

Xmas theoretical workshop

# Massive black hole assembly in nuclear star clusters

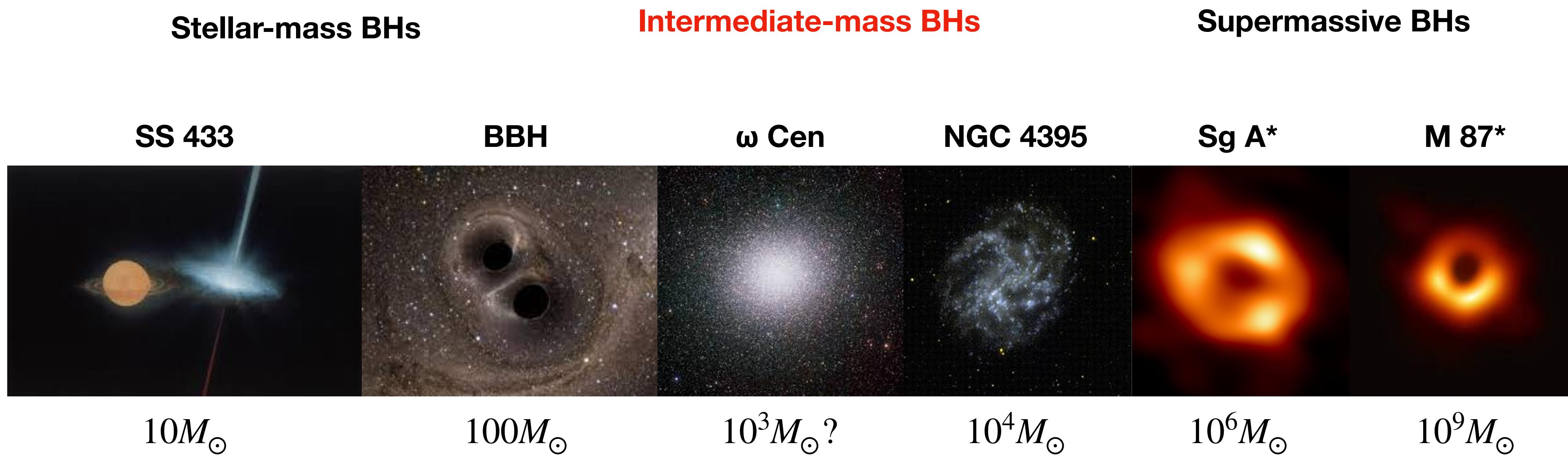
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*Johns Hopkins University*

Co-authors: Emanuele Berti, Joseph Silk

e-Print: [2212.06845](https://arxiv.org/abs/2212.06845) [astro-ph.HE]

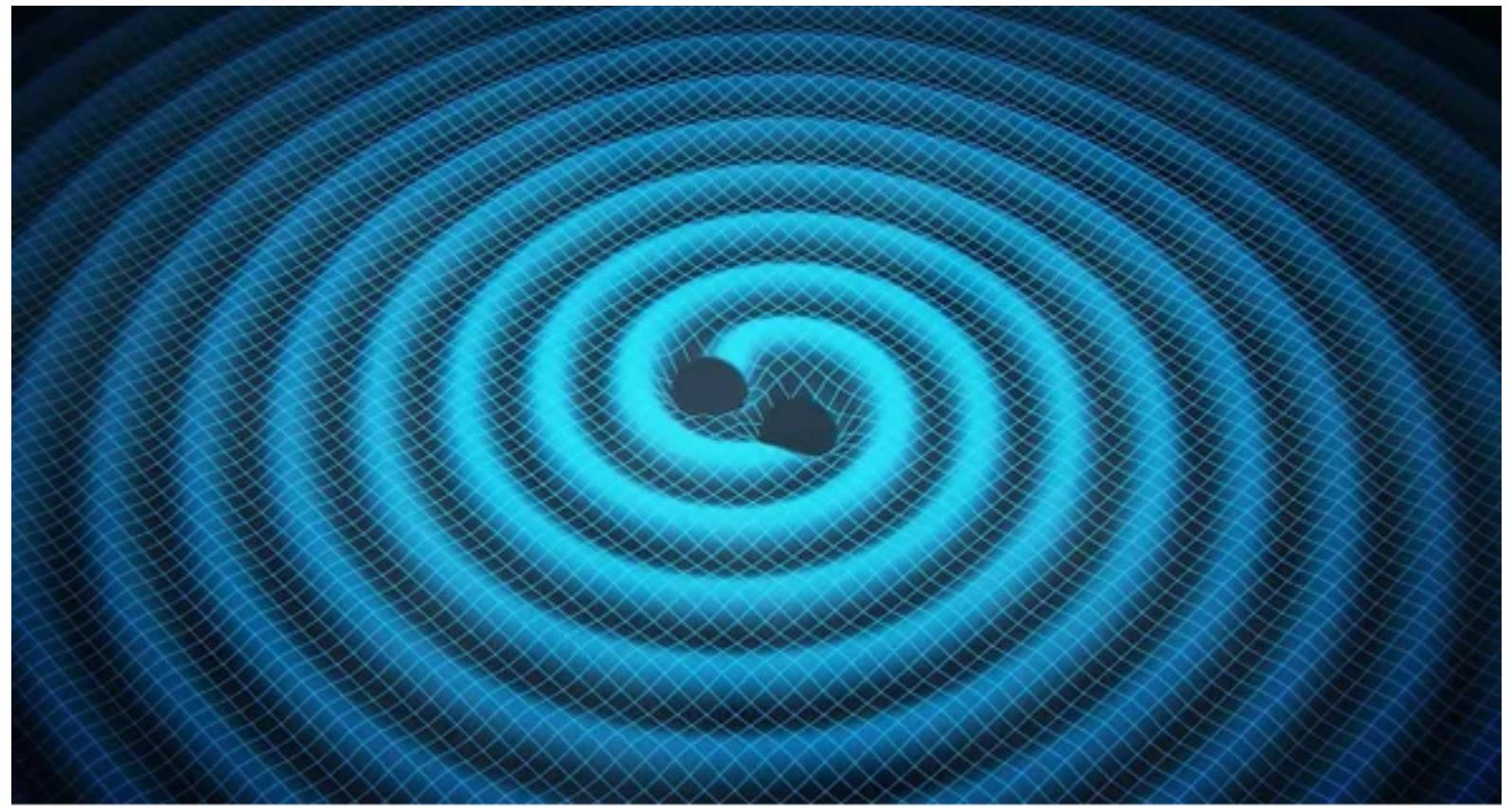
(December 21, 2022)

# Black hole mass spectrum



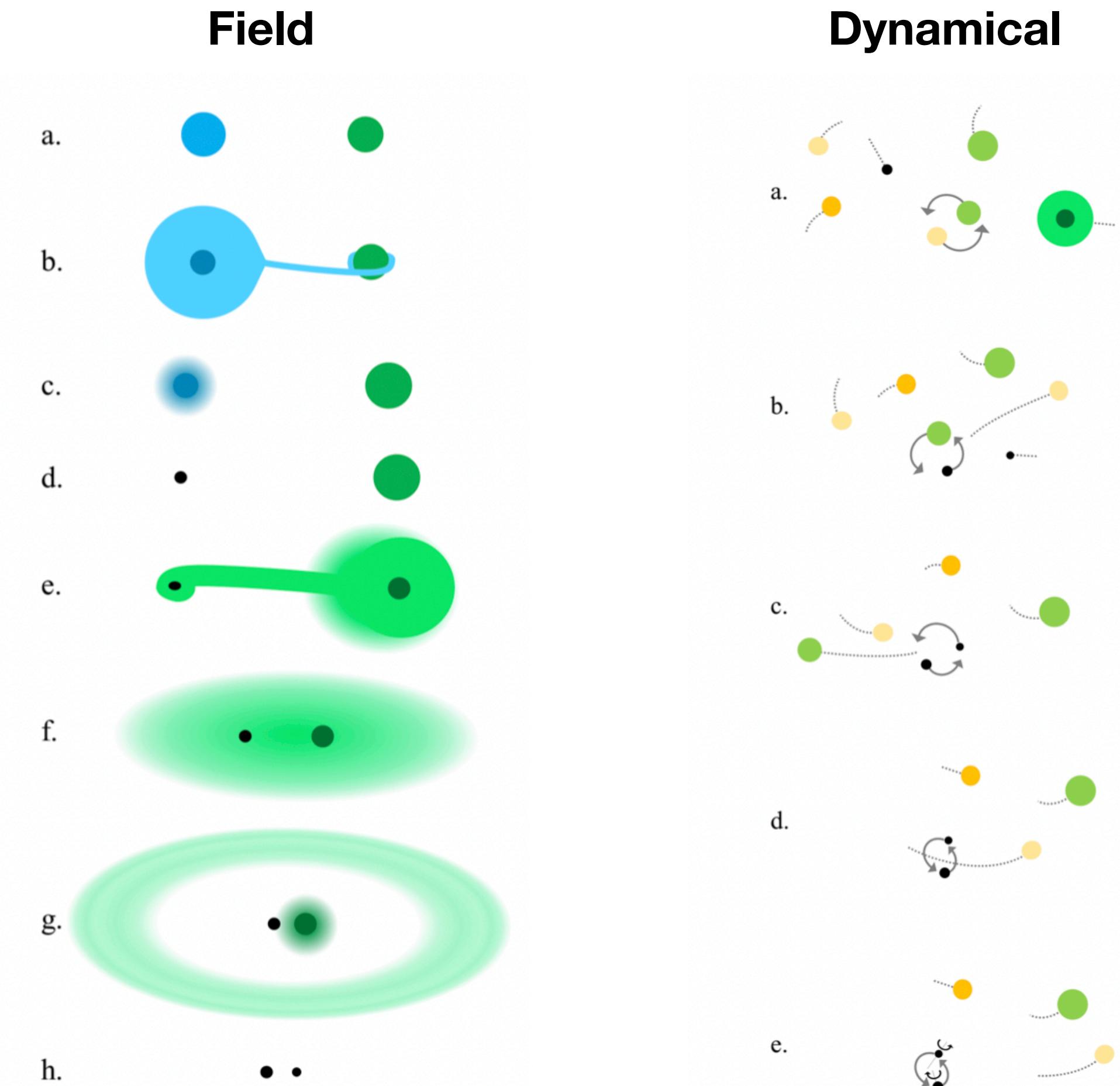
**How do massive BHs assemble?**

# Origin of GW events



Credit: (NASA/JPL)

- LIGO-Virgo seen 90 BBH merger events.
- How do they form?



