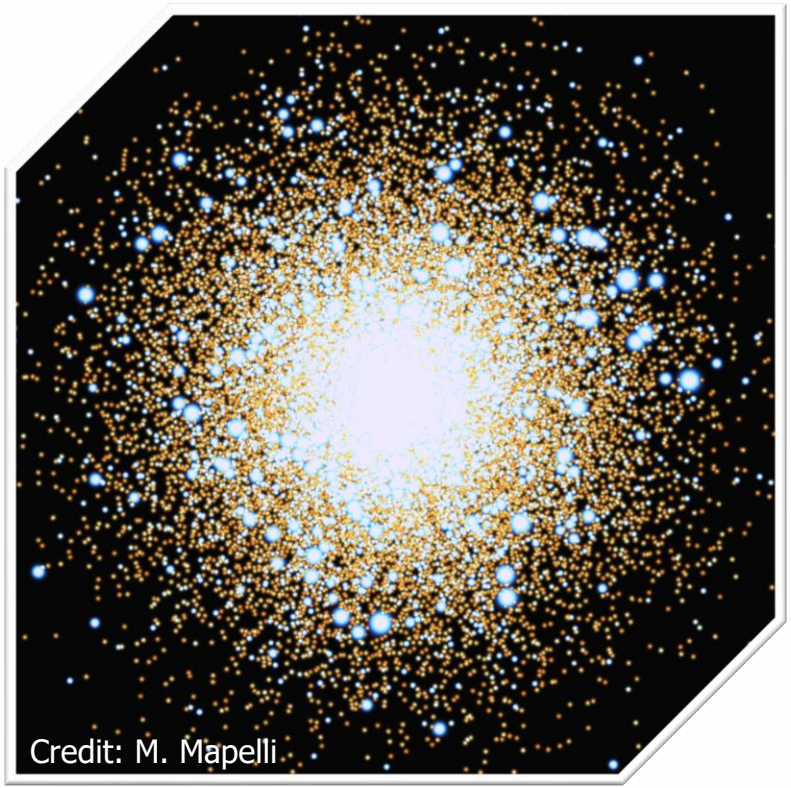
15th September 2023



Star Clusters and the nursery of Binary Black Holes

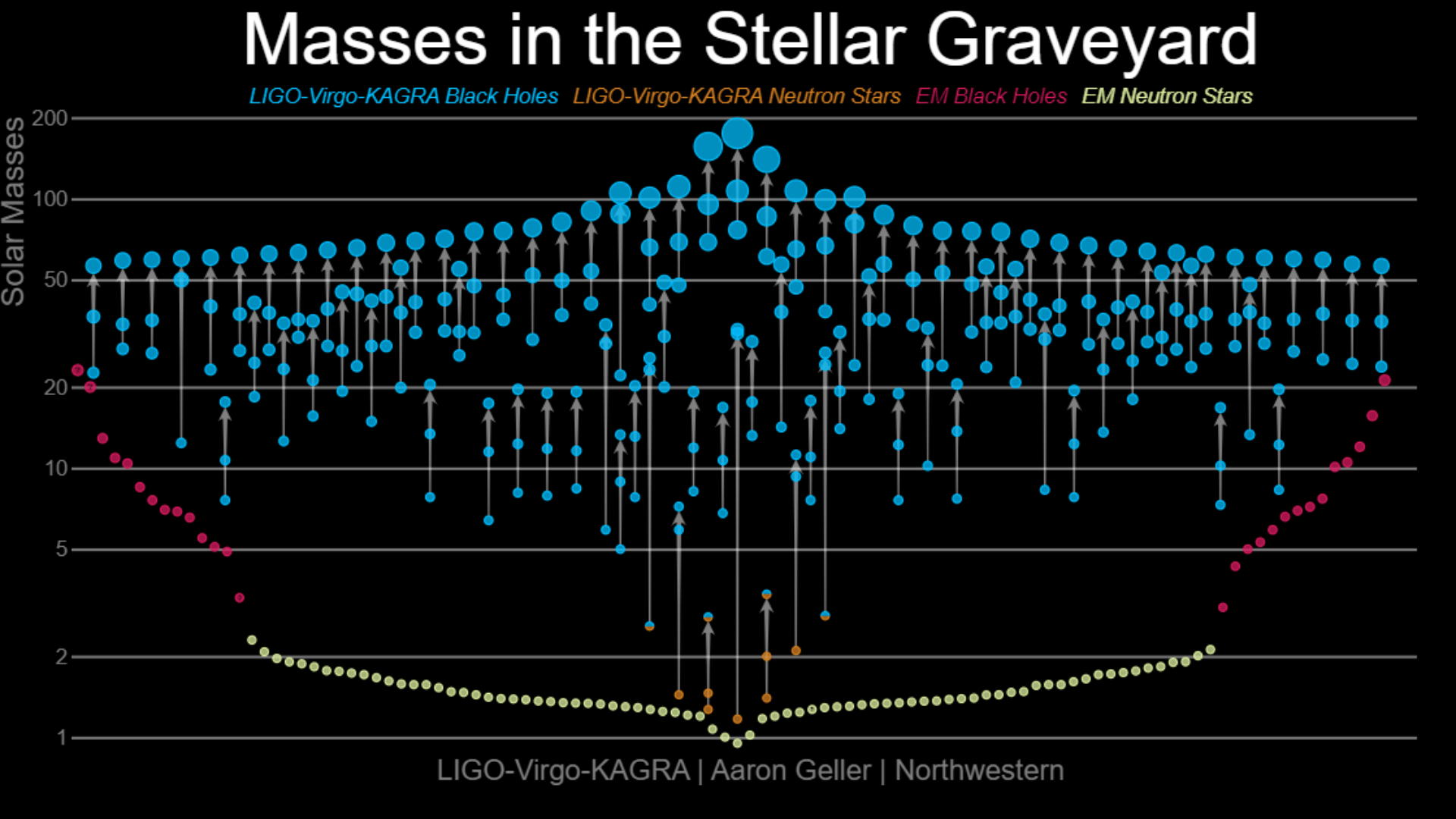
Stefano Torniamenti

University of Padova

Collaborators:
M. Mapelli, S. Rastello, B. Mestichelli, C. Perigois, M. Gieles, M. Arca Sedda

