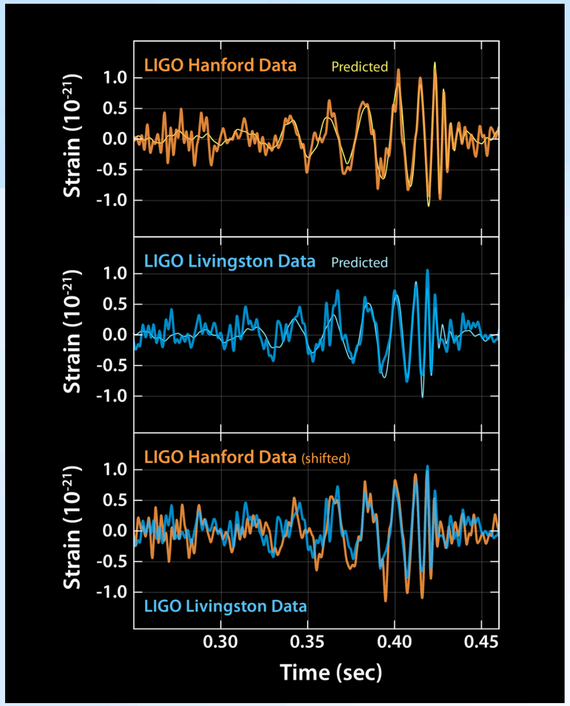
- Cyg X-1, star-stellar mass BH binary
- Dynamical evidence of Sgr A*, supermassive BH
- EHT image

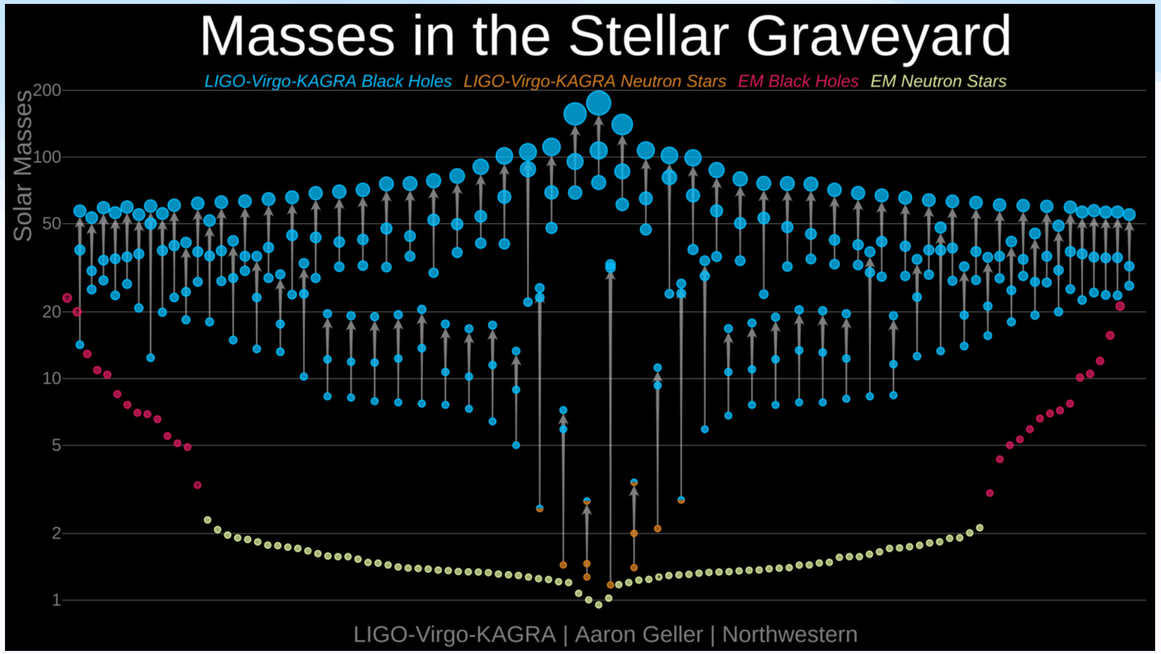




Black Holes are REAL!

- GW from stellar-mass BH binaries





What about massive BH binaries?

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

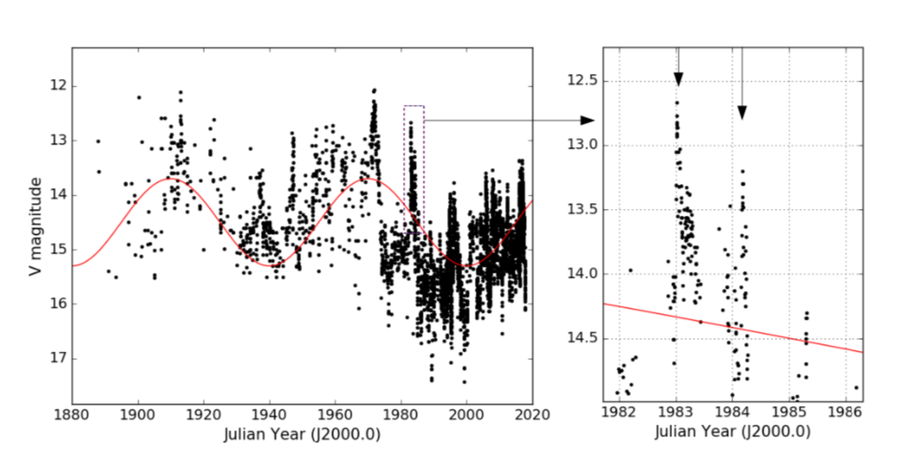
- Can we do more before LISA’s launch?

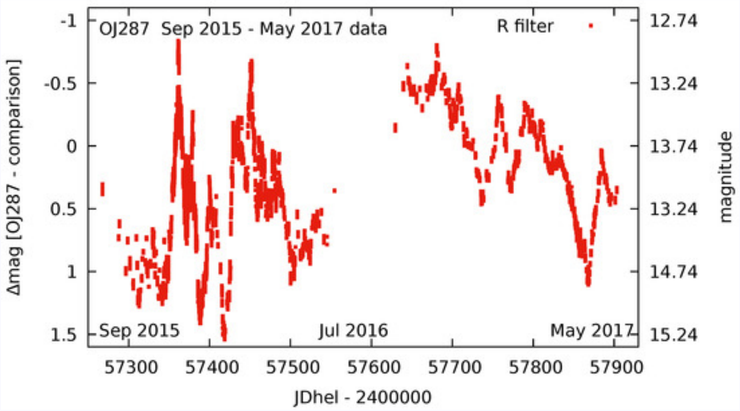
Quasi-Periodic Eruptions from OJ-287

- OJ 287 is a bright blazar at a redshift of z ~ 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

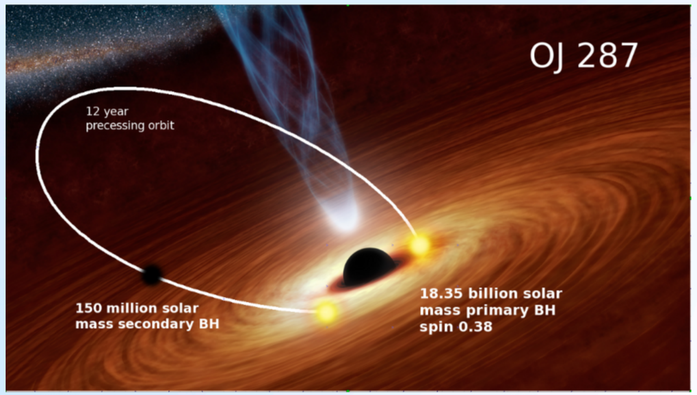
II.Long term variations with 60 years period

