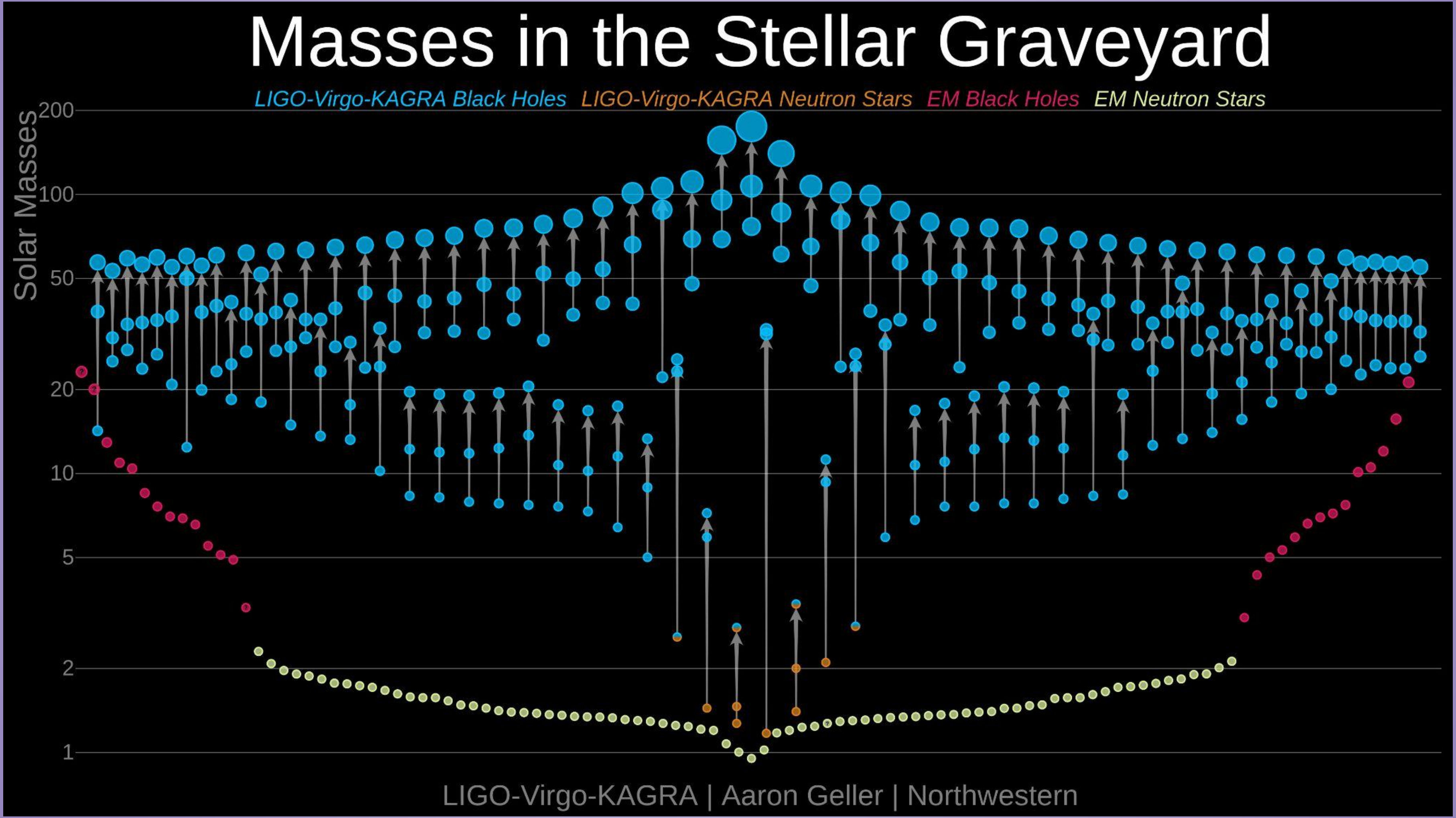
Eccentric Mergers in Disks of Active Galactic Nuclei

Gaia Fabj
Niels Bohr International Academy

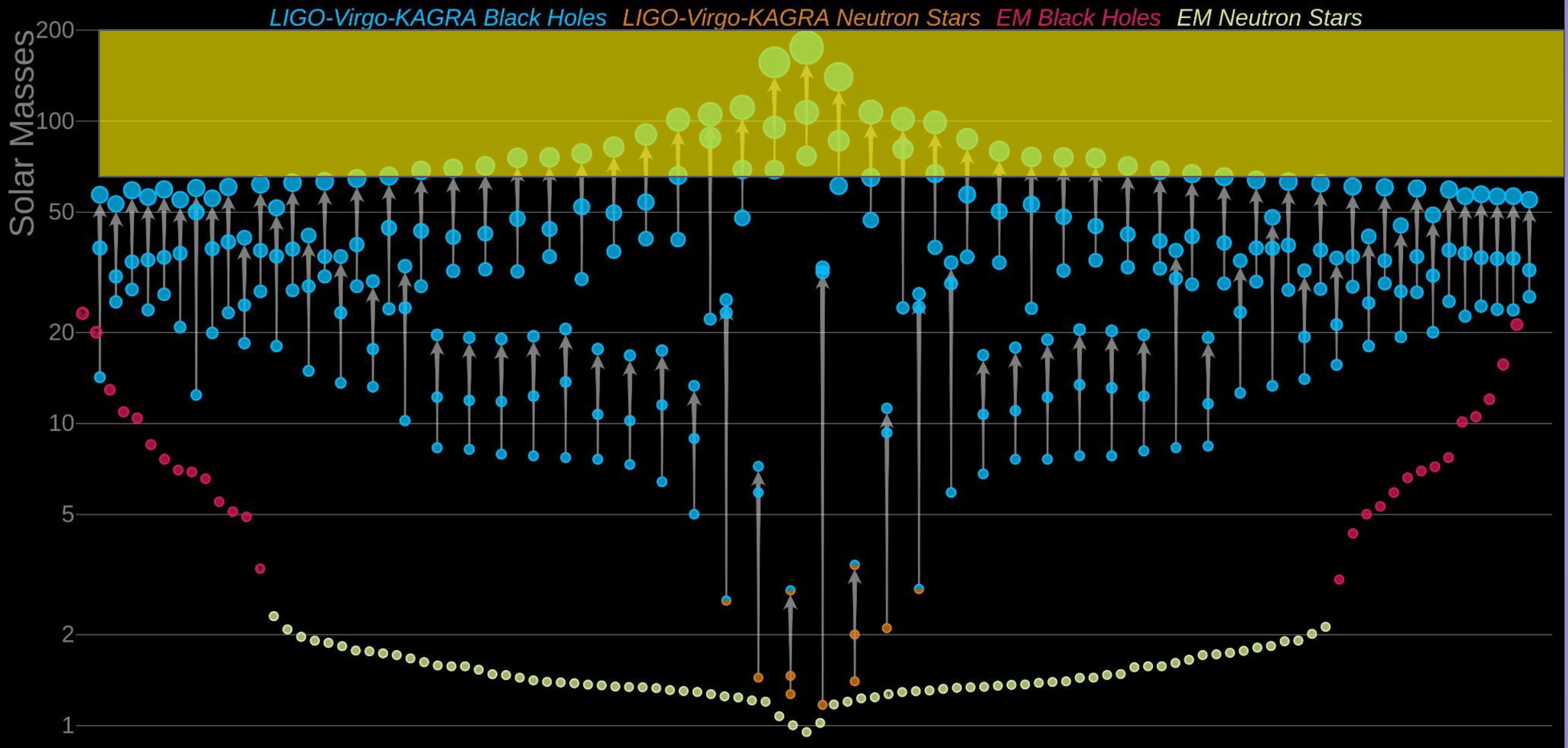
MODEST-24

23.08.2024

GW ASTRO NBIA


Masses in the Stellar Graveyard
LIGO-Virgo-KAGRA Black Holes
LIGO-Virgo-KAGRA Neutron Stars
EM Black Holes
EM Neutron Stars
Solar Masses
200
100
50
20
10
5
2
1
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

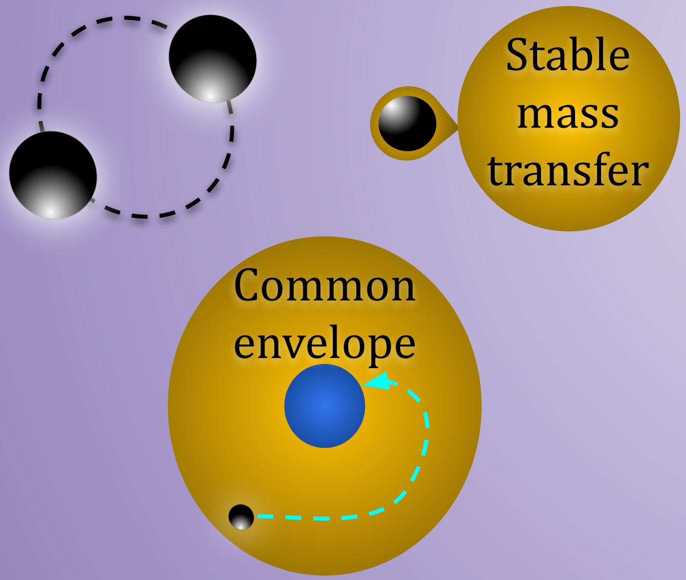
Masses in the Stellar Graveyard



LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

Proposed GW Formation Channels

Isolated



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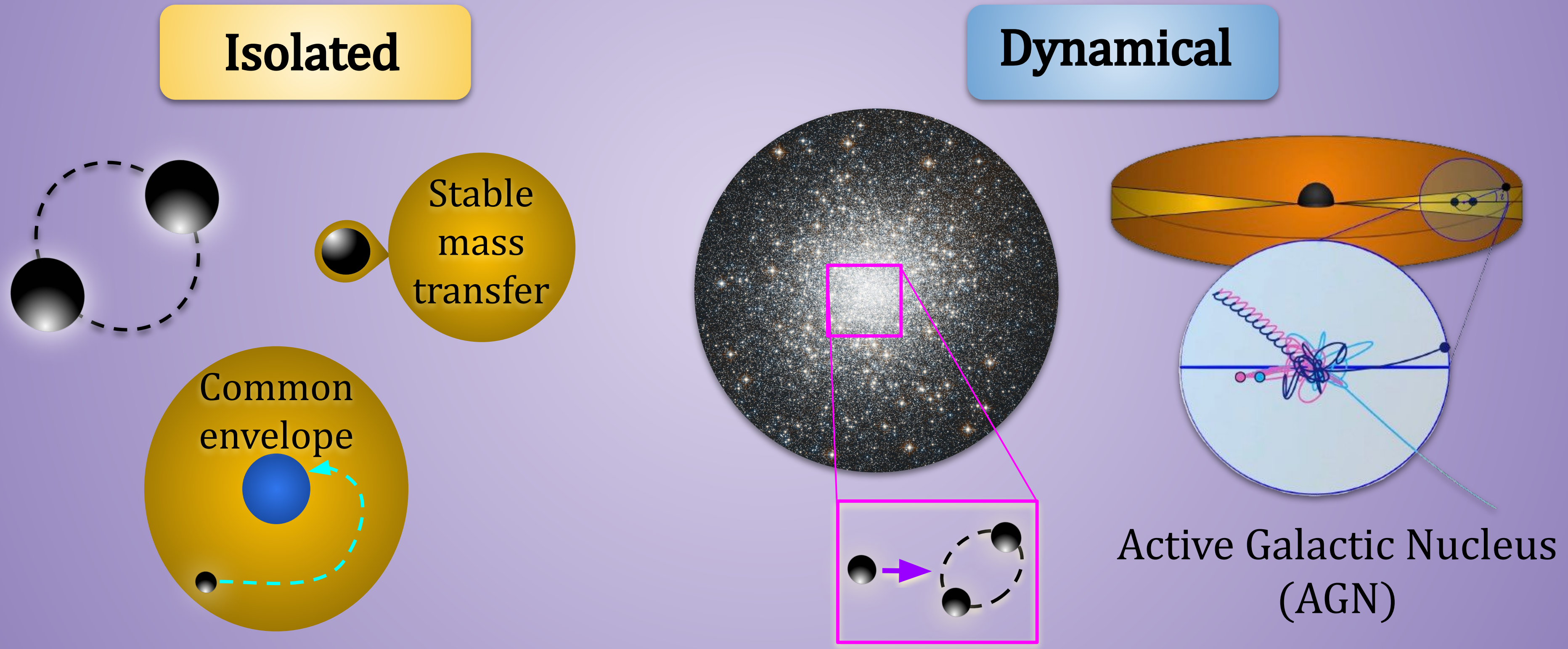
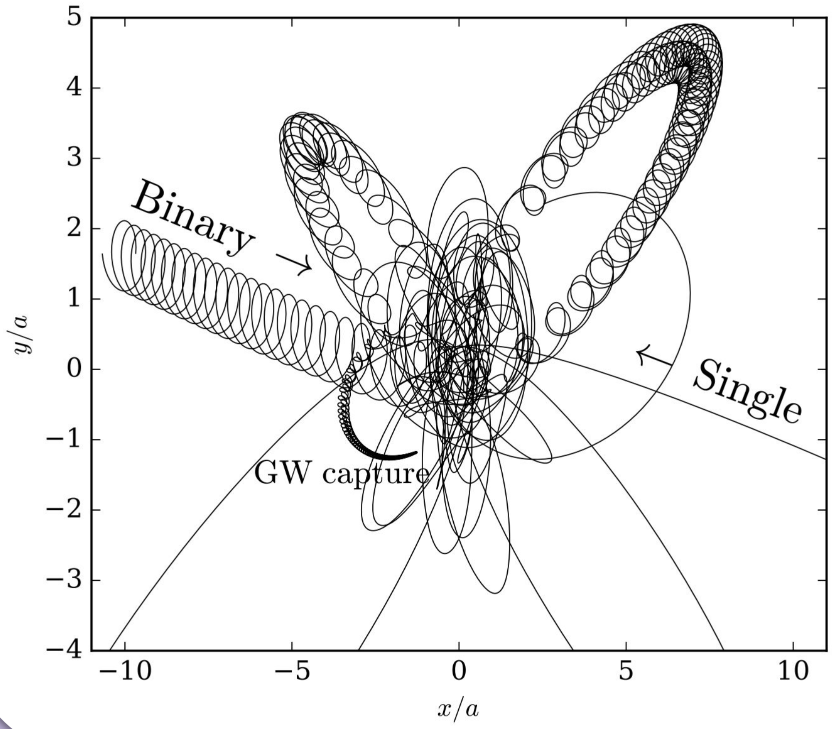


