



Merging Black Hole Binaries in AGN disks: Formations and Evolutions

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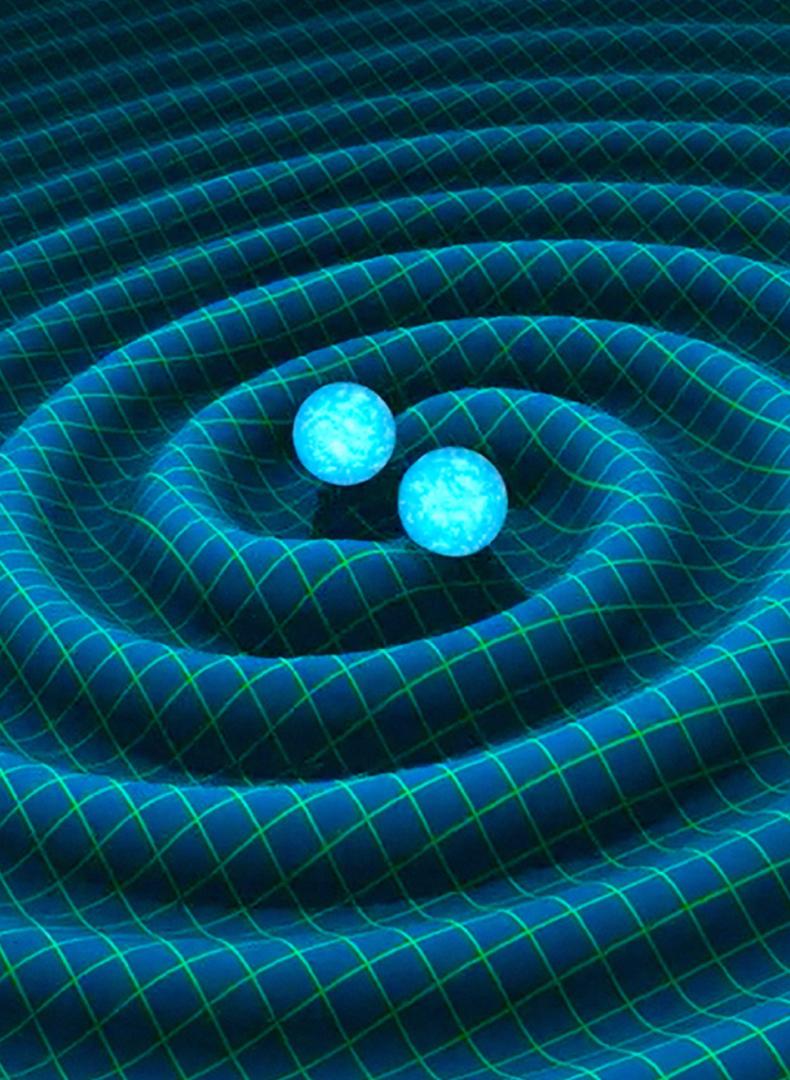
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What are black hole (BH) binaries and why do we care about them?

- Gravitational Wave (GW):
 - predicted by General Relativity
 - first detected by LIGO in 2016
 - one of the most accurate verifications of Einstein's Theory of Relativity
- BH binaries:
 - the **simplest** system that produces GW
 - LIGO (and others) detects their mergers

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Merging BH binaries in AGN disks

- A two-body system with only two point masses
→ never contract or merge
- A binary embedded in a gaseous disk
→ may contract or even merge