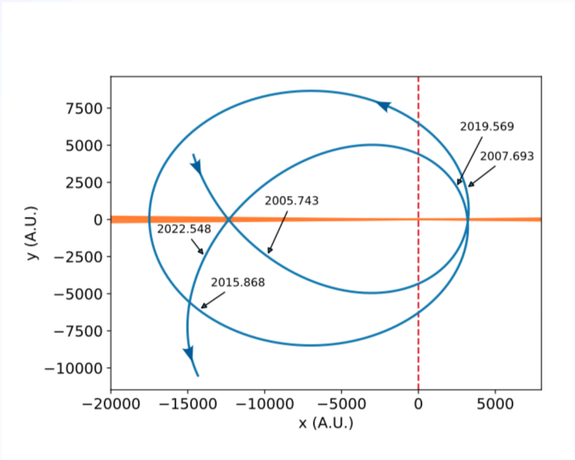


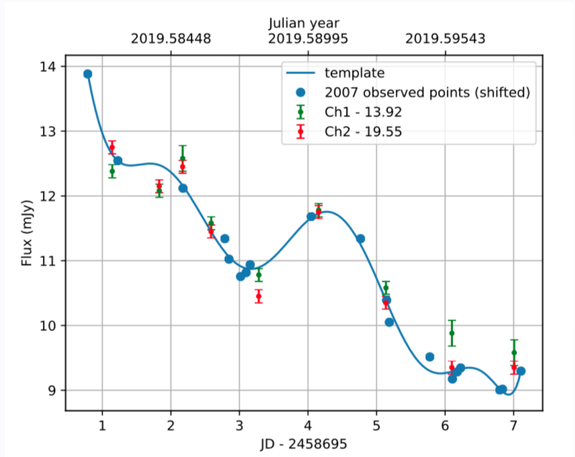


Binary BH model of OJ 287

- 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

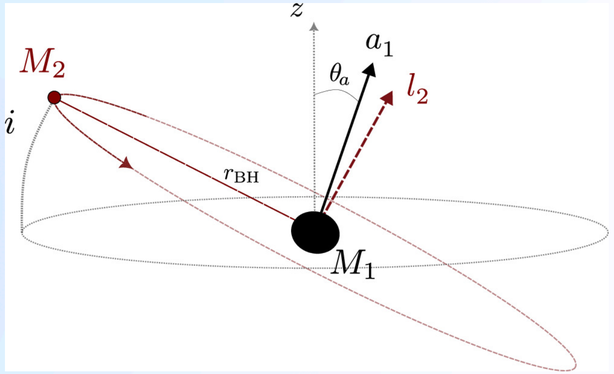


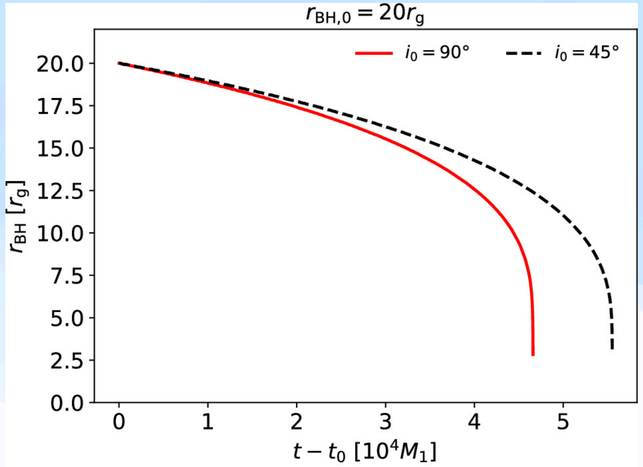


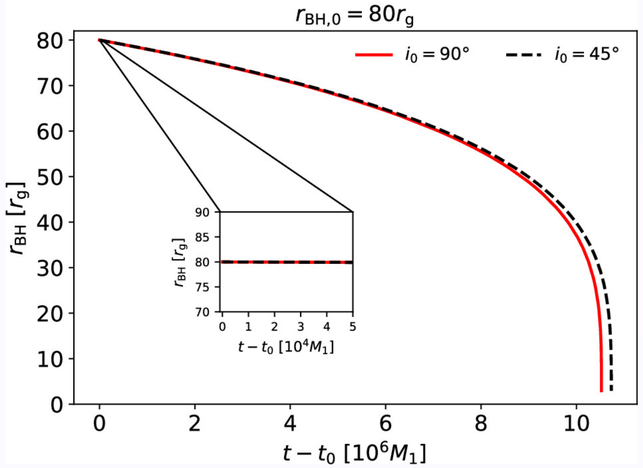


GRMHD simulations of BH-Disk interactions

- 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



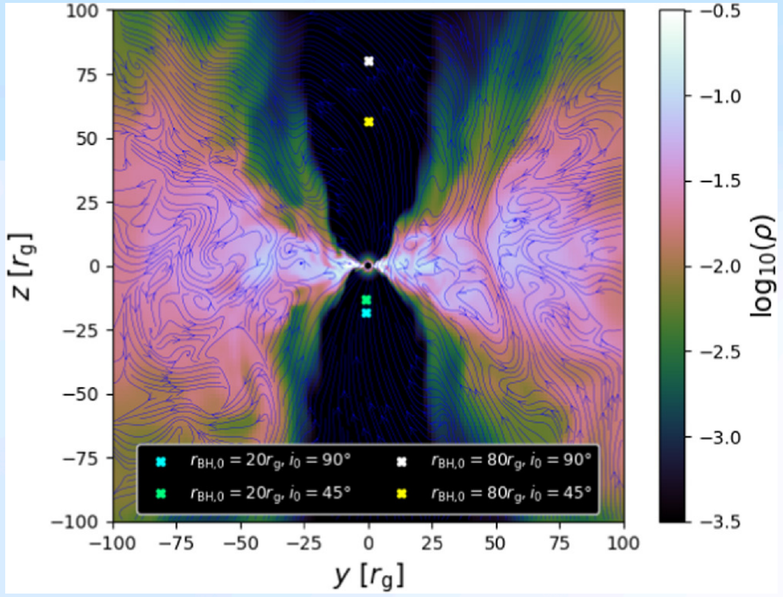


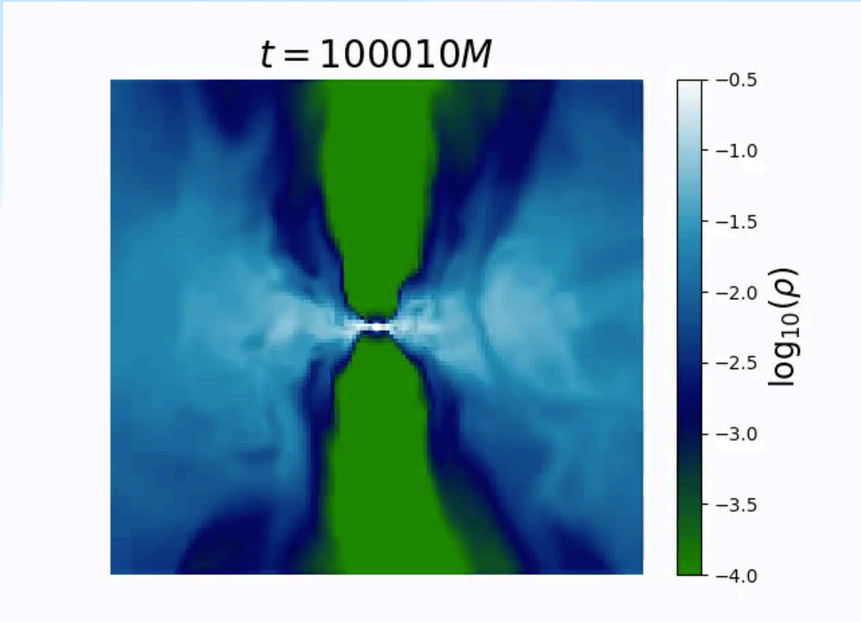


Thick MAD Disk

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

- q=0.1 fixed.