Three-body Scatterings & Eccentric Mergers

- **BH Binary + single** interactions → eccentric mergers
- Entering LIGO/Virgo/Kagra (LVK) band at **high eccentricity** ($e > 0.1$)
- GW capture of original or newly-formed binary (**three-body merger**)



Samsing et al. (2018)

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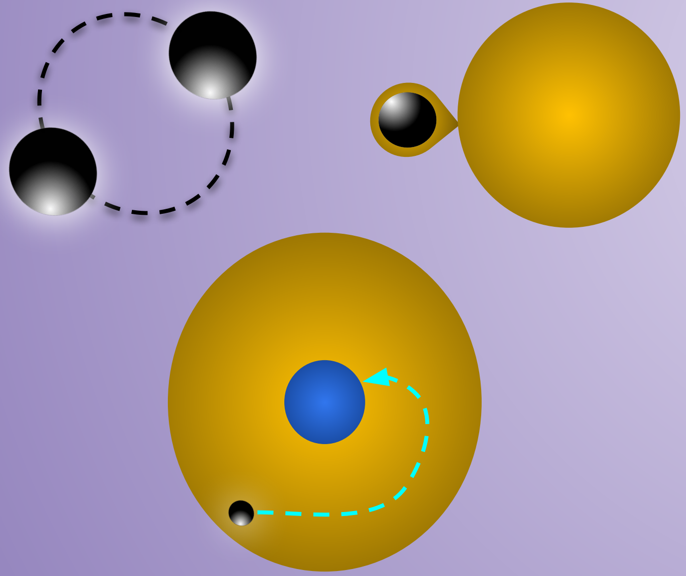
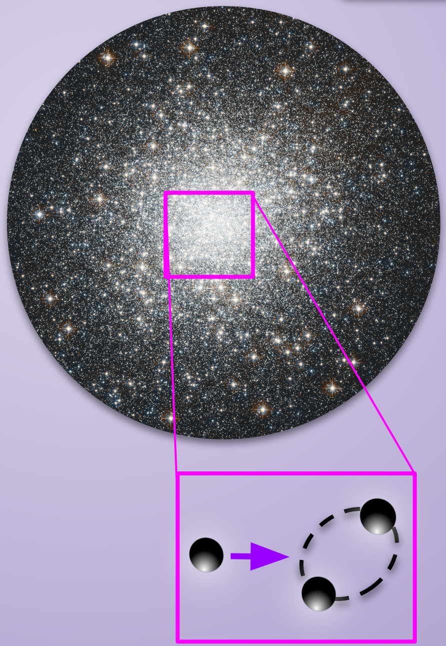
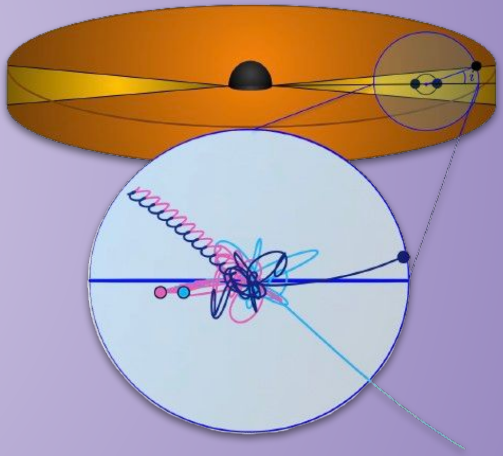


Dynamical





Active Galactic Nucleus
(AGN)

Proposed GW Formation Channels

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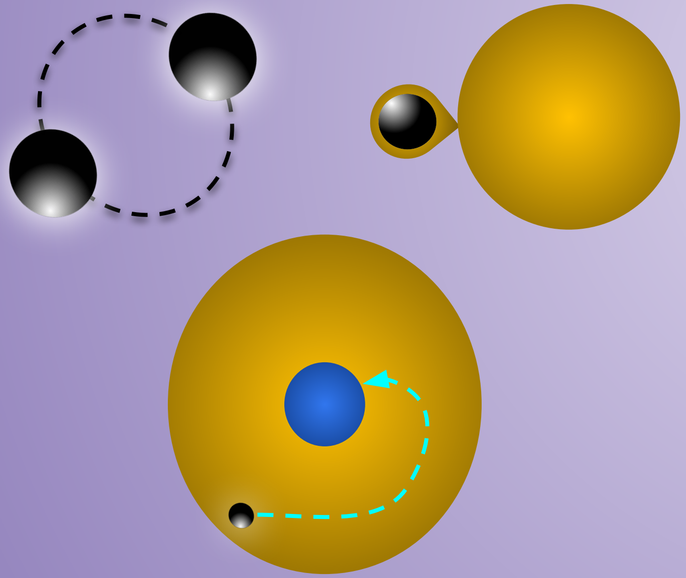

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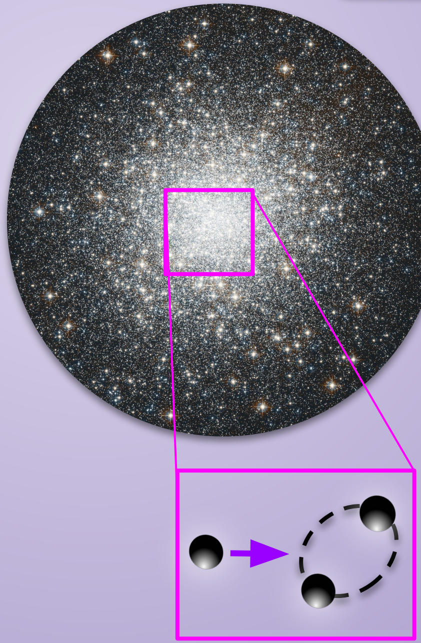

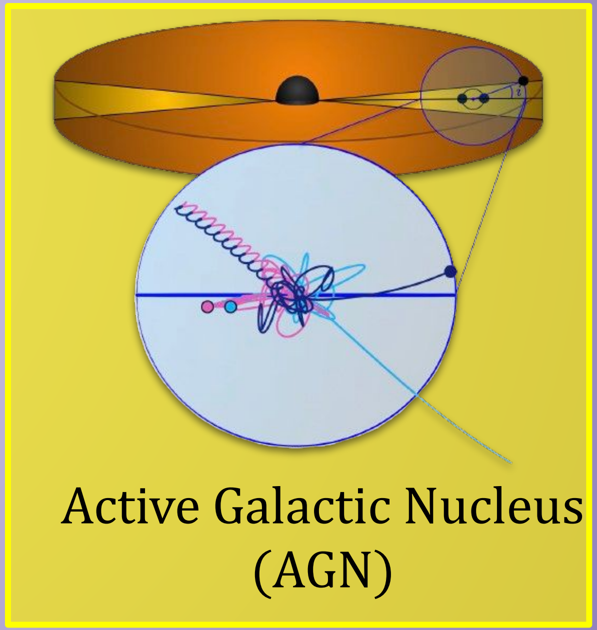

GW190521

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GW190521

Article Talk

From Wikipedia, the free encyclopedia

GW190521 (initially **S190521g**)[5] was a gravitational wave signal resulting from the merger of two black holes. It was possibly associated with a coincident flash of light; if this association is correct, the merger would have occurred near a third supermassive black hole.[2][6] The event was observed by the LIGO and Virgo detectors on 21 May 2019 at 03:02:29 UTC,[7] and published on 2 September 2020.[4][5][8] The event had a Luminosity distance of 17 billion light years away from Earth,[note 1][5][9] within a 765 deg^2 area[note 2][10] towards Coma Berenices, Canes Venatici, or Phoenix.[1][2][6][11]

At 85 and 66 solar masses ($M_\odot$) respectively, the two black holes comprising this merger are the largest progenitor masses observed to date.[12] The resulting black hole had a mass equivalent to 142 times that of the Sun, making this the first clear detection of an intermediate-mass black hole. The remaining 9 solar masses were radiated away as energy in the form of gravitational waves.[4][5][8]

Physical significance [edit]

GW190521 is a significant discovery due to the masses of the resulting large black hole and of one or

GW190521

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High masses (in mass gap)