Mandel & Farmer (2022)

# Hierarchical mergers

PHYSICAL REVIEW LETTERS 125, 101102 (2020)

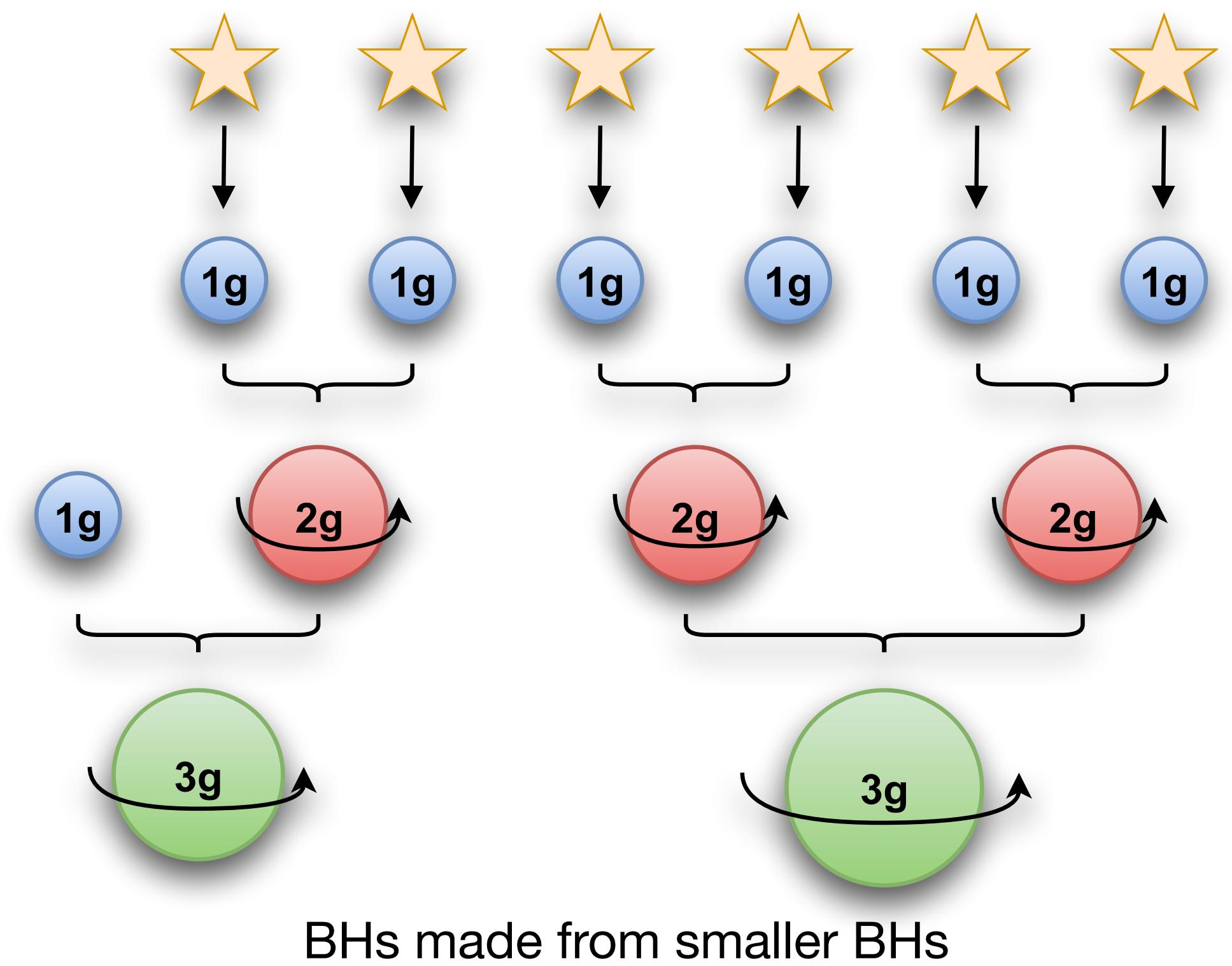
Editors' Suggestion

Featured in Physics

**GW190521: A Binary Black Hole Merger with a Total Mass of  $150 M_{\odot}$**

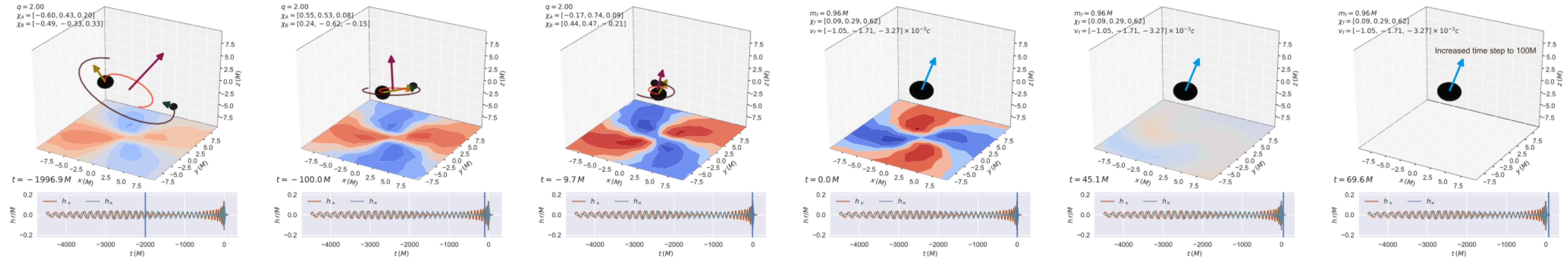
R. Abbott *et al.*<sup>\*</sup>

(LIGO Scientific Collaboration and Virgo Collaboration)



# The gravitational rocket

Inspiral, merger, ringdown and kick



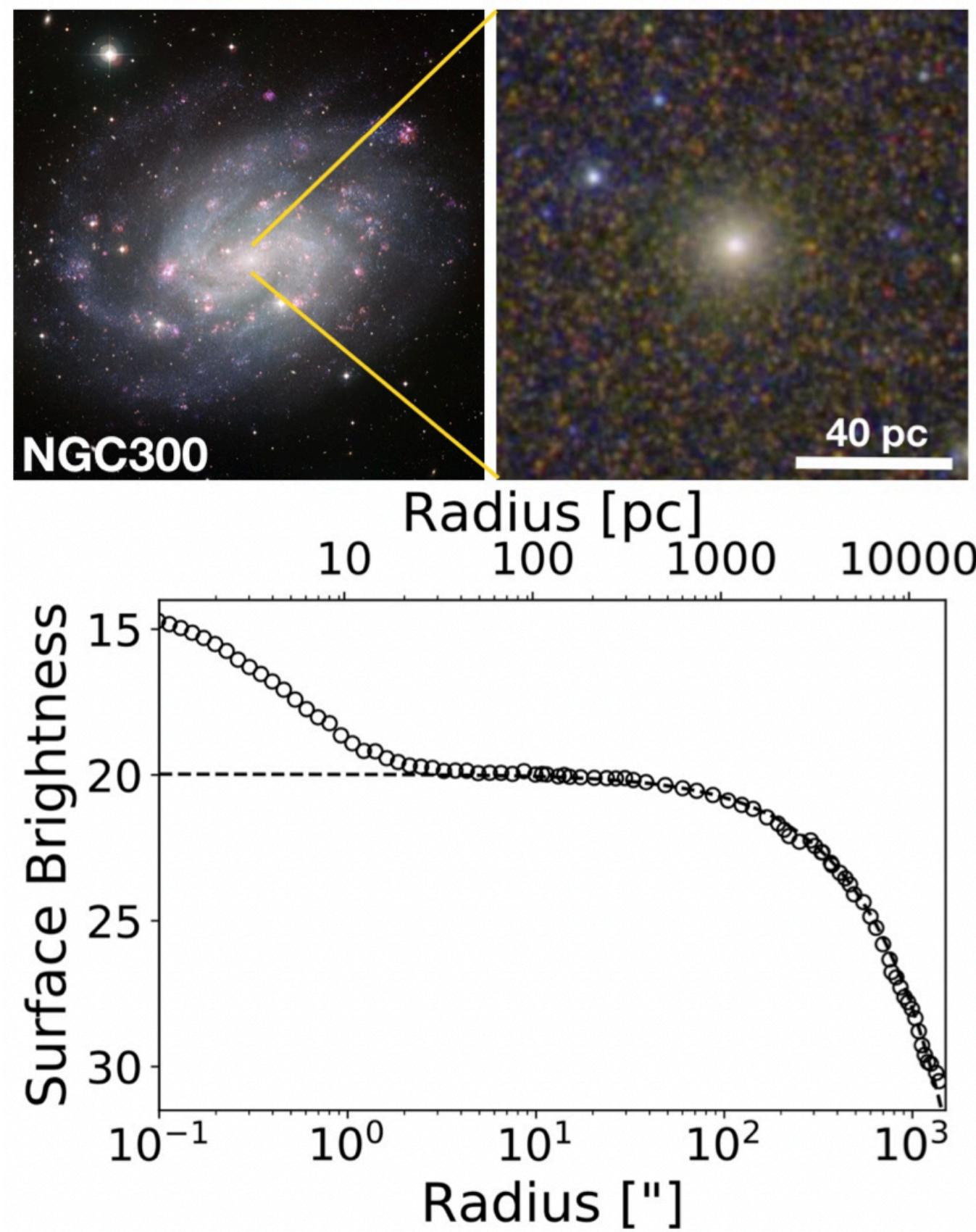
Varma et al. (2019)

Asymmetric GW emission imparts a recoil;