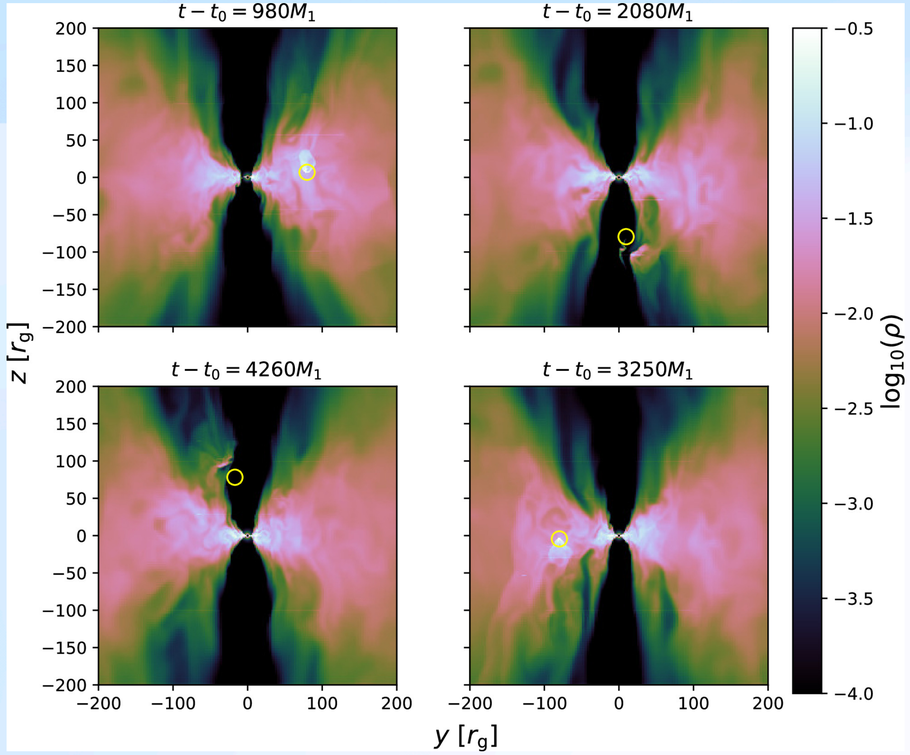


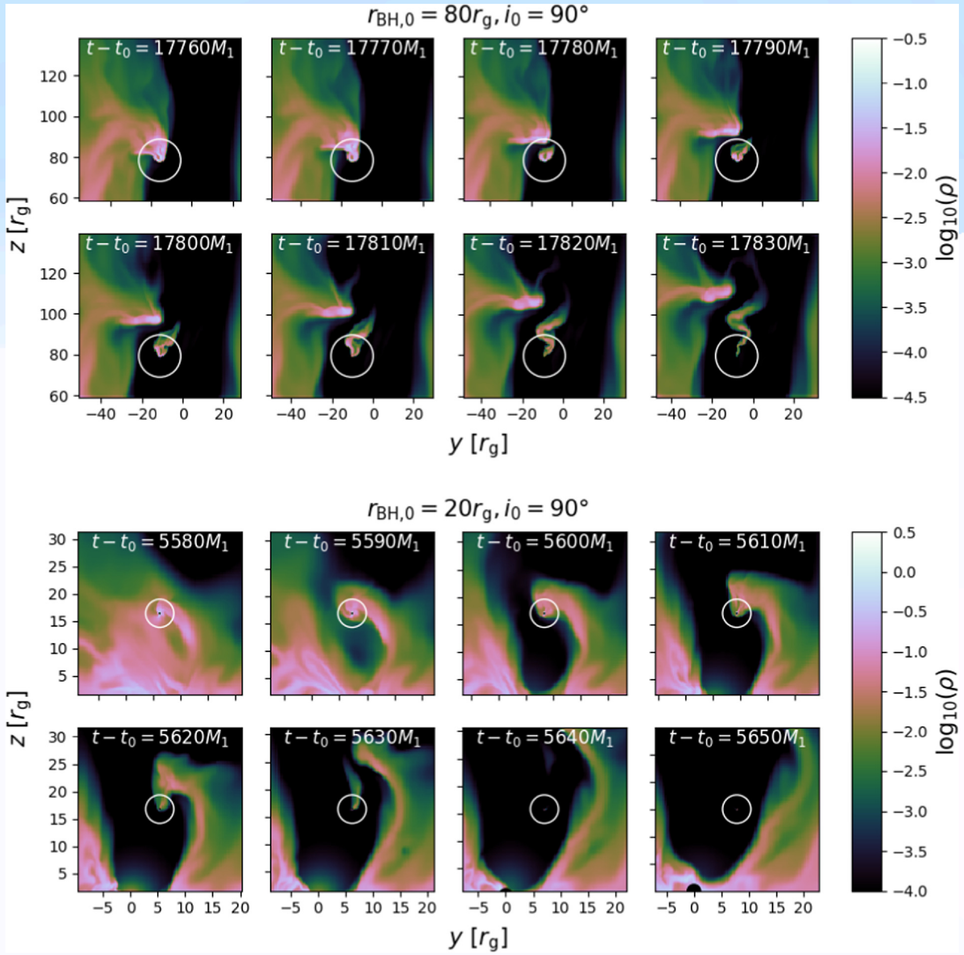


Thick MAD Disk: Morphology

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

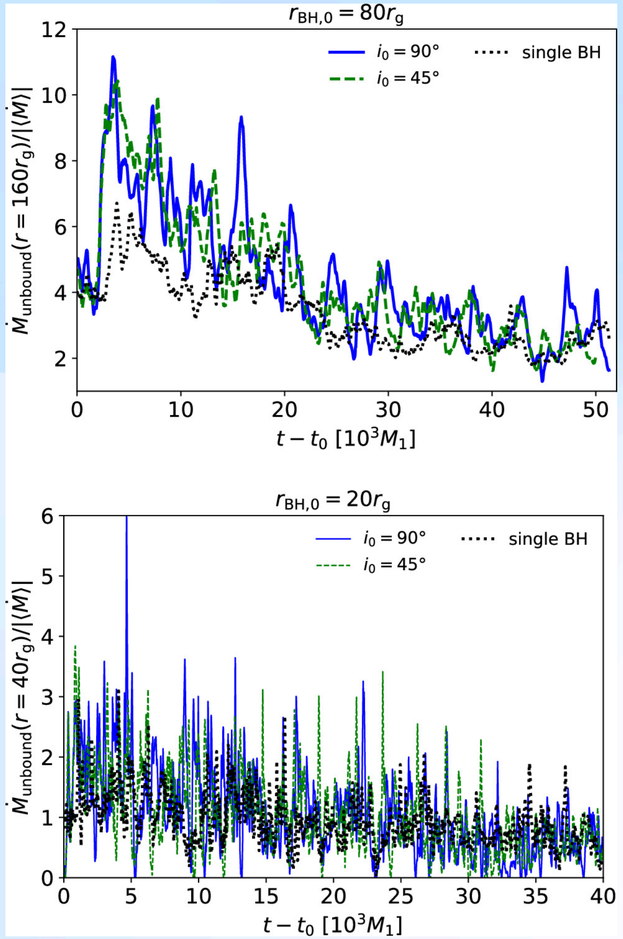
- Bow shock from BHL accretion
- Mass is dragged out by the secondary