The LIGO & Virgo Collab+20

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The LIGO & Virgo Collab+20

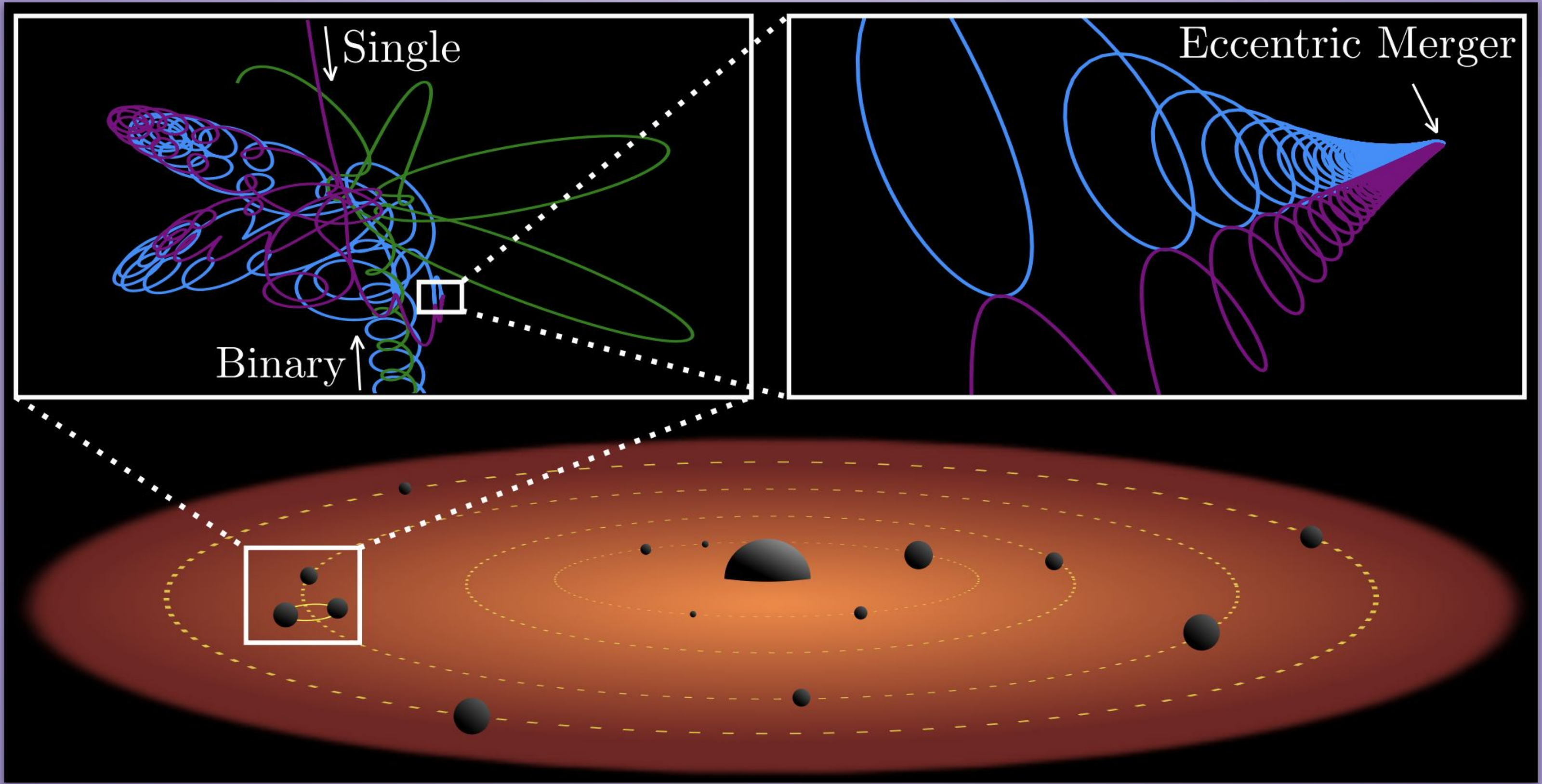
Possible eccentricity

Romero-Shaw+20, Gayathri+22

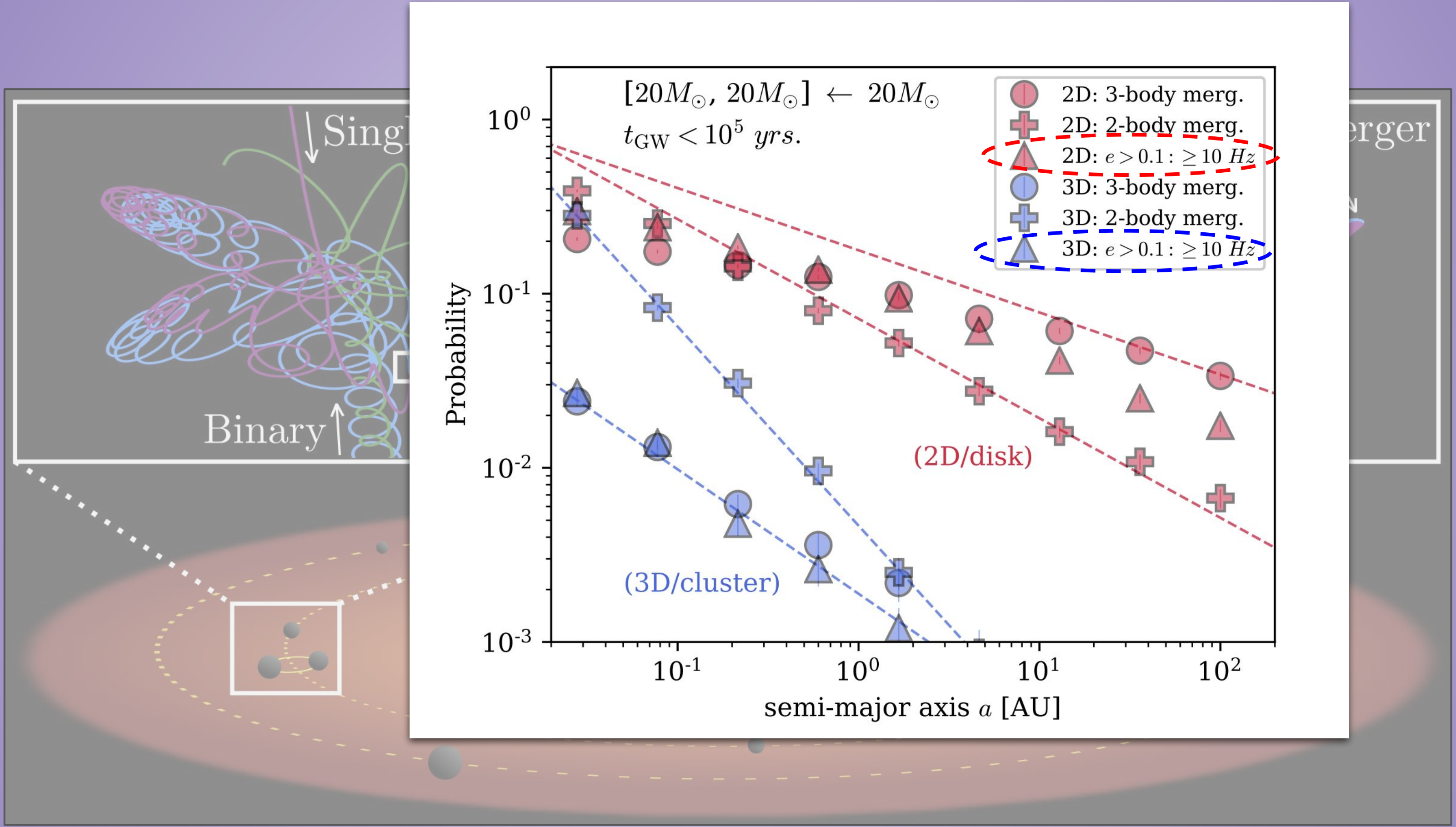
Possible EM counterpart

Graham+20

AGN channel can explain it!



Samsing J., et al., 2022, Nature, 603, 237



$[20M_\odot, 20M_\odot] \leftarrow 20M_\odot$
$t_{\rm GW} < 10^5$ $yrs.$
2D: 3-body merg.
2D: 2-body merg.
2D: $e > 0.1 : \geq 10$ Hz
3D: 3-body merg.
3D: 2-body merg.
3D: $e > 0.1 : \geq 10$ Hz
Probability
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-1}
10^0
10^1
10^2
semi-major axis a [AU]
(2D/disk)
(3D/cluster)
Singl
Binary
erger

How do we get a population of BHs embedded in the disk?

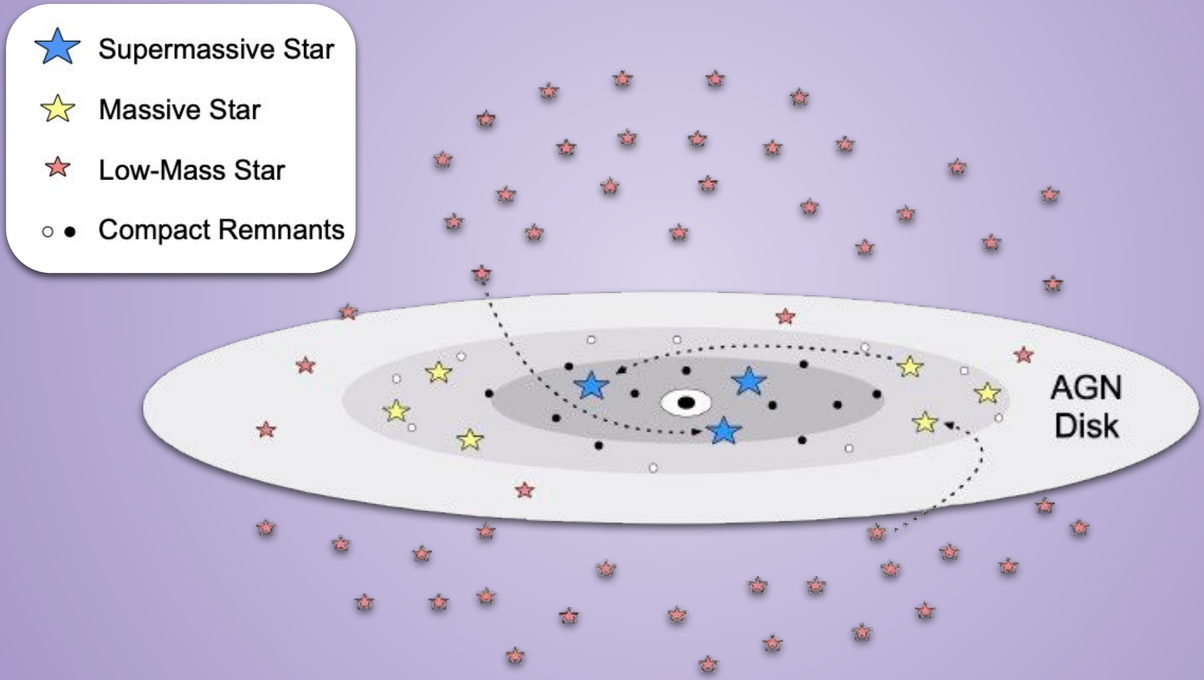
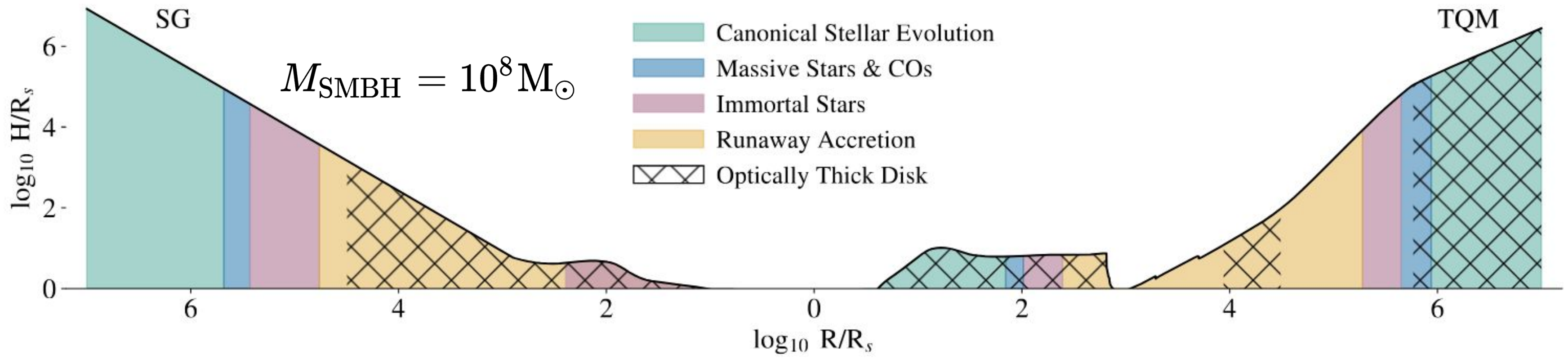


Fig. from Cantiello et al. (2021)

What kind of stars can we find in an AGN disk?



Fabj G. , Dittmann A.J., Cantiello M., Perna R., Samsing J. (in prep.)

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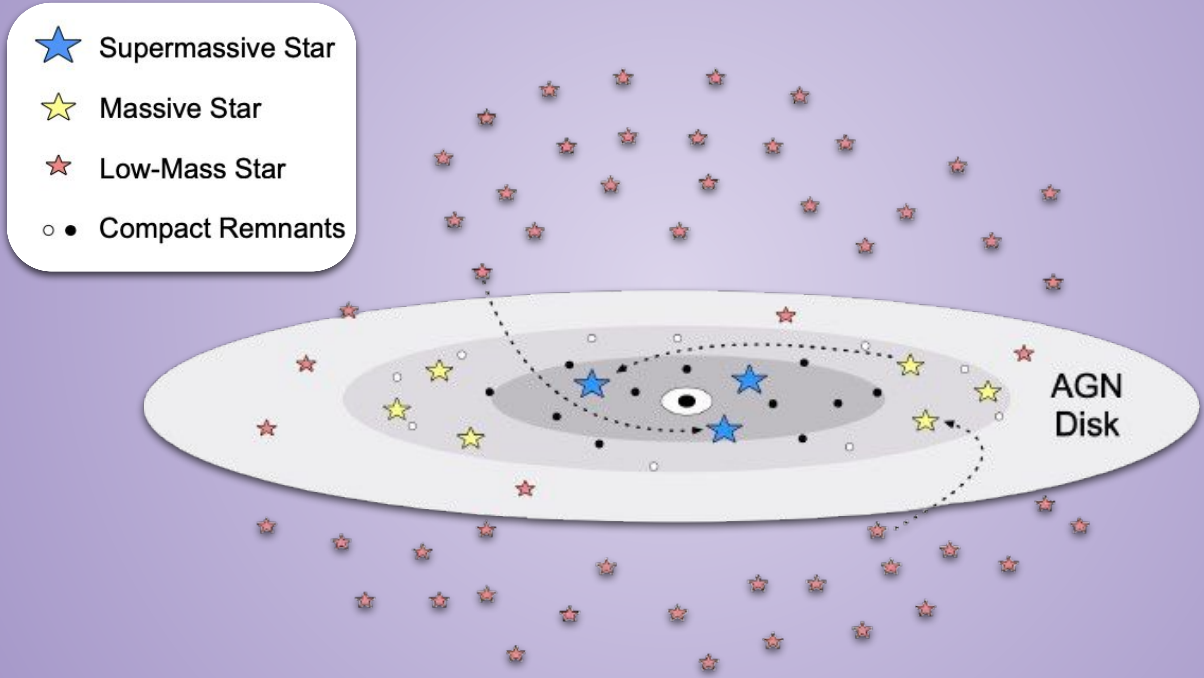