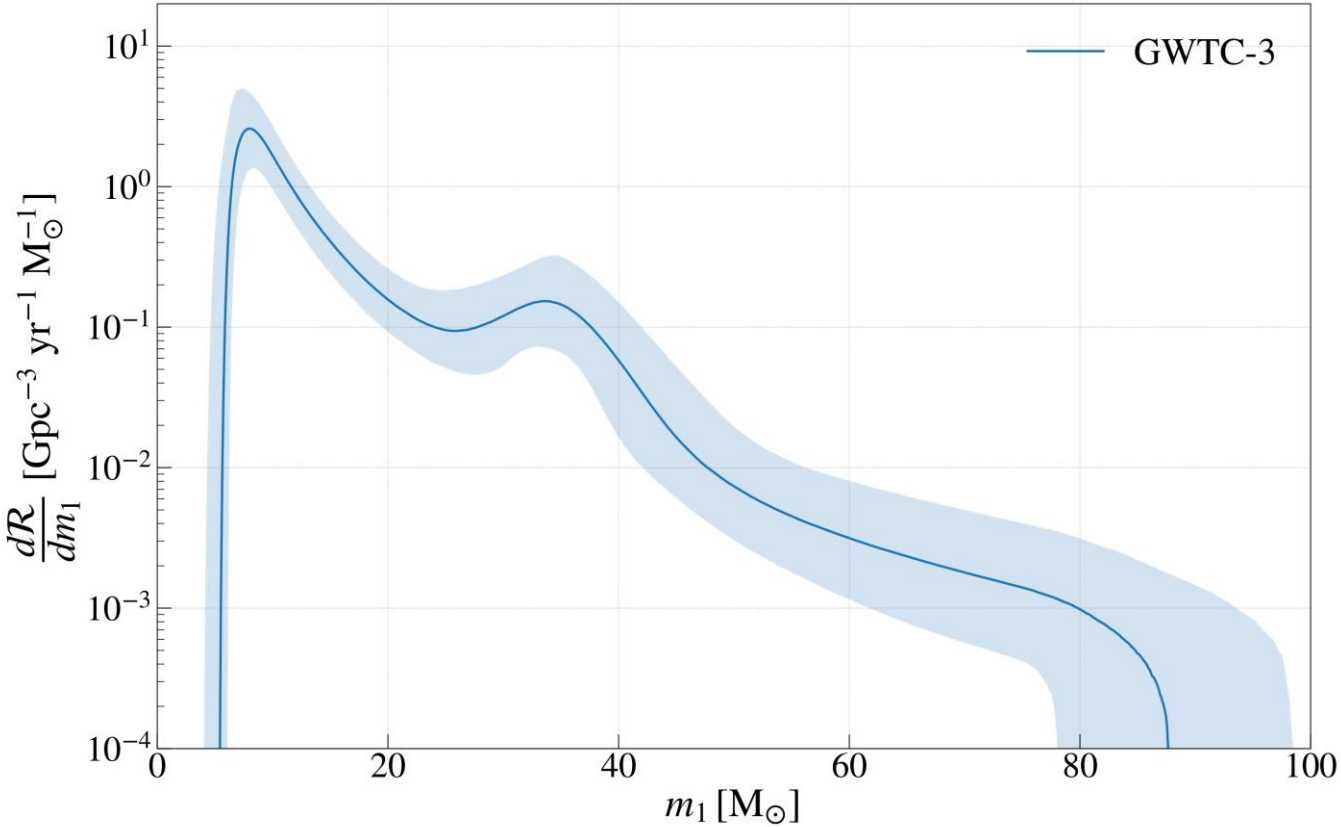
and the Demoblack group

Two in a million - The interplay between binaries and star clusters


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

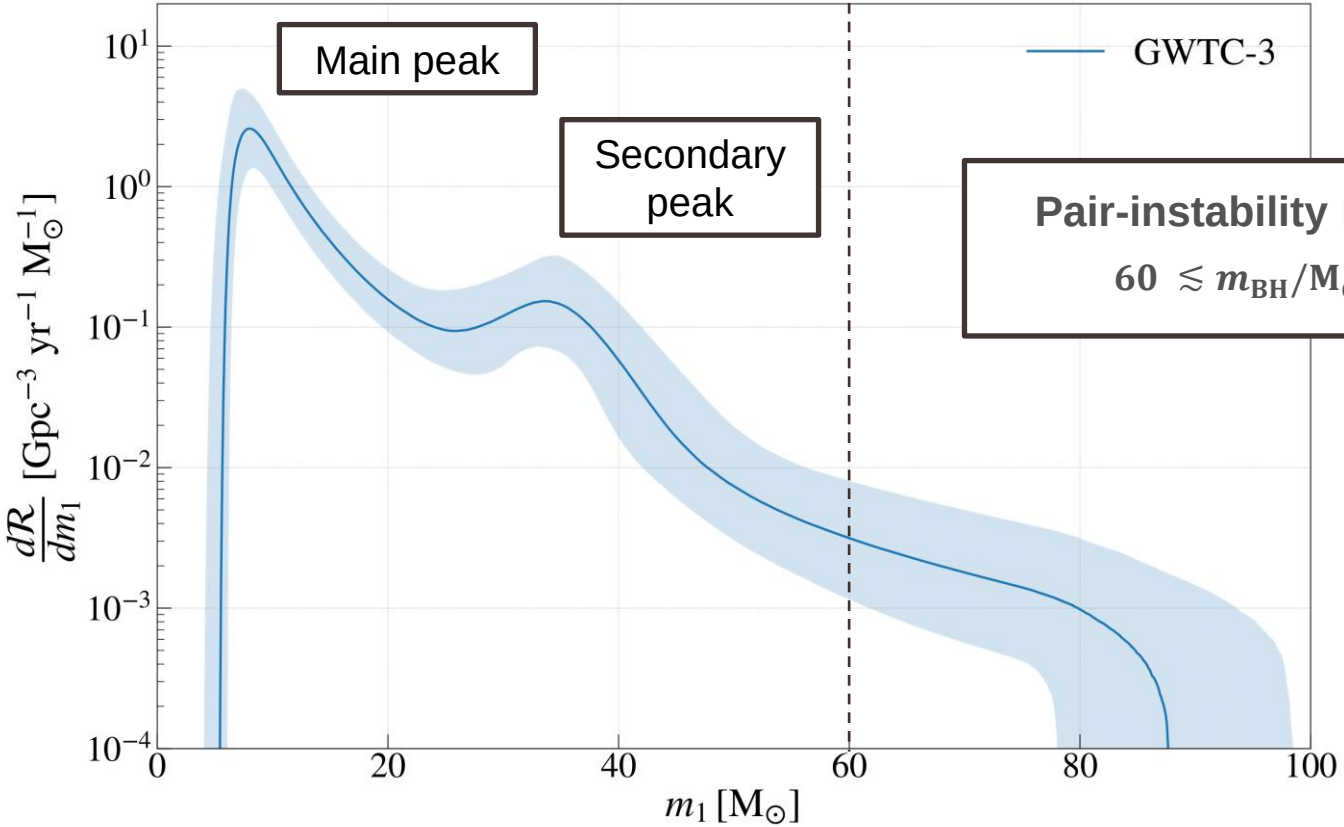
