

# Merging Black Hole Binaries in AGN disks: Formations and Evolutions

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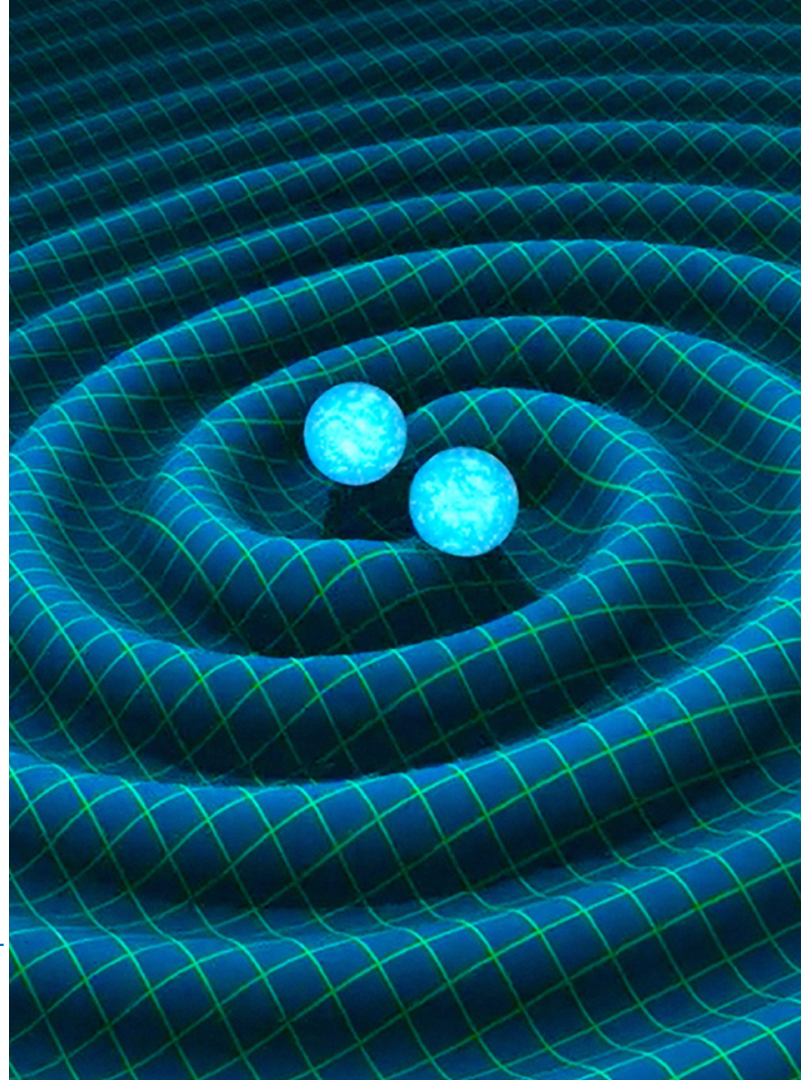
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# What are black hole (BH) binaries and why do we care about them?

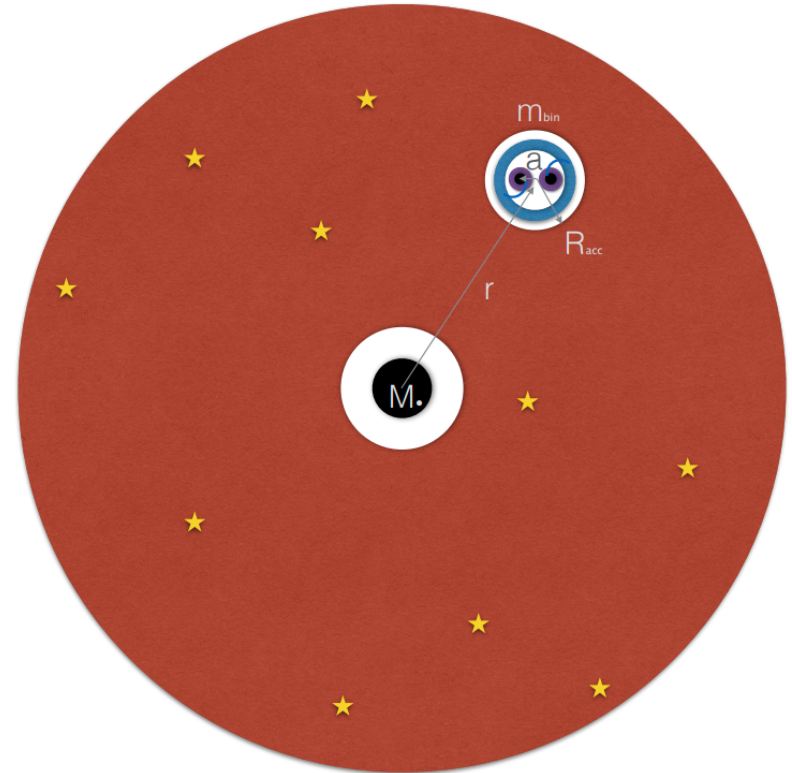
- Gravitational Wave (GW):
  - predicted by General Relativity
  - first detected by LIGO in 2016
  - one of the most accurate verifications of Einstein's Theory of Relativity
- BH binaries:
  - the **simplest** system that produces GW
  - LIGO (and others) detects their mergers