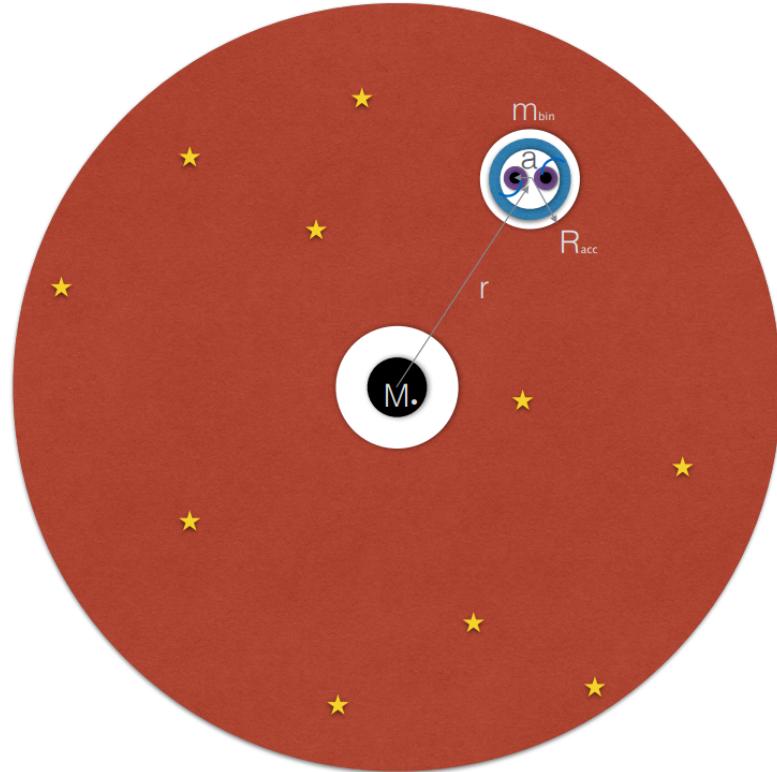


Diagram Credits: Stone et al. 2017

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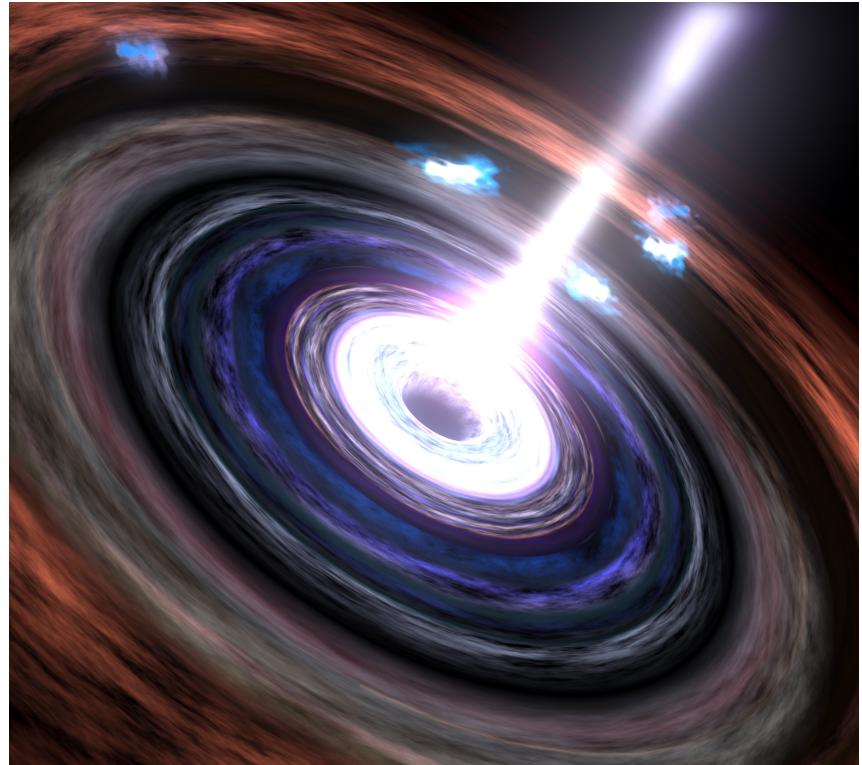
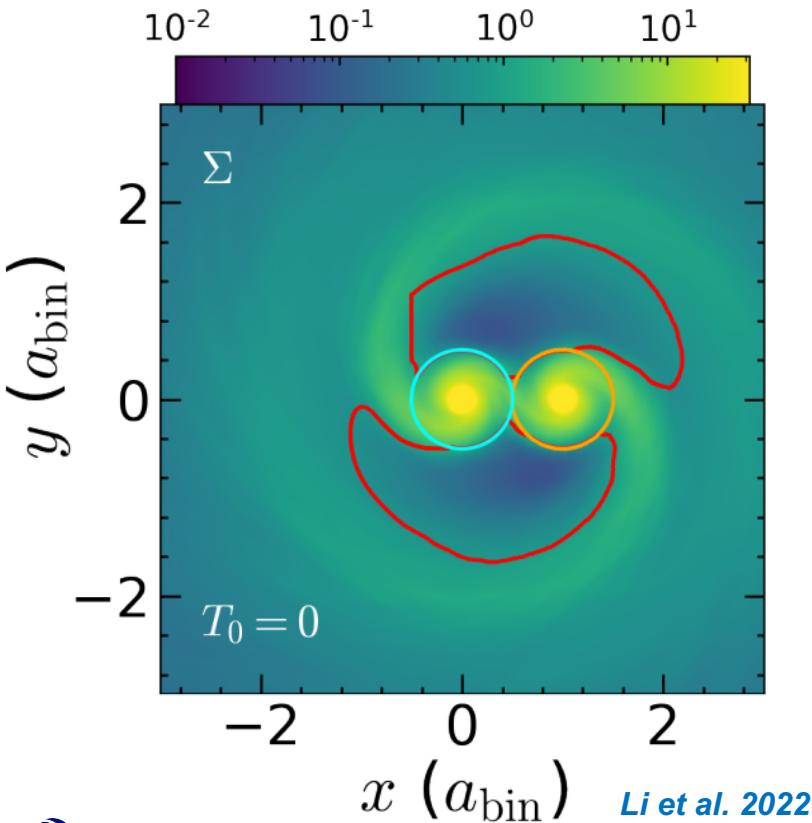