GW primary mass distribution

The LIGO Scientific Collaboration+ 2021a,b



GW primary mass distribution

The LIGO Scientific Collaboration+ 2021a,b



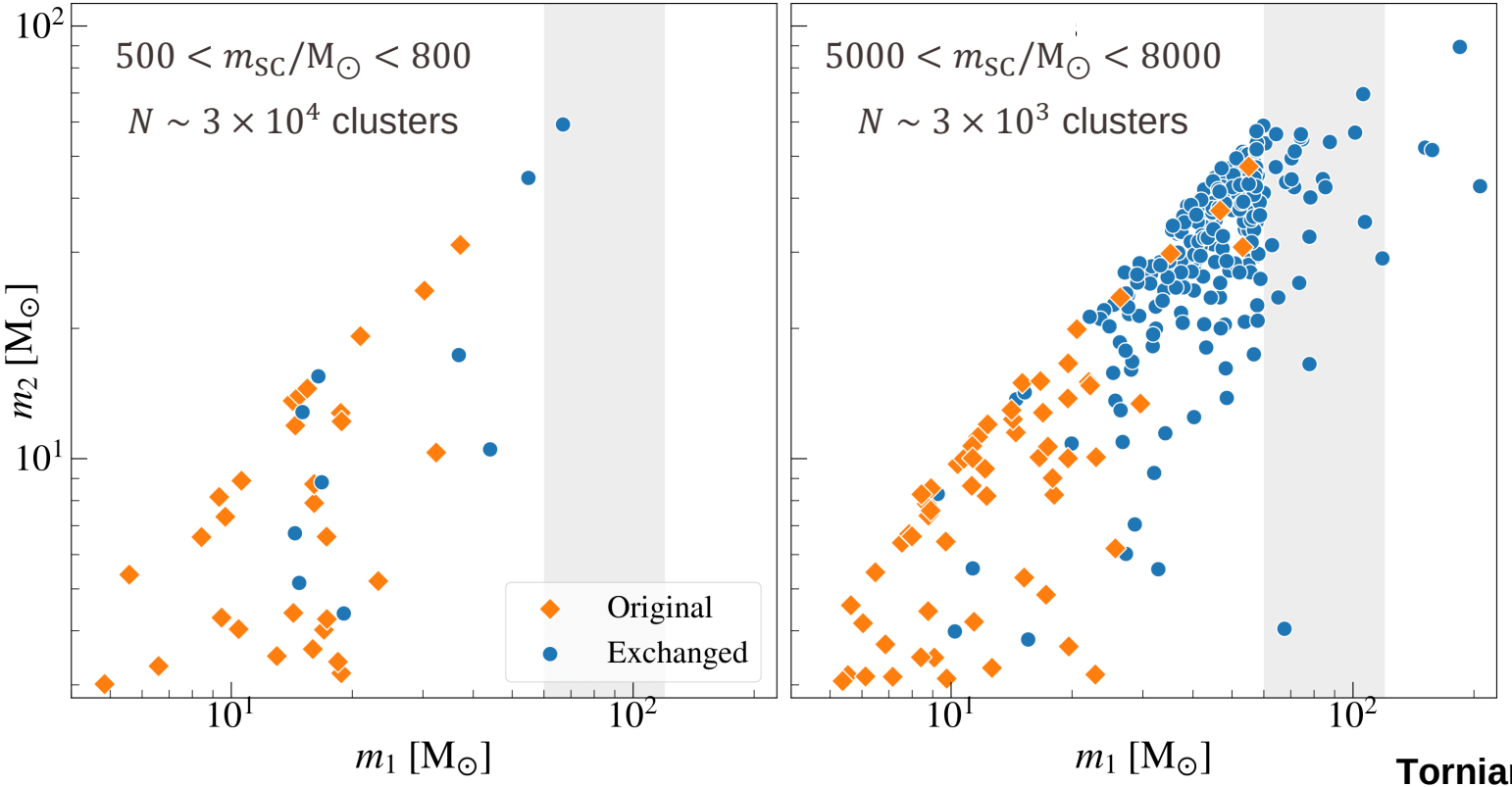
Pair-instability mass gap?