*Image Credits: R. Hurt/Caltech-JPL*



# Merging BH binaries in AGN disks

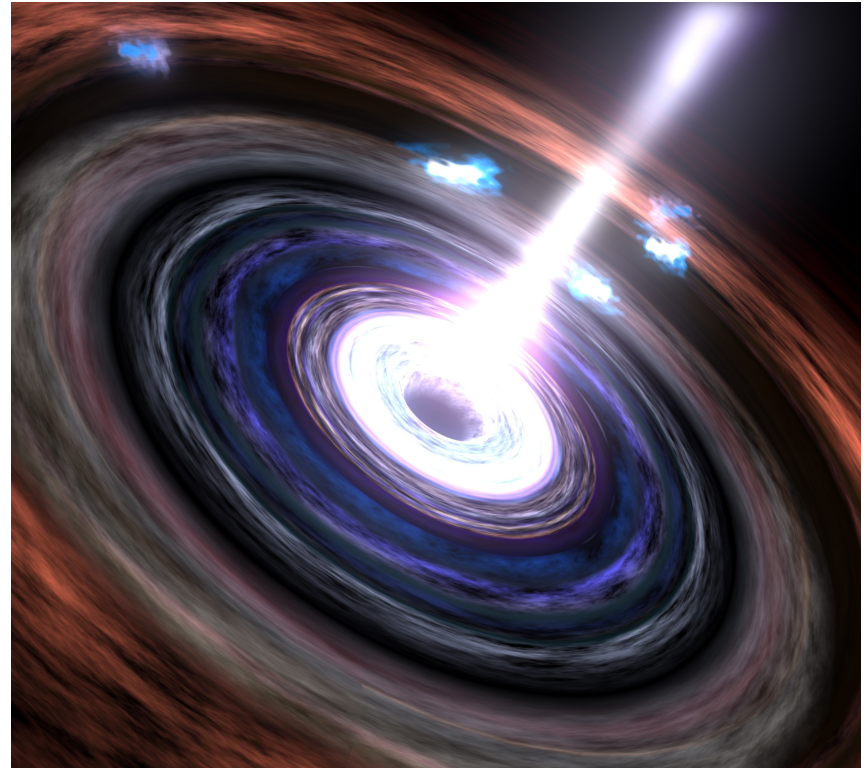
- A two-body system with only two point masses  
→ never contract or merge
- A binary embedded in a gaseous disk  
→ may contract or even merge