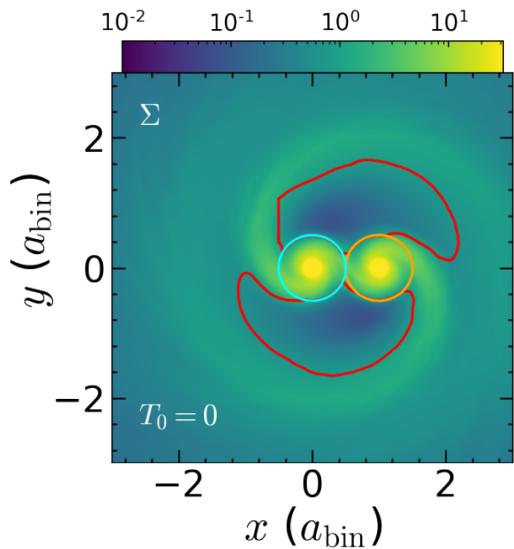
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Evolutions of BH binaries in AGN disks:

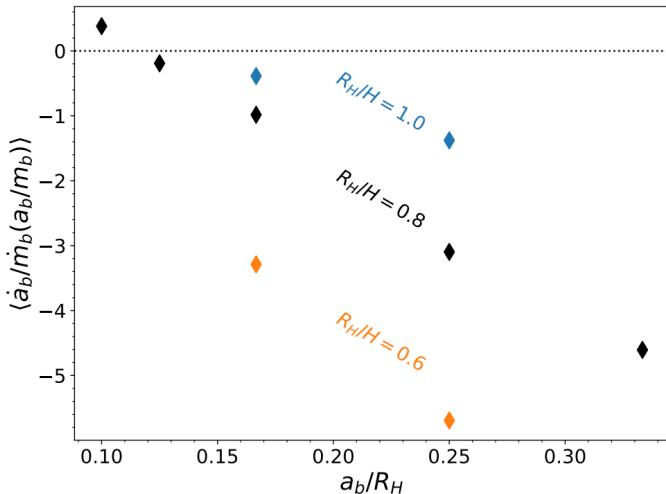


- We use hydrodynamics simulations to study the evolution of embedded binaries.
- The gas and binary interact via gravity.
- The gas distribution around the binary is highly non-linear.

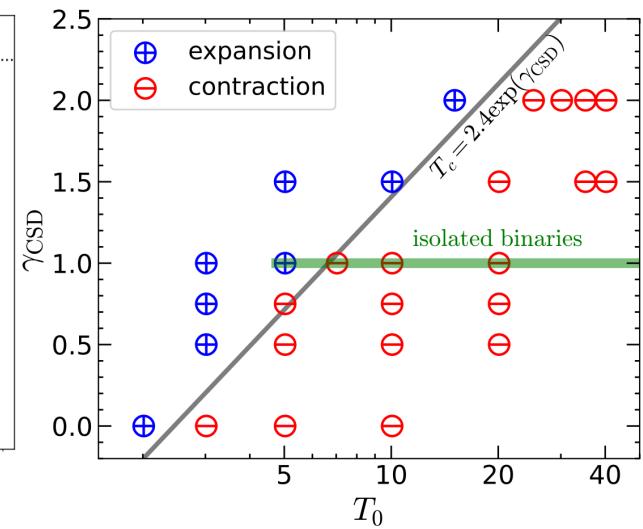
Evolutions of BH binaries in AGN disks:



Li et al. 2022



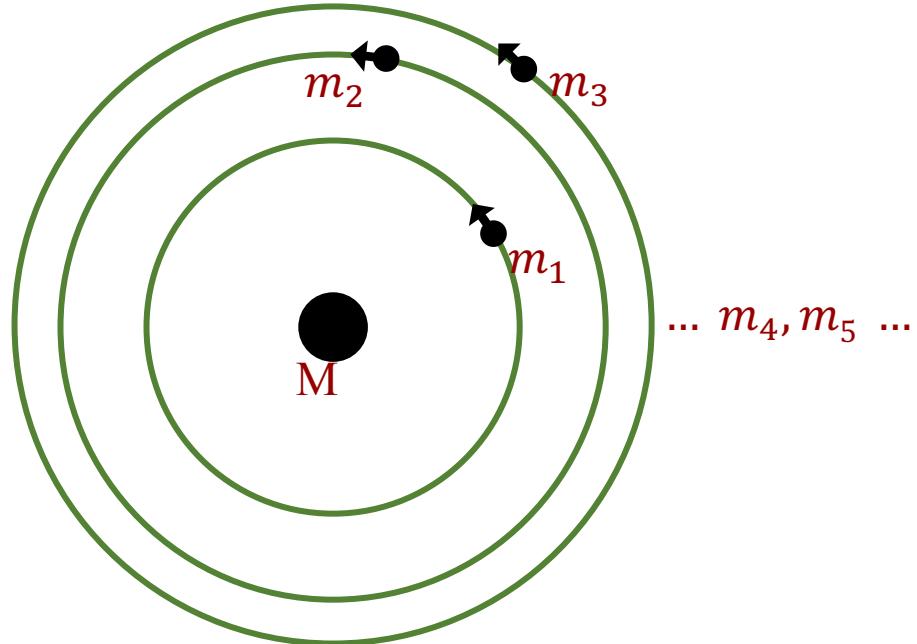
Dempsey et al. 2022



Li et al. 2022

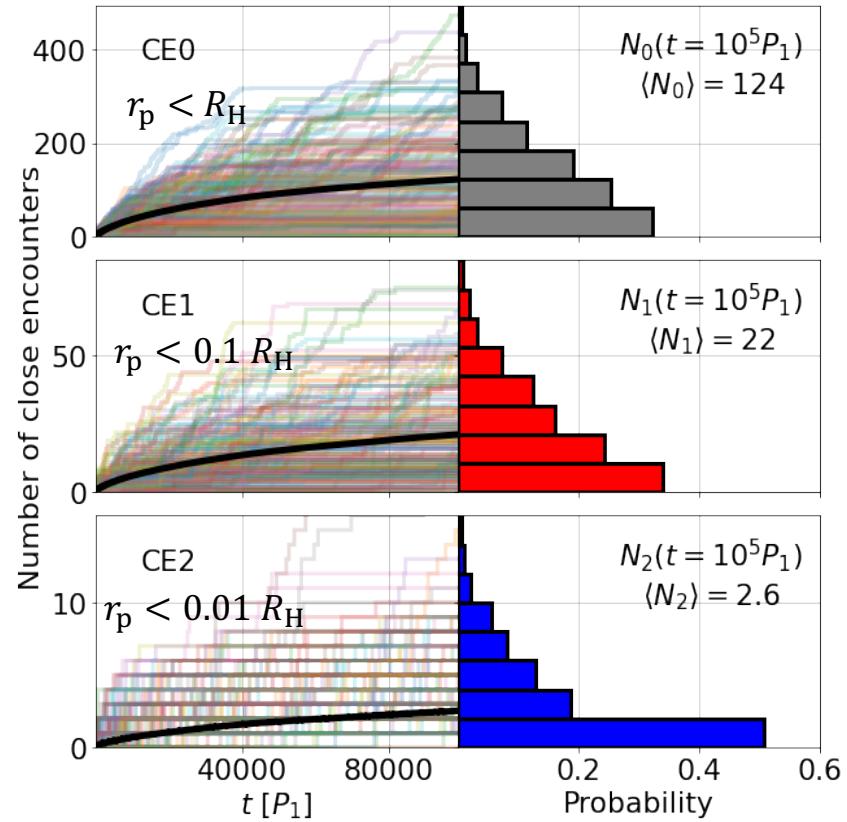
Q: How to form BH binaries in AGN disks?

- Close encounters between embedded single BHs.



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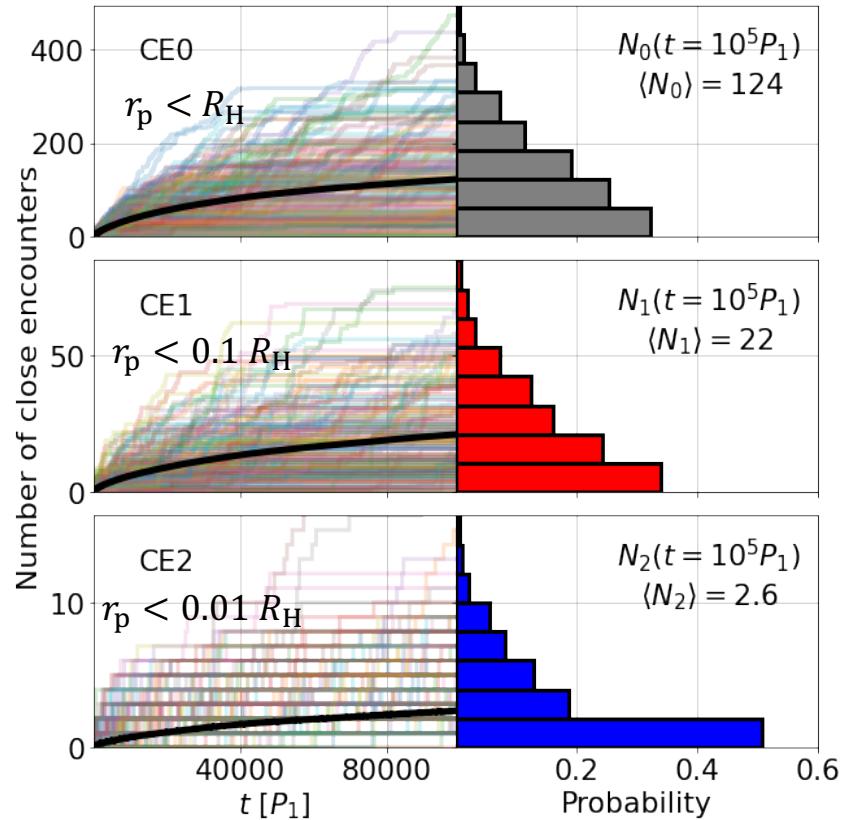
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- However...