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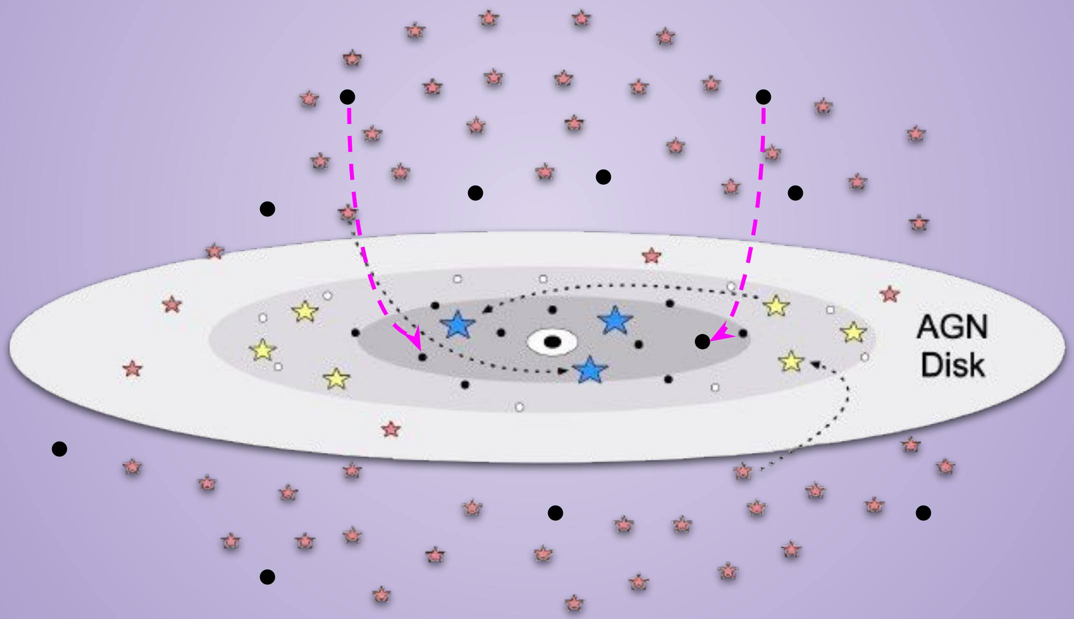

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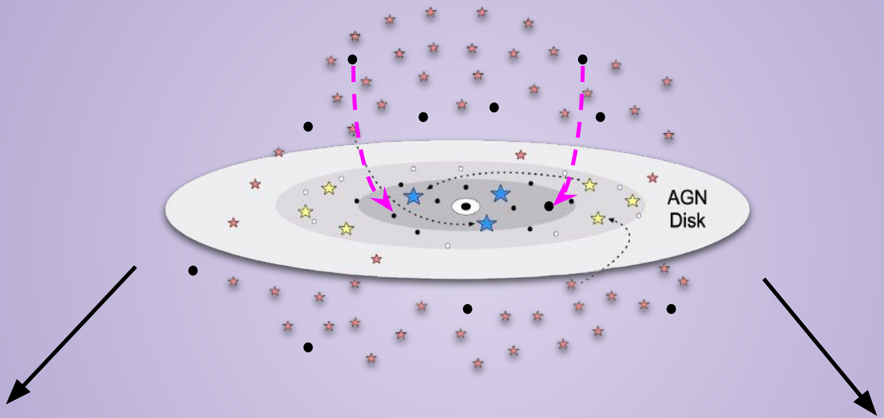
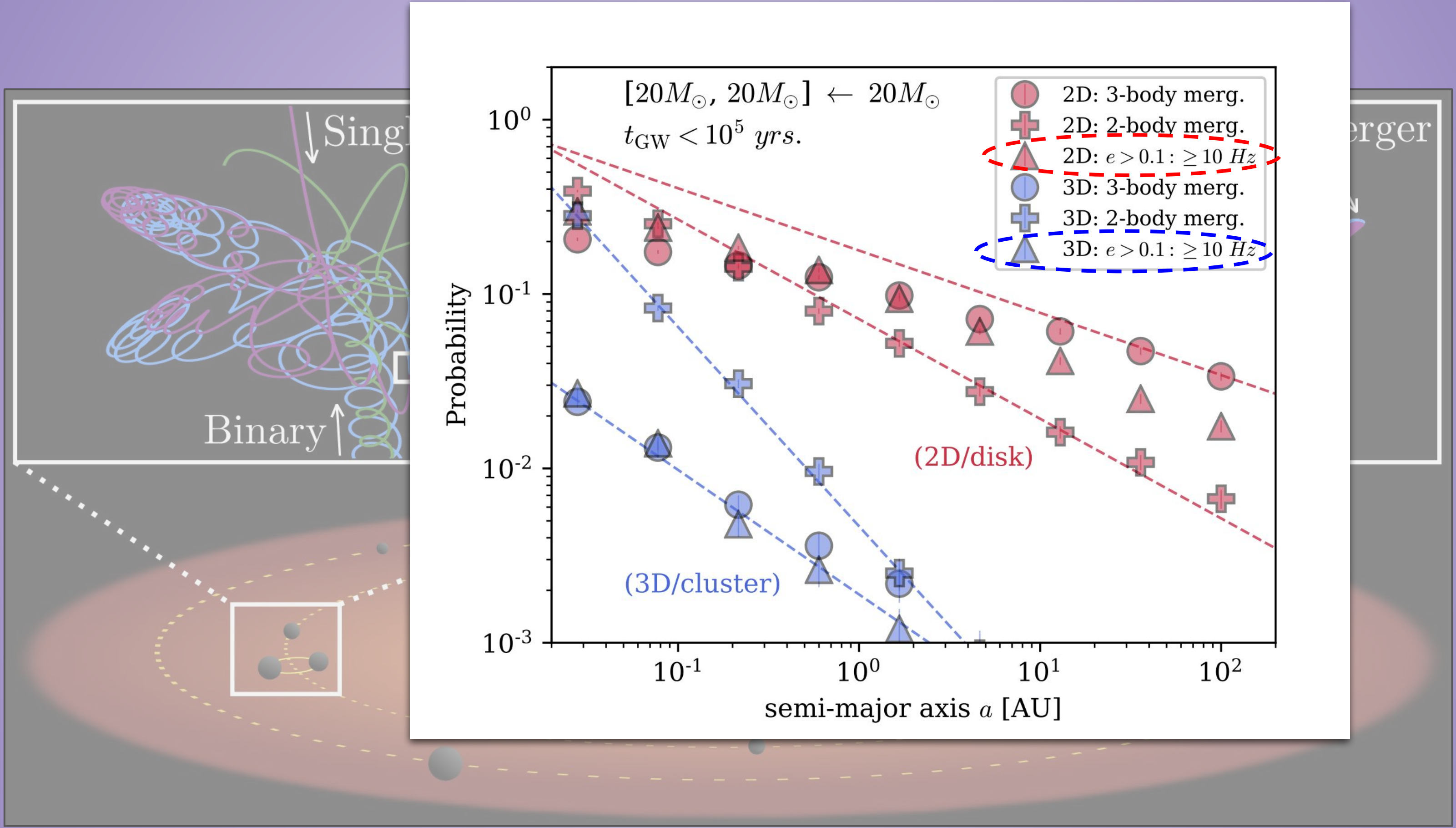


Stellar evolution inside the disk

Cantiello+21, Jermin+21, Jermin+22, Dittmann+21,23, **Fabj** +(in prep.)

Disk capture of initially inclined COs

e.g . Panamarev+18, **Fabj** +20, Macleod & Lin20, Nasim, **Fabj** +23, Wang+24



Single
Binary
erger
$[20M_\odot, 20M_\odot] \leftarrow 20M_\odot$
$t_{\rm GW} < 10^5$ yrs.
2D: 3-body merg.
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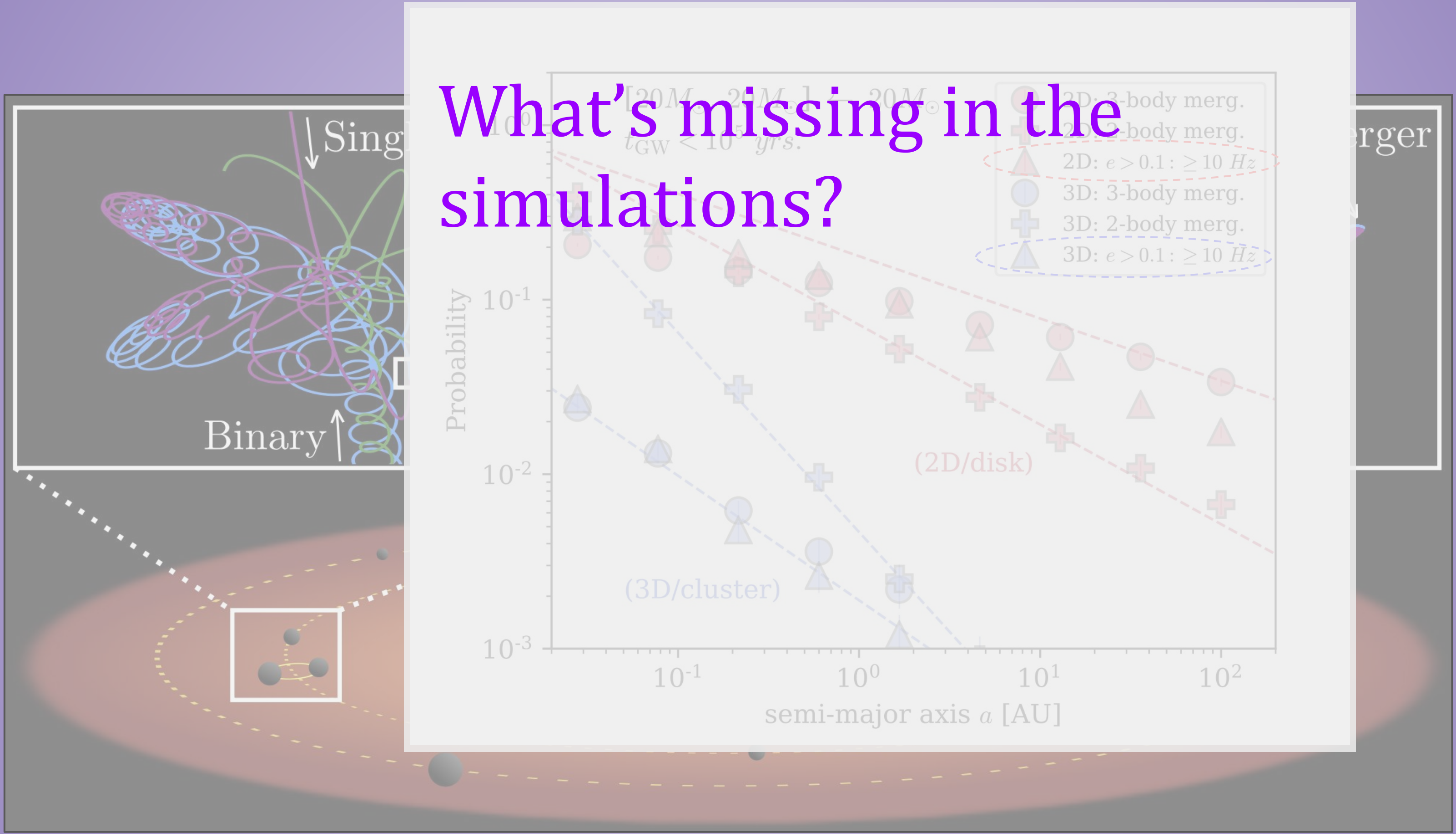
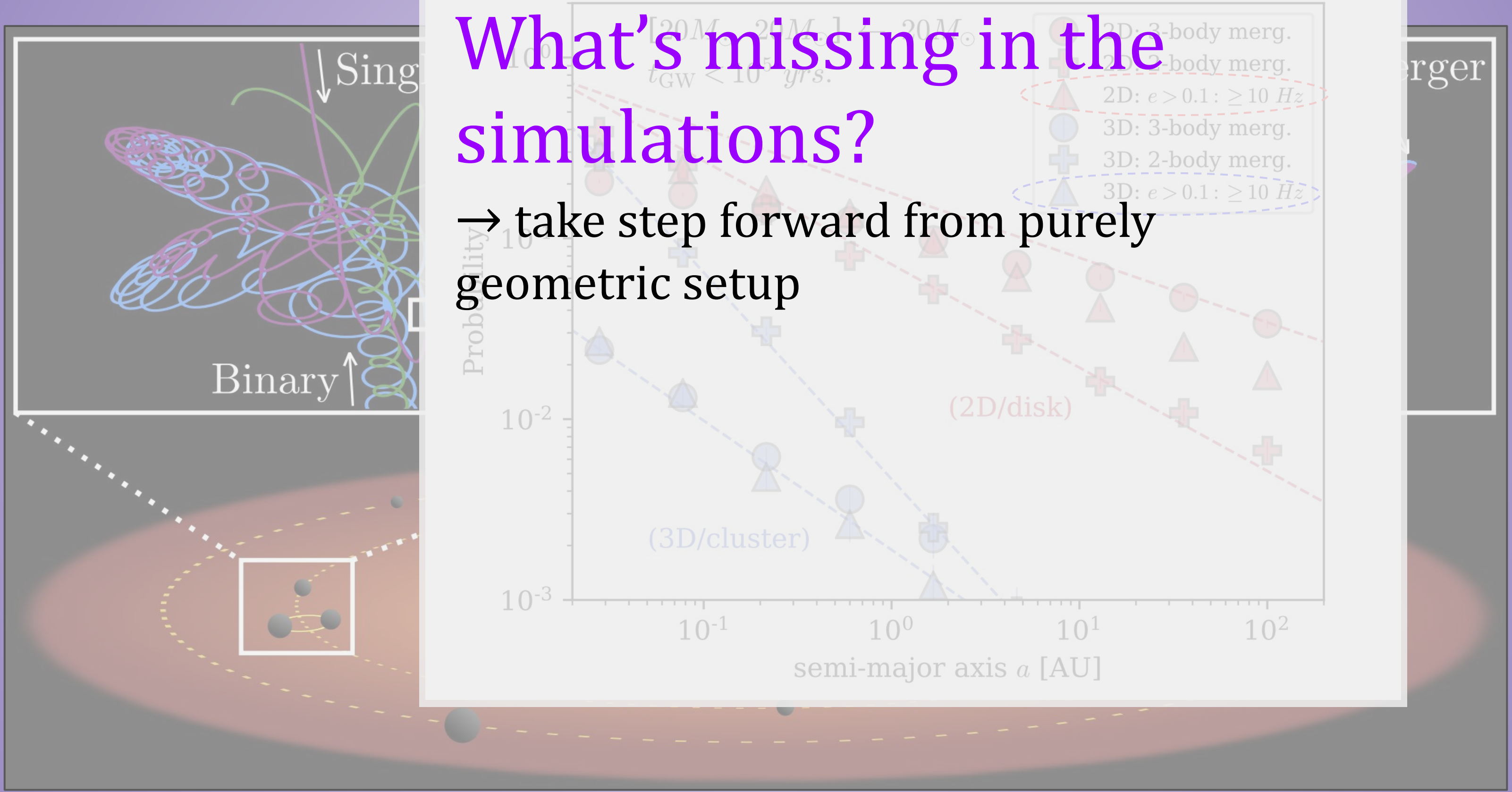
3D: 2-body merg.
3D: $e > 0.1 : \geq 10$ Hz
Probability
(2D/disk)
(3D/cluster)
semi-major axis a [AU]