*Diagram Credits: Stone et al. 2017*

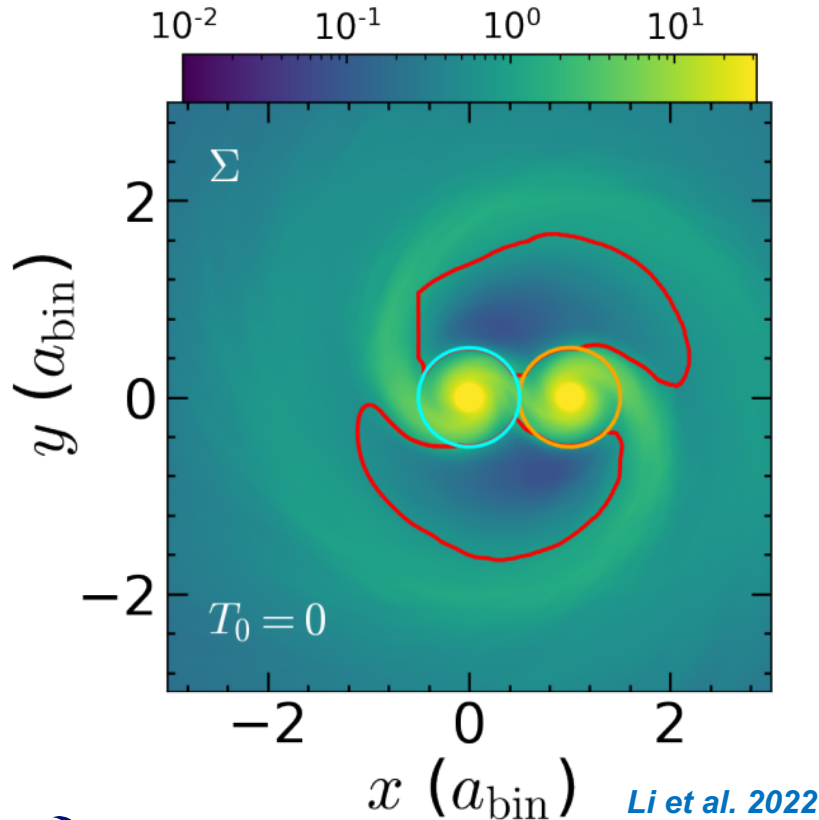
# Merging BH binaries in AGN disks

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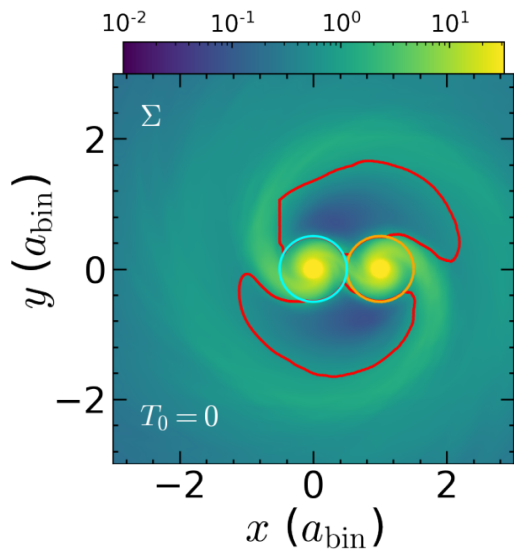
*Image Credits: NASA/GSFC Conceptual Image Lab*

# Evolutions of BH binaries in AGN disks:

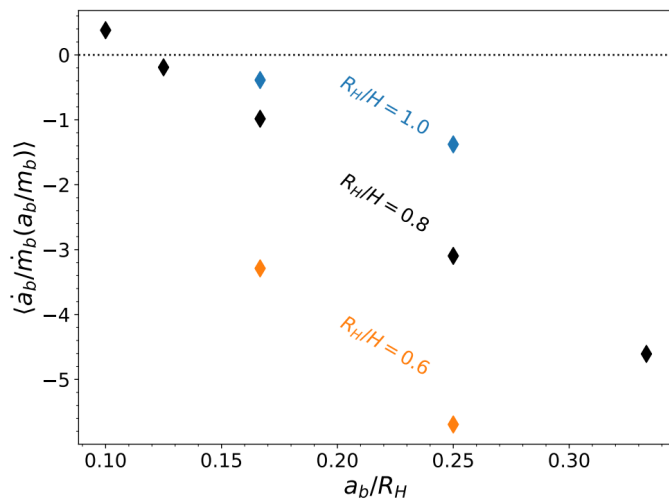


- We use hydrodynamics simulations to study the evolution of embedded binaries.
- The gas and binary interact via gravity.
- The gas distribution around the binary is highly non-linear.

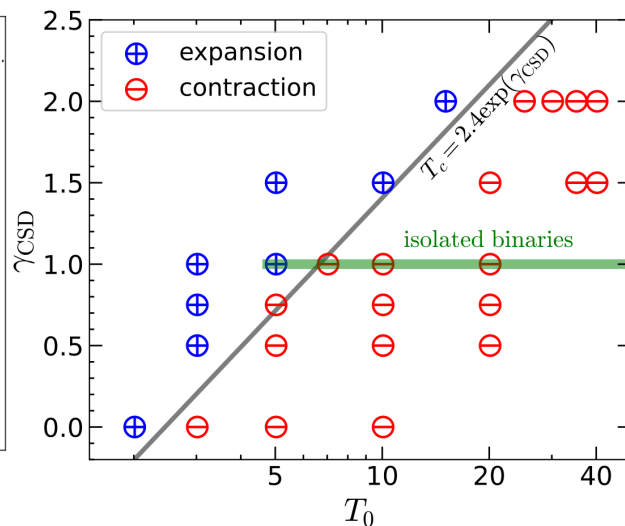
# Evolutions of BH binaries in AGN disks:



Li et al. 2022



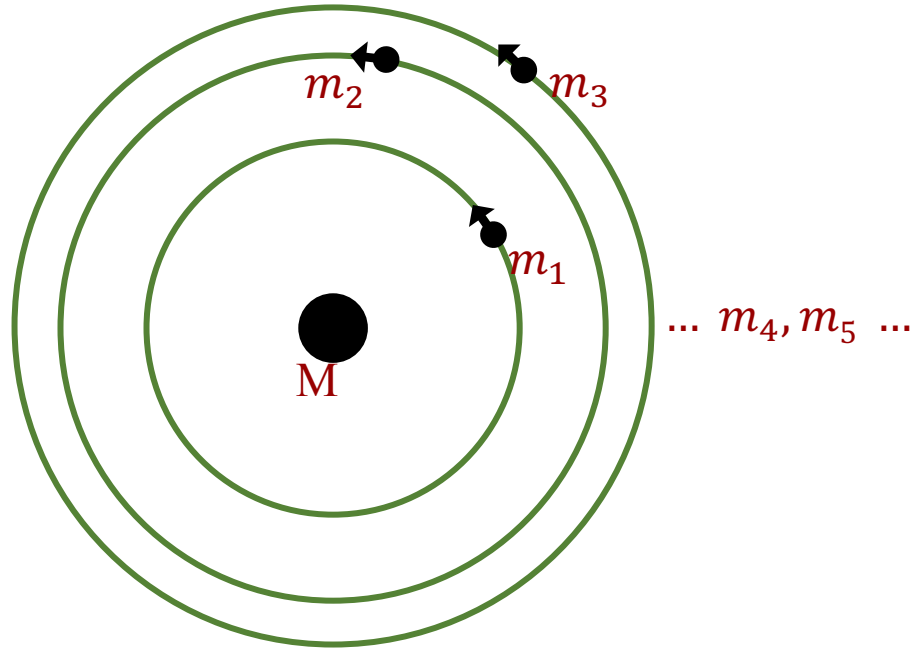
Dempsey et al. 2022



Li et al. 2022

# Q: How to form BH binaries in AGN disks?

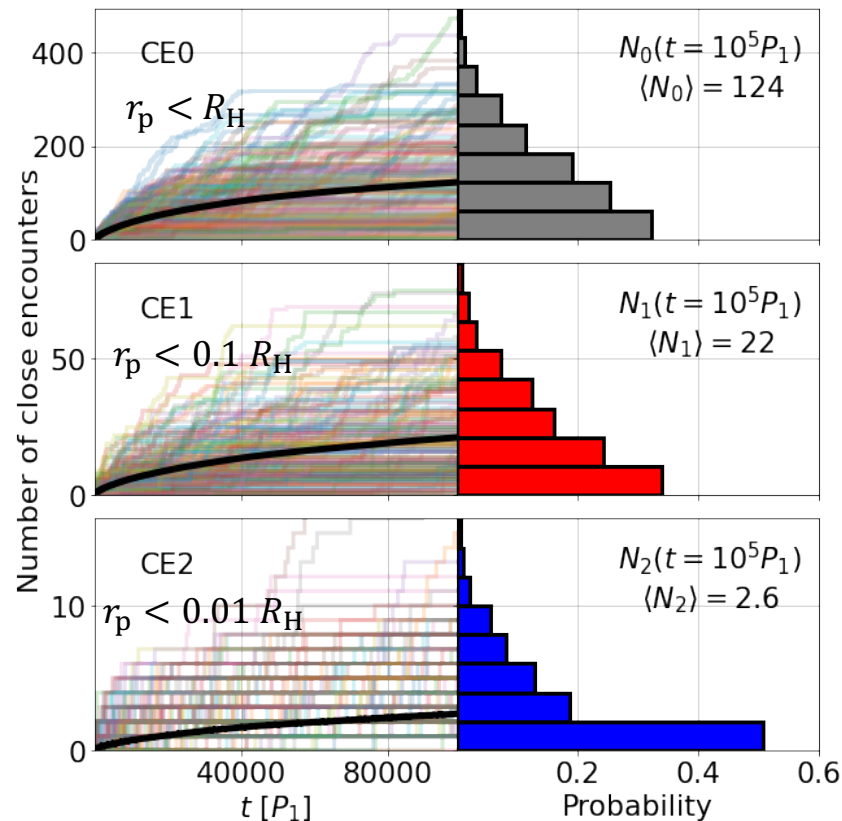
- Close encounters between embedded single BHs.





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- However...