$60 \lesssim m_{\rm BH}/{\rm M}_\odot \lesssim 120$

Belczynski+ 2016
Woosley 2017
Spera & Mapelli 2017
Giacobbo+ 2018
Marchant 2019

Young star clusters

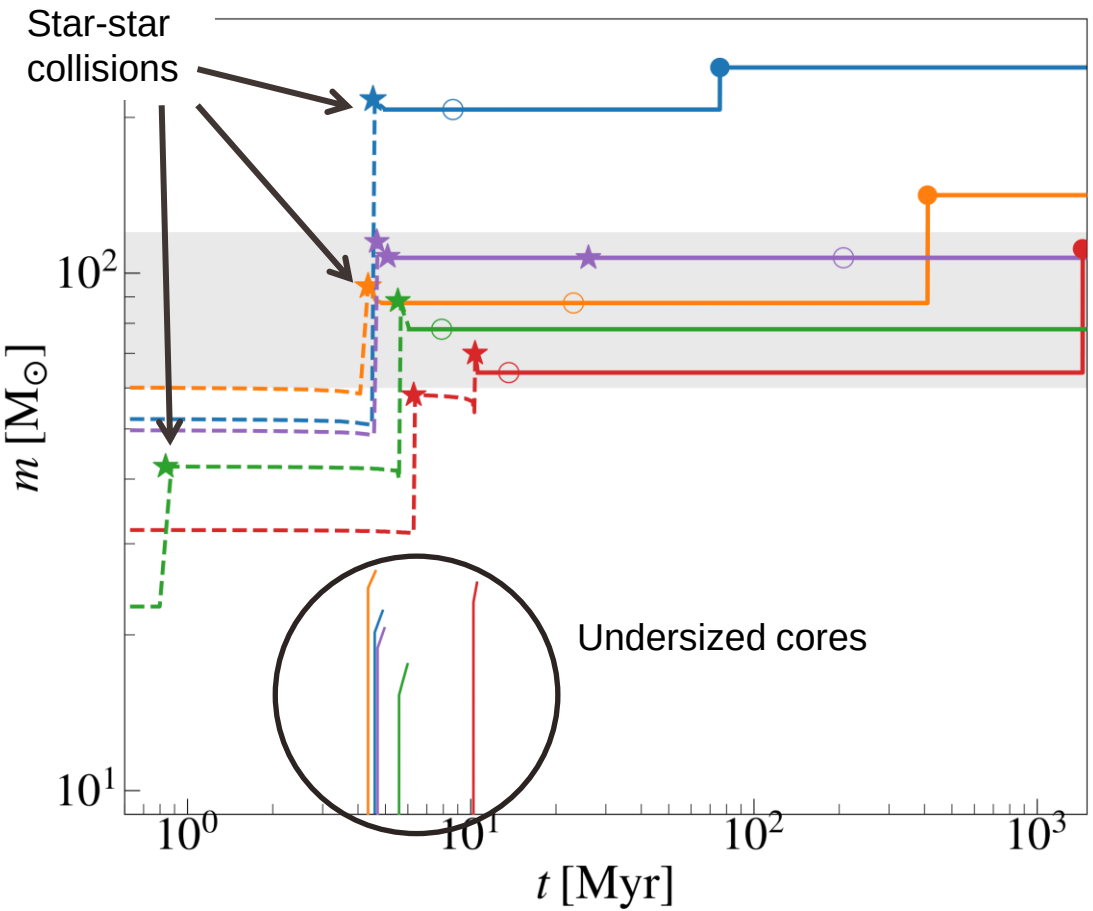
Original: from primordial binaries | **Exchanged:** from dynamical encounters



Torniamenti+ 2022

NBODY6++GPU (Wang+ 2015) + **MOBSE** (Mapelli 2017, Giacobbo+ 2018, Giacobbo & Mapelli 2018)

Star-star collisions in YSCs



Torniamenti+ 2022

Poster N.2

Star-star collisions in GCs

Benedetta Mestichelli's master thesis

Direct *N*-body code PeTar.

Wang+ 2020

- **MOBSE**: stellar and binary evolution.

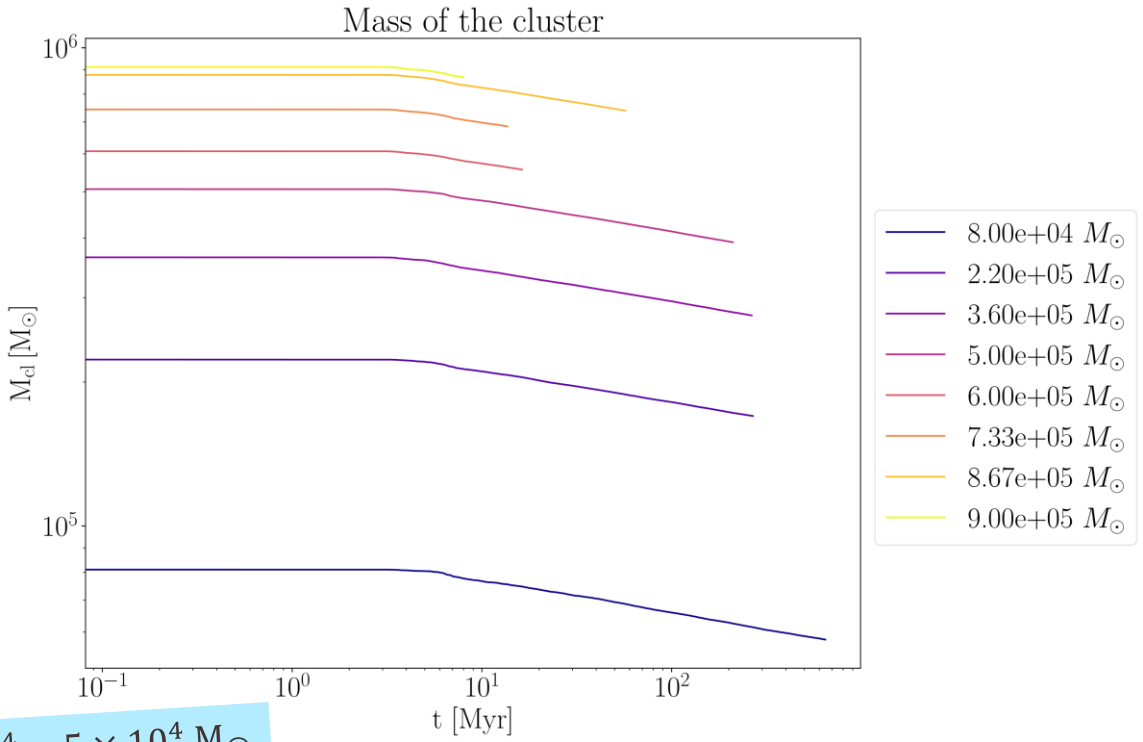
  Mapelli+ 2017, Giacobbo+ 2018

- Milky Way-like galactic potential.

  galpy, Bovy 2015

- Observation-based primordial binaries.