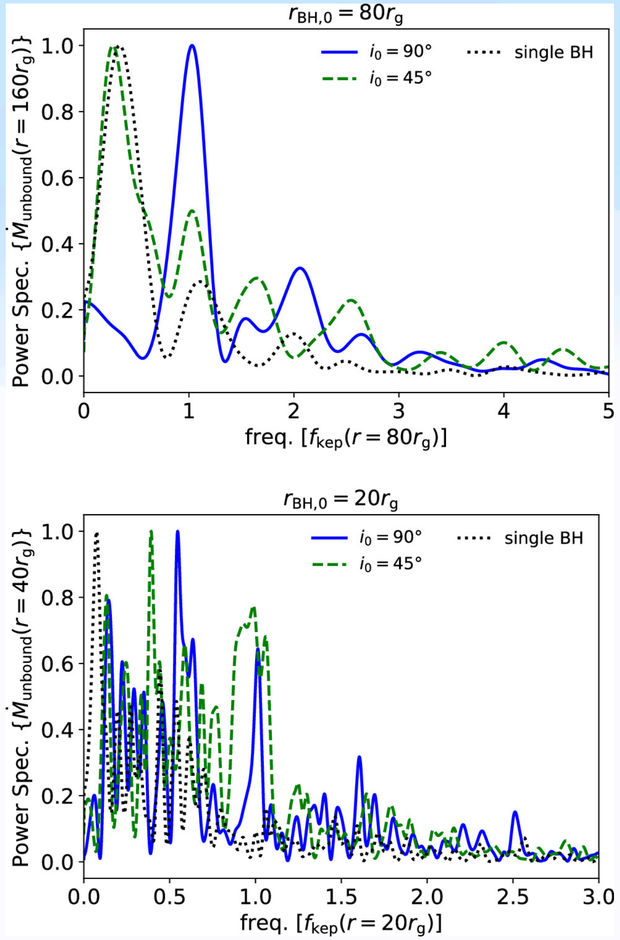




Thick MAD Disk: mass outflow rate

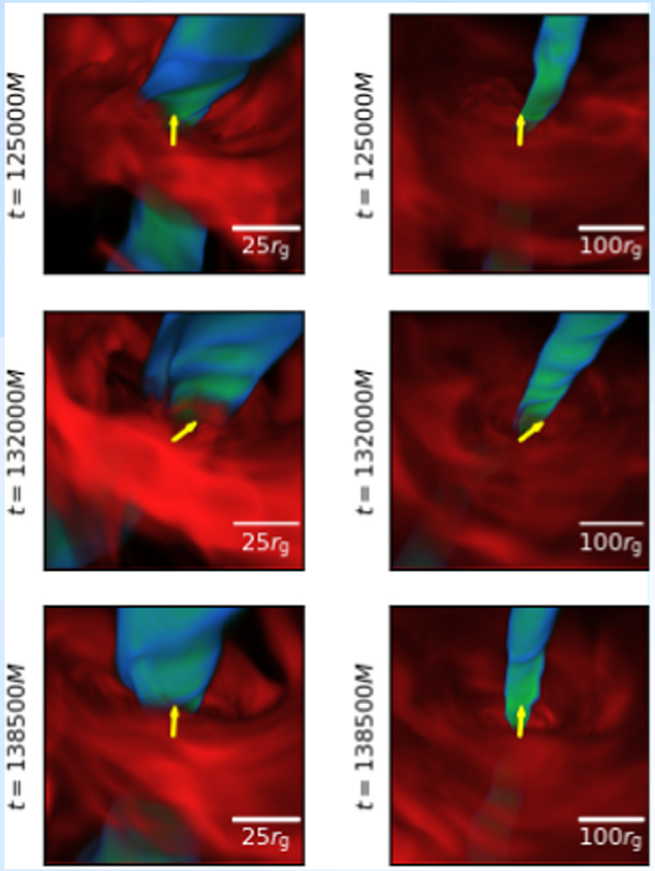
Sean M. Ressler, Luciano Combi, Xinyu Li, Bart Ripperda, and Huan Yang (2404.02193)

