The strong impact of IMF in star cluster dynamics

Modest 2024/8/20

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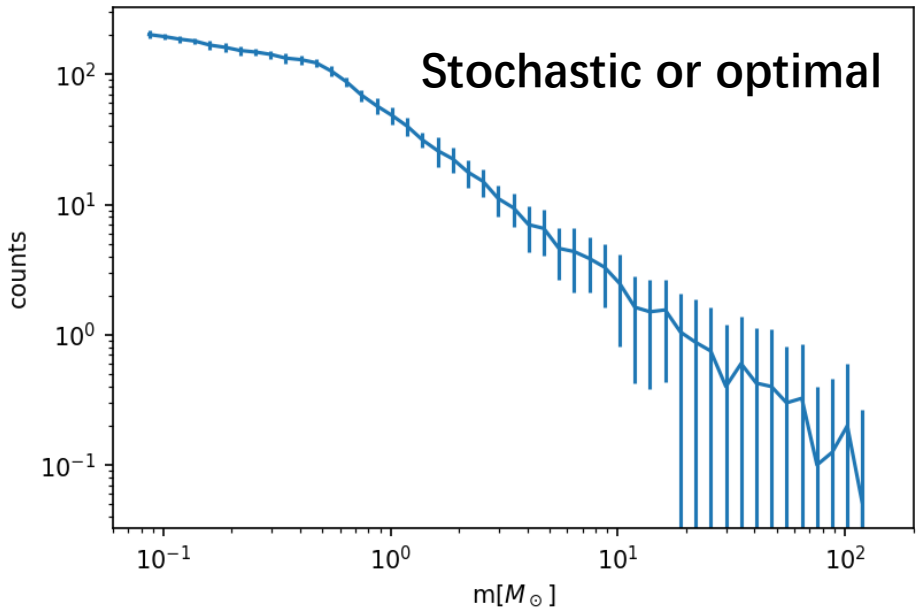
Does IMF have a universal shape?

- How dynamical evolution of star cluster reflect the properties of IMF ?

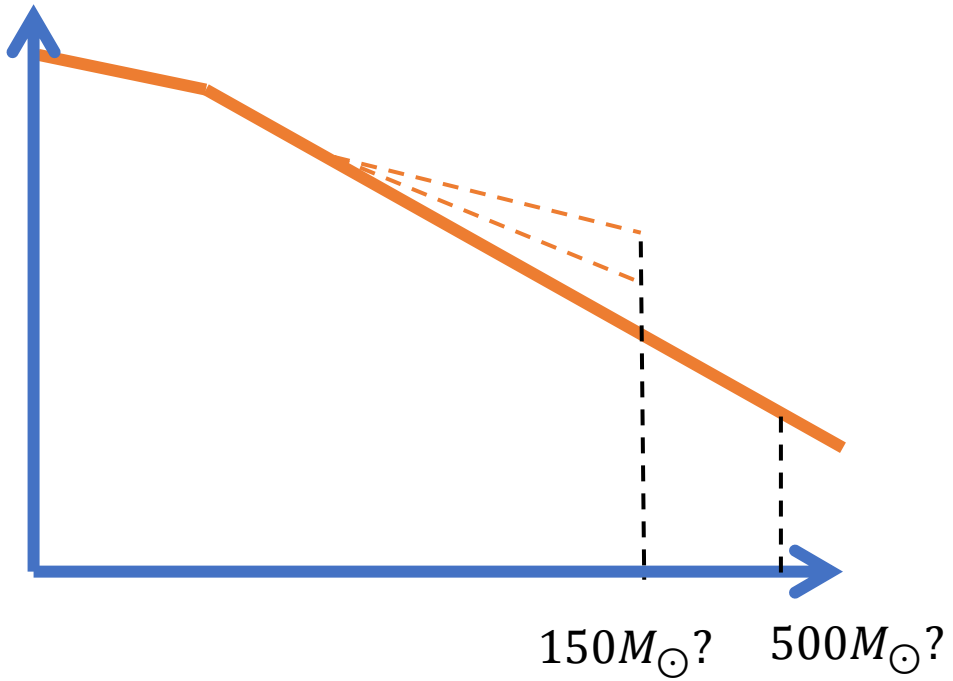
Sampling of IMF

(Weidner+2006,2013, Yan+2017)



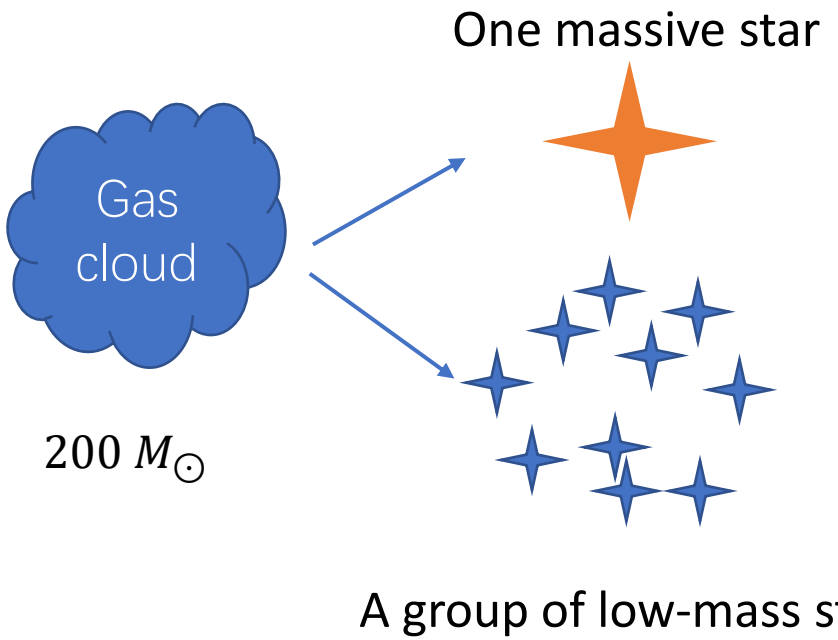
Varying the shape of IMF

(Marks+2012, Natalia's and Ugo's talks)

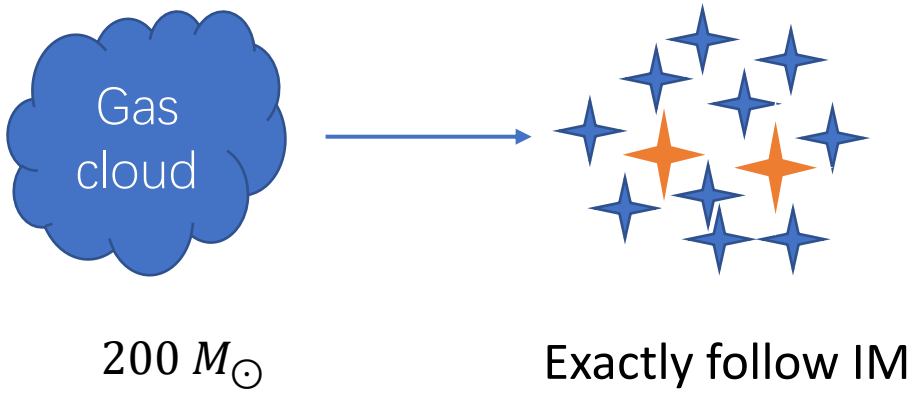


Stochastic or optimal sampling of IMF ?

- Stochastic star formation
- Randomly-sampled IMF

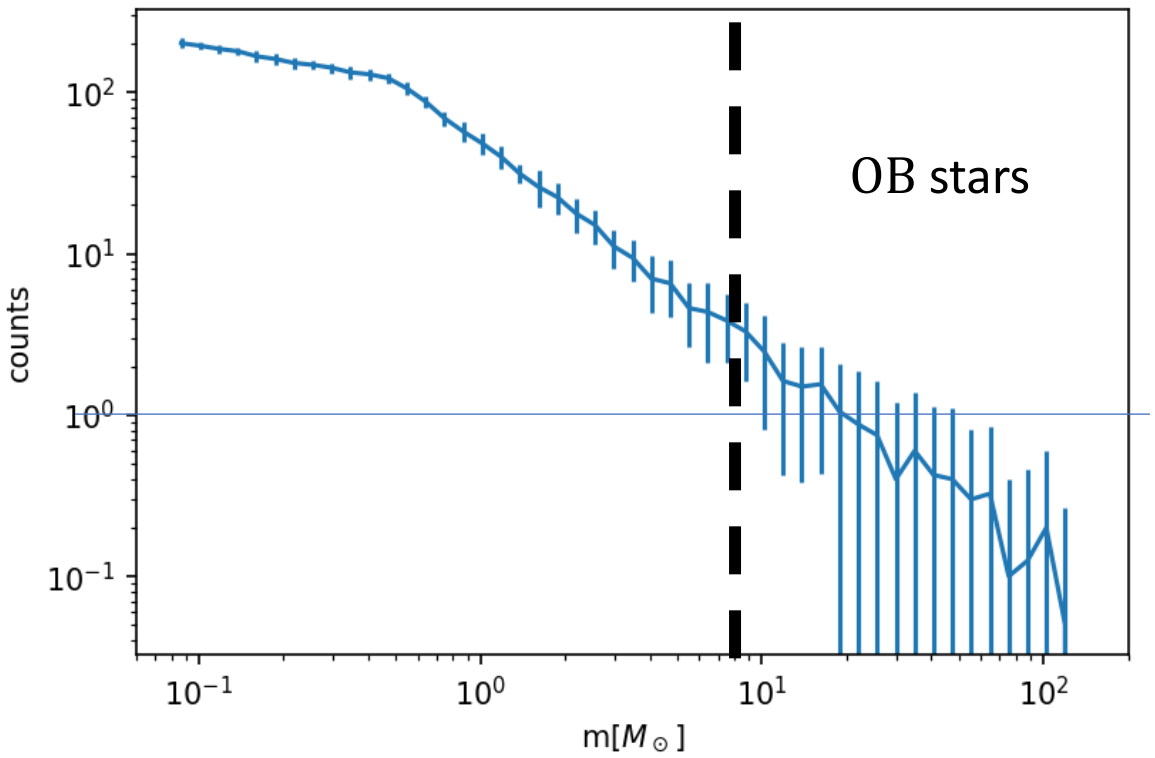


- Self regularized star formation
- Optimally-sampled IMF (Yan+2017)