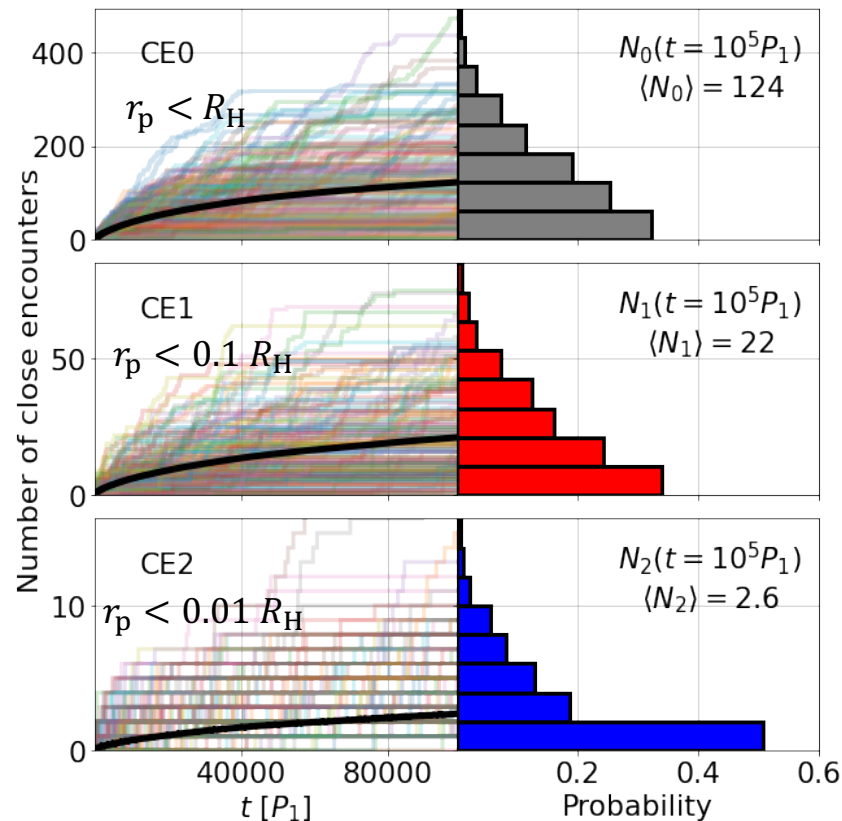


*Li et al. 2022*



## Q: How to form BH binaries in AGN disks?

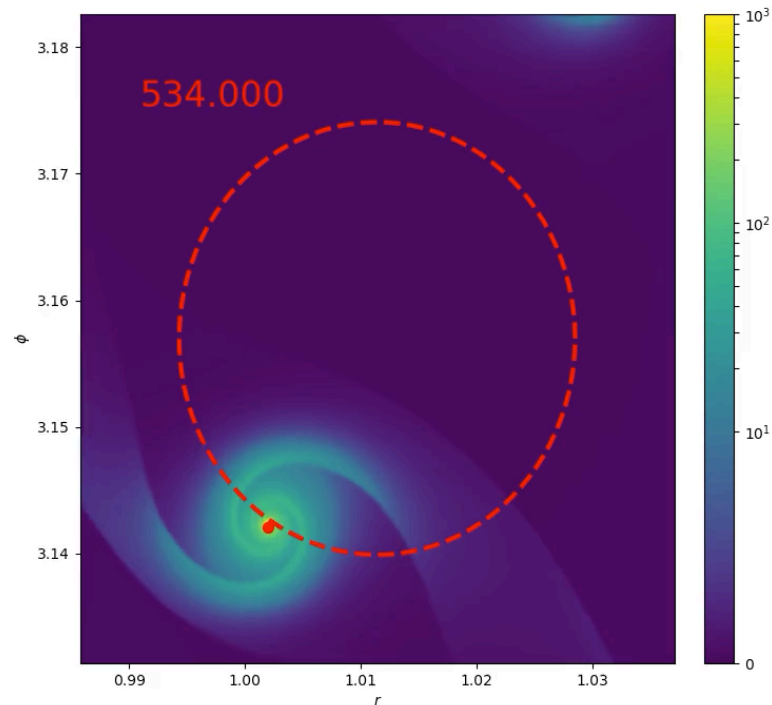
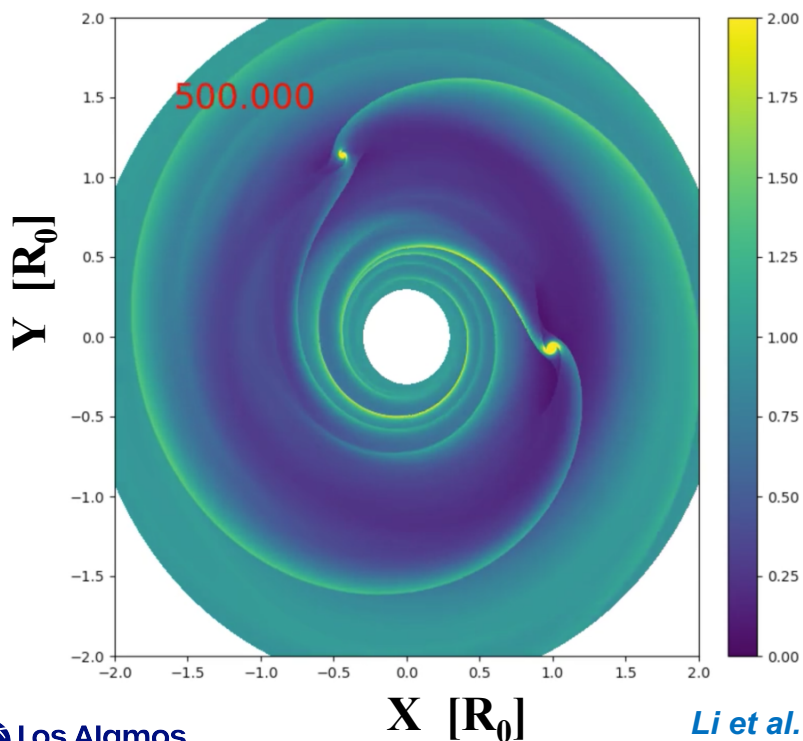
- Close encounters between embedded single BHs.
- However:
  - BHs are accelerated to  $\sim$  their relative escape velocity during close encounters, so **energy dissipation** is needed.
  - Gas **disks** may introduce this dissipation.