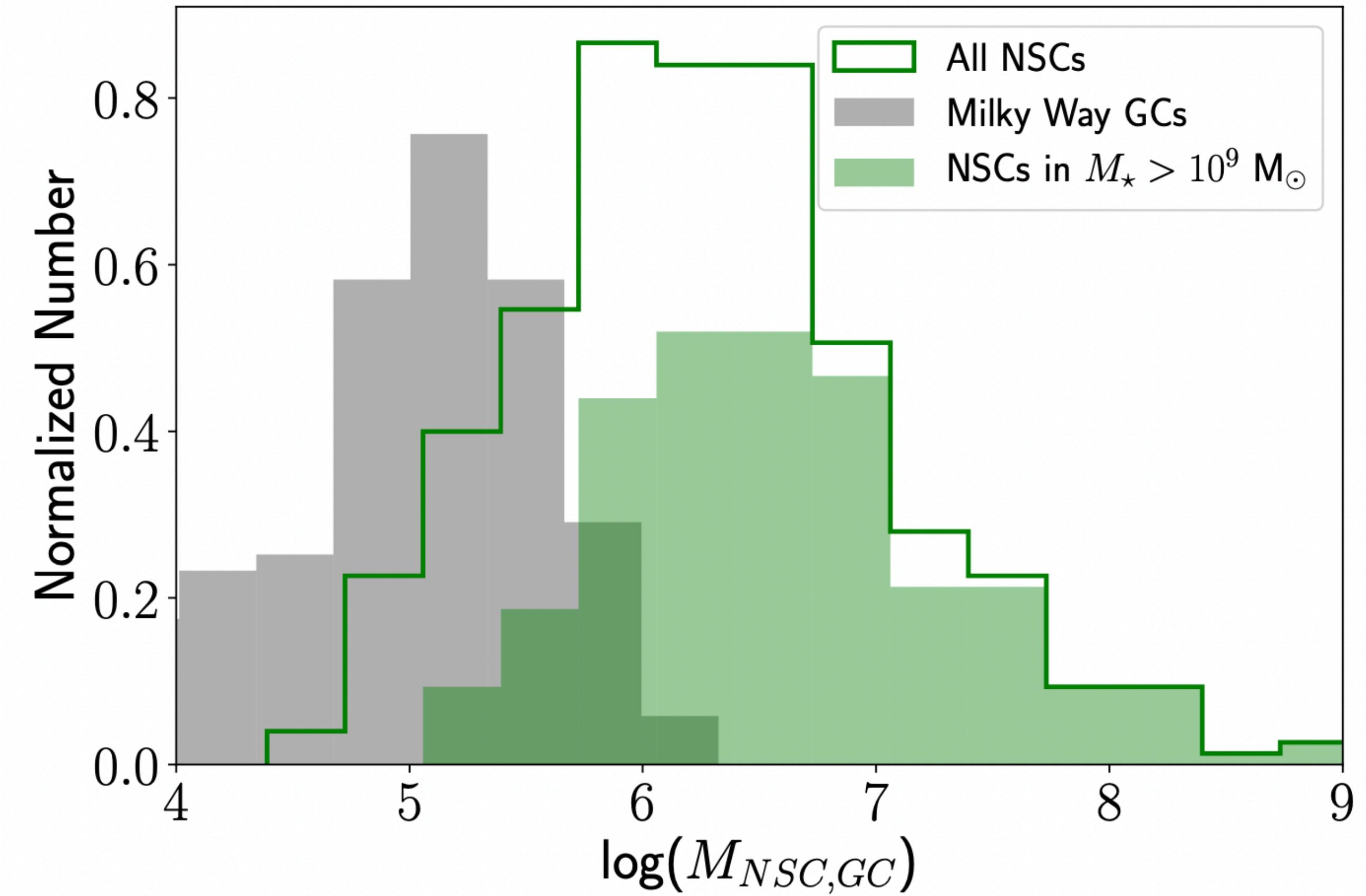
$$\nu_{\text{GW}} > \nu_{\text{esc}} \Rightarrow \text{ejection}$$

Retention requires  $\nu_{\text{esc}} \gtrsim O(100) \text{ km/s}$

# Nuclear star clusters

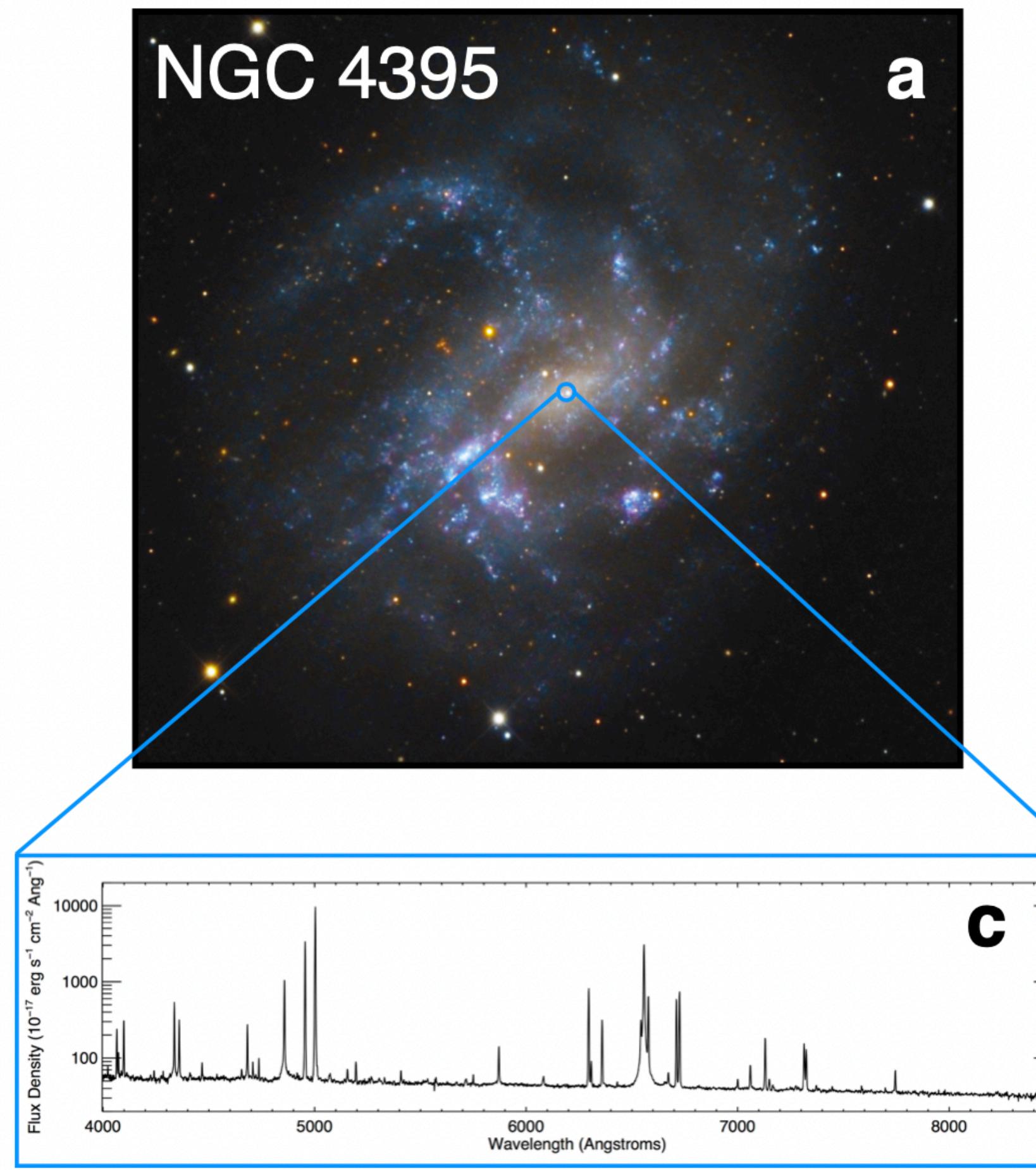


Neumayer et al. (2020)

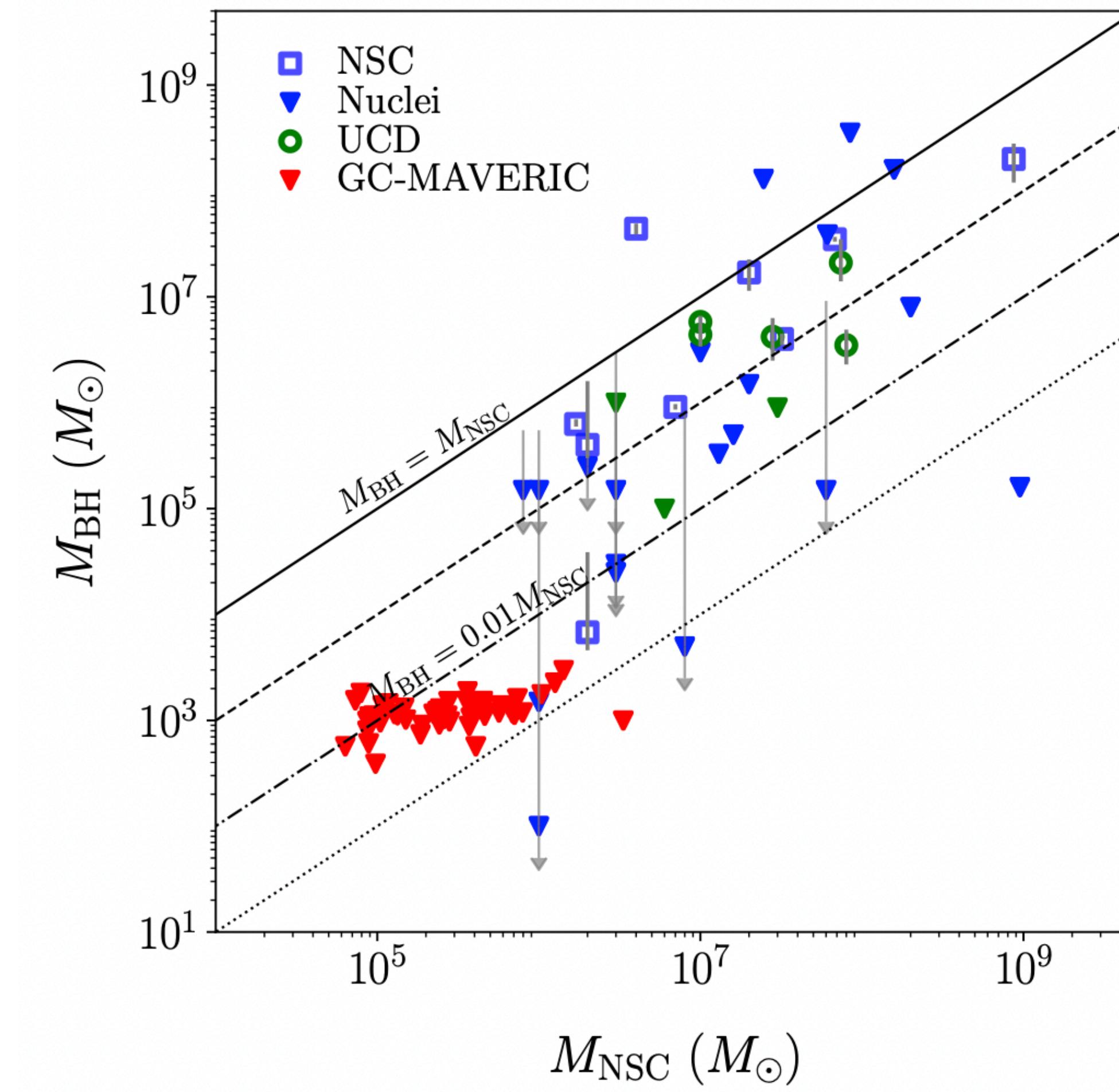


Neumayer et al. (2020)