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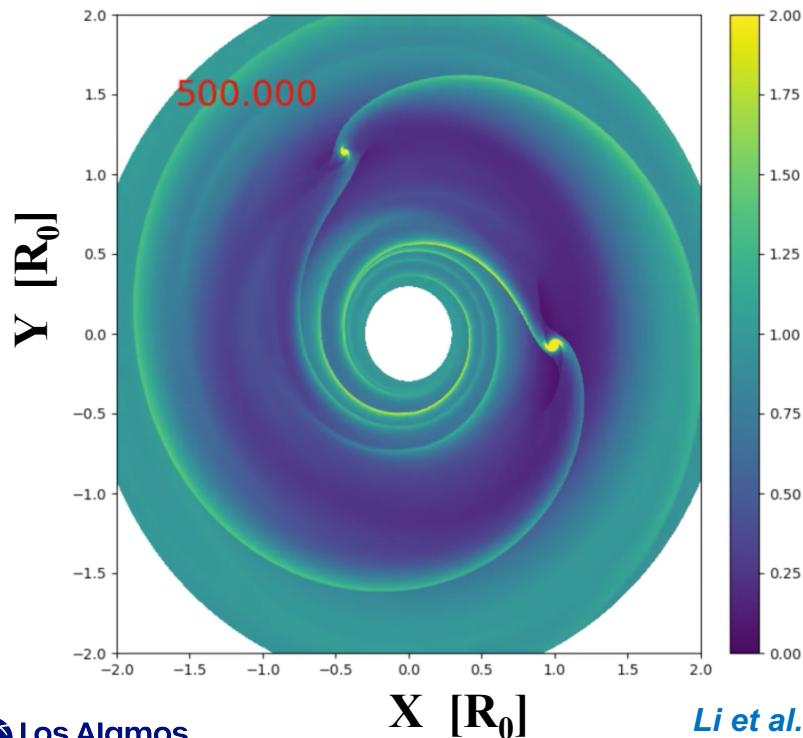
- Close encounters between embedded single BHs.
- However:
 - BHs are accelerated to \sim their relative escape velocity during close encounters, so **energy dissipation** is needed.
 - Gas **disks** may introduce this dissipation.



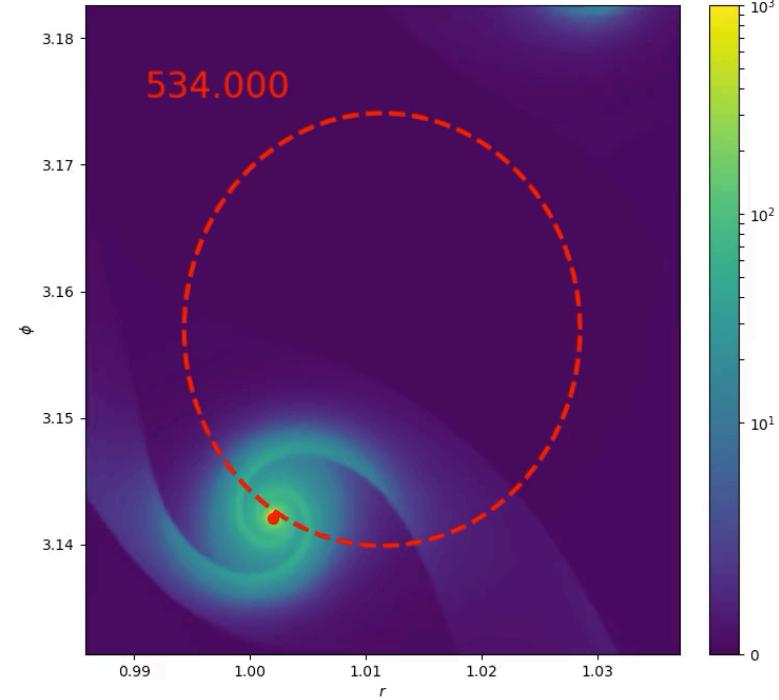
Li et al. 2022

Q: How to form BH binaries in AGN disks?

A: Close encounters with the assistance from gas!