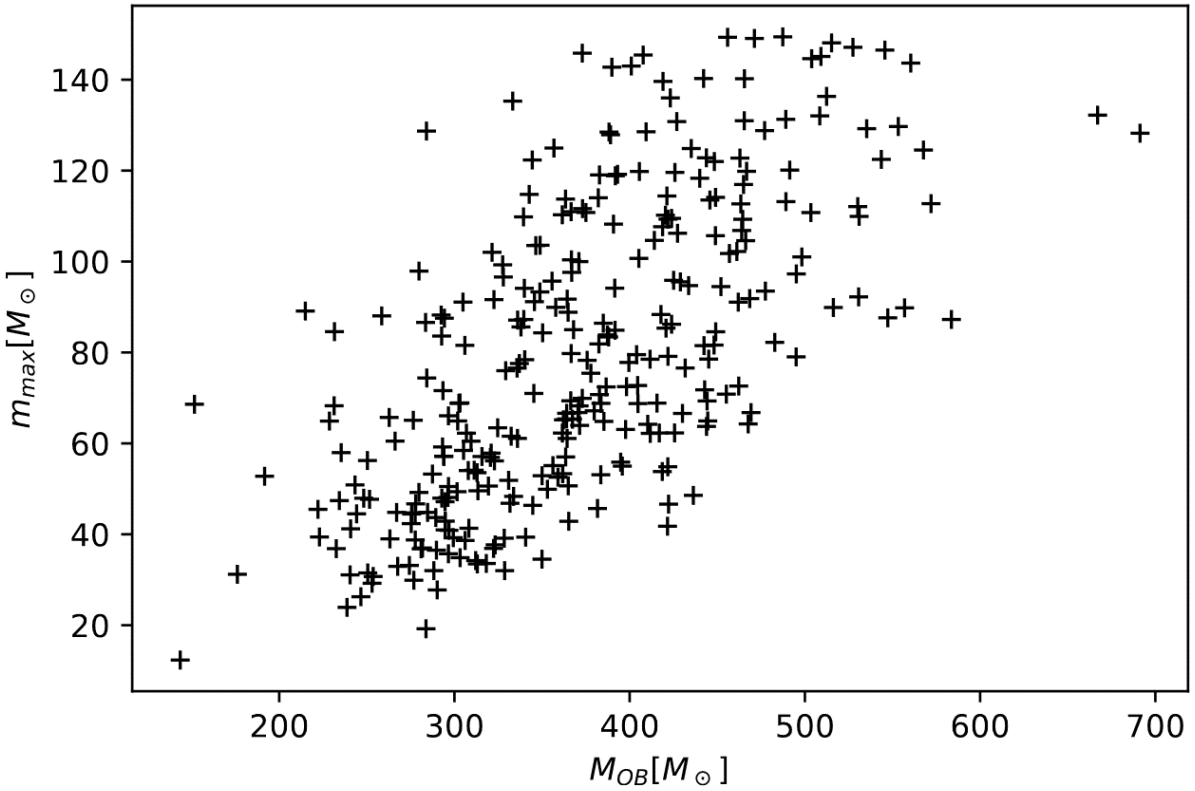


Random sampling→ the number of massive stars has significant uncertainty

Sampling IMF for total mass of 1600 $M_\odot$

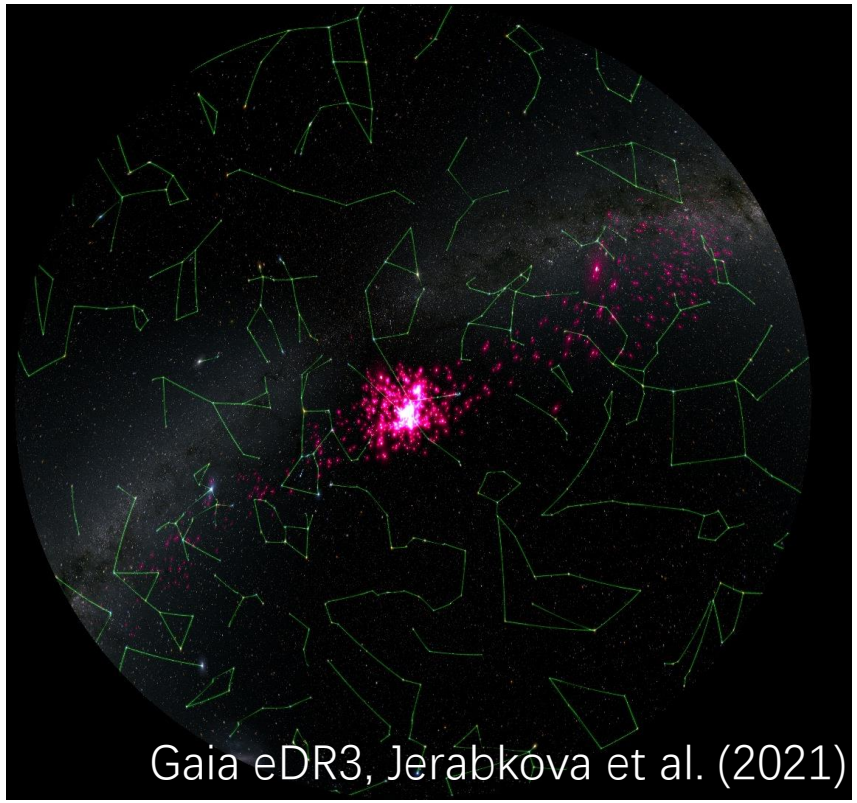


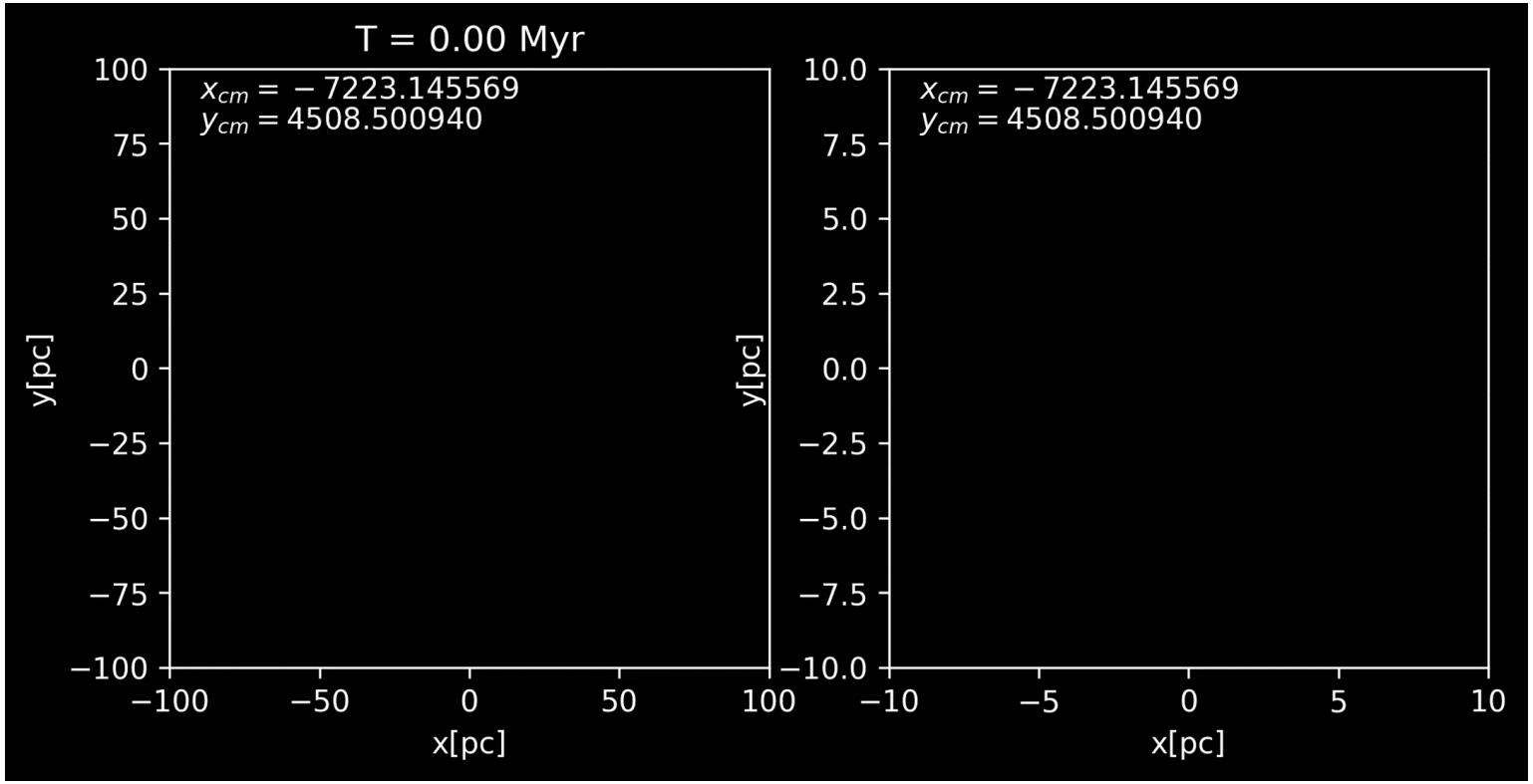
Total OB star mass v.s. Maximum mass of stars