  Torniamenti+ 2021

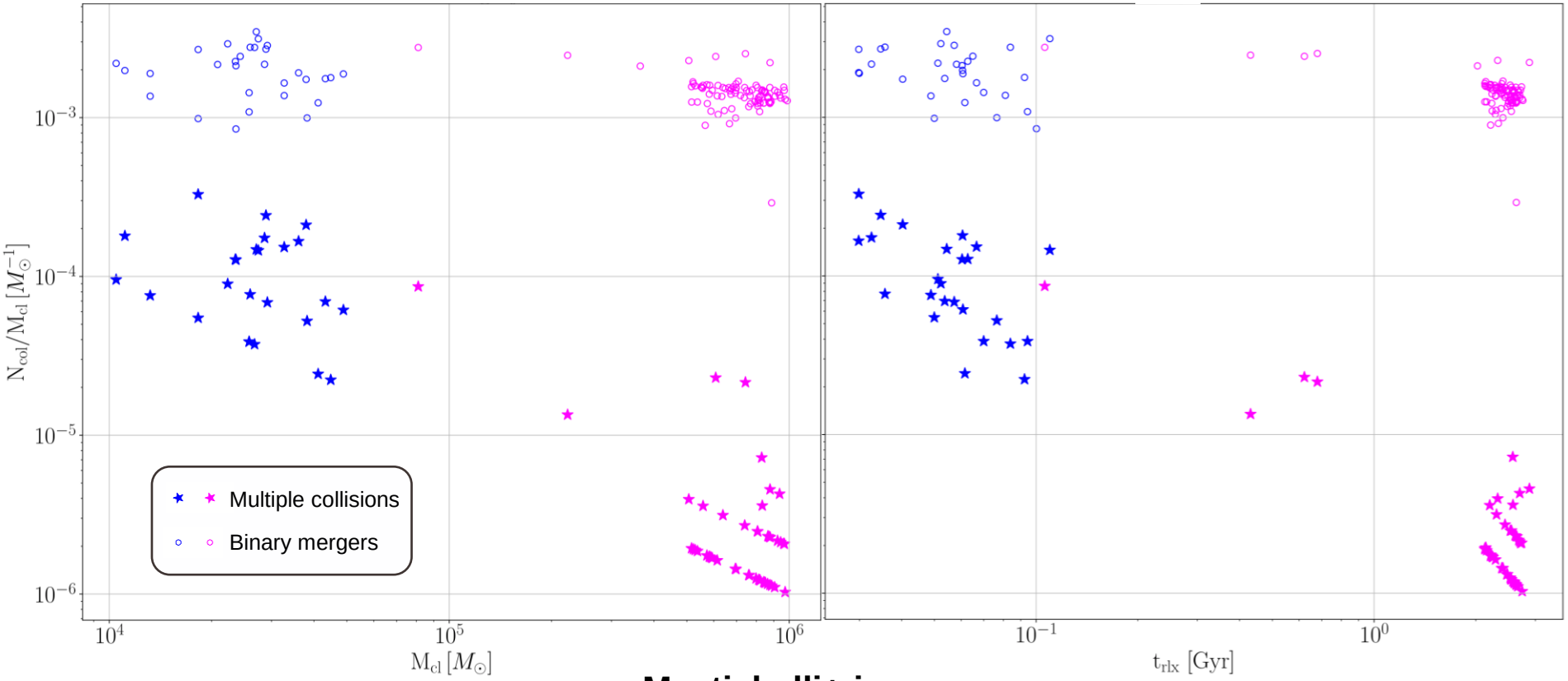


~ 30 clusters with $m_{SC} = 10^4 - 5 \times 10^4$ $M_\odot$

~ 100 clusters with $m_{SC} = 10^5 - 10^6$ $M_\odot$

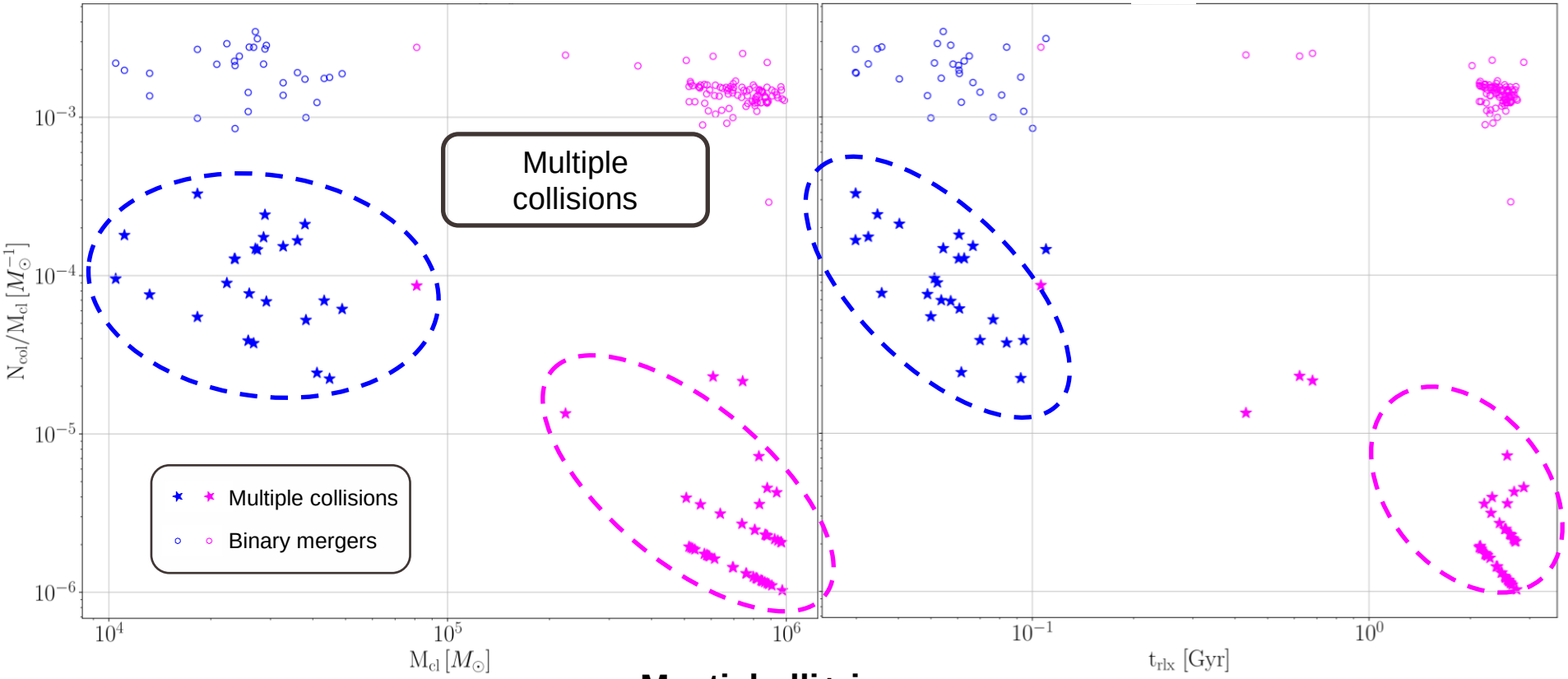
Mestichelli+ in prep.