Li et al. 2022

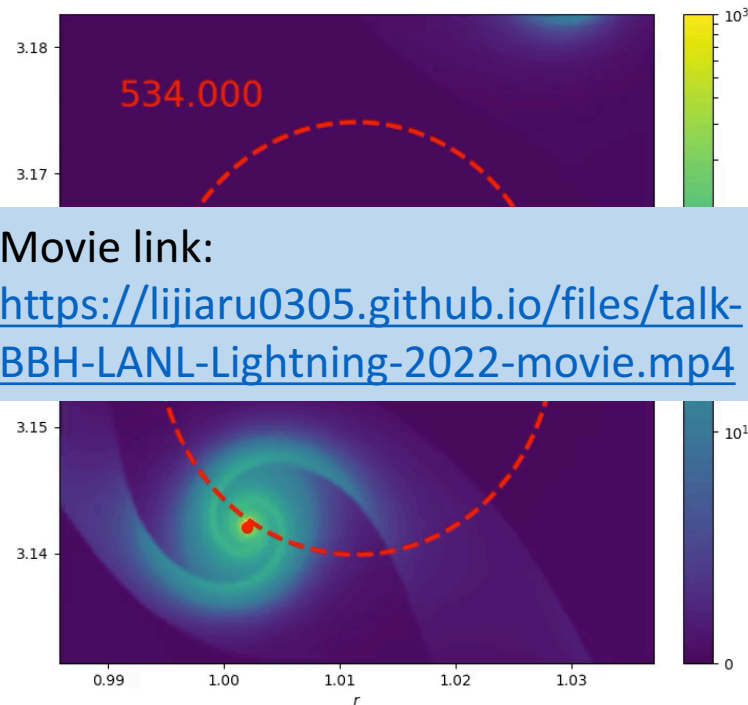
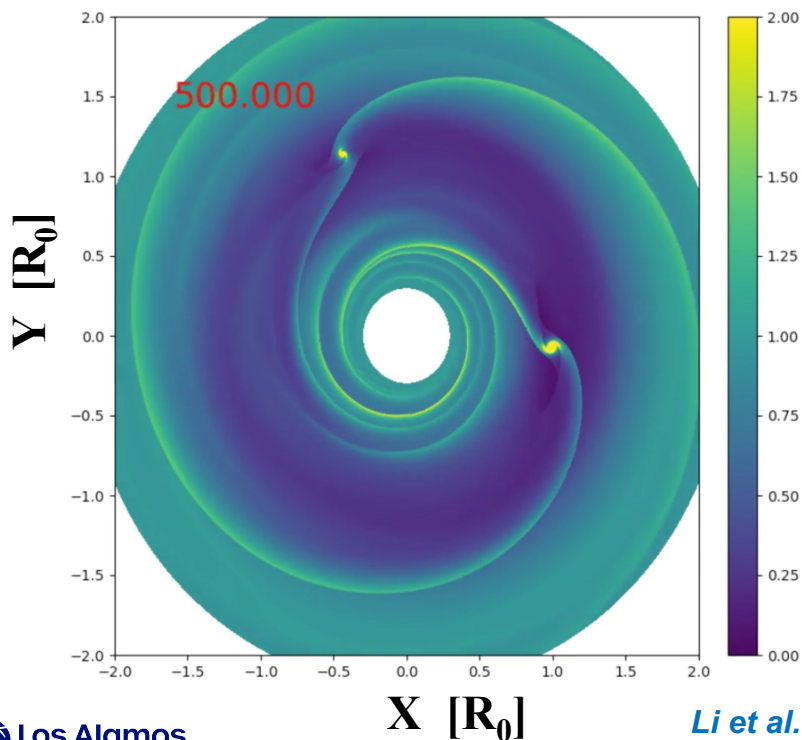
**Q: How to form BH binaries in AGN disks?**