N-body models for Hyades-like open clusters

Using PeTar N-body code: https://github.com/lwang-astro/PeTar

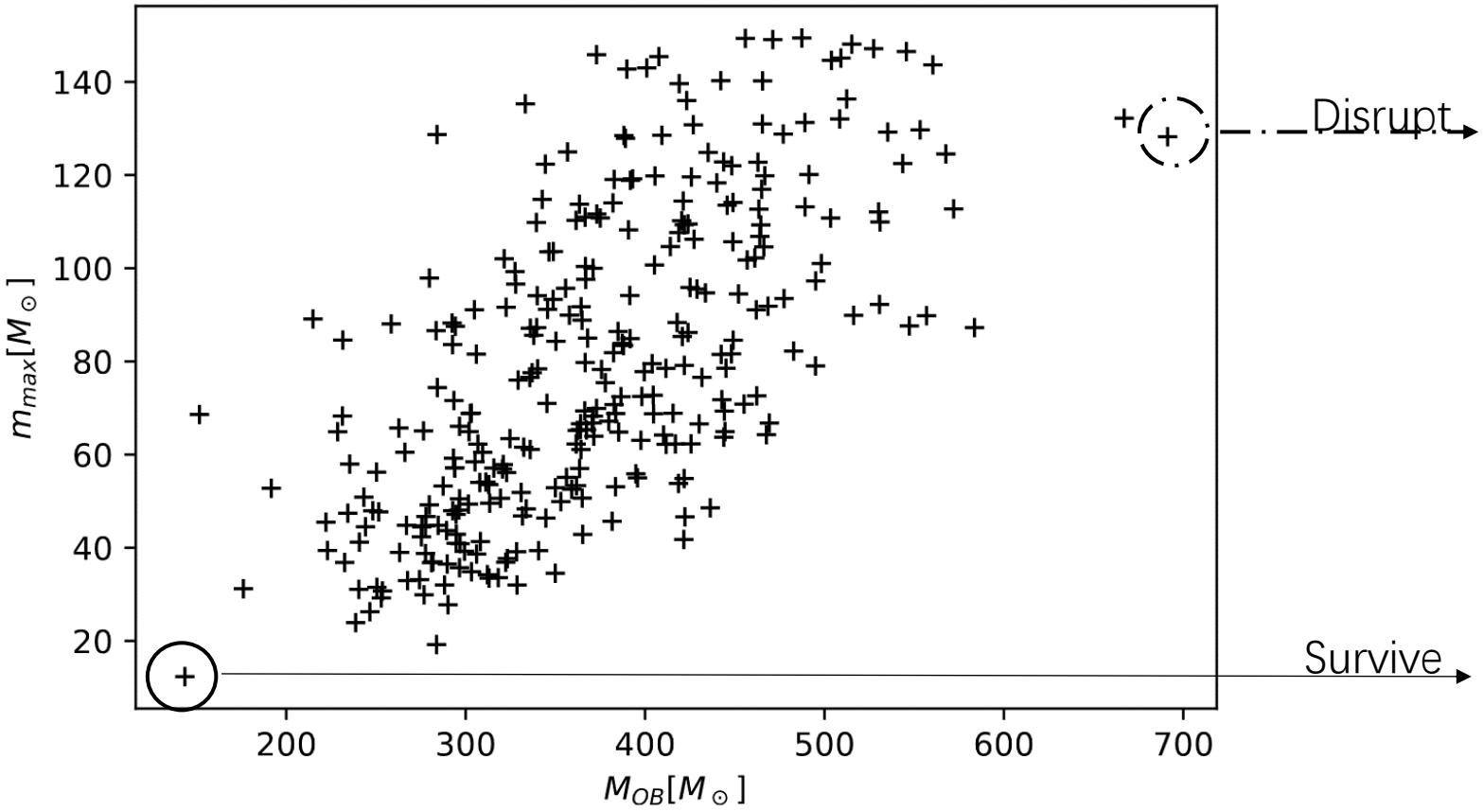


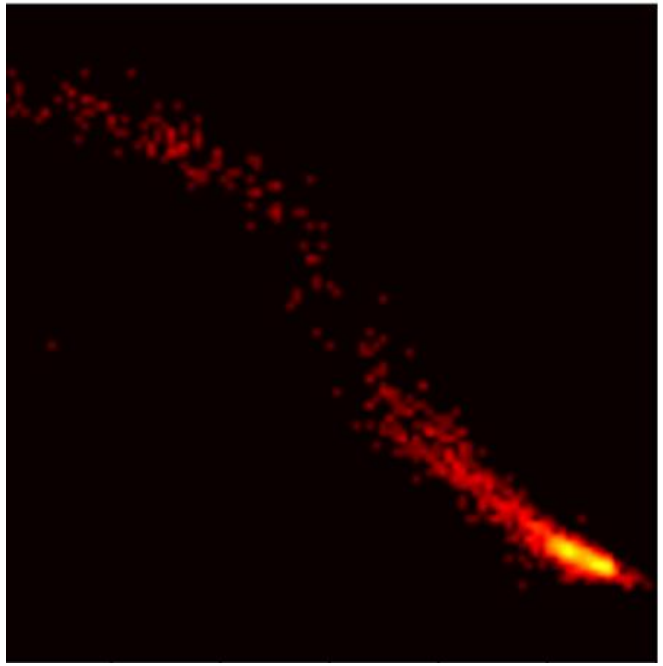


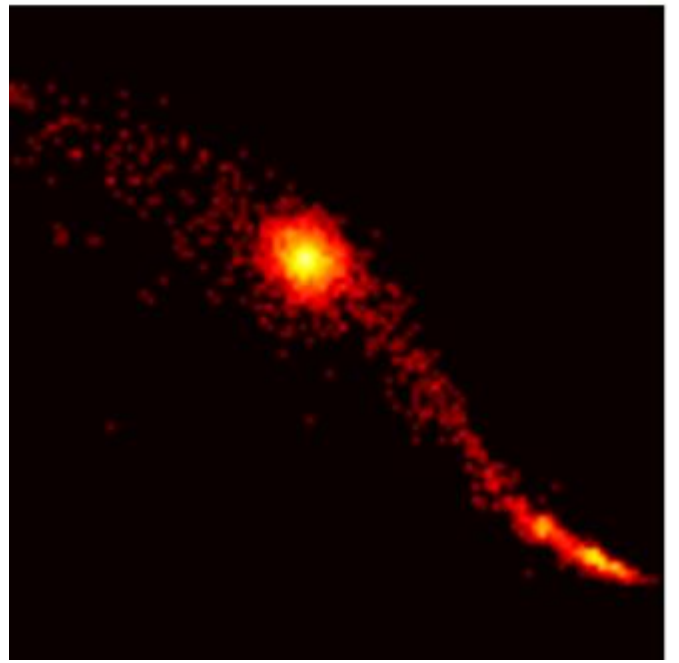
(Wang & Jerabkova 2021)

Identical initial conditions + random sampling IMF → divergent outcomes

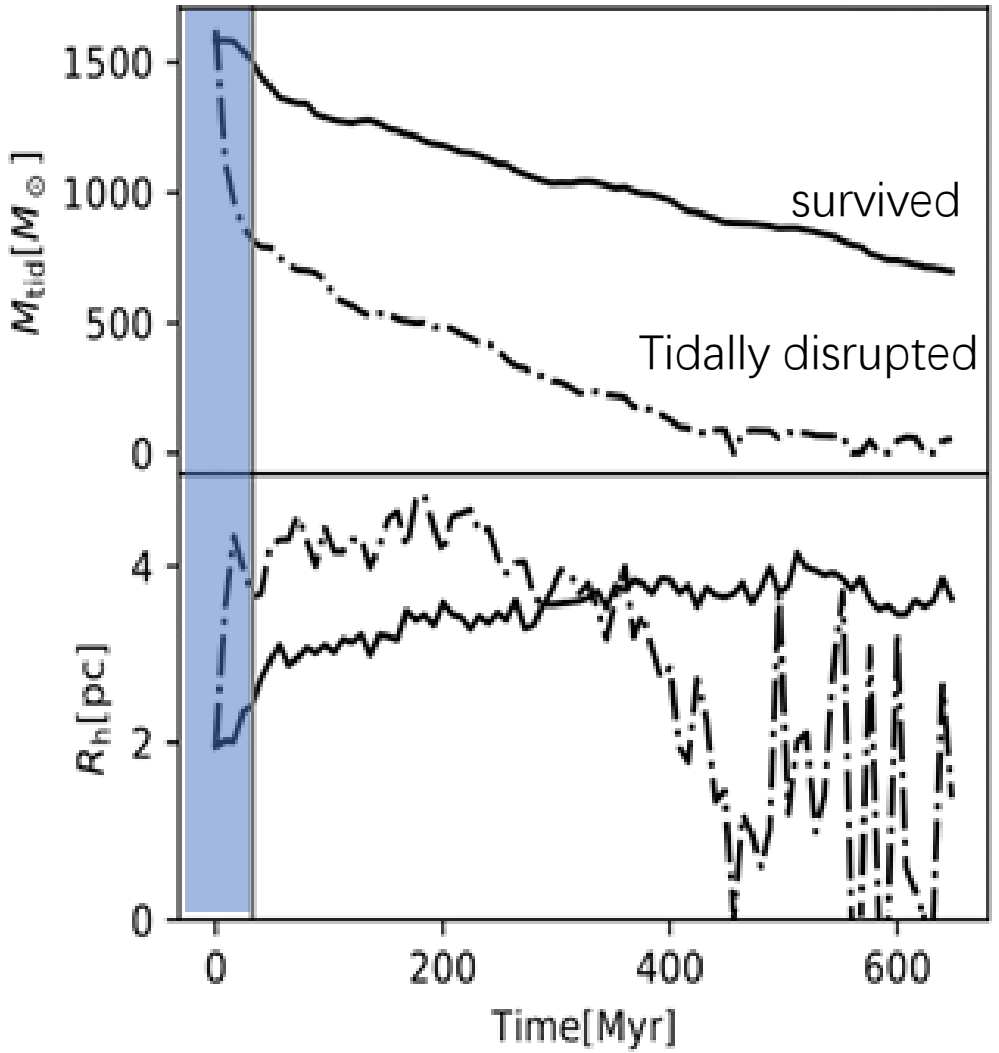
- 300 individual N-body models with the same mass and size