What’s missing in the simulations?



What's missing in the simulations?

→ take step forward from purely geometric setup



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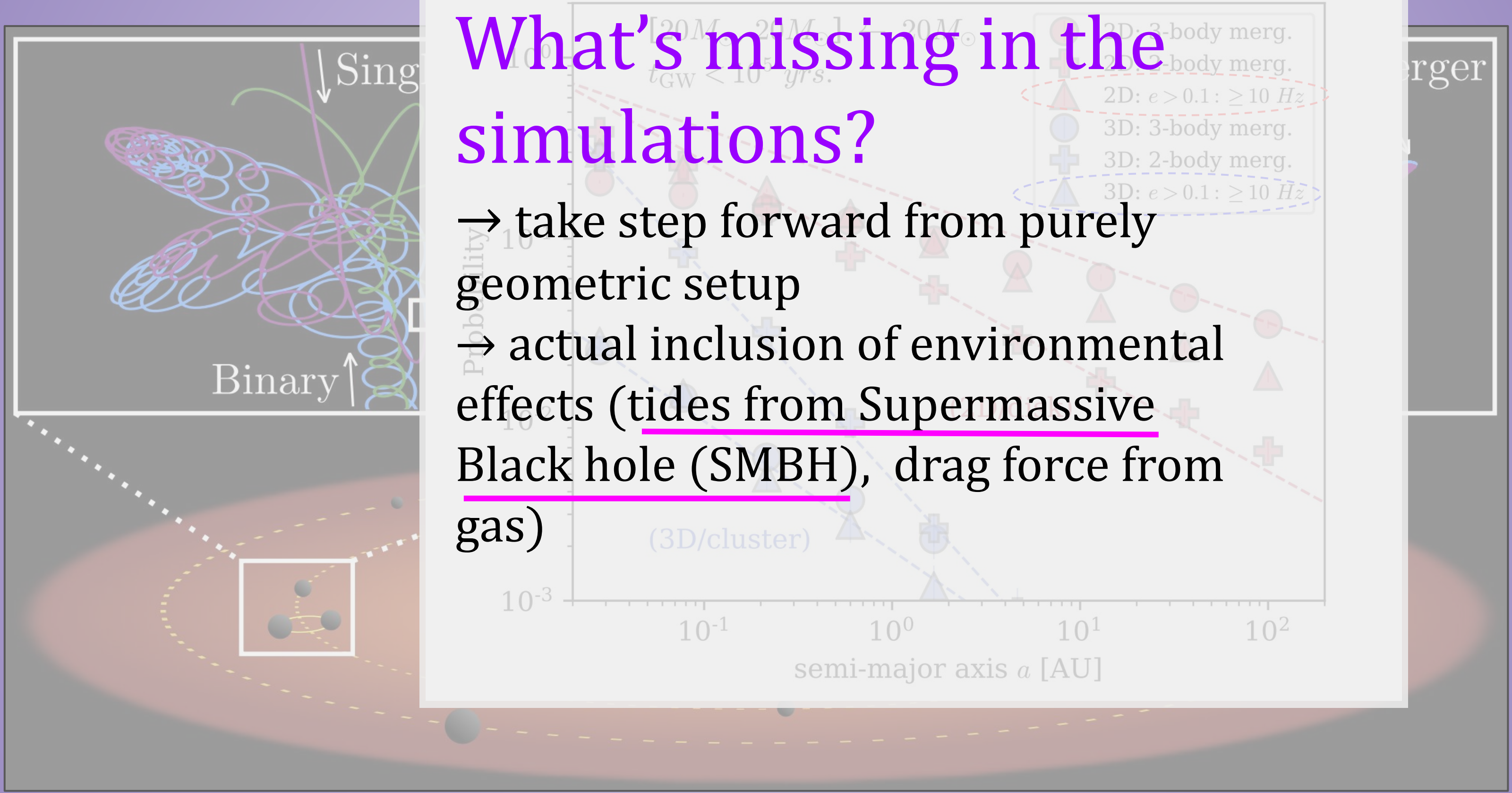
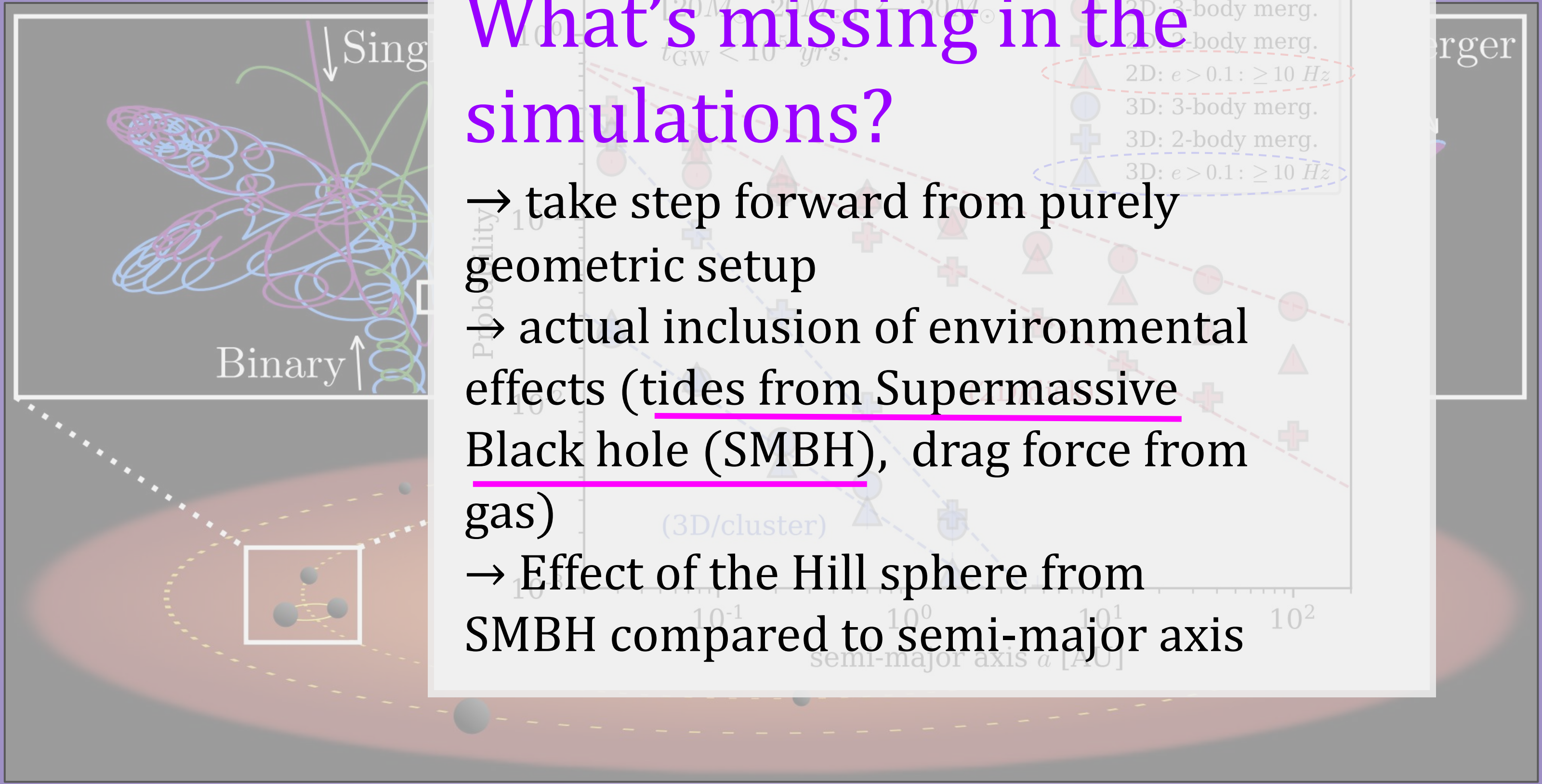
→ actual inclusion of environmental effects (tides from Supermassive Black hole (SMBH), drag force from gas)

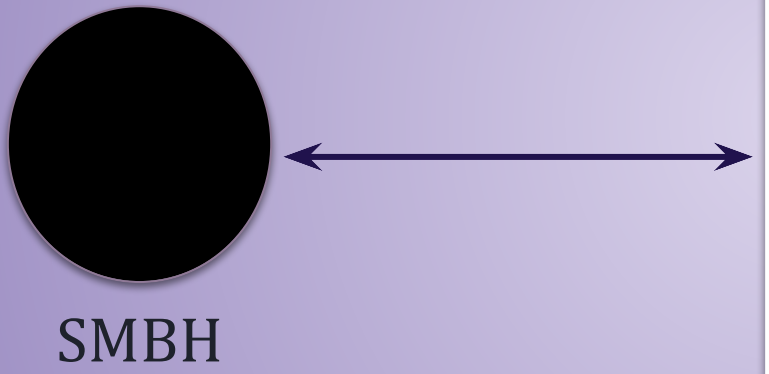


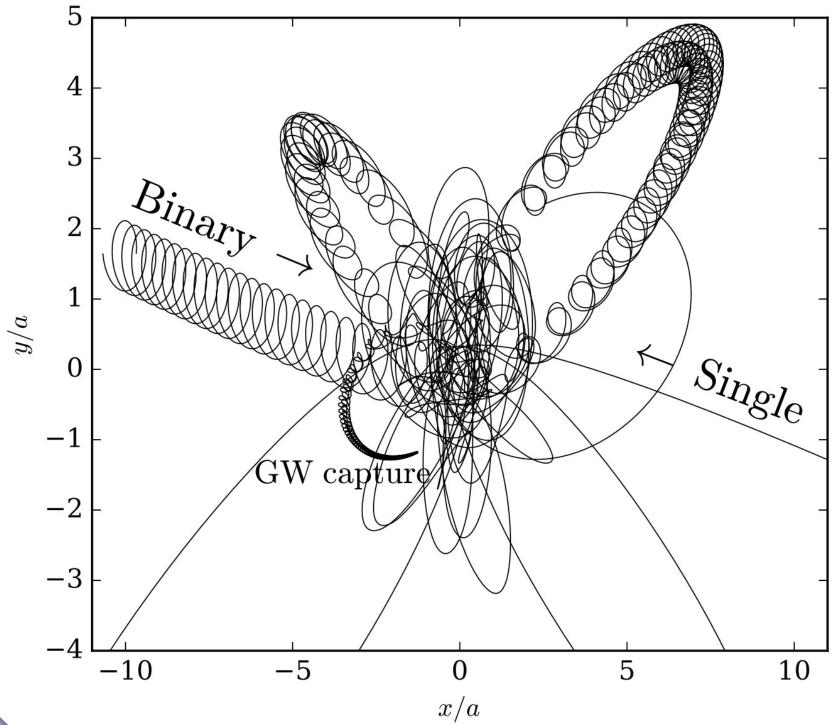
What's missing in the simulations?