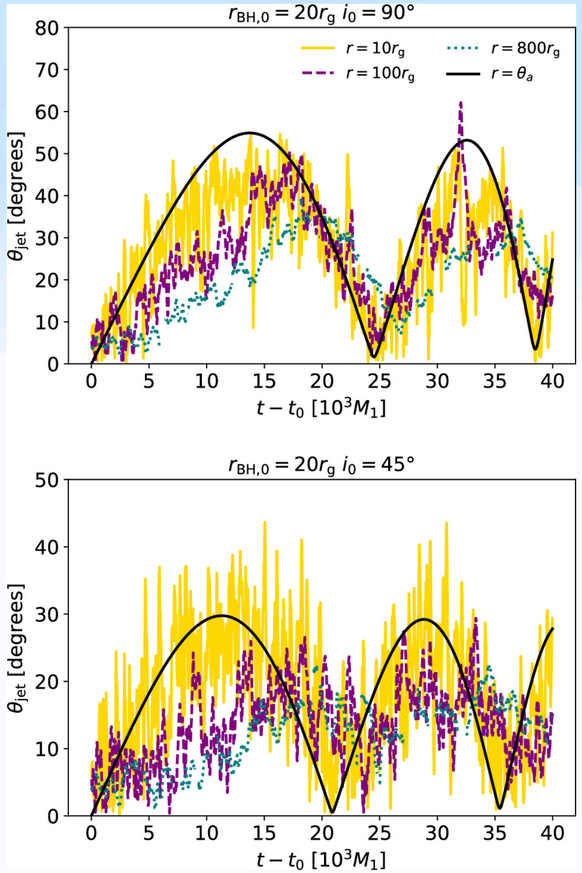




Thick MAD Disk: spin-orbit coupling

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





Thick MAD Disk: summary

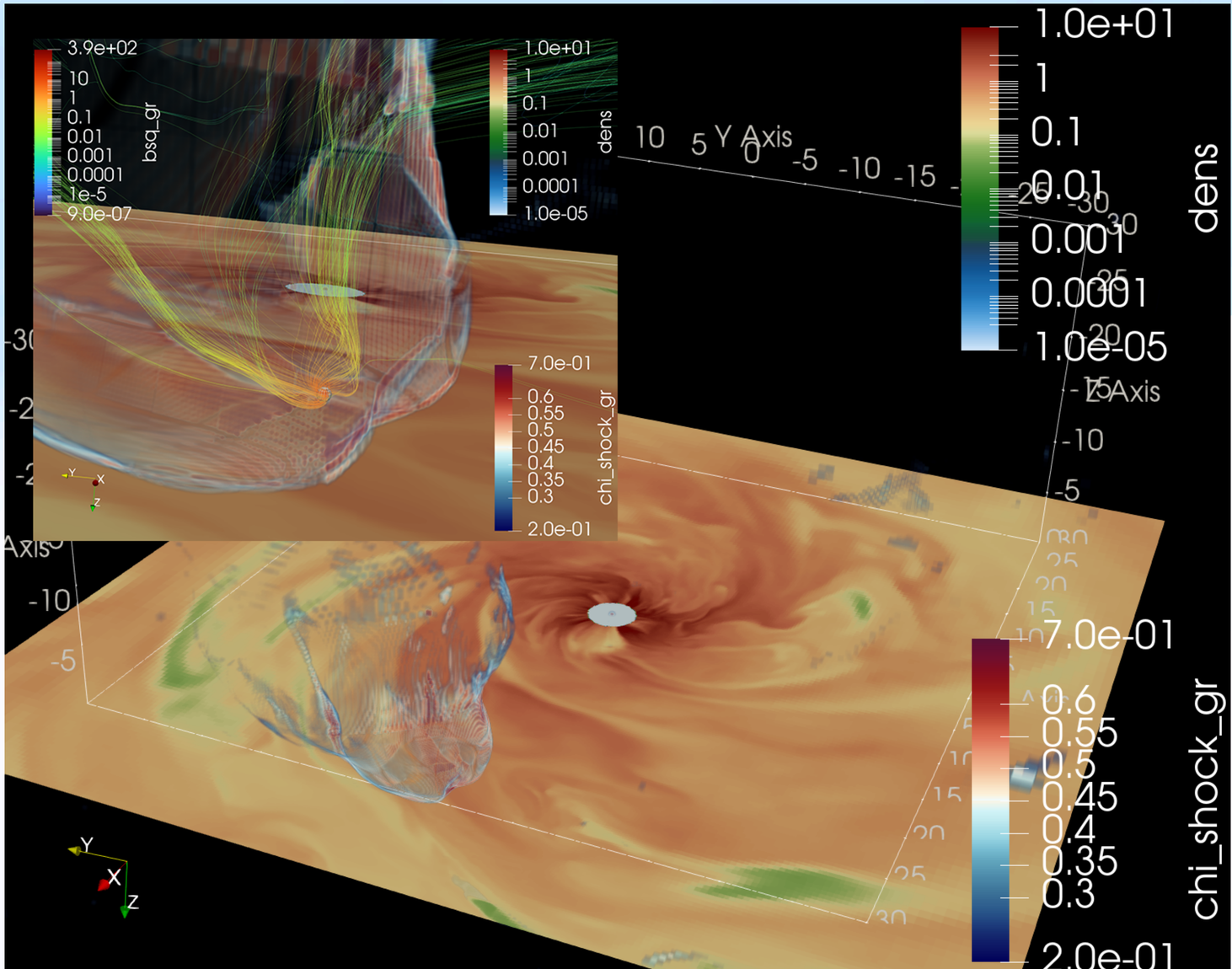
Sean M. Ressler, Luciano Combi, Xinyu Li, Bart Ripperda, and Huan Yang (2404.02193)

- 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 MAD Disk: lensing flares

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

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



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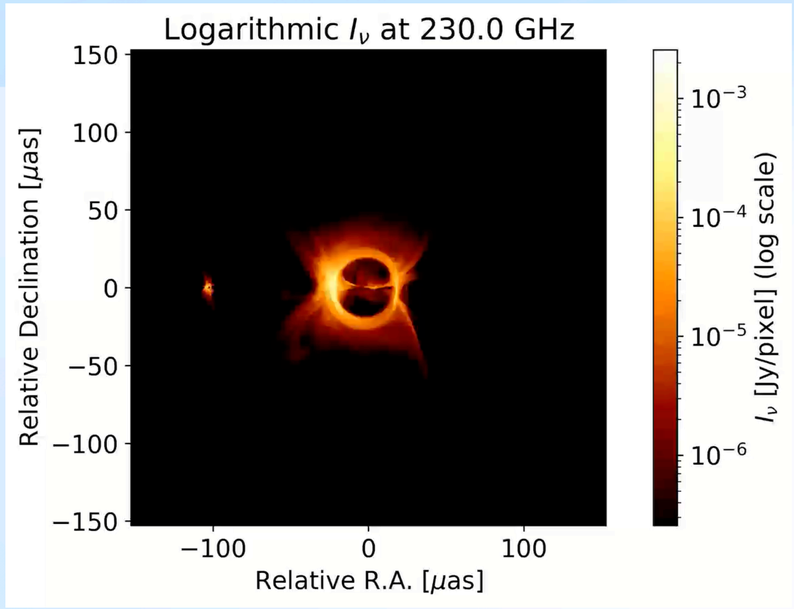
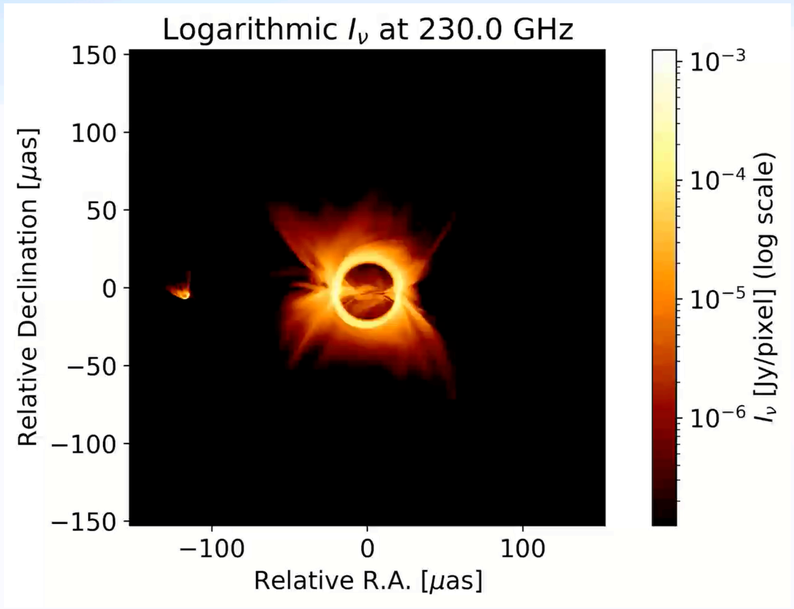
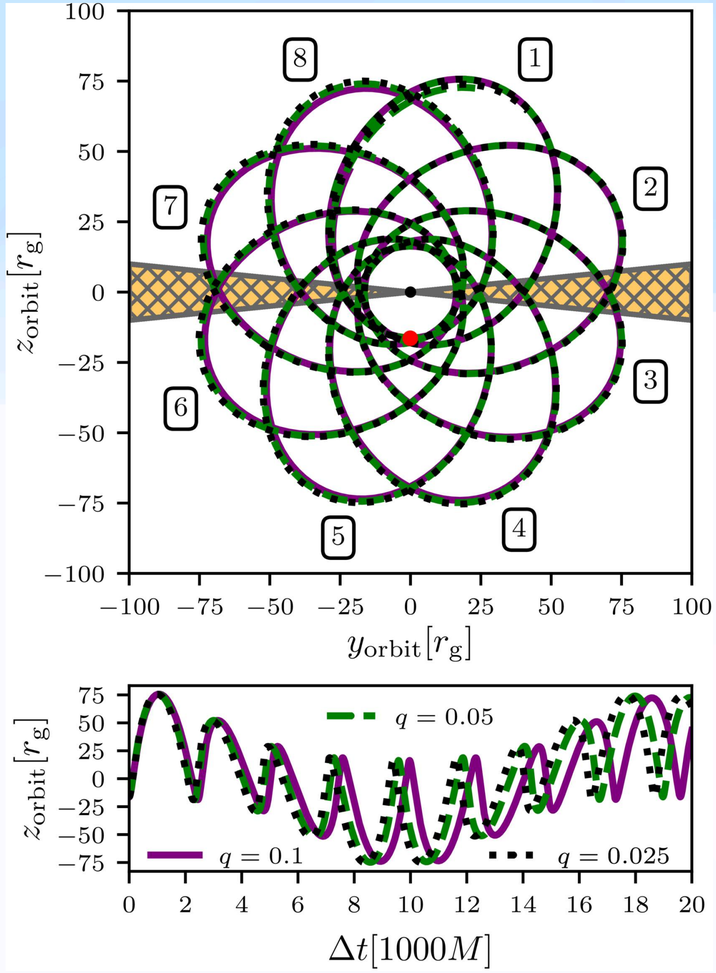