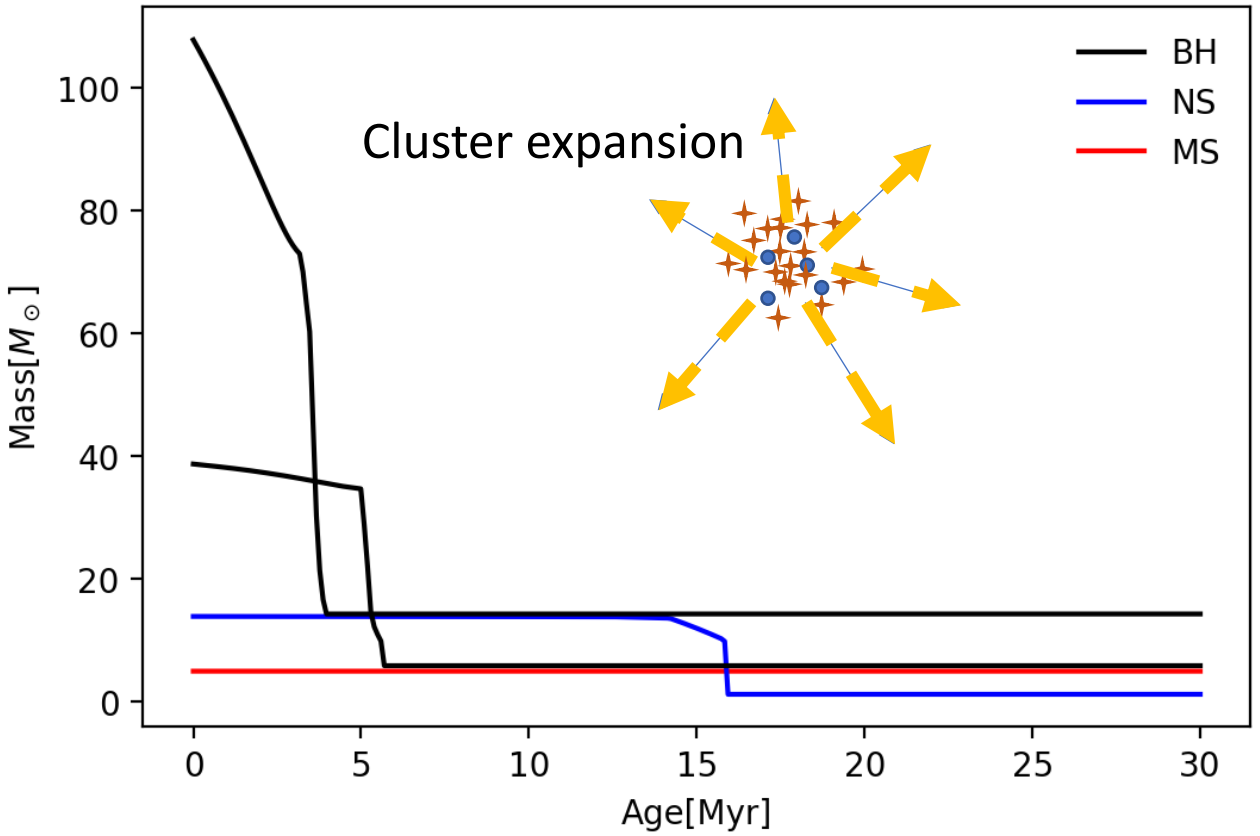




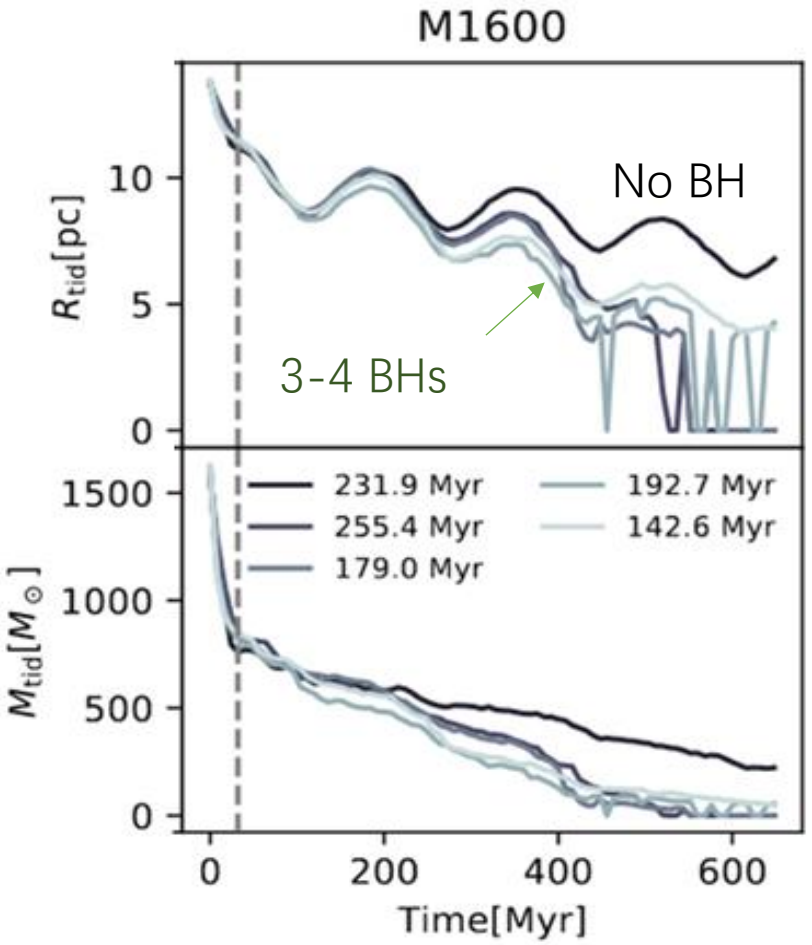
Fast mass loss of massive stars drives cluster expansion < 30 Myr



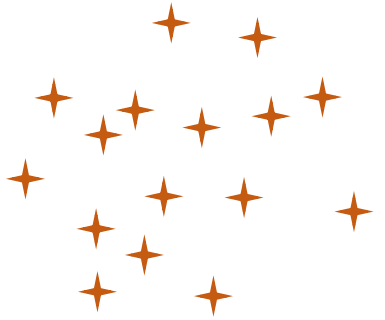
Mass loss of stars within 30 Myr



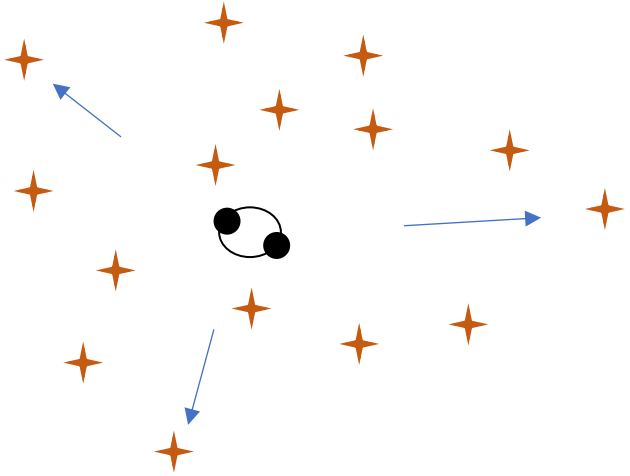
Binary black hole heading > 30 Myr



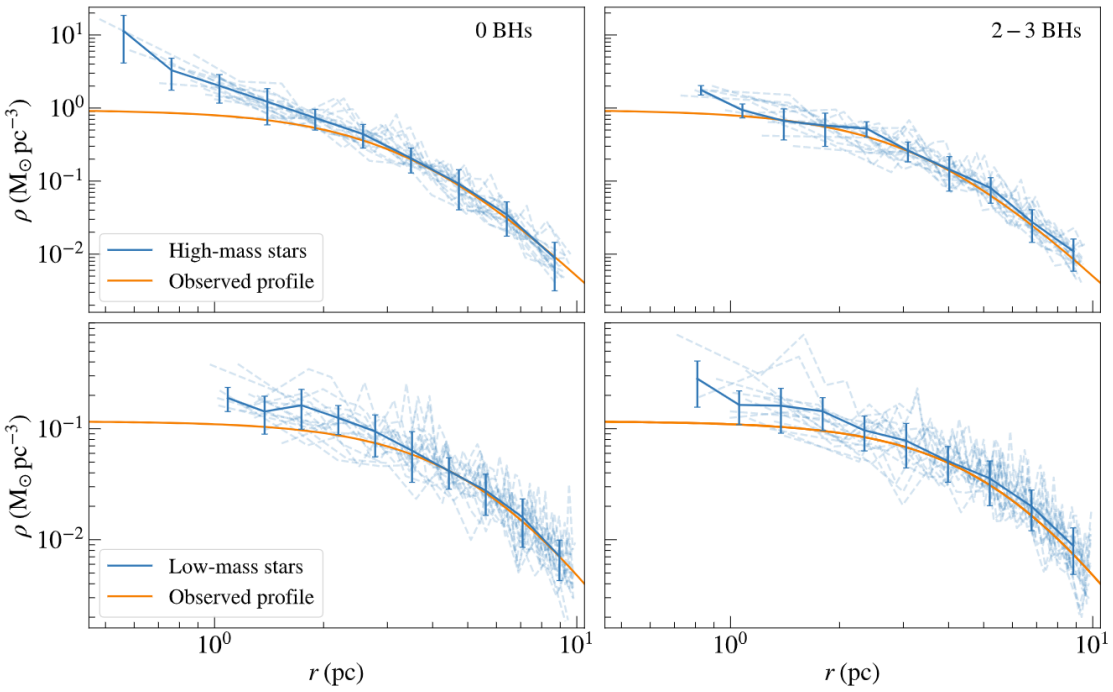
Star cluster can keep dense core without BH