→ take step forward from purely geometric setup
→ actual inclusion of environmental effects (tides from Supermassive Black hole (SMBH), drag force from gas)
→ Effect of the Hill sphere from SMBH compared to semi-major axis



Effect of Tides on Three-Body Encounters





Samsing et al. (2018)

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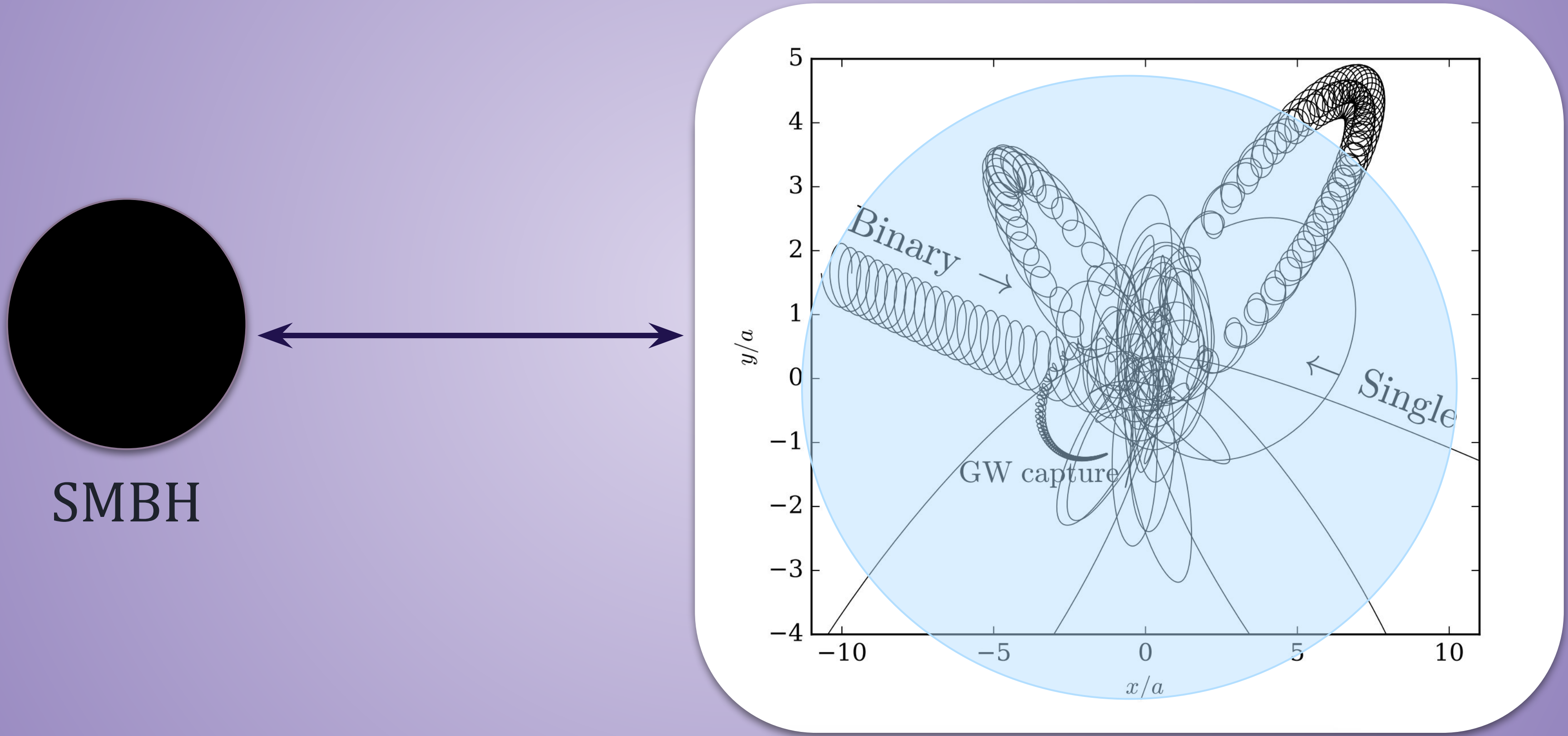
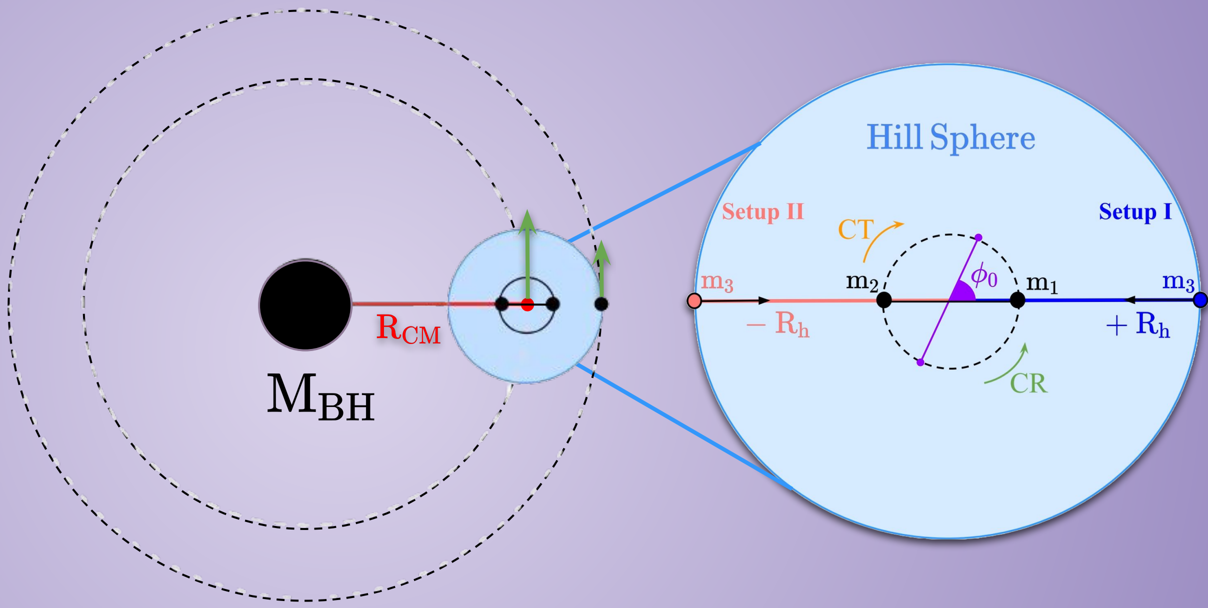


Samsing et al. (2018)

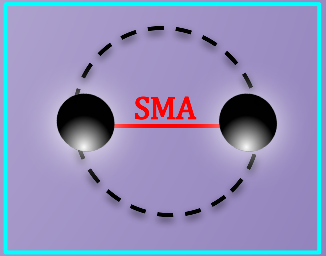
Scatterings Configuration

- Acceleration term due to SMBH ($10^8 M_\odot$)
- Place single sBH at Hill radius (10 AU)
- Vary binary semi-major axis (SMA)
- Two setups for single sBH impact parameter
- Co- and counter-rotating binary w.r.t. SMBH



Fabj & Samsing (submitted)
ArXiv: 2402.16948

$$R_H = R_{CM}\left(\frac{m_{bh}}{M_{BH}}\right)^{1/3}$$



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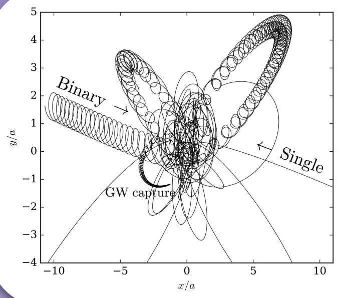

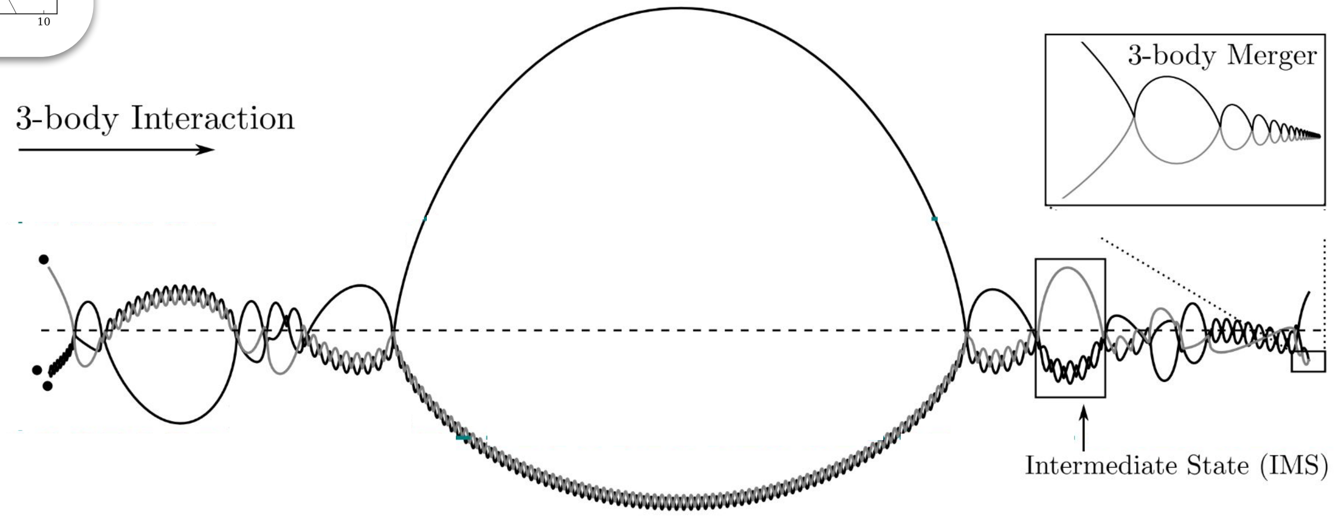

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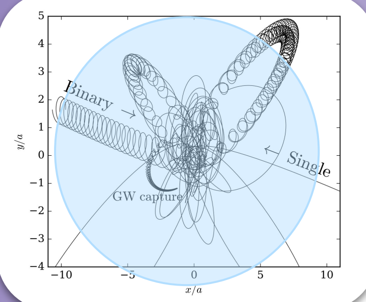