Thin Disk: OJ-287 like system

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

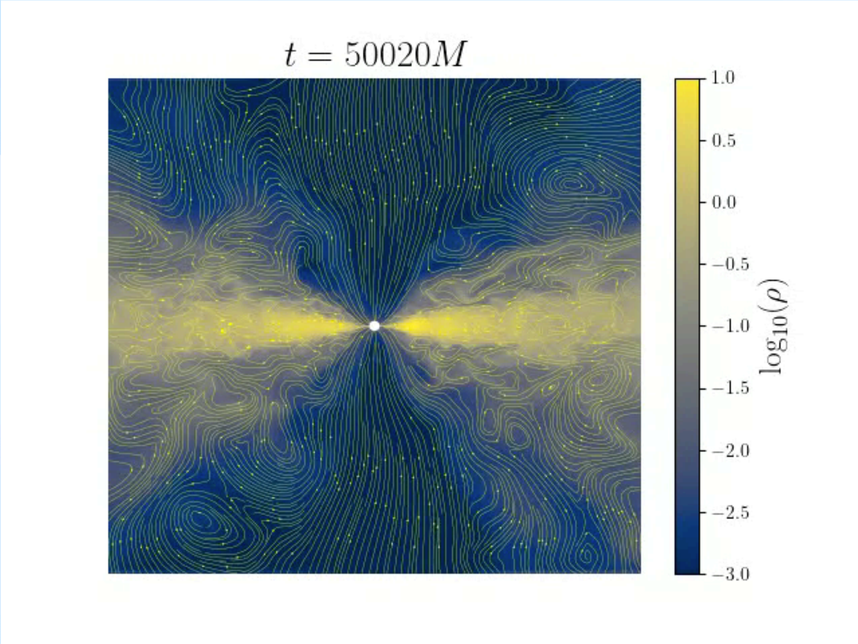
- Adding a cooling term to keep the disk thin
- H/R=0.1, q=0.1, 0.05, 0.025