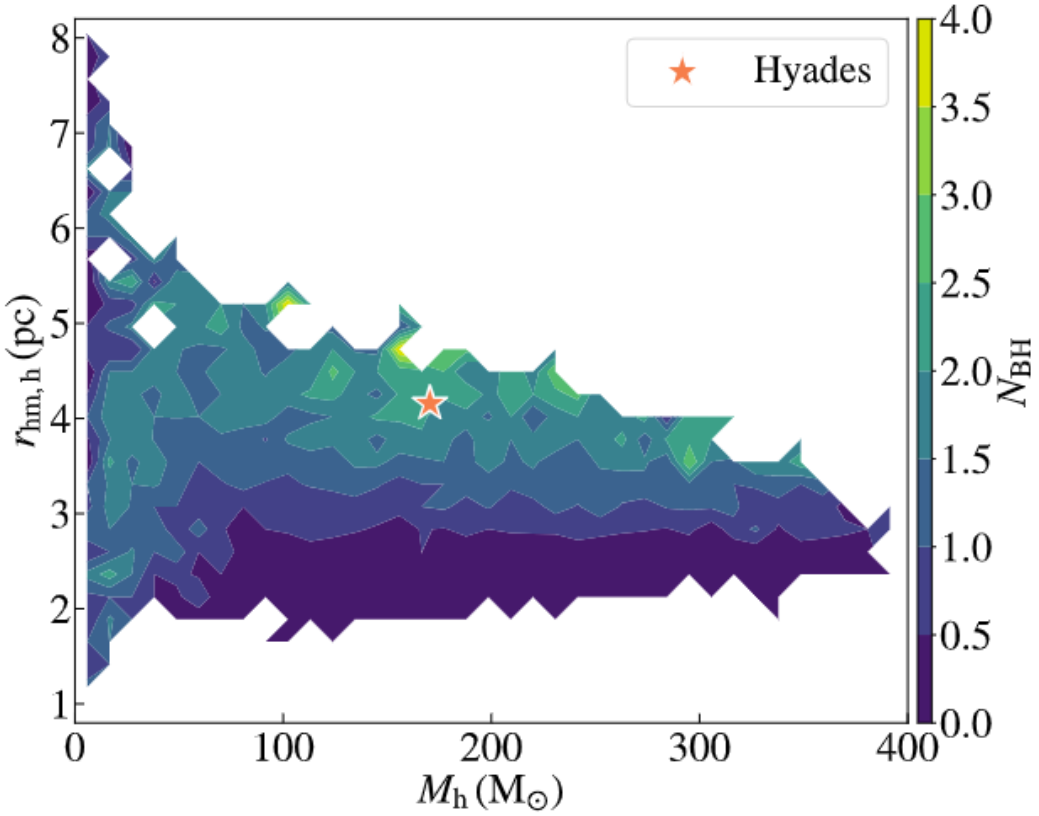


Binary BH eject light stars out → cluster expands



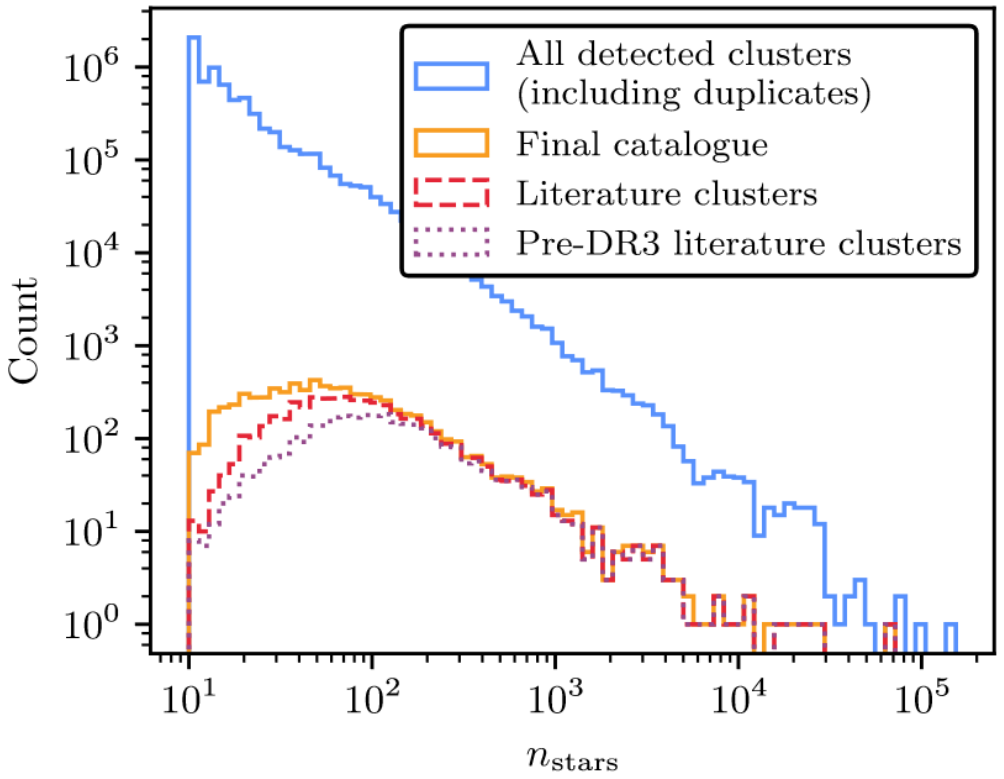
The dynamical features of open clusters reflect the presence of black holes





S. Torniamenti et al (2023, MNRAS)

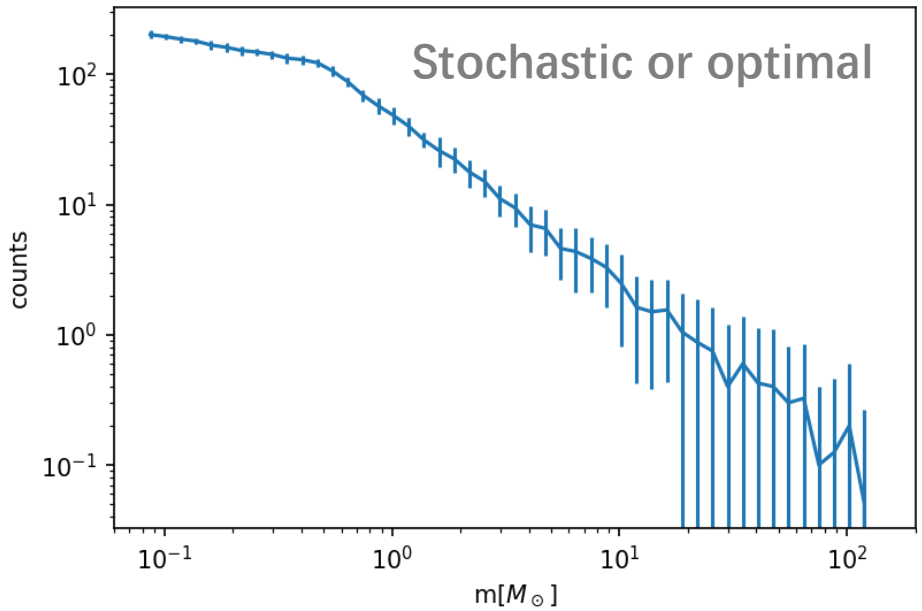
Detecting BHs in open clusters



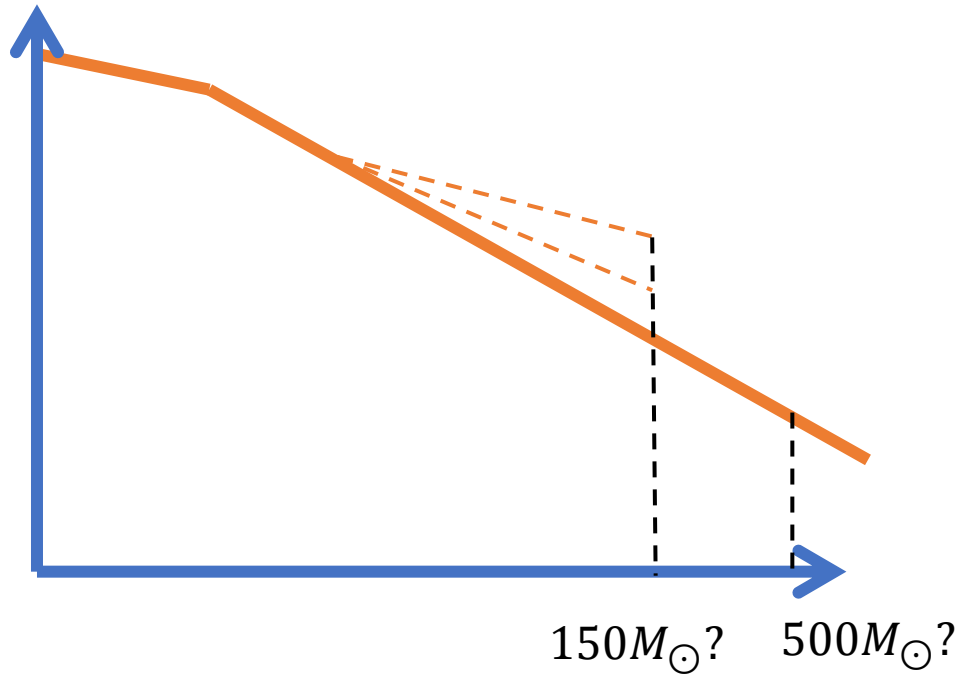
Gaia DR3 Open cluster (OC) catalog (Hunt+2023)

- Build a library of N-body models for open clusters (Zepeng Zheng)
  - Each cluster: 300 models
  - Total: up to 10^5 models
- Machine learning method to find BHs in Gaia OC catalog
- What is the preferred sampling of IMF for OCs

Sampling of IMF

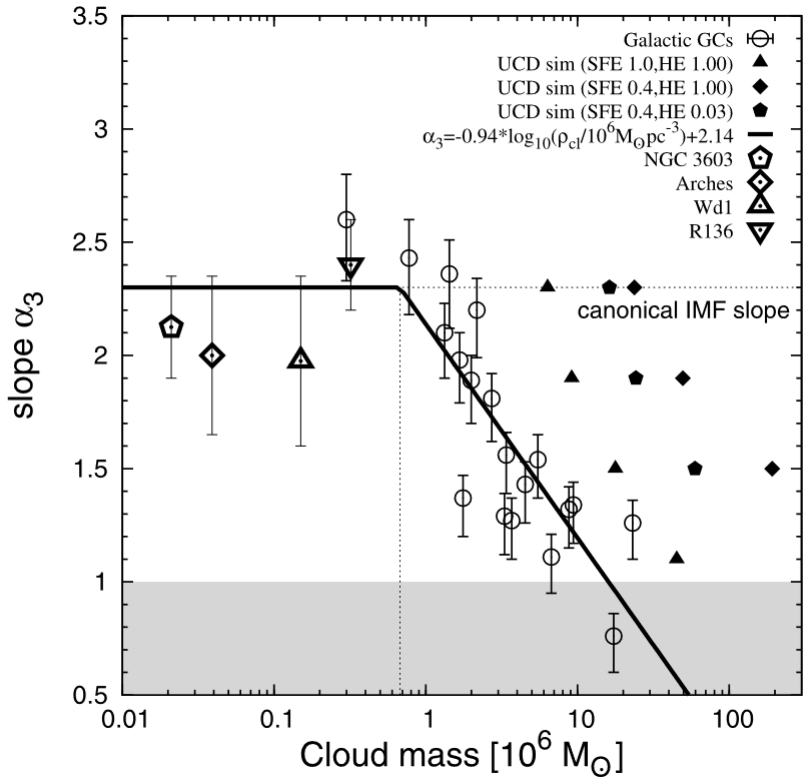


Varying the massive part of IMF



Vary the top part of IMF → Vary BH population

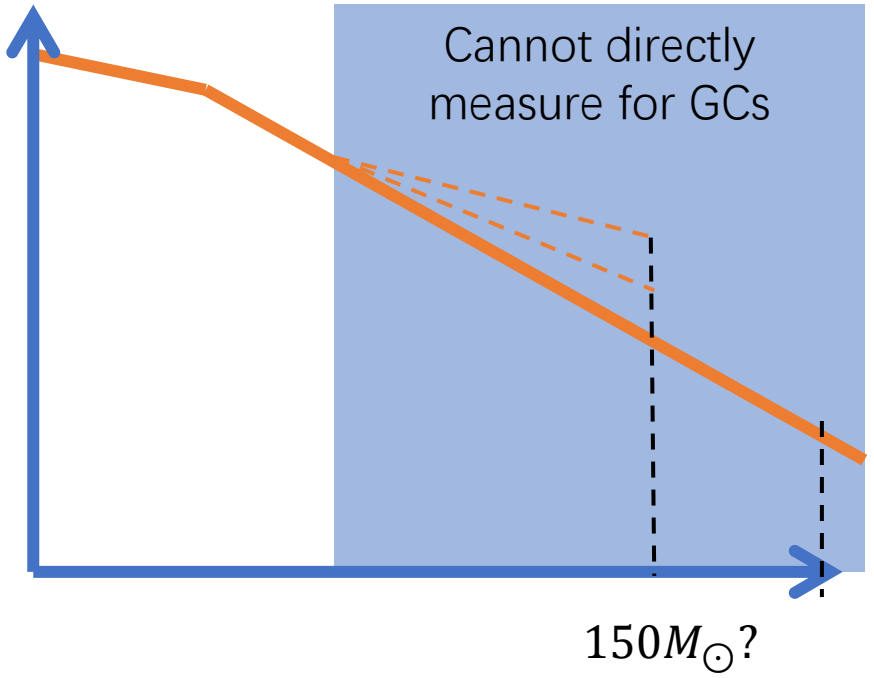
Globular clusters (GCs) might contain top-heavy IMF (Marks+2012)