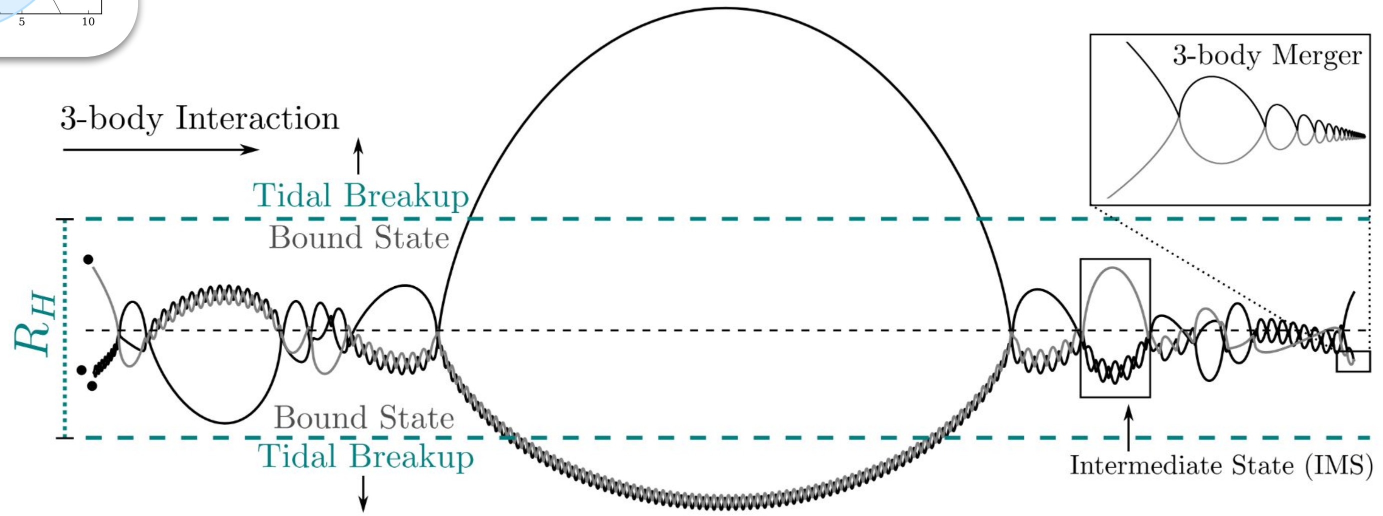

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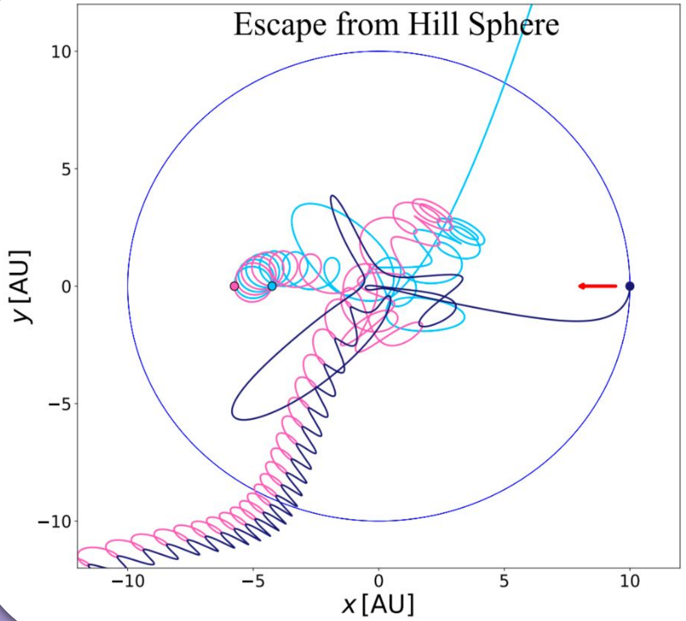
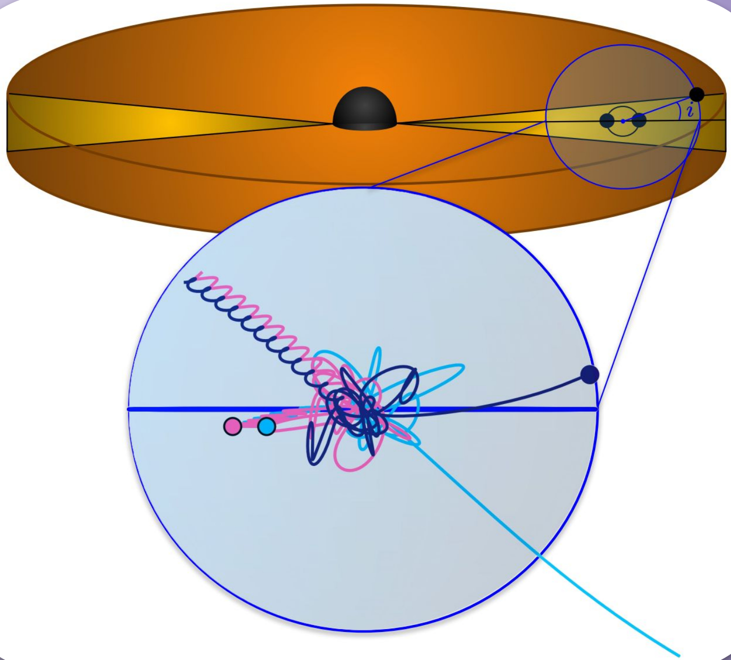
Examples of Binary-Single Encounters

Co-Planar



Out-of-Plane



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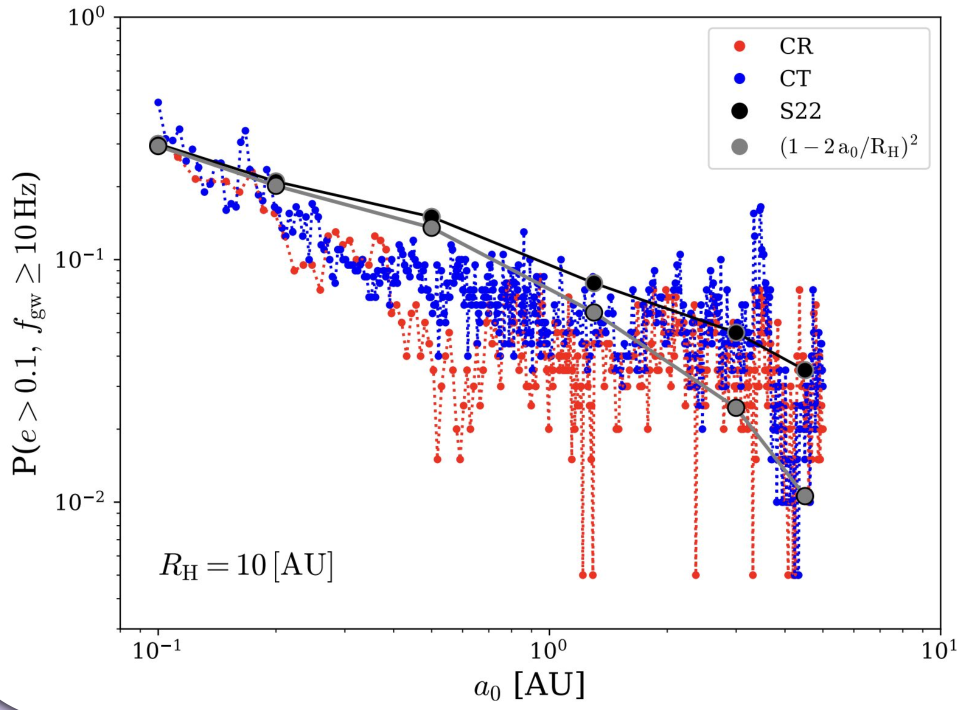
Effect of Tides on Merger Probability

- Prob. follows power law at low SMA
- Significant effect as SMA approaches size of the Hill radius
- Two main effects: correction due to tidal field and fluctuations



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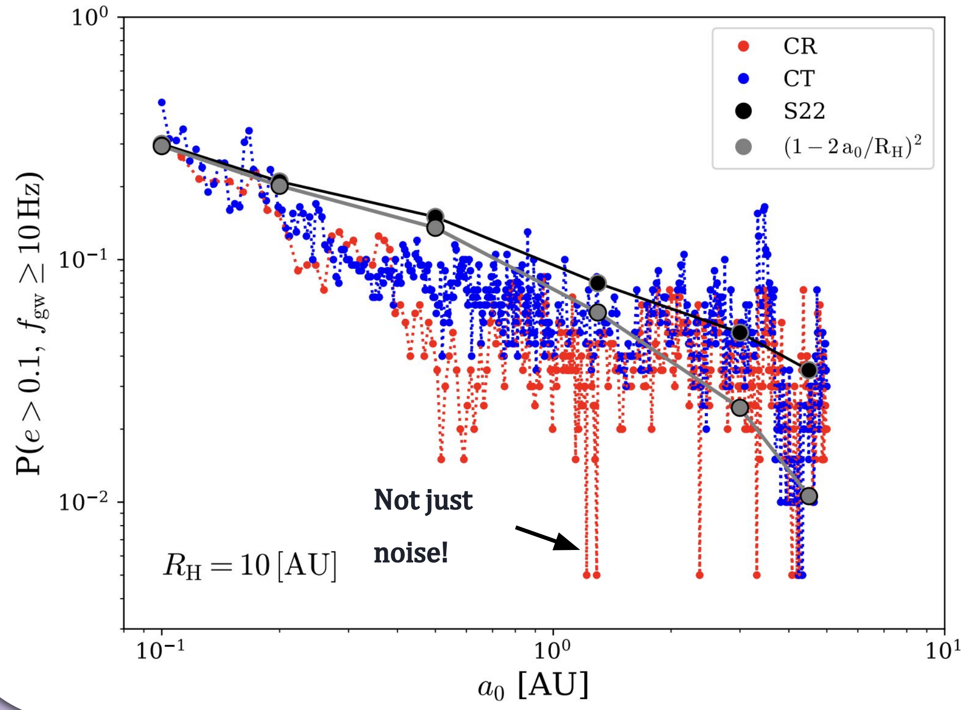

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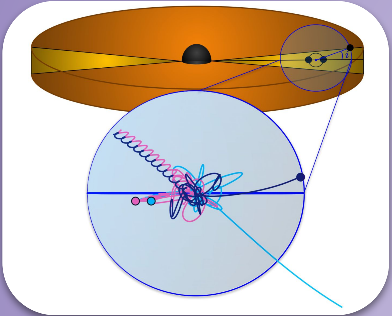
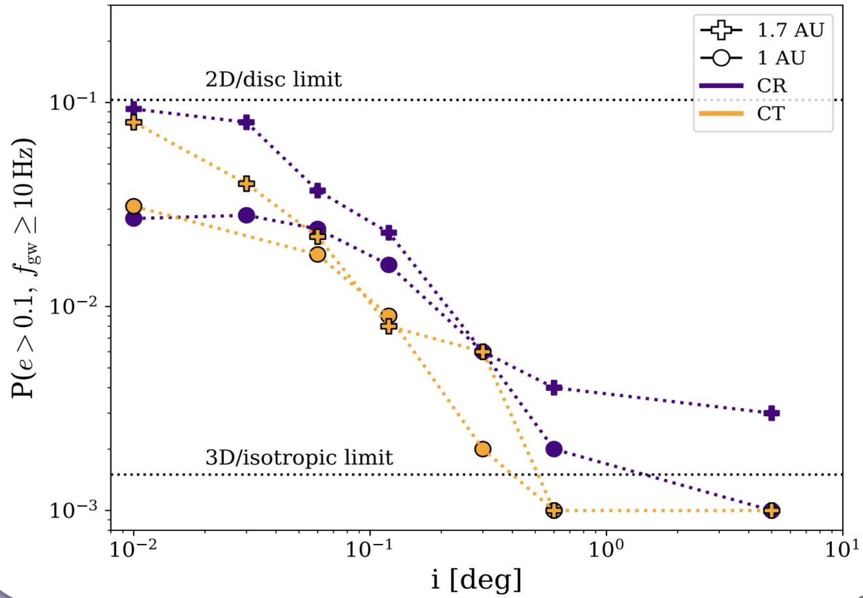
Probability for Out-of-plane Interactions





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Summary & Conclusions

- Possible GW formation channels → focus on the AGN channel (why? GW190521)

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  - Correction factor, fluctuating trend of probability, effect of inclination
  - **See also** Leigh et al. 2018; Trani et al. 2019; Ginat & Perets 2021; Rom et al. 2023; Trani et al. 2024

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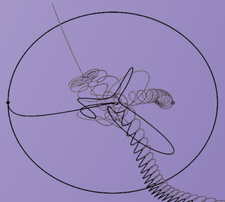
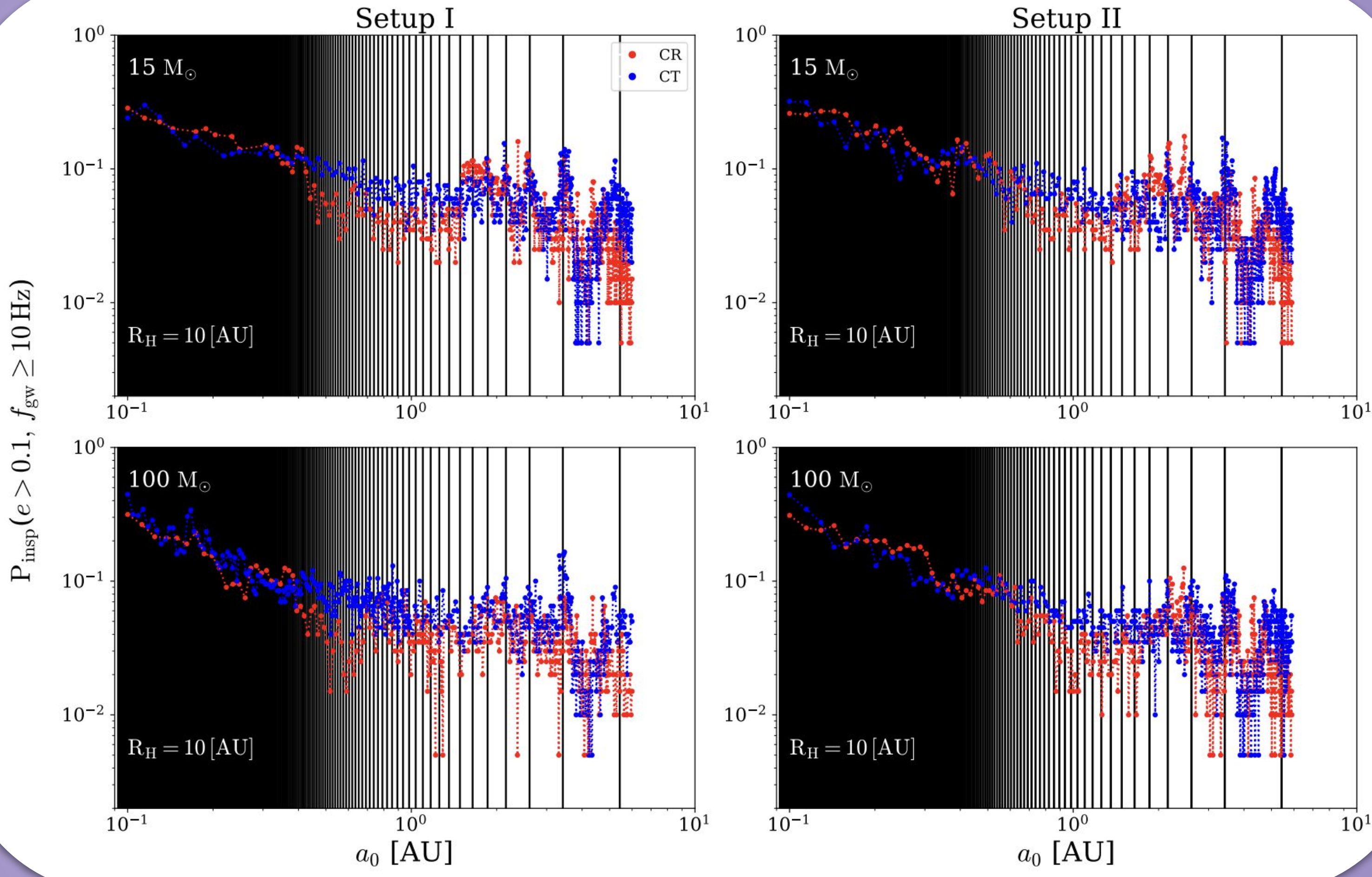
- Next step → inclusion of the **effects of gas drag** from the accretion disk