# Intermediate-mass BHs



Reines (2022)

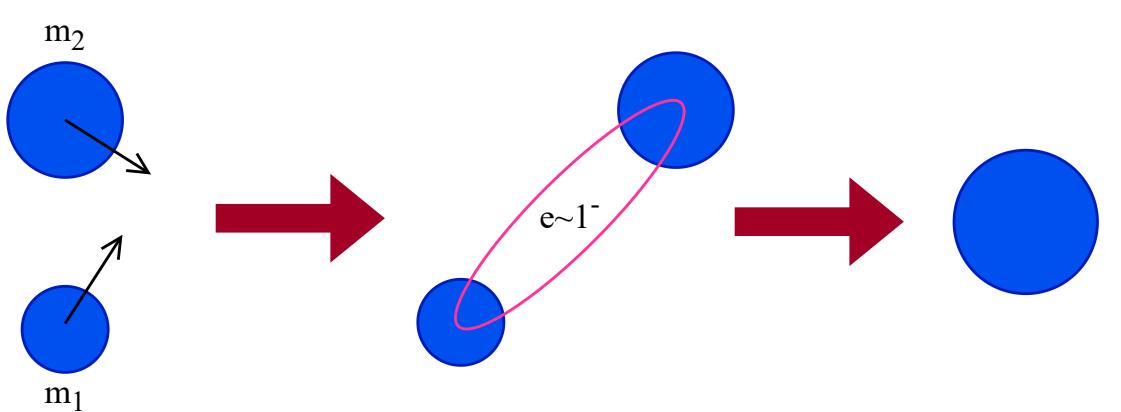
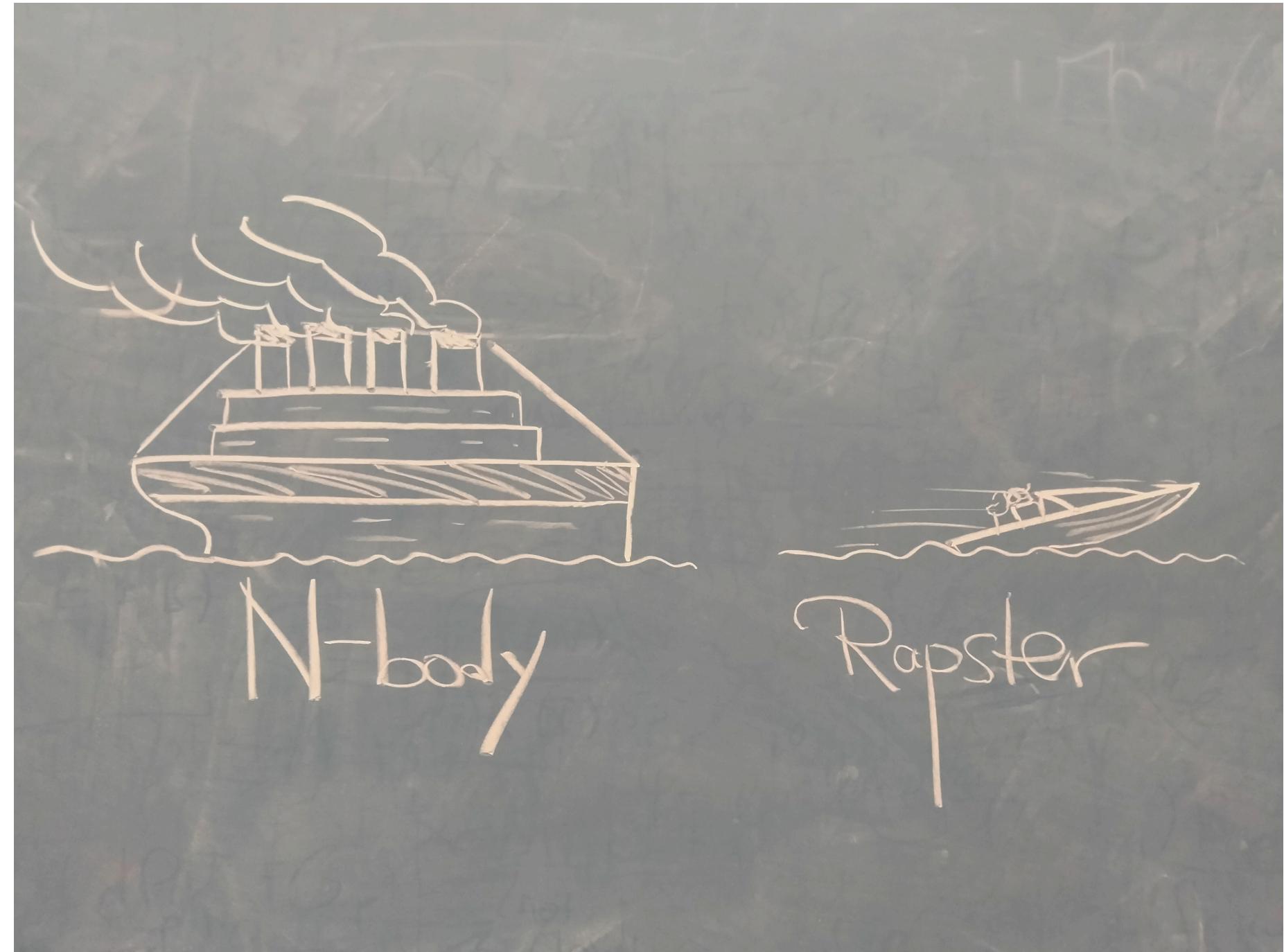


Greene et al. (2020)

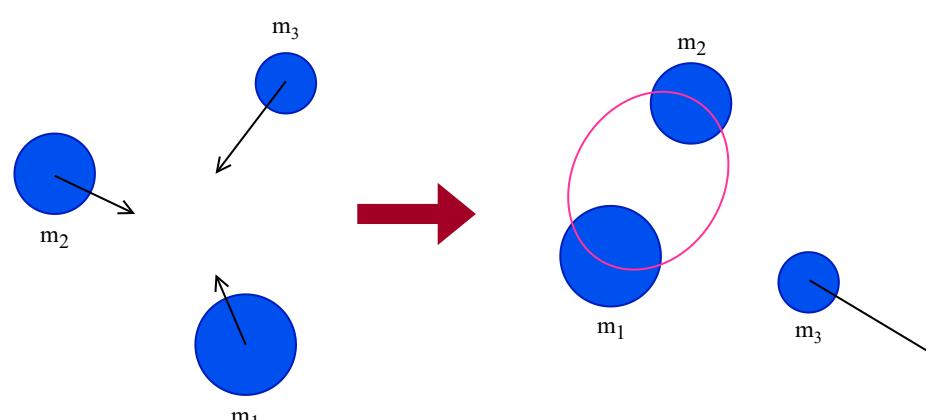
# Rapster: Rapid cluster

e-Print: 2210.10055 [astro-ph.HE]

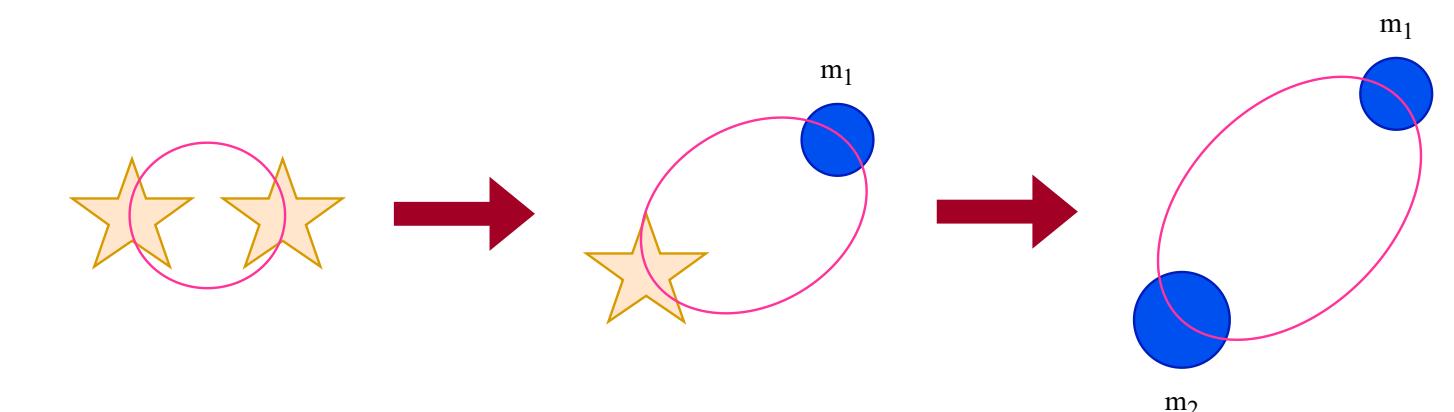
- GitHub: **Kkritos/Rapster**
- Simulate dynamical mergers within seconds
- Some processes included:



two-body capture

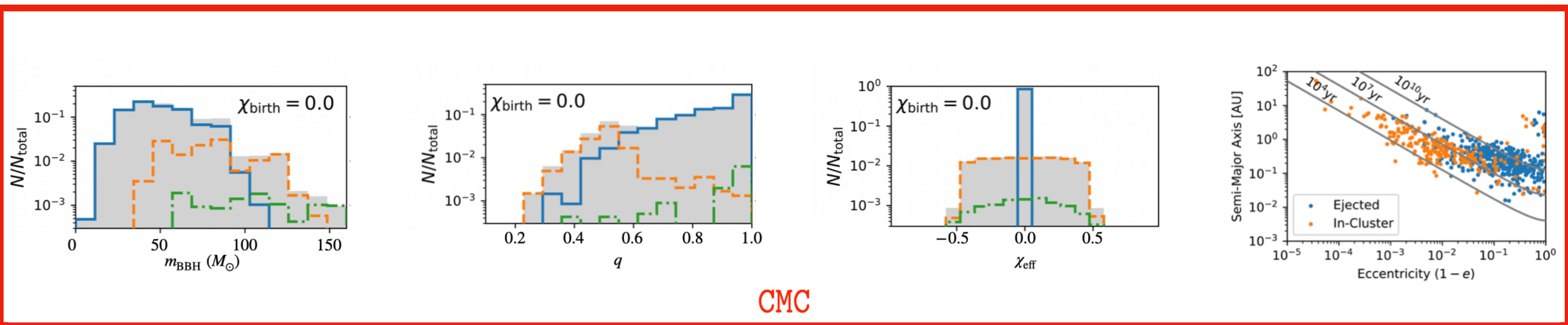
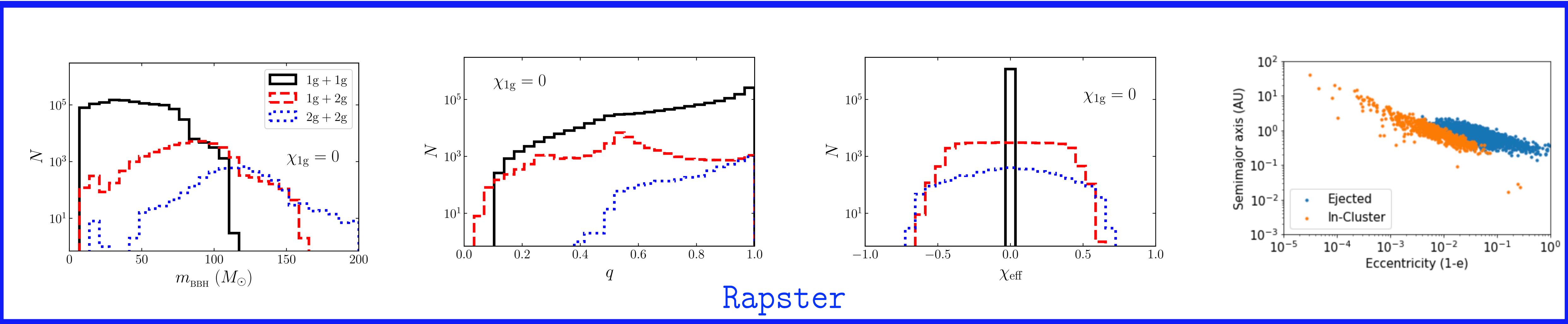


three-body binary

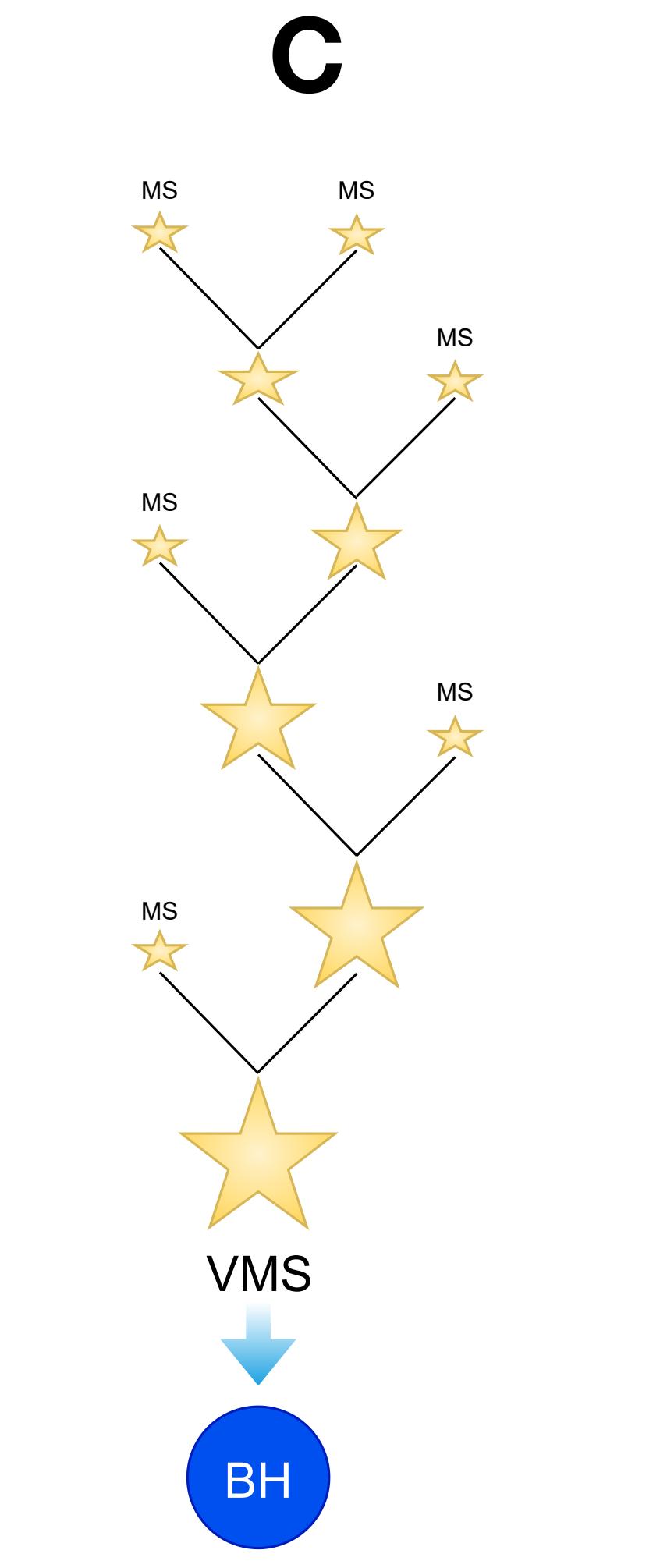
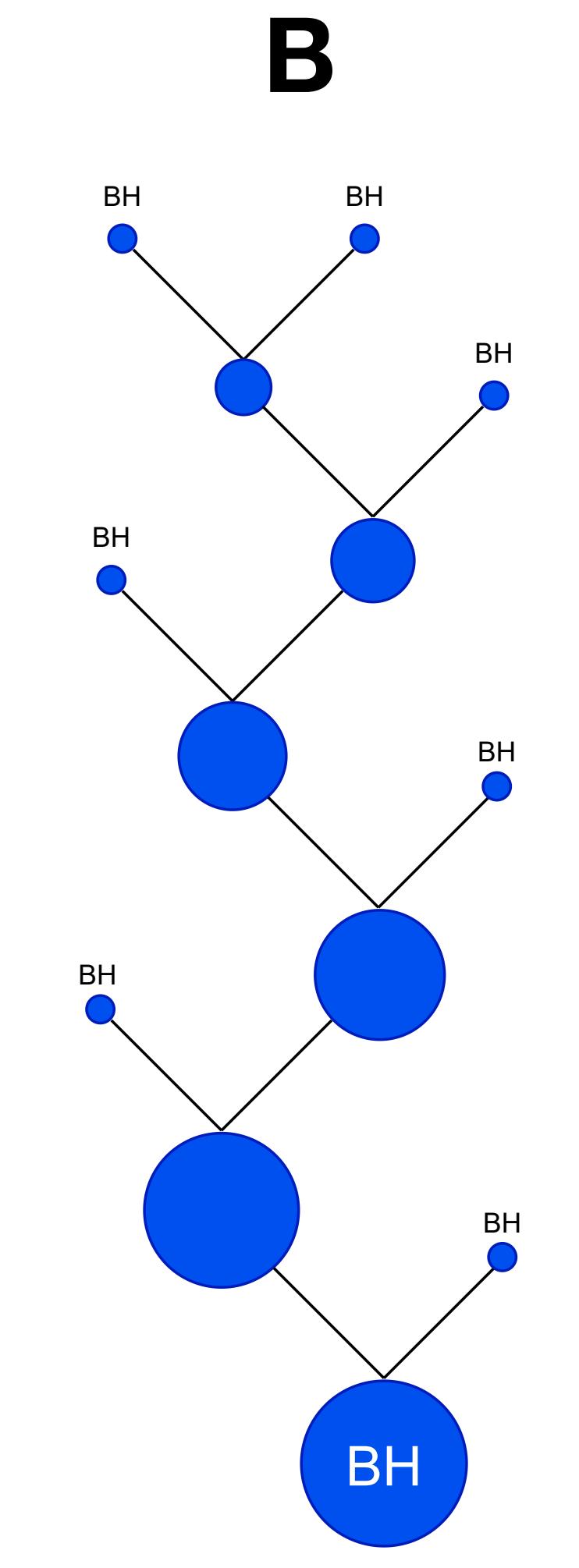
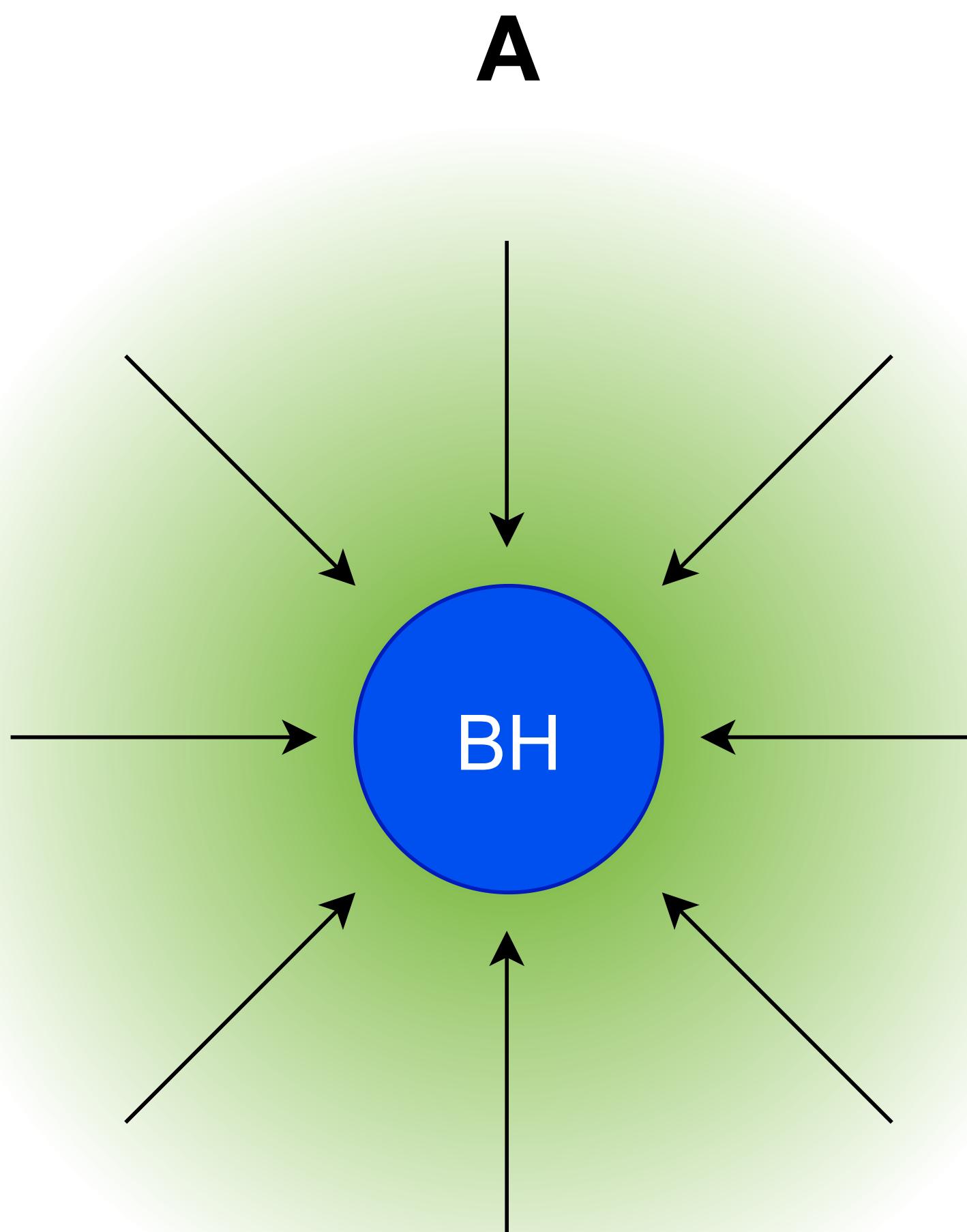