$0.08 < m \leq 0.5\ M_\odot \quad \alpha_1 = -1.3$

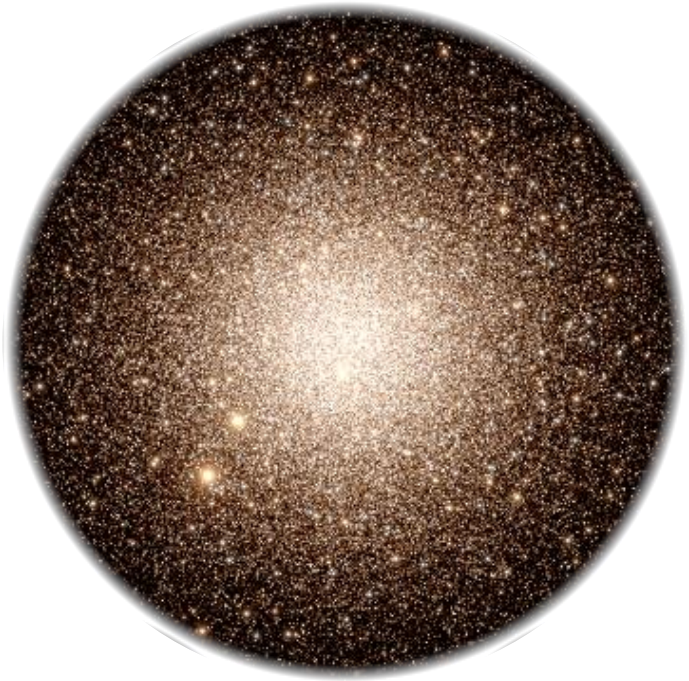
$0.5 < m \leq 1 M_\odot \quad \alpha_2 = -2.3$

$1 < m < m_{\max}$ vary α_3 or maximum mass



The top part of IMF affect the morphology of GCs

- Kroupa+(1993) IMF
- $\alpha_3 = -2.7 \rightarrow N_{BH} = 245$

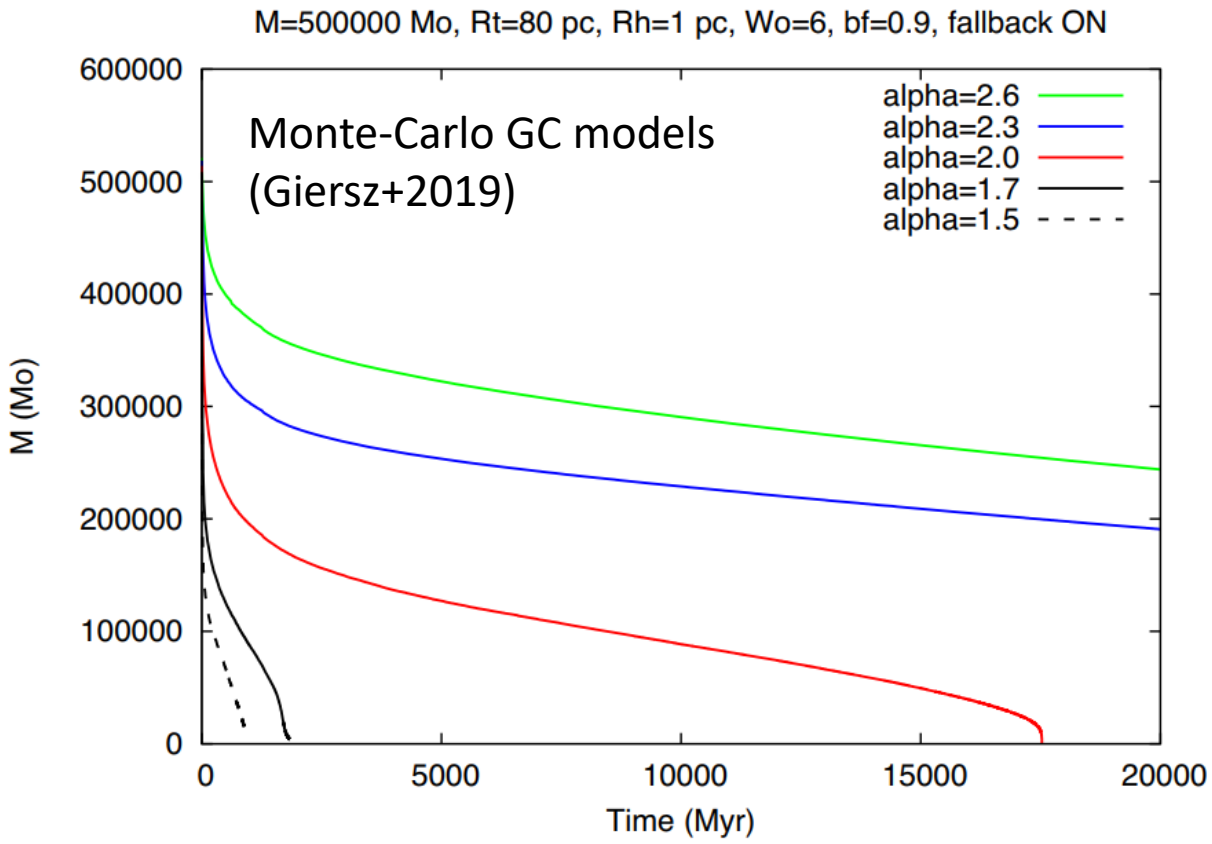


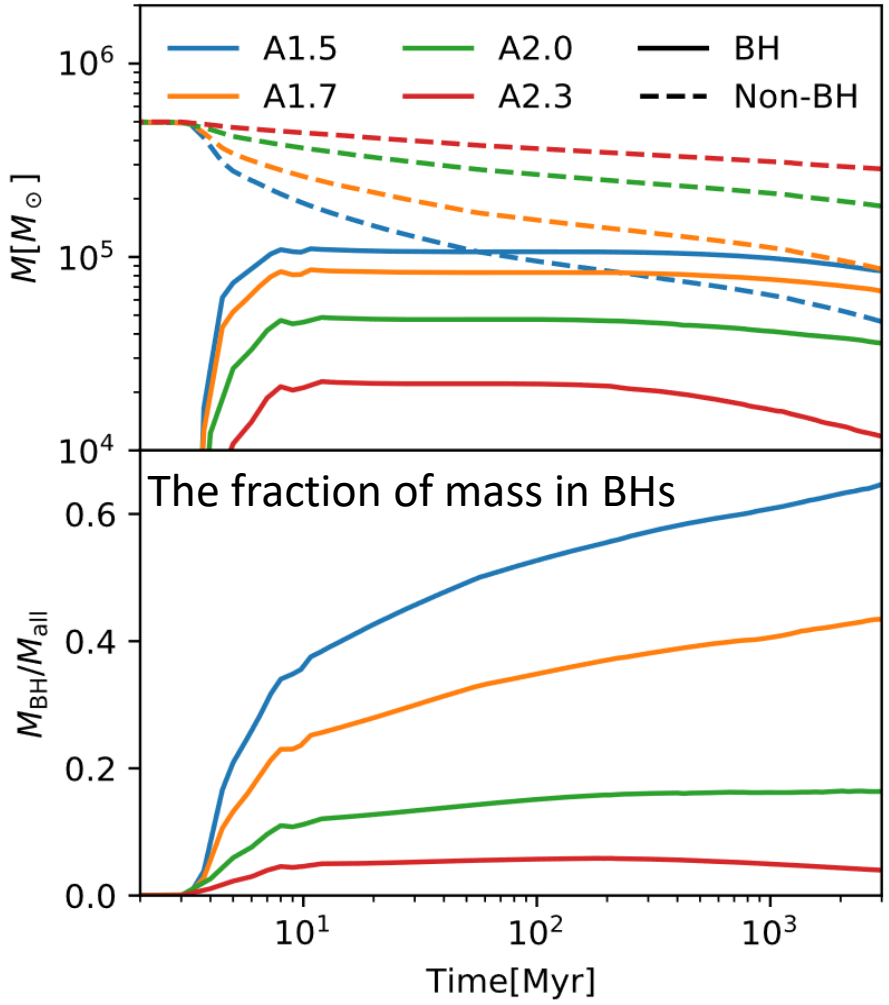
- Kroupa (2001) IMF
- $\alpha_3 = -2.3 \rightarrow N_{BH} = 1037$

DRAGON models (Wang et al, 2016)