Star-star collisions in GCs



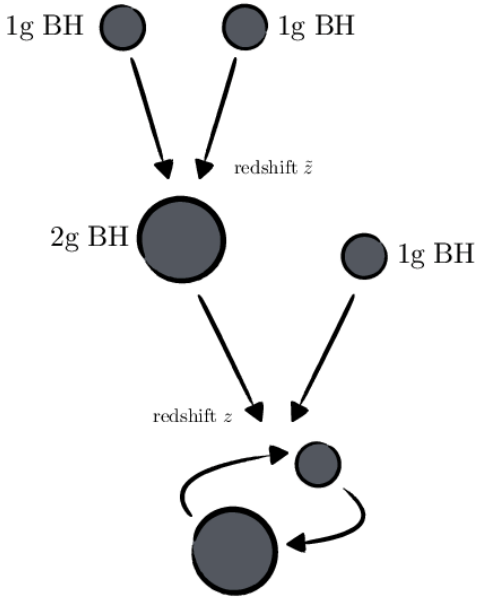
Mestichelli+ in prep.

Star-star collisions in GCs

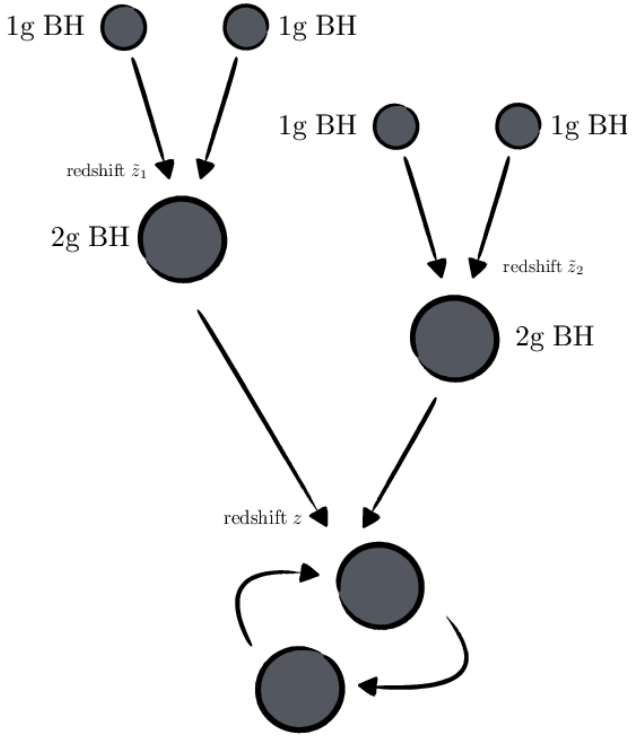


Mestichelli+ in prep.

Hierarchical mergers



ng+1g mergers



ng+ng mergers

Miller & Hamilton 2002; Fishbach+ 2017; Gerosa & Berti 2017; Gerosa & Fishbach 2021

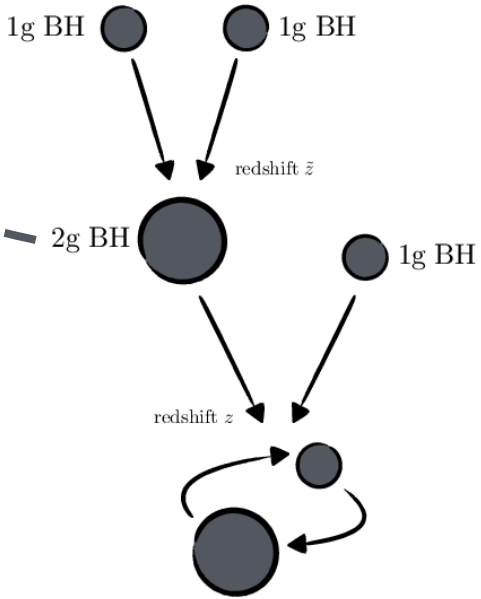
from Gerosa & Berti 2017

Hierarchical mergers

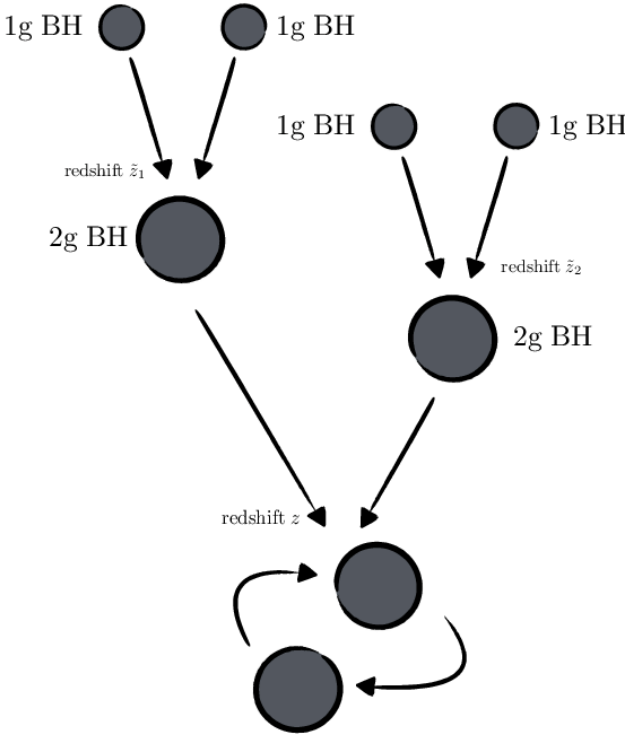
Relativistic recoil on the BH remnant up to ~ 1000 km/s.