**A: Close encounters with the assistance from gas!**

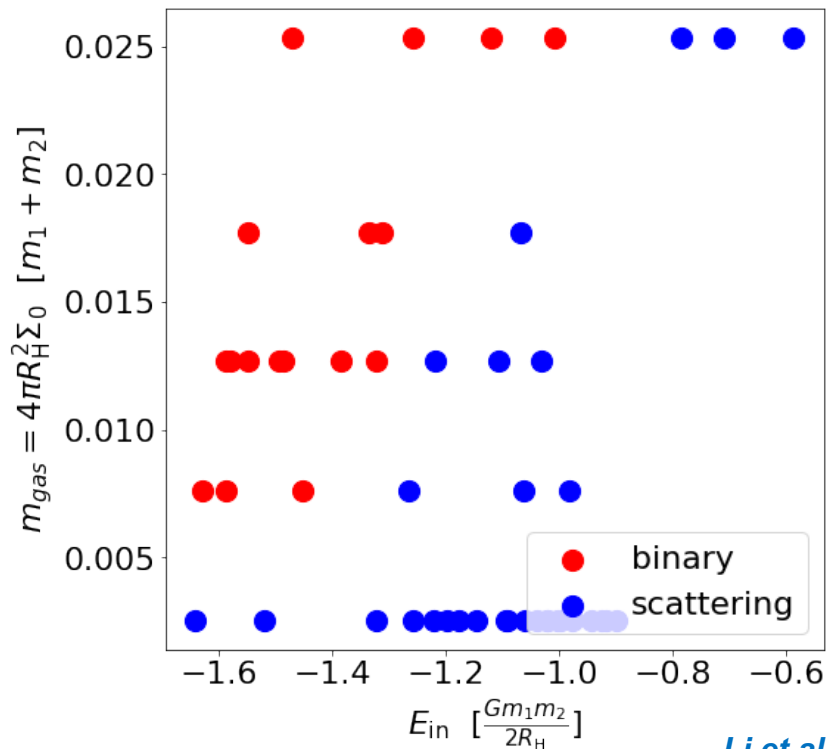


**Q: How to form BH binaries in AGN disks?**

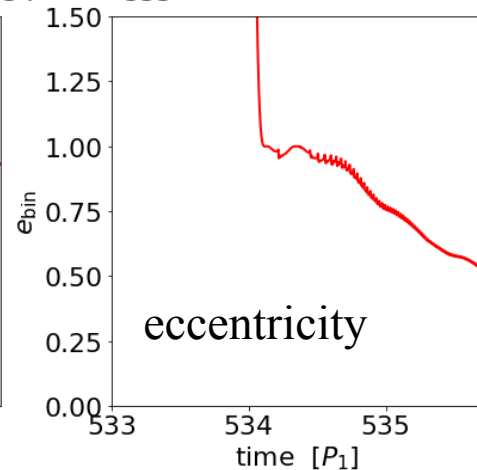
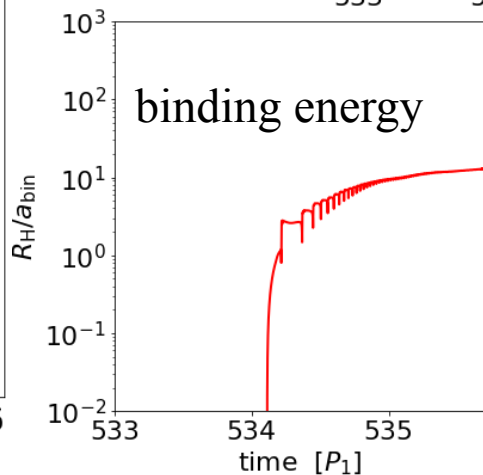
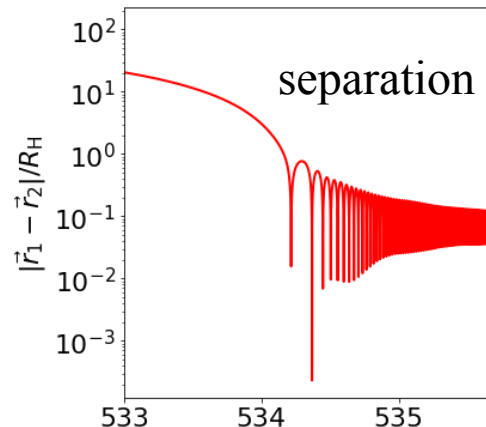
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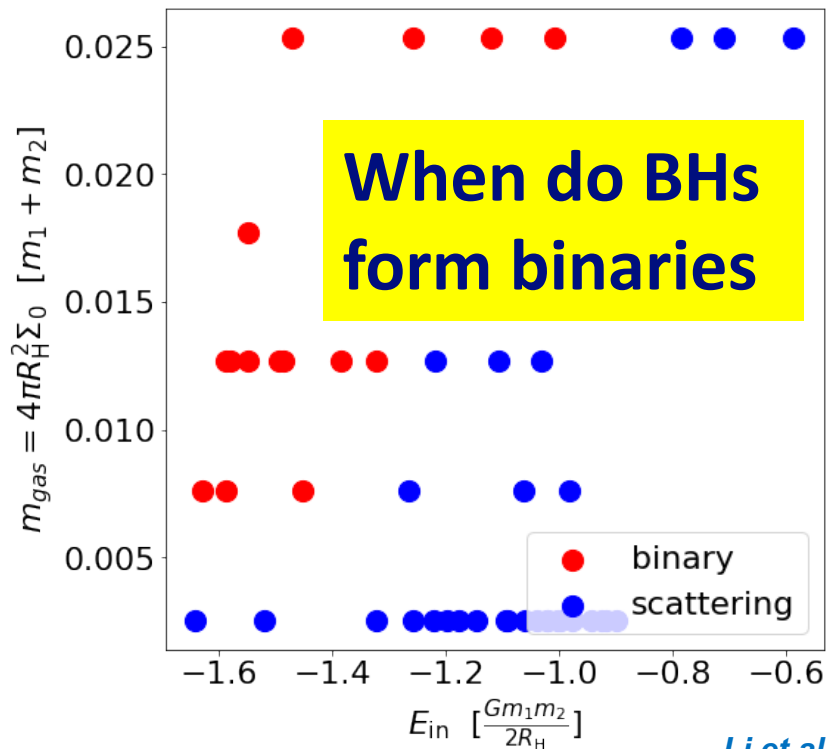