Top-heavy IMF → fast dissolution of GCs + more BHs

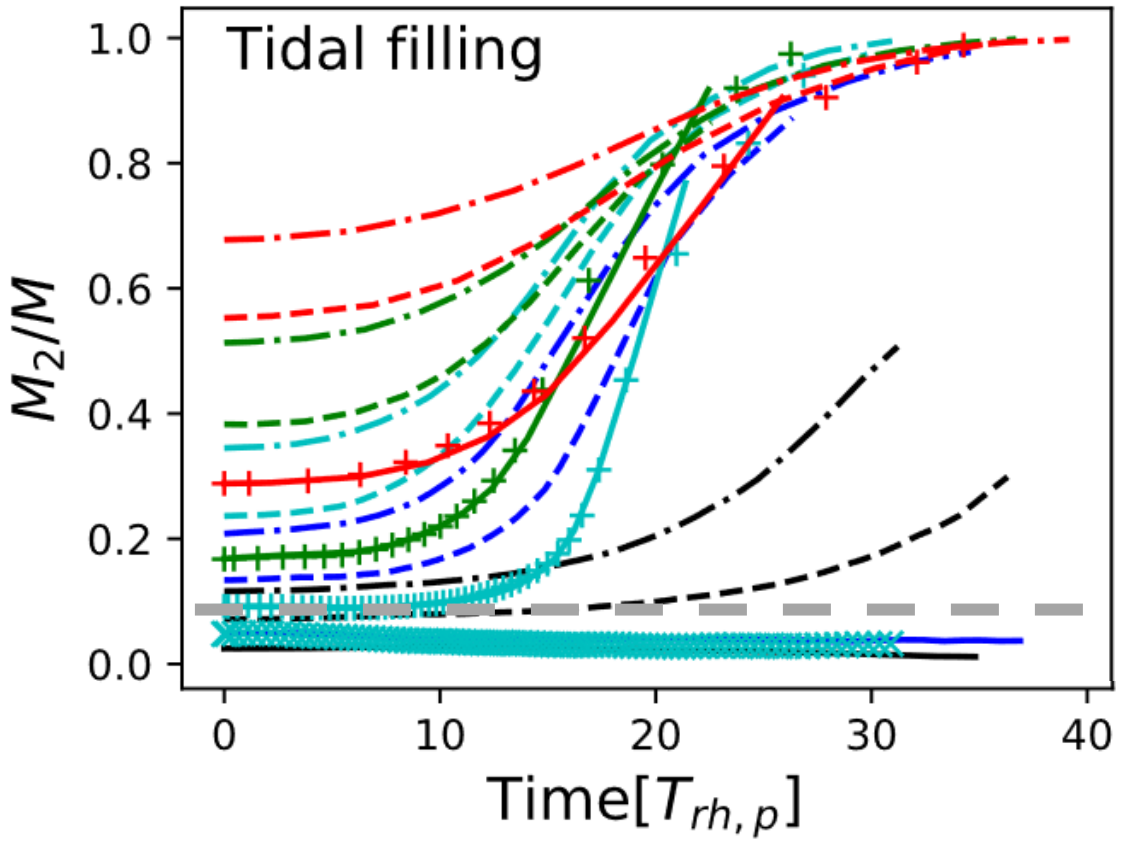
GC dissolute within 3 Gyr for $\alpha > -1.7$





N-body models (Wang+2021)

GCs will eventually evolve into two extreme cases



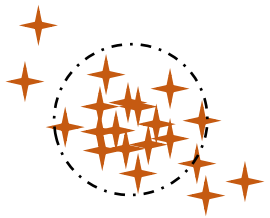
Breen & Heggie (2013), Wang (2020)

Dark cluster with only BHs
(Banerjee 2011)

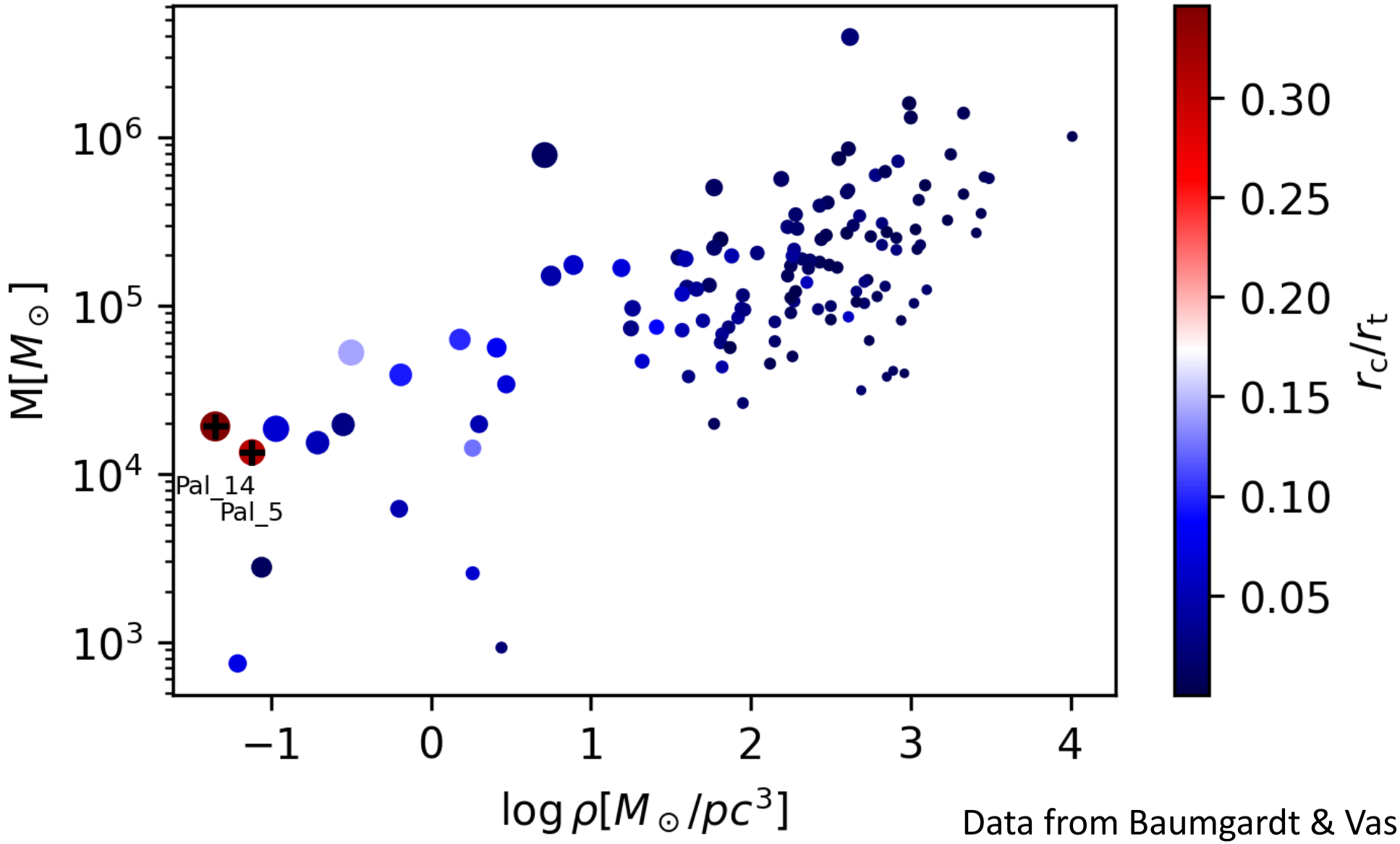
- We may only observe a biased population of GCs in the Milky Way
- GC with top-heavy IMF might have already been disrupted or have become dark clusters

Kroupa (2001) IMF

GCs with no BH

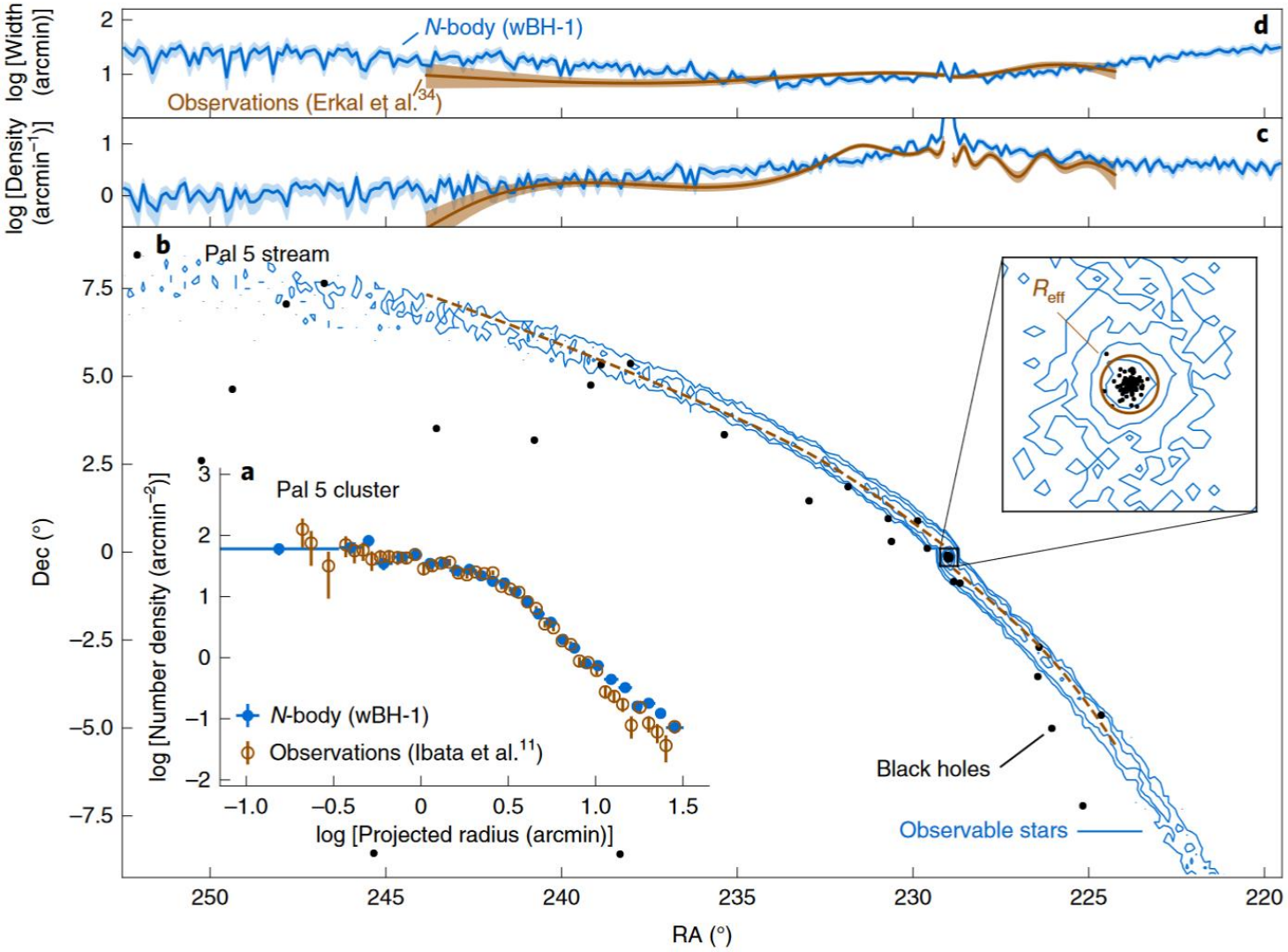


Which observed GC may have a top-heavy IMF ?