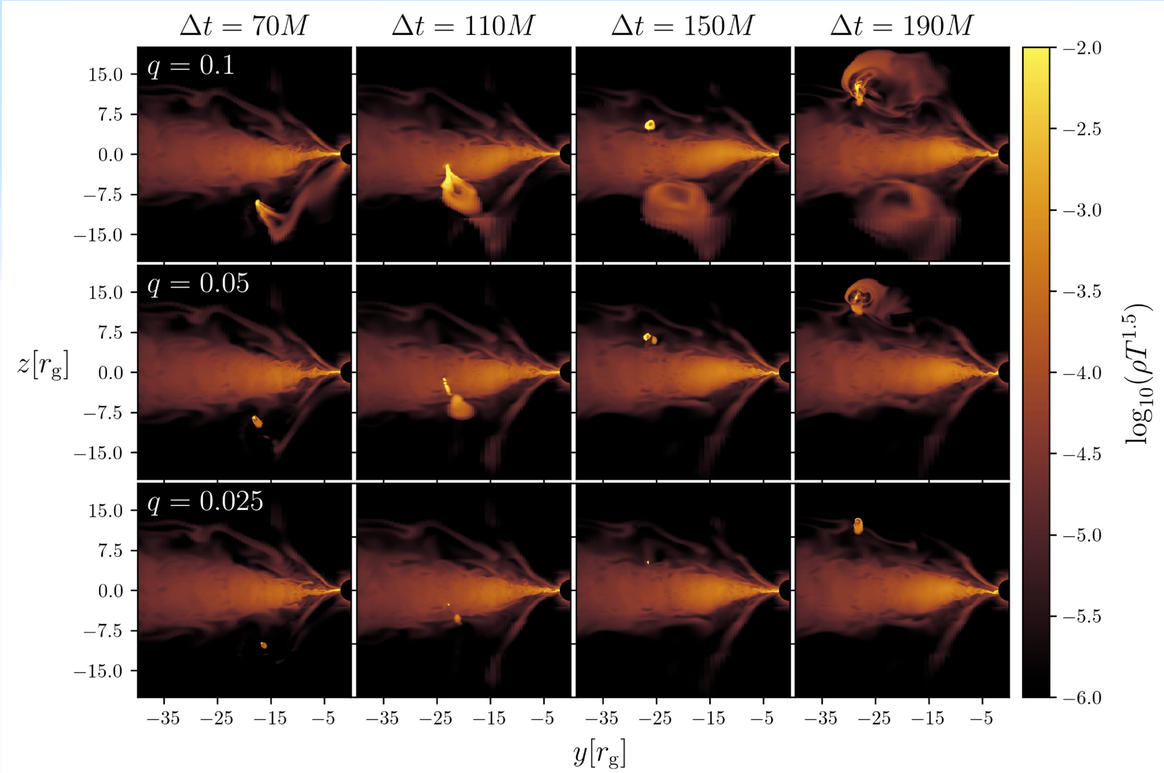


Thin Disk: morphology

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

- Jets from the boosted secondary

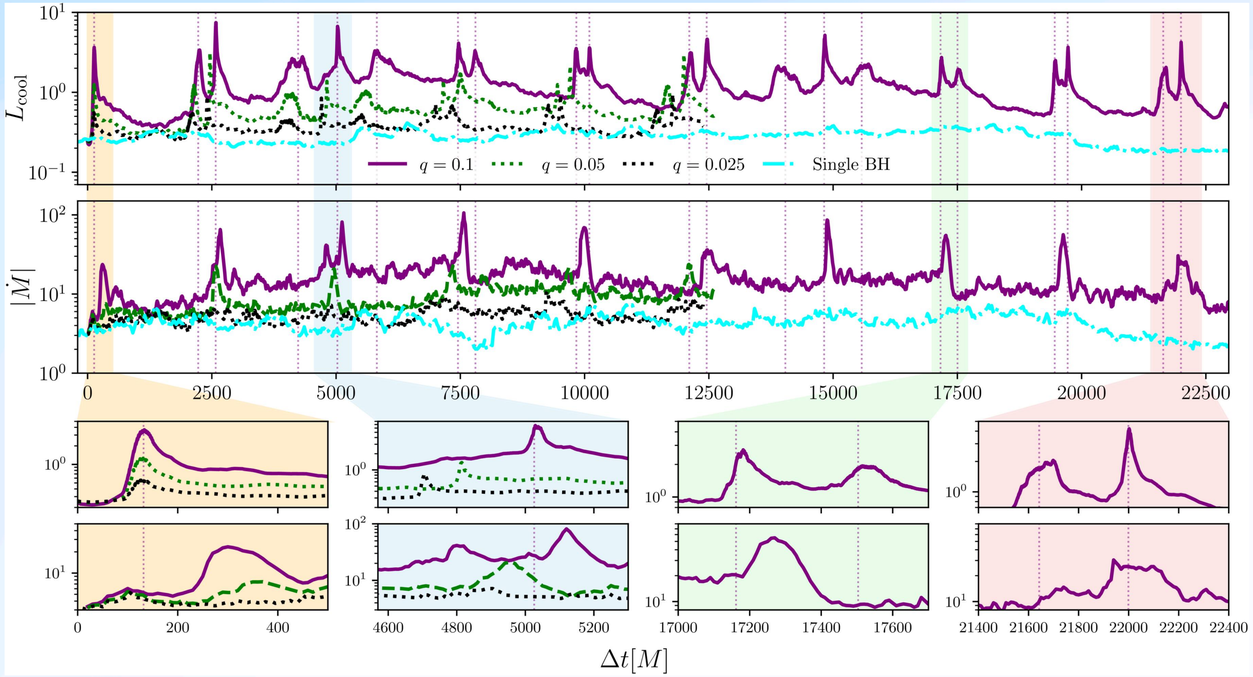




Thin Disk: light curve

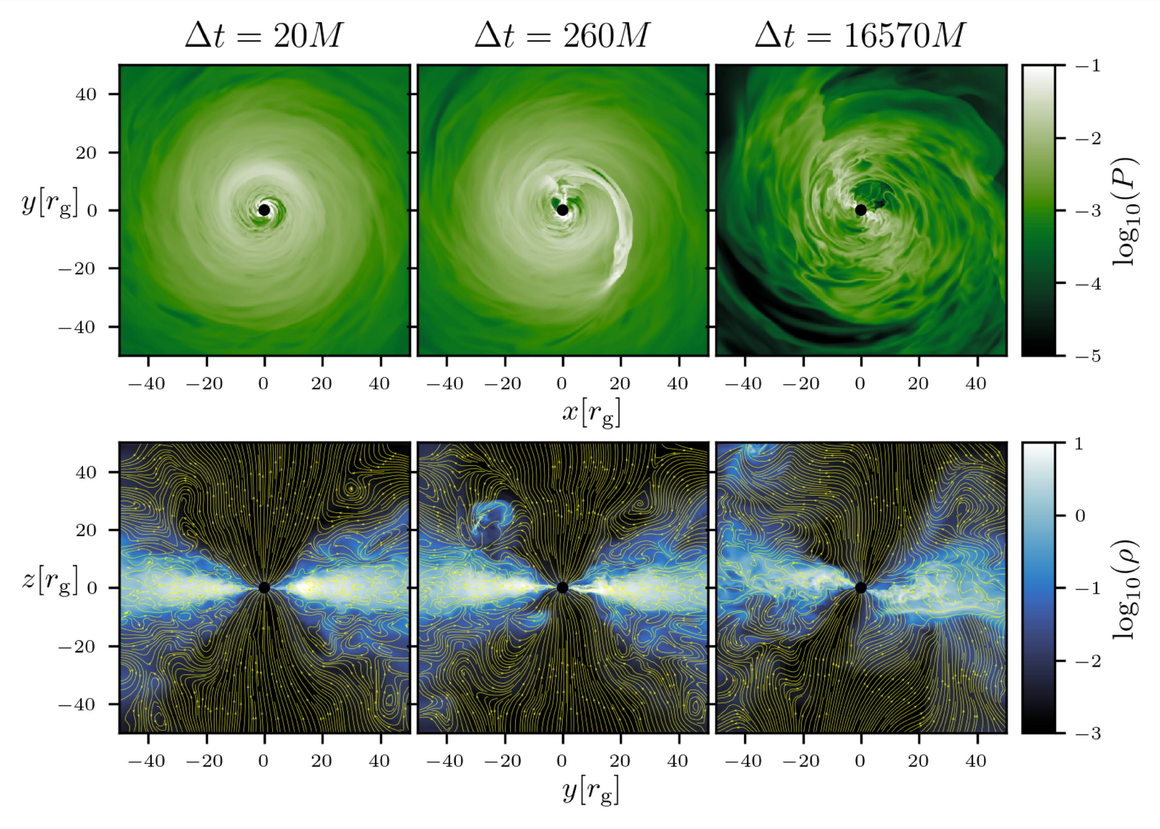
Sean M. Ressler, Luciano Combi, Bart Ripperda, Xinyu Li (2509.18241)

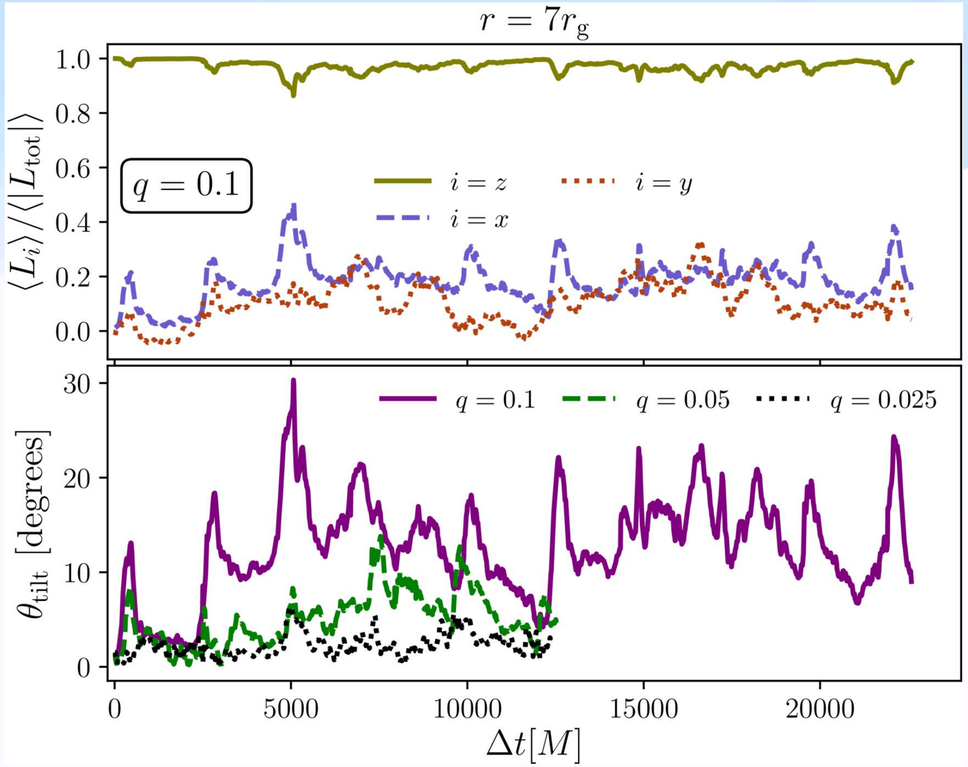
- Each impact of the secondary with the disk results in a spike.
- Short timescale variabilities exhibit observed features.