Campanelli+ 2007

Effective in massive and long-lived star clusters (e.g., **GCs, NSCs**).



ng+1g mergers



ng+ng mergers

Miller & Hamilton 2002; Fishbach+ 2017; Gerosa & Berti 2017; Gerosa & Fishbach 2021

from Gerosa & Berti 2017

Fastcluster

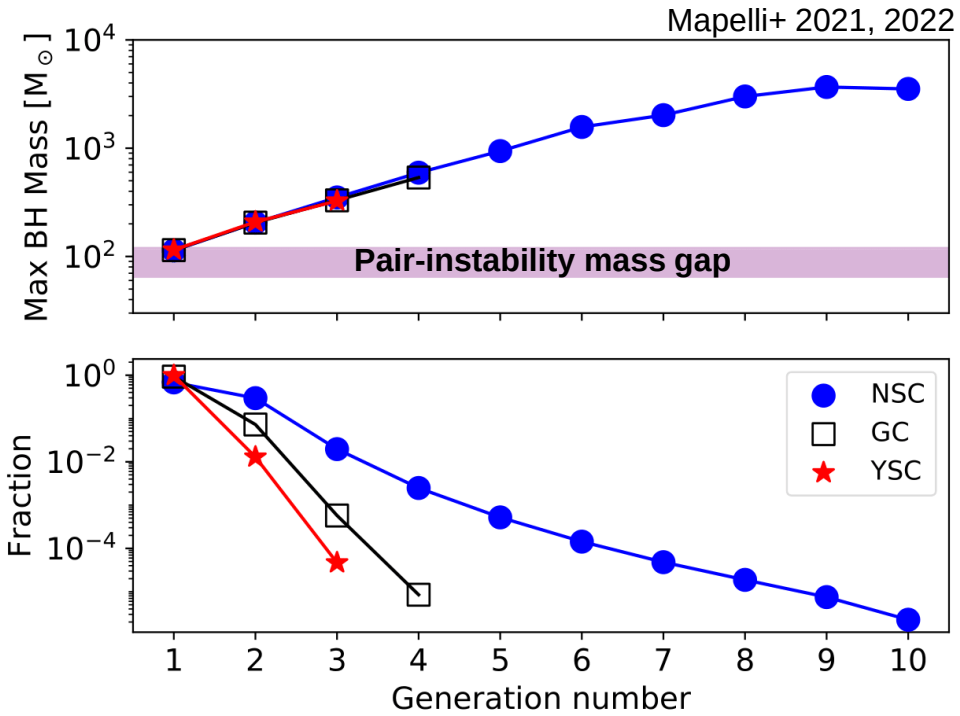
Population-synthesis code for BBHs in star clusters

https://gitlab.com/micmap/fastcluster_open

1) Initial BHs from population synthesis catalogs (e.g., MOBSE, SEVN).
Mapelli+ 2017, Giacobbo+ 2018, Iorio+ 2023

2) BBH orbital evolution:

- dynamical pair-up and hardening,
- GW emission,
- relativistic recoil.



also cBHBd (Antonini+ 2019, 2020, 2023); Fragione+ 2020; B-POP (Arca Sedda+ 2021); Rapster (Kritos+ 2022a,b); Fragione & Rasio 2023

Fastcluster

Population-synthesis code for BBHs in star clusters

https://gitlab.com/micmap/fastcluster_open

GC evolution

clusterBH (Antonini & Gieles 2020)

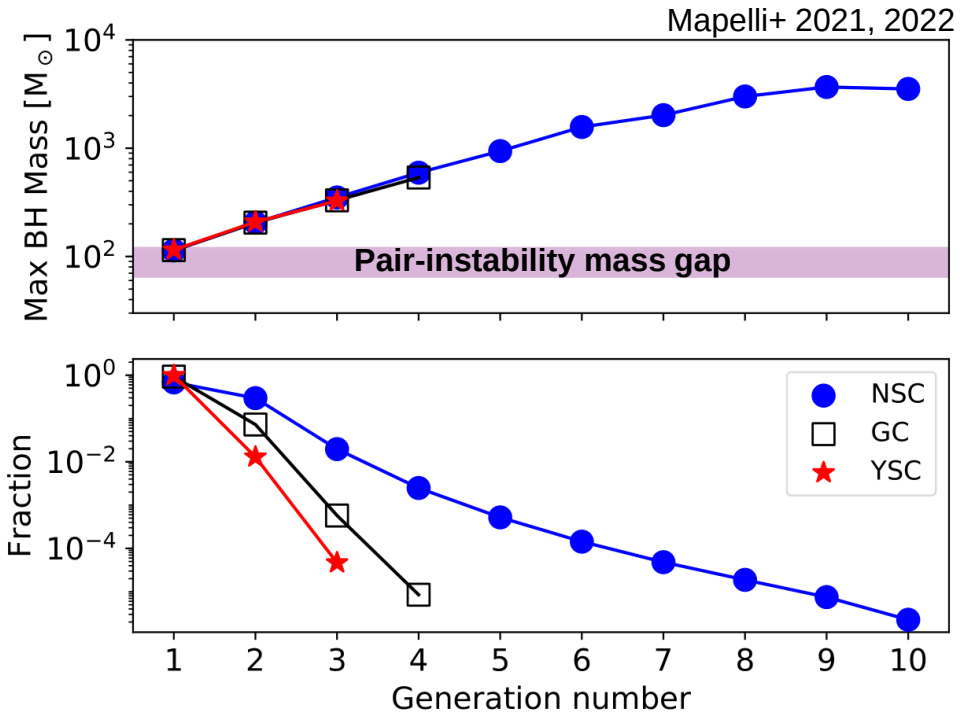
- Stellar mass loss.
- Relaxation.