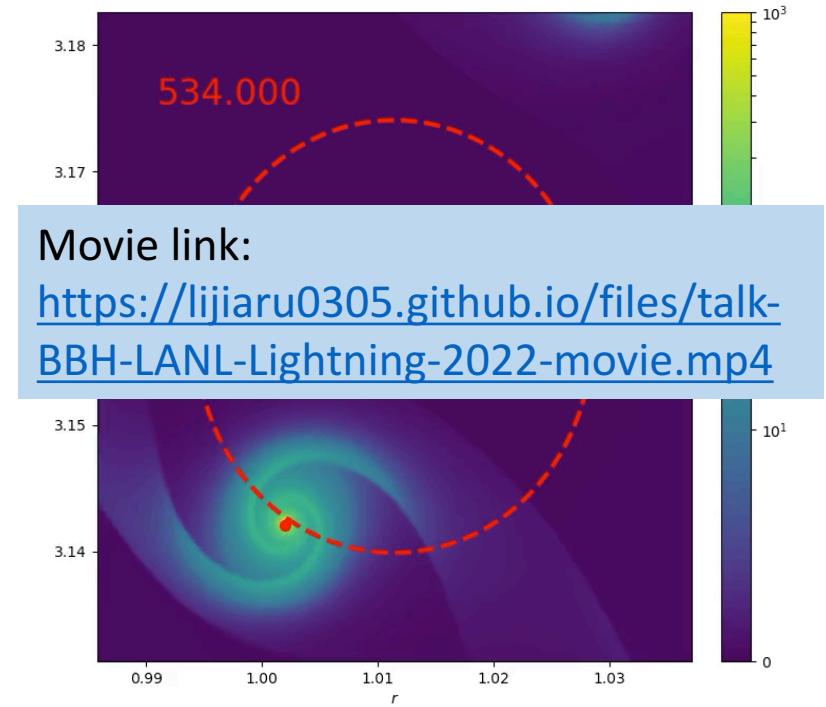
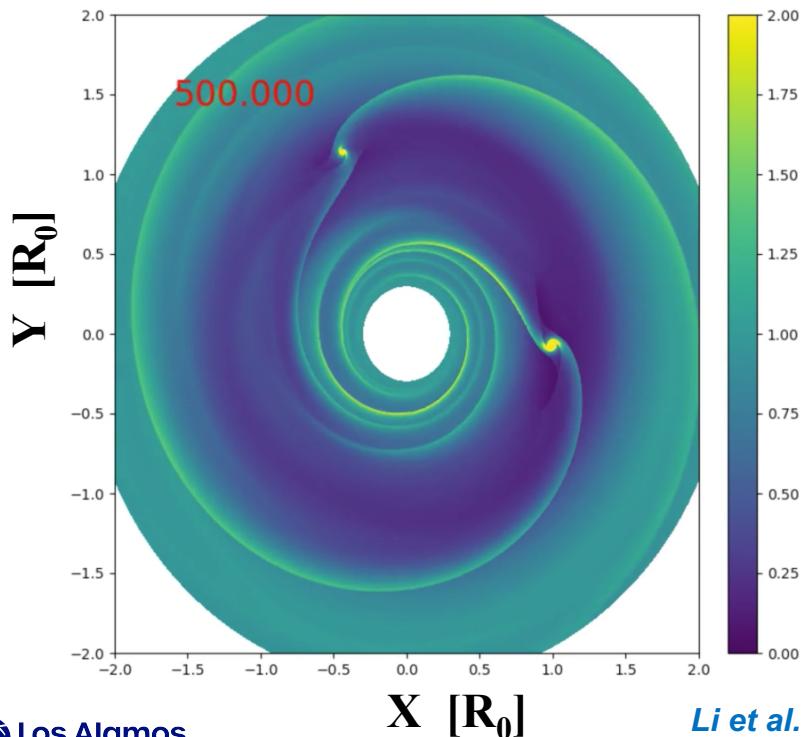