Thin Disk: disk tilt

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





Thin Disk: takeaway

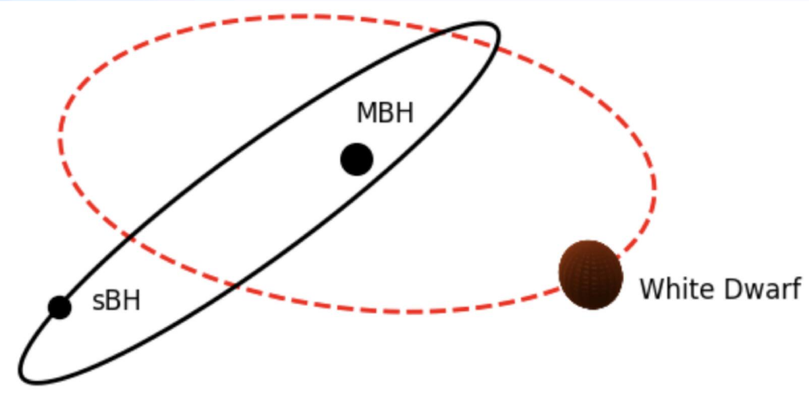
Sean M. Ressler, Luciano Combi, Bart Ripperda, Xinyu Li (2509.18241)

- 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~0.1c.
- The event rate is calculated a few times per year within $z \leq 3$.



Micro-TDE between EMRI and WD

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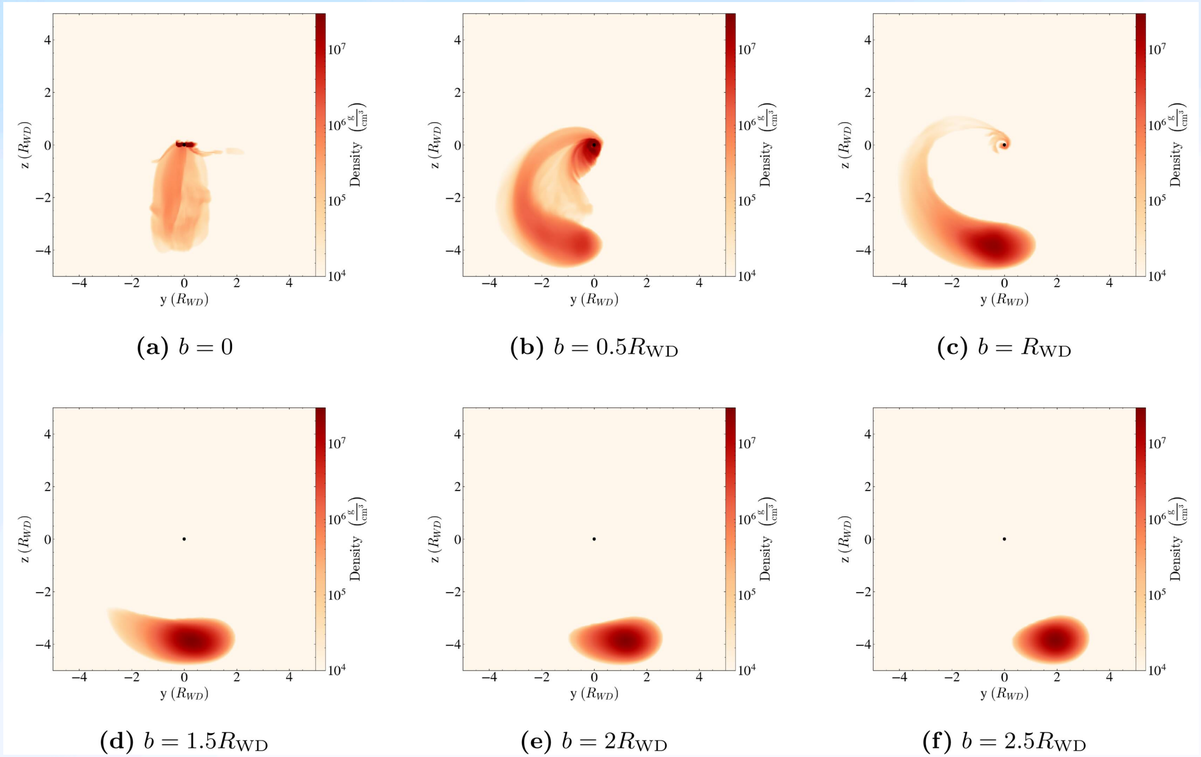
- The WD will be tidally disrupted by the sBH.
- Hydrodynamical simulations.



(a) $b = 0$ **(b)** $b = 0.5R_{\rm WD}$ **(c)** $b = R_{\rm WD}$

(d) $b = 1.5R_{\rm WD}$ **(e)** $b = 2R_{\rm WD}$ **(f)** $b = 2.5R_{\rm WD}$

Micro-TDE between EMRI and WD

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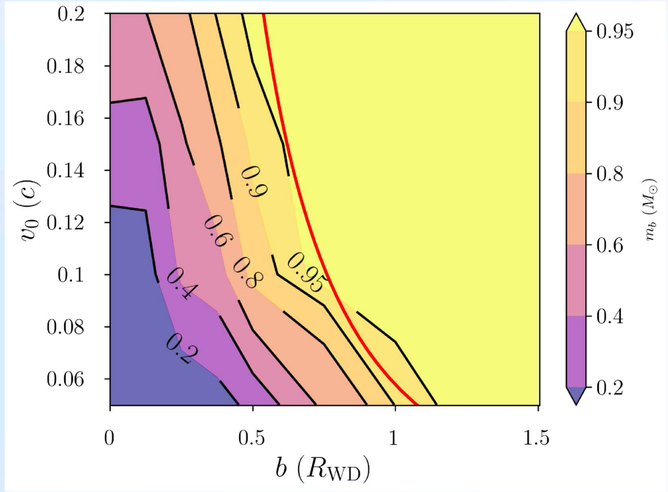
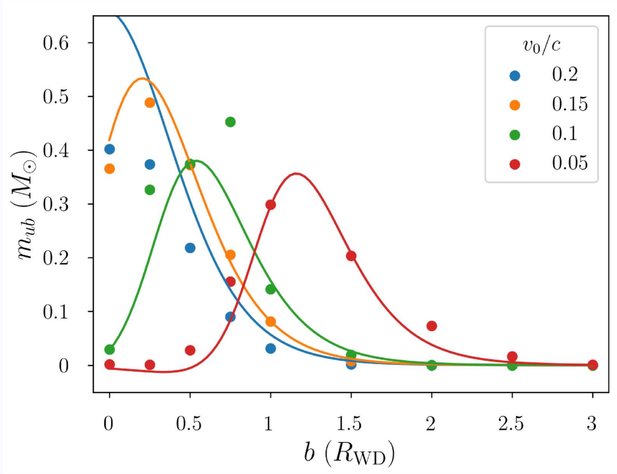
Fate of the WD material:

- Accreted onto the sBH -> X-ray burst
- Remain bound
- Unbound from the sBH-WD system, may accrete onto the MBH -> 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


THANK YOU FOR LISTENING TO OUR PRESENTATION
ANY QUESTIONS?
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