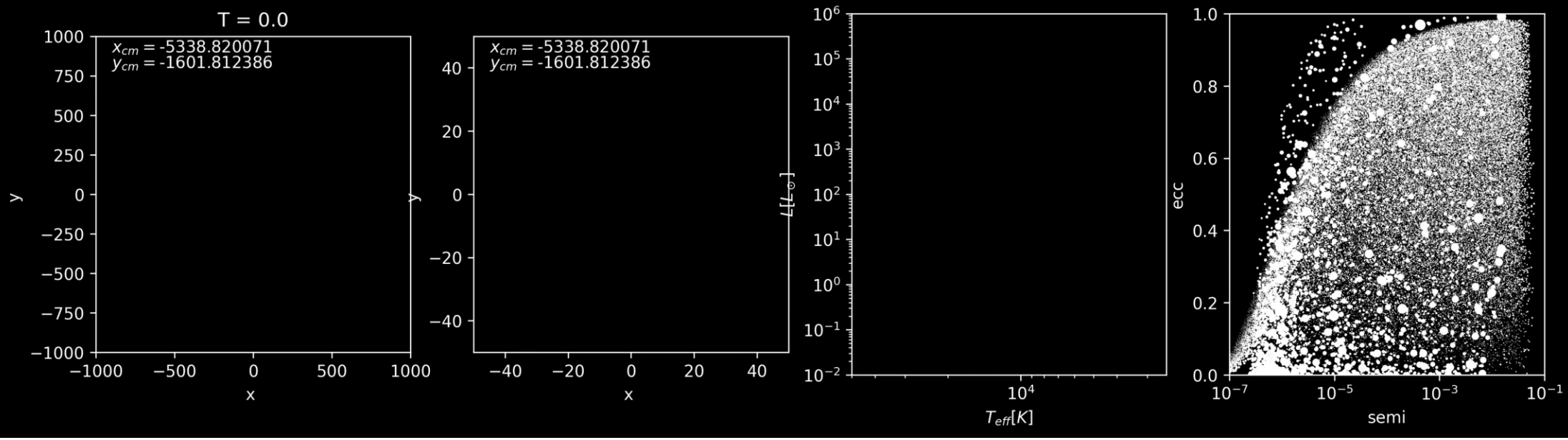
Data from Baumgardt & Vasiliev (2021)

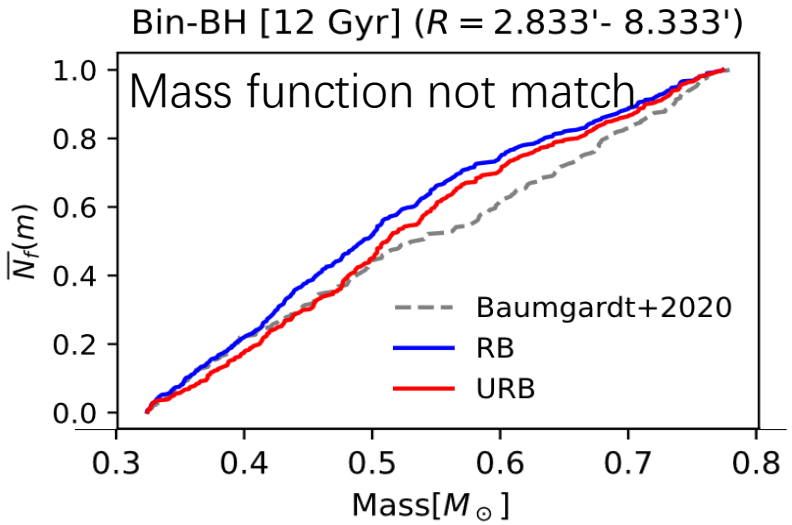
Pal 5 may contain a large number of BHs



Gieles+2021

N-body models of Pal 5 with binaries and tidal streams





Wang+2024

- Compare mass functions with resolved and unresolved binaries (see Henriette Wirth's talk)

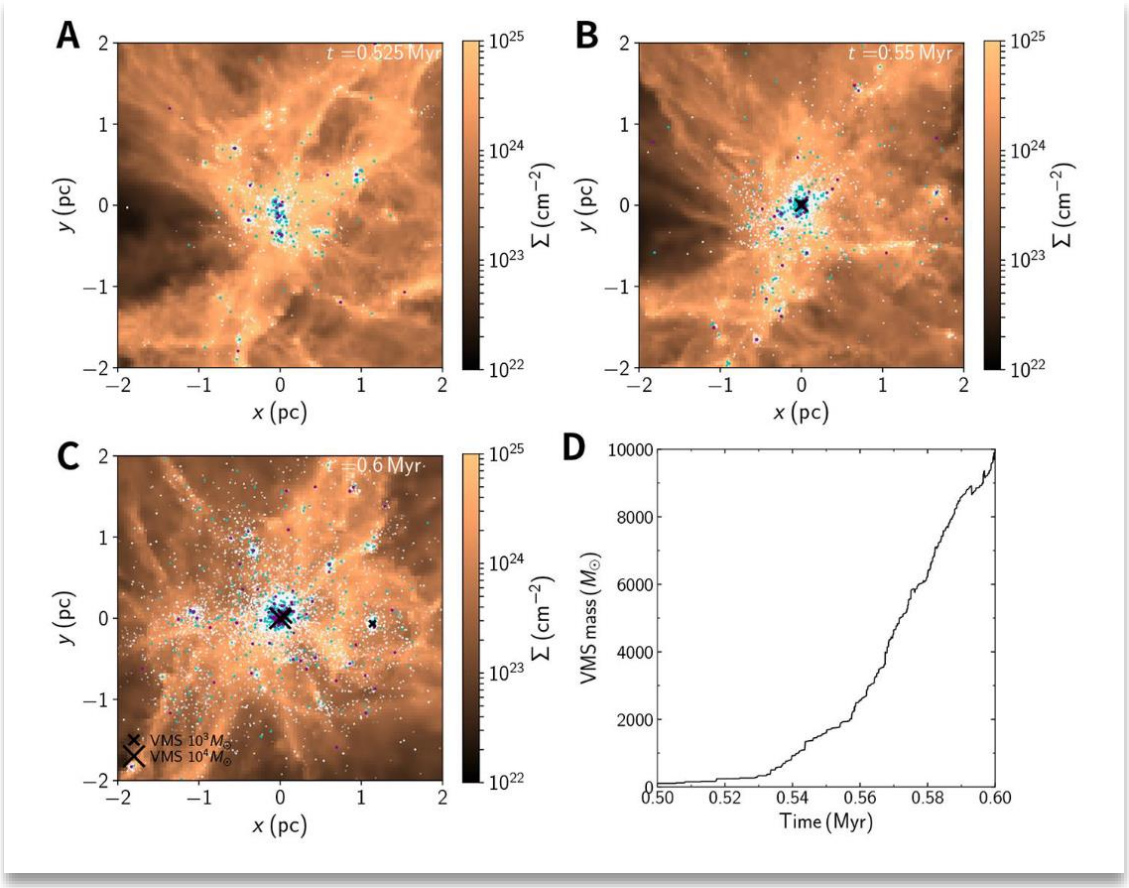
Next step: find a possible top-heavy IMF that fit observation of Pal 5 and tidal stream

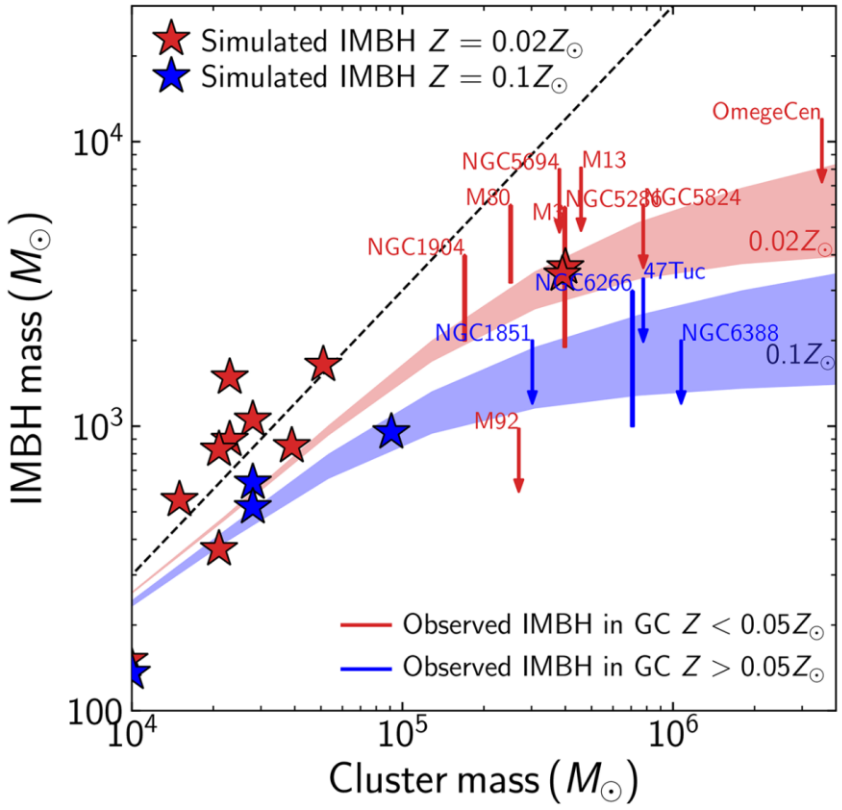
Summary

- Dynamical evolution of star clusters is sensitive to the top part of IMF ($> 8\ M_{\odot}$)
  - Fast mass loss of massive stars (<30 Myr)
  - Binary BH heating (>30 Myr)
- By comparing dynamical models with observations, we may constrain the number of BHs and characterize the top end of IMF in star clusters
  - Open cluster → how to sample IMF (stochastic or optimal)
  - Globular clusters → top-heavy IMF

Runaway collisions during globular cluster formation

ASURA+BRIDGE code: SPH, PeTar, radiation feedback, BSEEMP (Fujii+2021a,b,2022, also see poster of Yunyu Wang)





Fujii+2024, Science