binary-single interactions

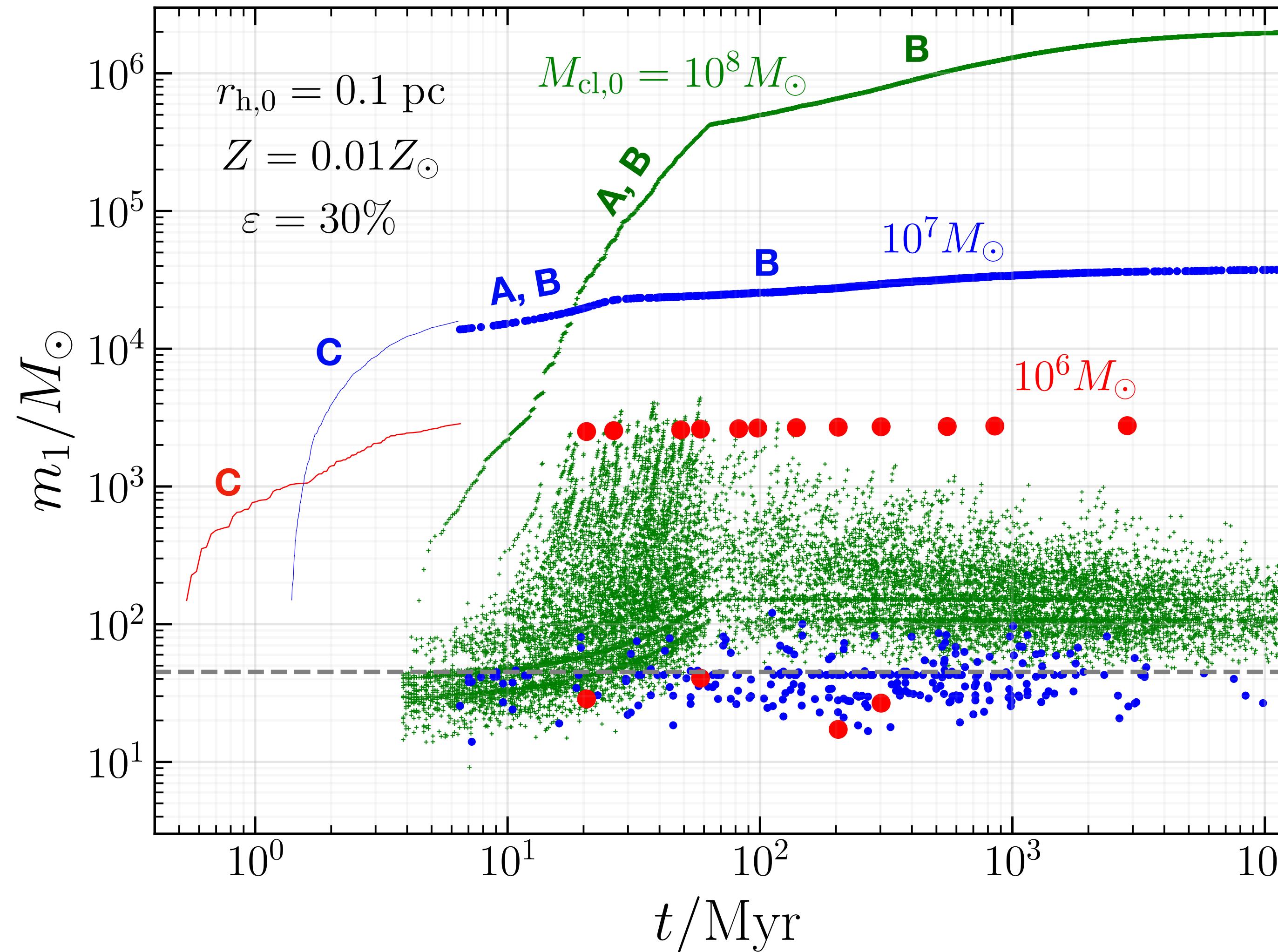
# Comparison with N body



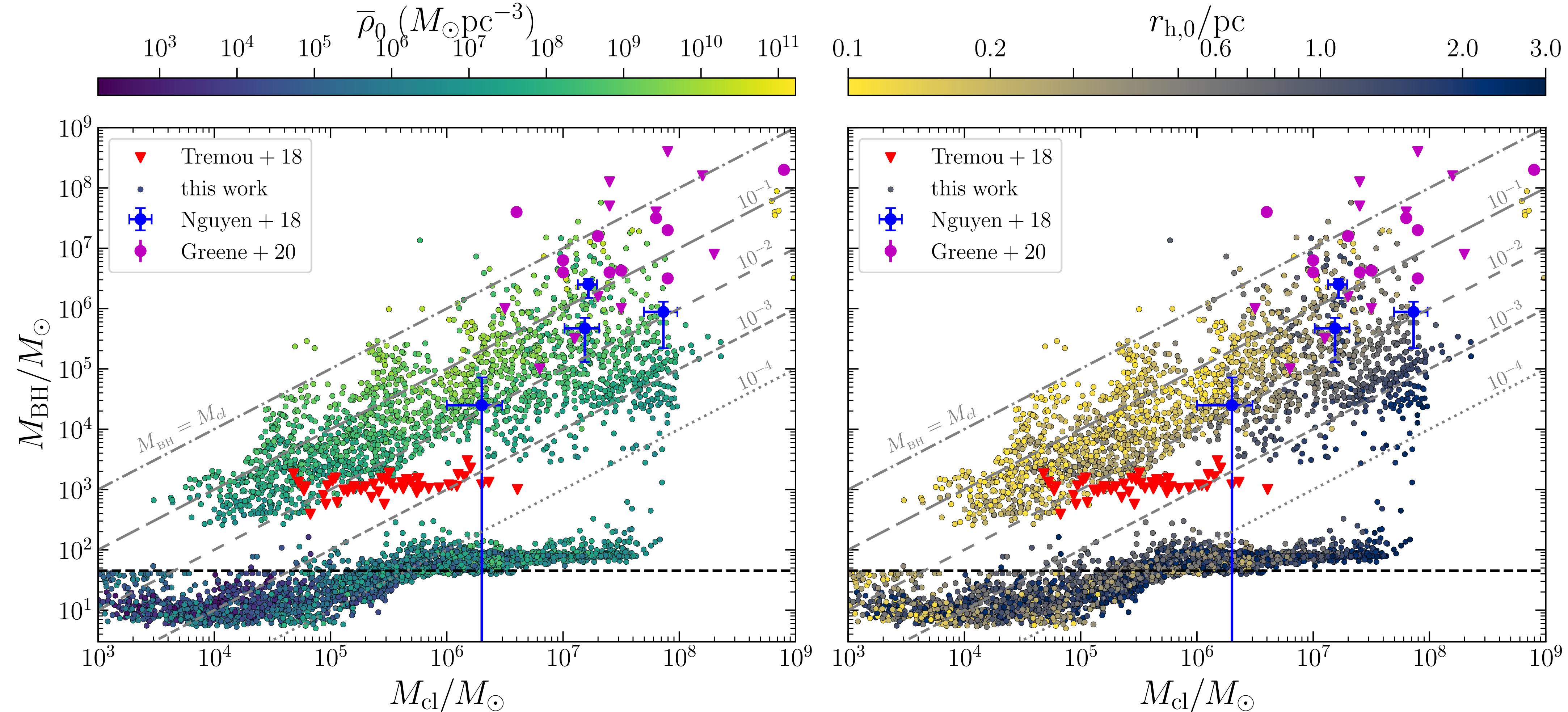
# Growth channels



# Merger tree histories

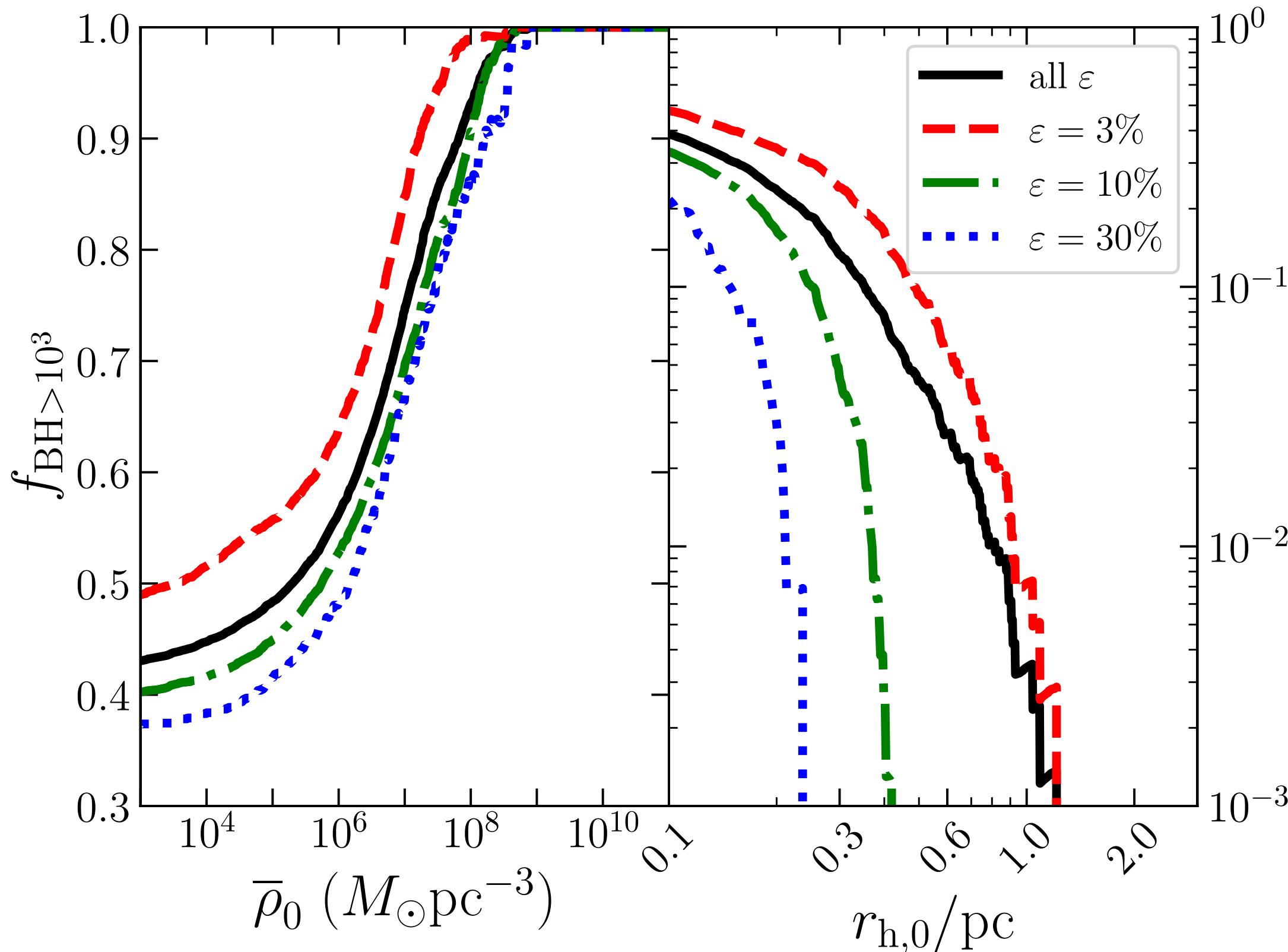


# Comparison with local data

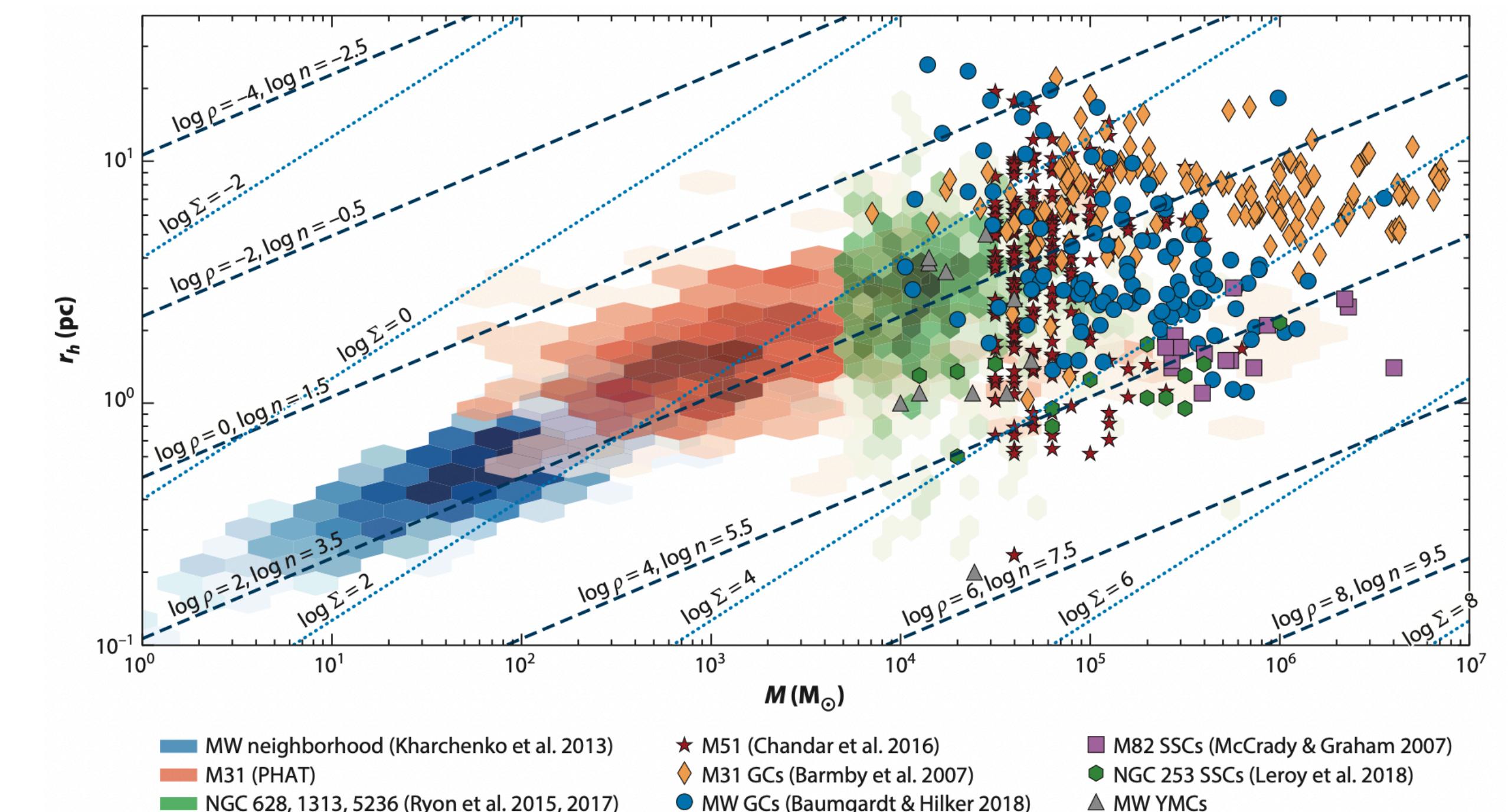


# Initial radius of globulars

**Probability of IMBH formation**

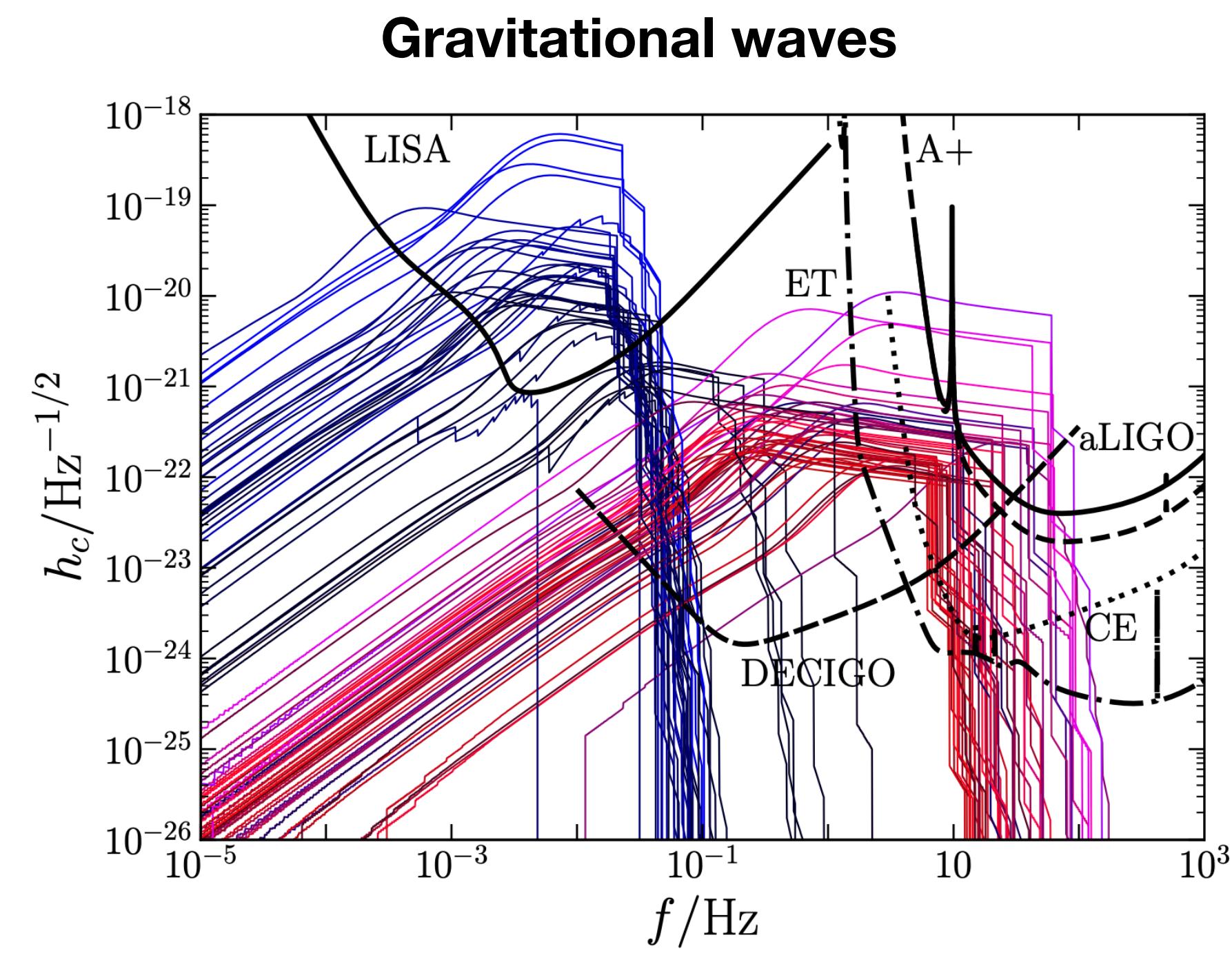