Li et al. in prep

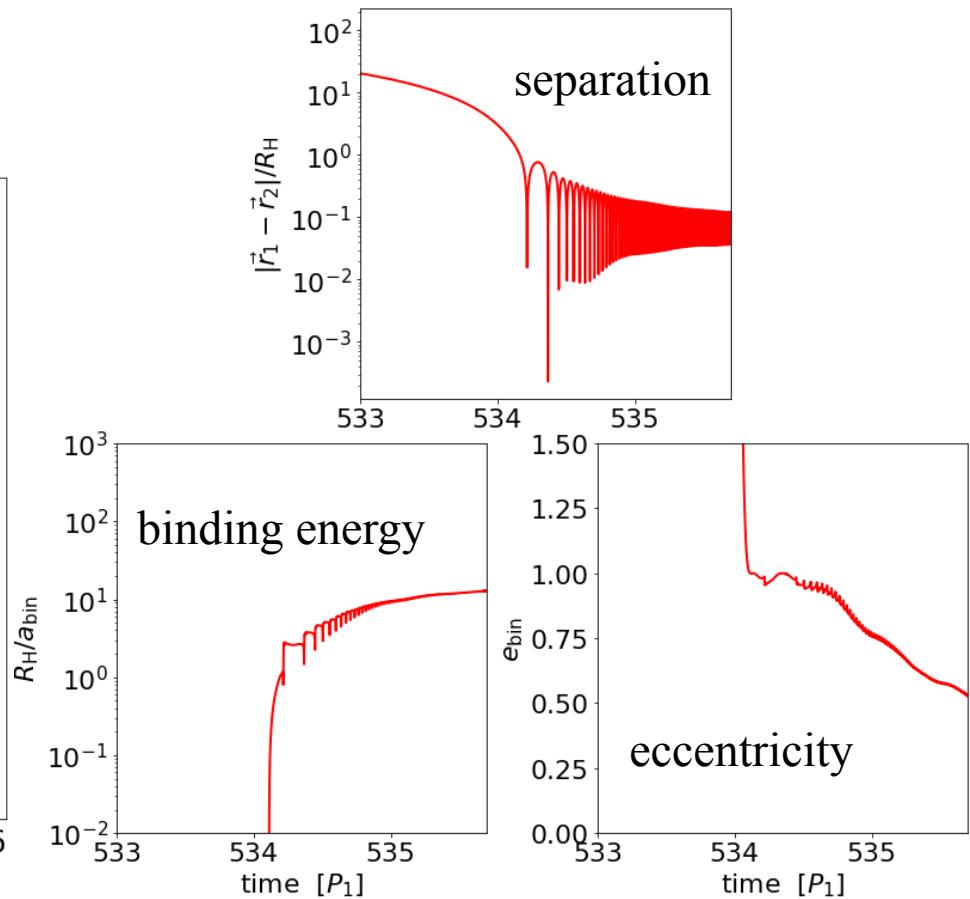
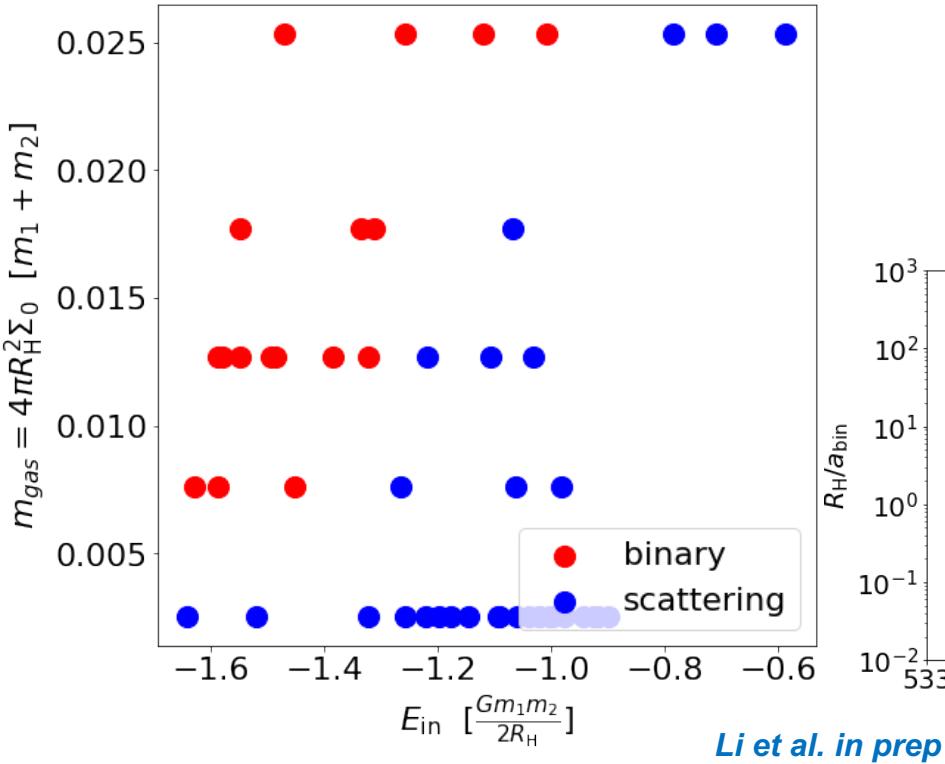