# What do we learn?



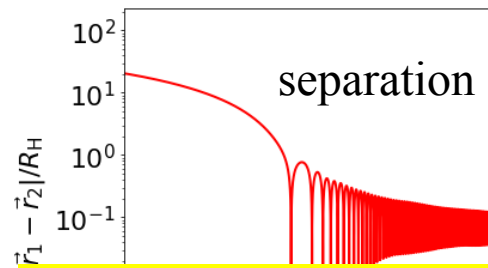
*Li et al. in prep*



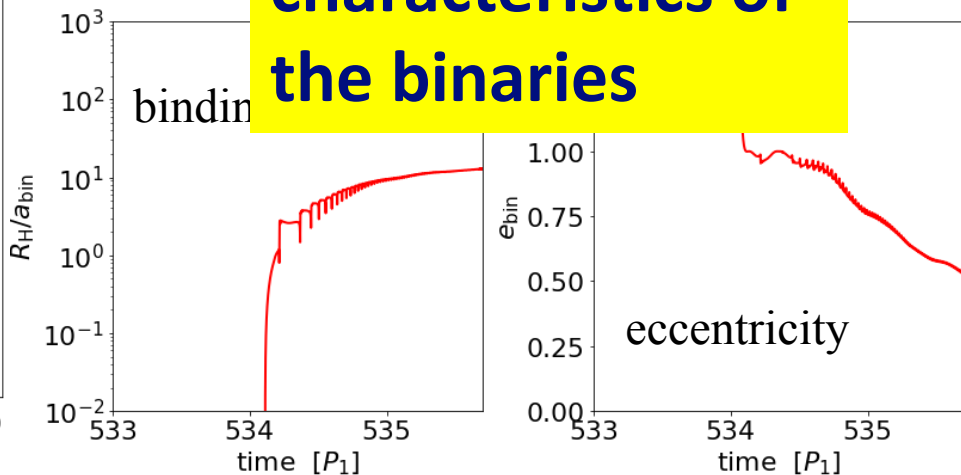
# What do we learn?



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**What are the characteristics of the binaries**



# 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.