**Mass-radius relation for star clusters**

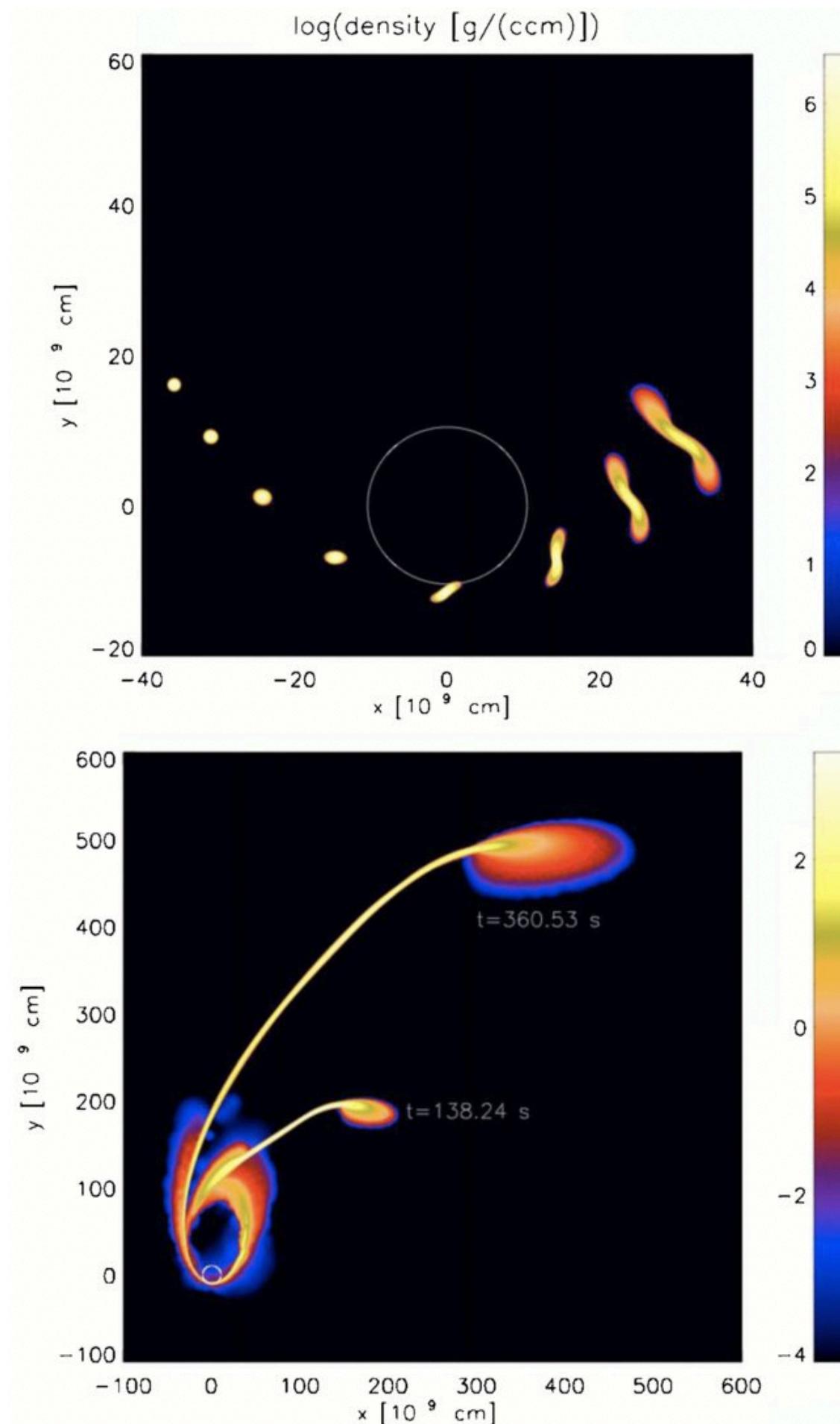


Krumholz et al. (2019)

# Observations

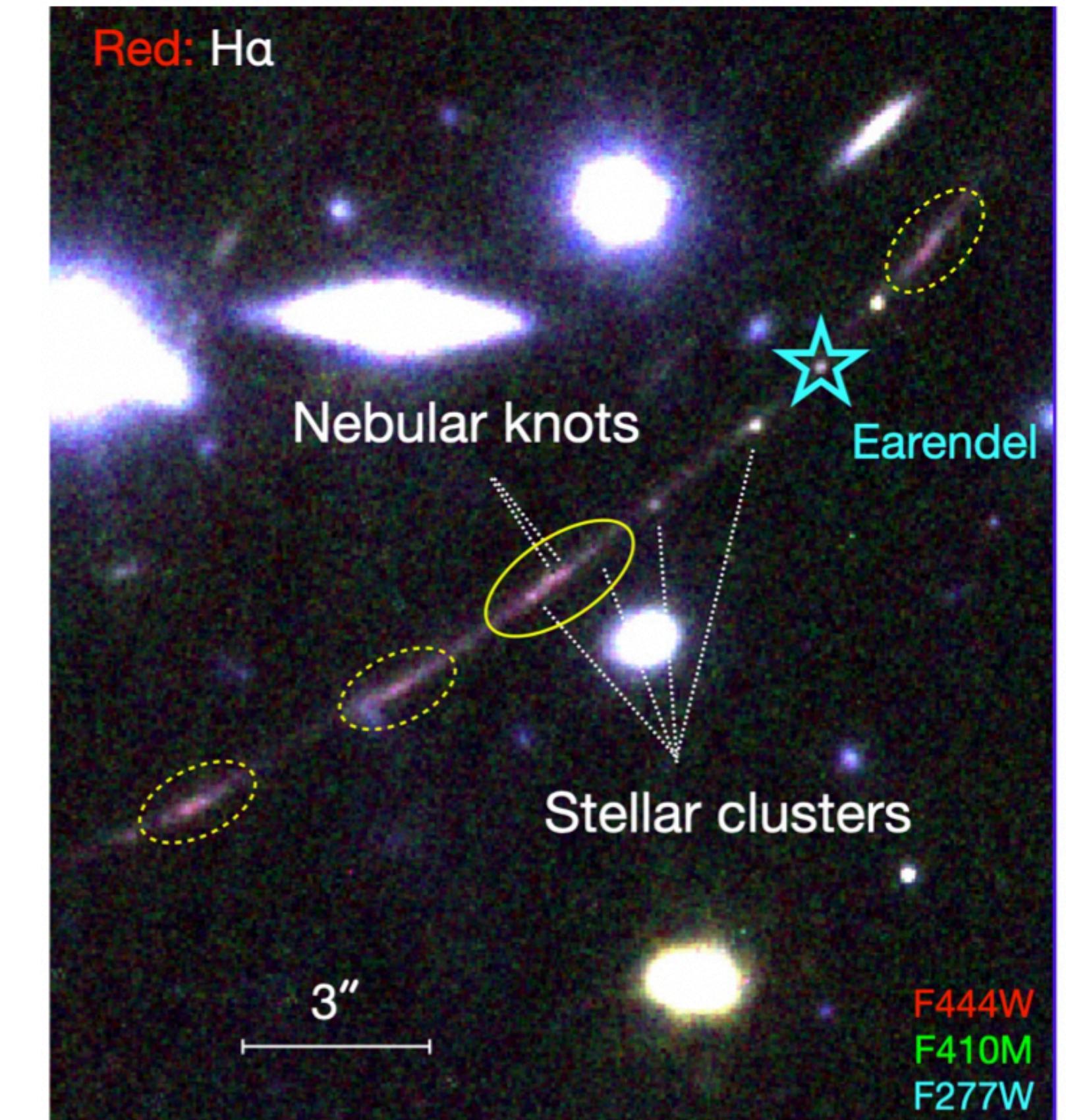


Tidal disruption events



Rosswog et al. (2009)

JWST probes star clusters at  $z \approx 6$



Vanzella et al. (2022)

# Conclusions

- IMBHs can assemble in NSCs via repeated BH mergers
- Our predictions resemble the observed range of NSCs in dwarf galaxies
- There are GW and TDE signatures of the IMBH formation process



A large, illuminated Christmas tree stands prominently in a snowy landscape. The tree is covered in numerous small, glowing yellow lights and topped with a single, bright gold star. It is surrounded by several other snow-covered evergreen trees of various sizes. The ground is a thick layer of white snow, and small snowflakes are visible in the air, creating a classic winter scene.

Thank you  
Merry Christmas!