Additional Information



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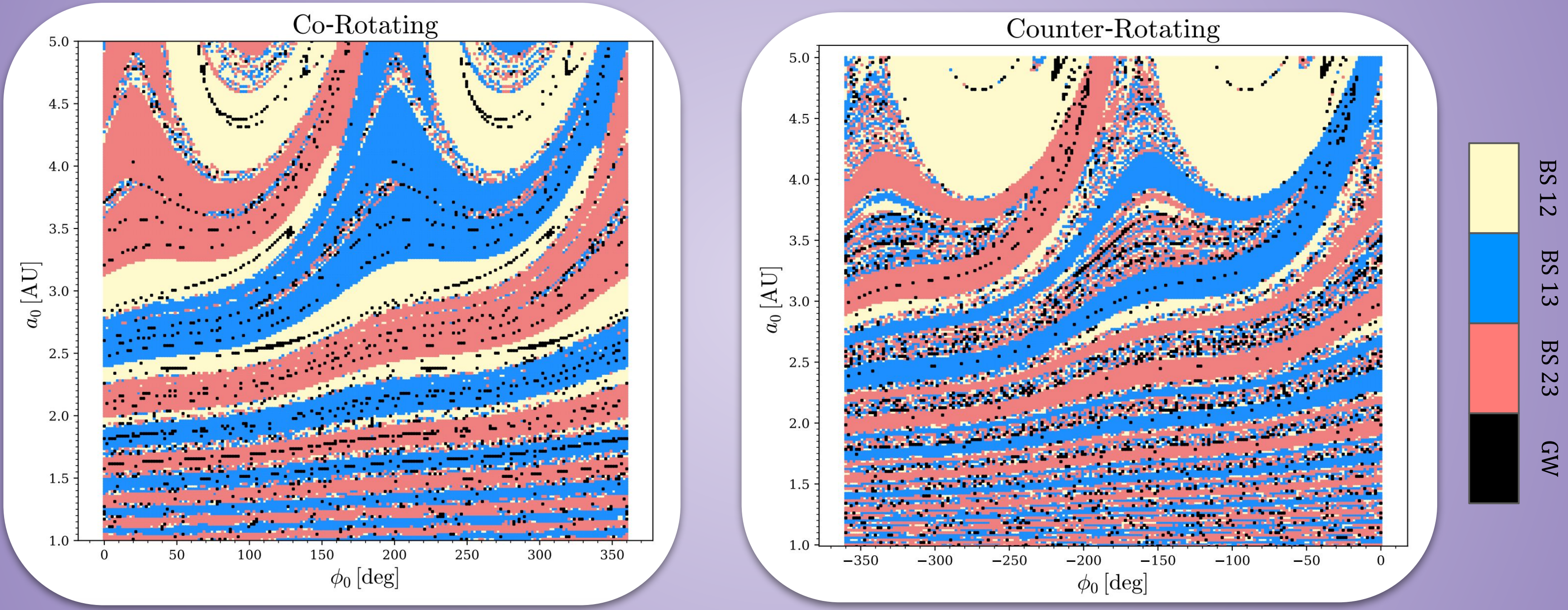
Phase-Space Distribution



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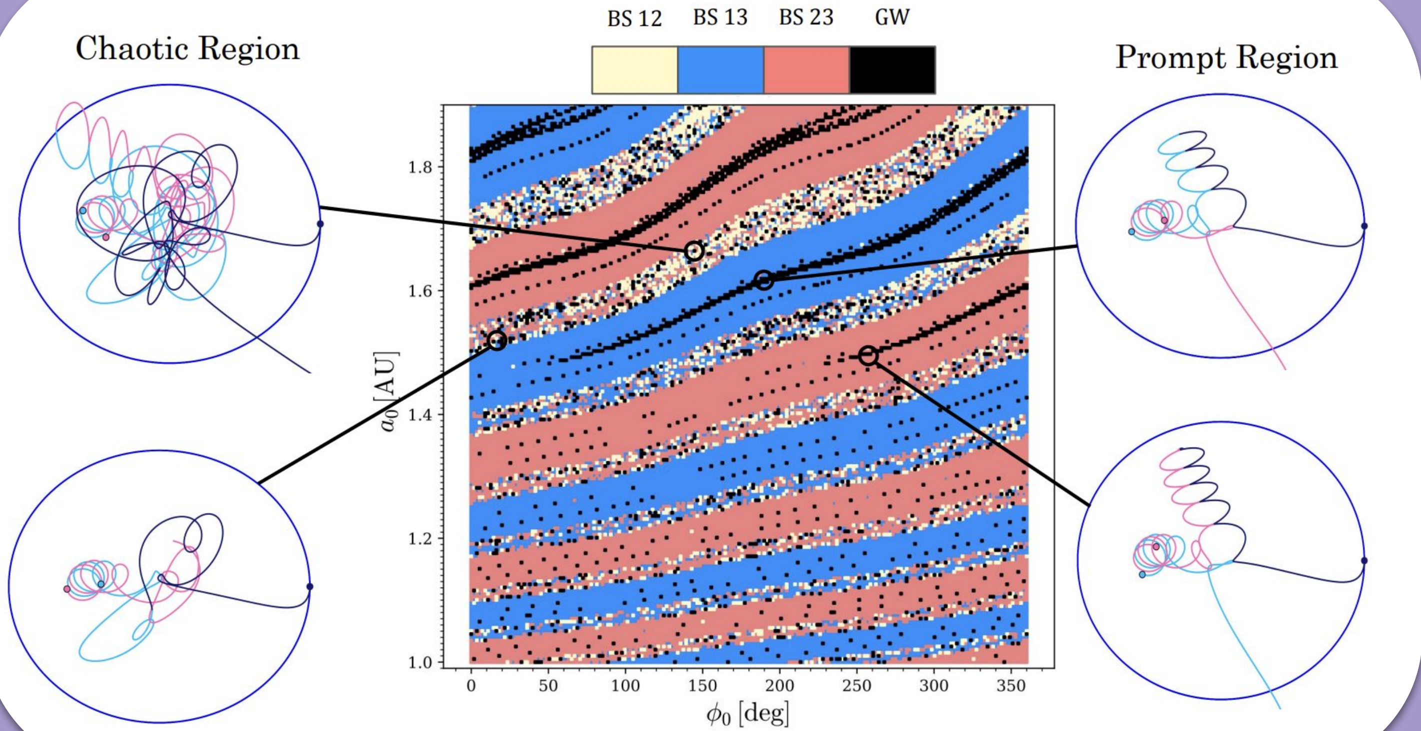

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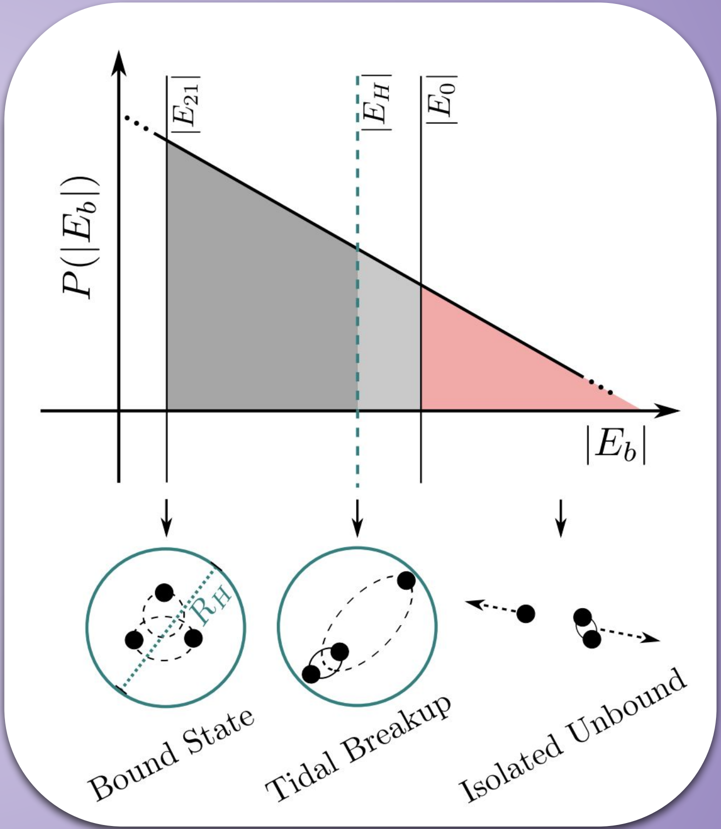
Effect of Tides on Merger Probability

- Evaluate analytically the influence of tidal field on number of interactions
- Energy distribution in presence of tides
- Statistical analysis of binary energy probability distribution
- Correction factor of $1 - \frac{2a_0}{R_H}$ for the probability



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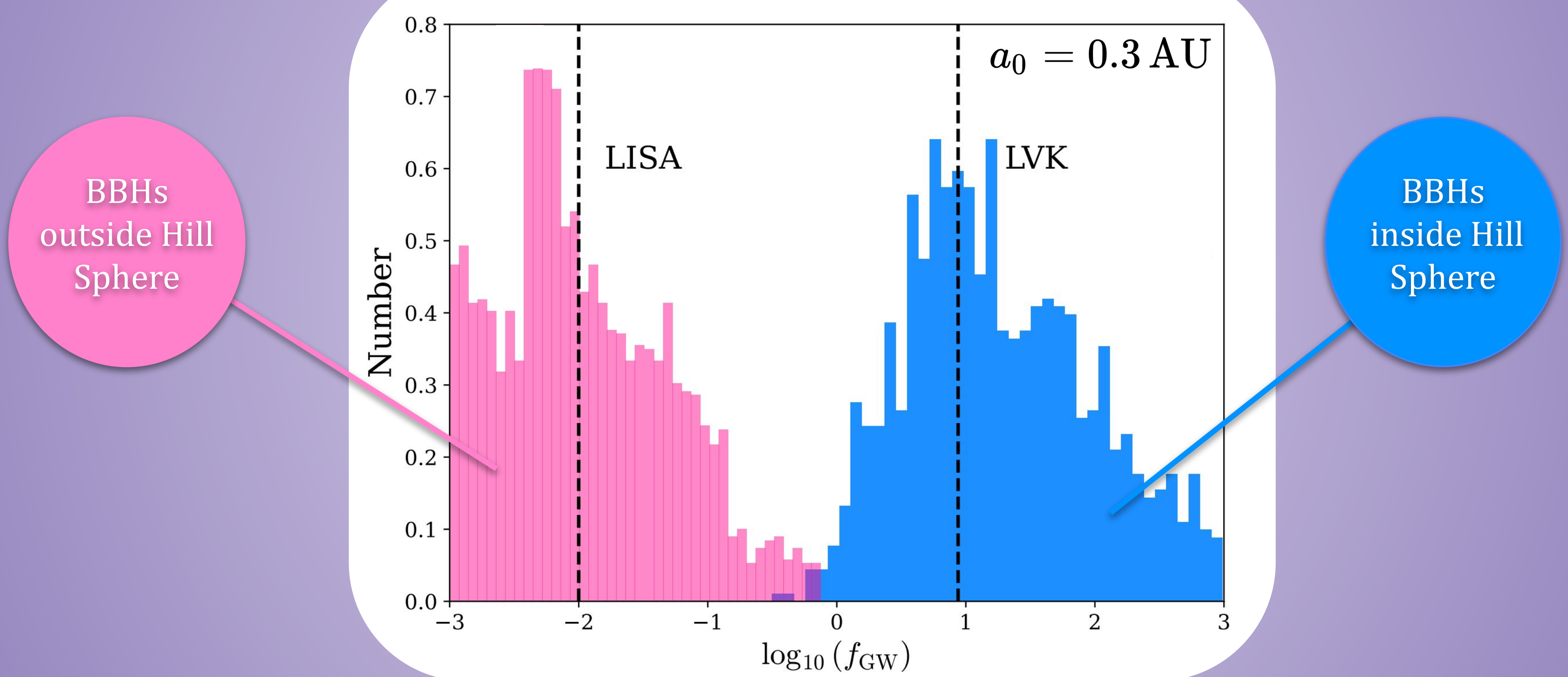
Peak Frequency Distribution



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