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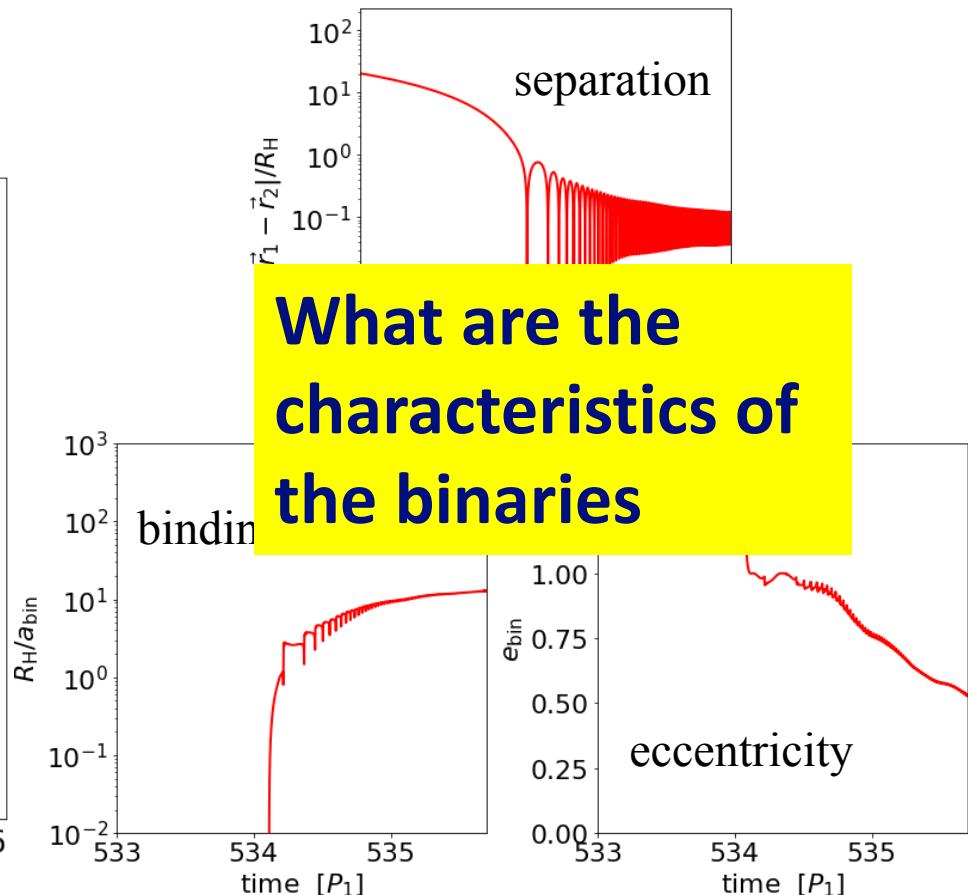
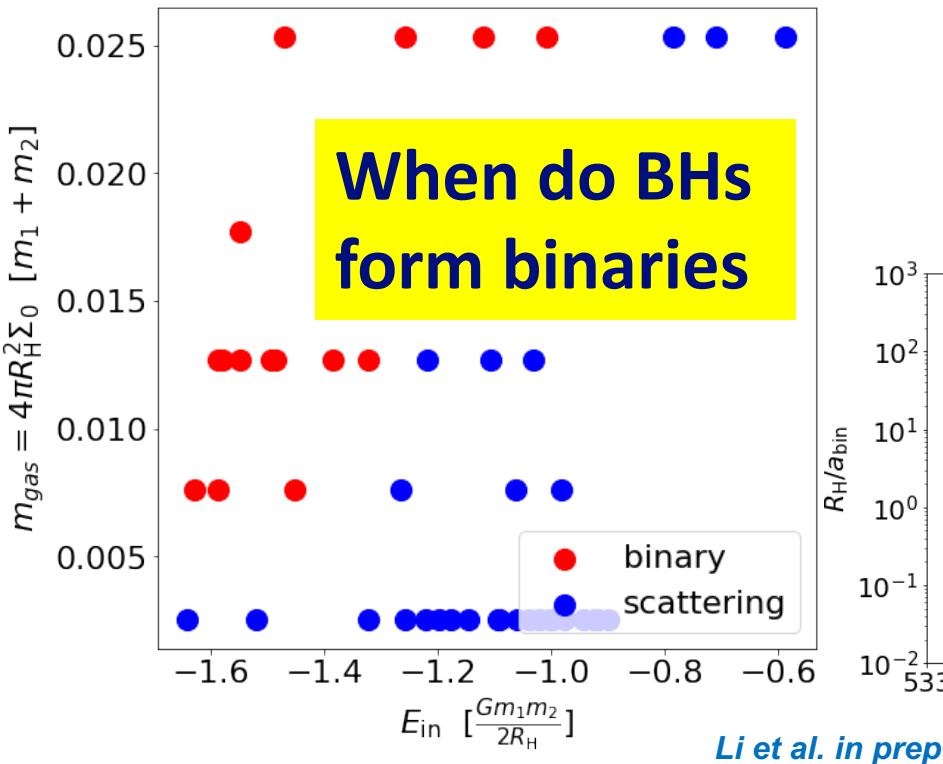
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What do we learn?



What do we learn?



Summary

- Mergers of BH binaries embedded in AGN disks are considered important sources of gravitational wave.
- The evolution of an embedded BH binary depends on the properties of the host AGN disk and relative orbit of the BHs.
- To form those binaries, gas effect is necessary.
- We use hydrodynamics simulations to model the formation process of those binaries, and calculate their relative orbits.

Reference

- Ya-Ping Li, Adam Dempsey, Hui Li, Shengtai Li, and Jiaru Li, “*Hot Circumsingle Disks Drive Binary Black Hole Mergers in Active Galactic Nucleus Disks*”, ApJ 928, L19, 2022.
- Jiaru Li, Dong Lai, and Laetitia Rodet, “*Long-term Evolution of Tightly-Packed Stellar Black Holes in AGN Disks: Formation of Merging Black-Hole Binaries via Close Encounters*”, ApJ accepted.
- Adam Dempsey, Hui Li, Bhupendra Mishra, and Shengtai Li, “*Contracting and Expanding Binary Black Holes in 3D Low-Mass AGN Disks: The Importance of Separation*”, submitted to AAS journals.