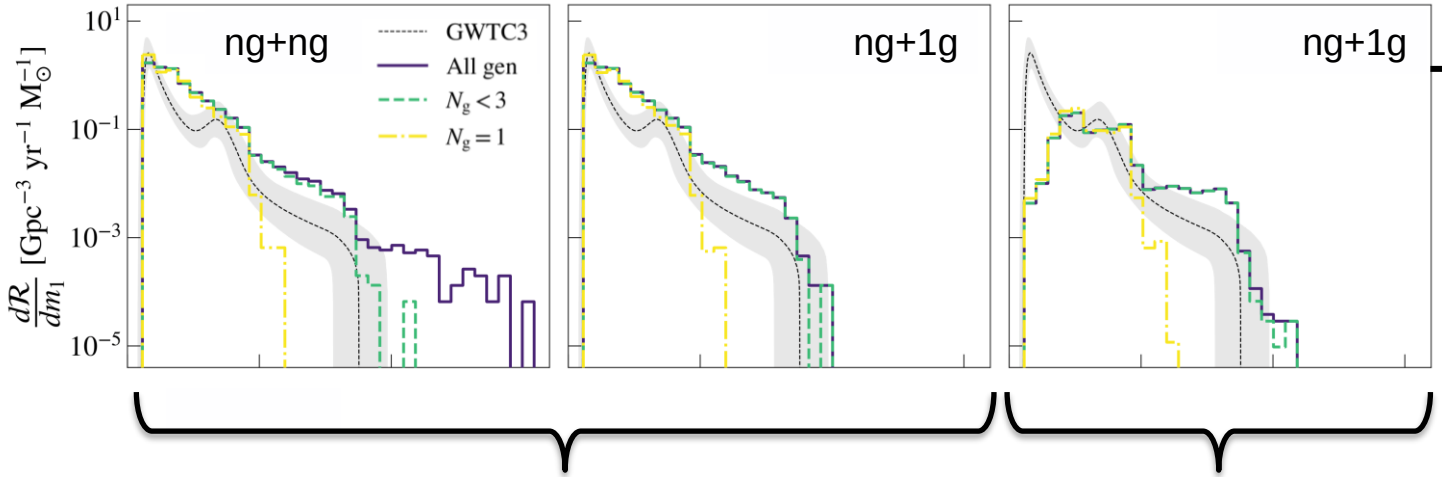
Breen & Heggie 2013

- Tidal stripping.

Gieles+ 2011

Torniamenti+ in prep.





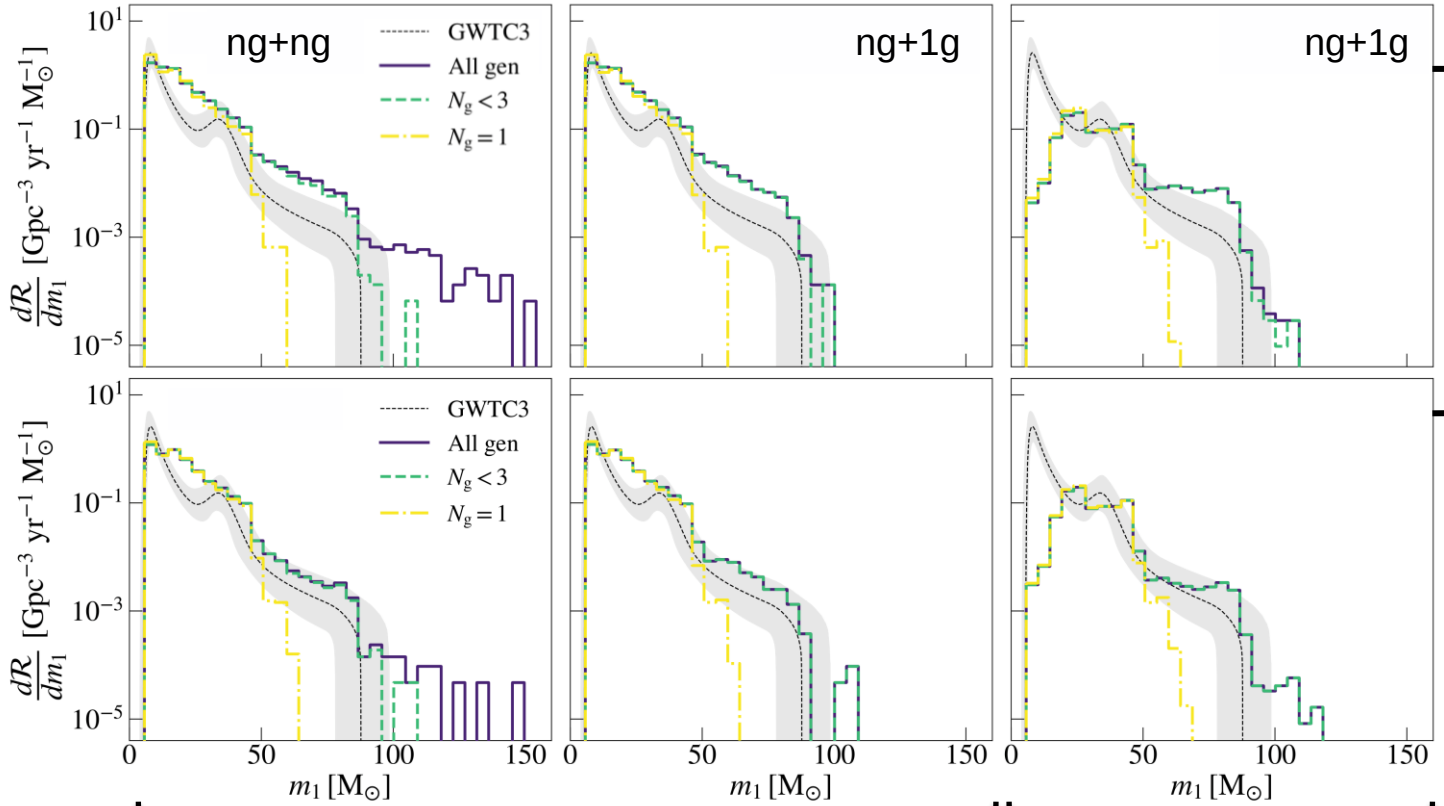
No GC evolution

BH sampling

Mapelli+ 2021, 2022

Antonini+ 2023

Torniamenti+ in prep.



No GC evolution

GC evolution

Stellar mass loss
+
Relaxation
+
Tidal stripping

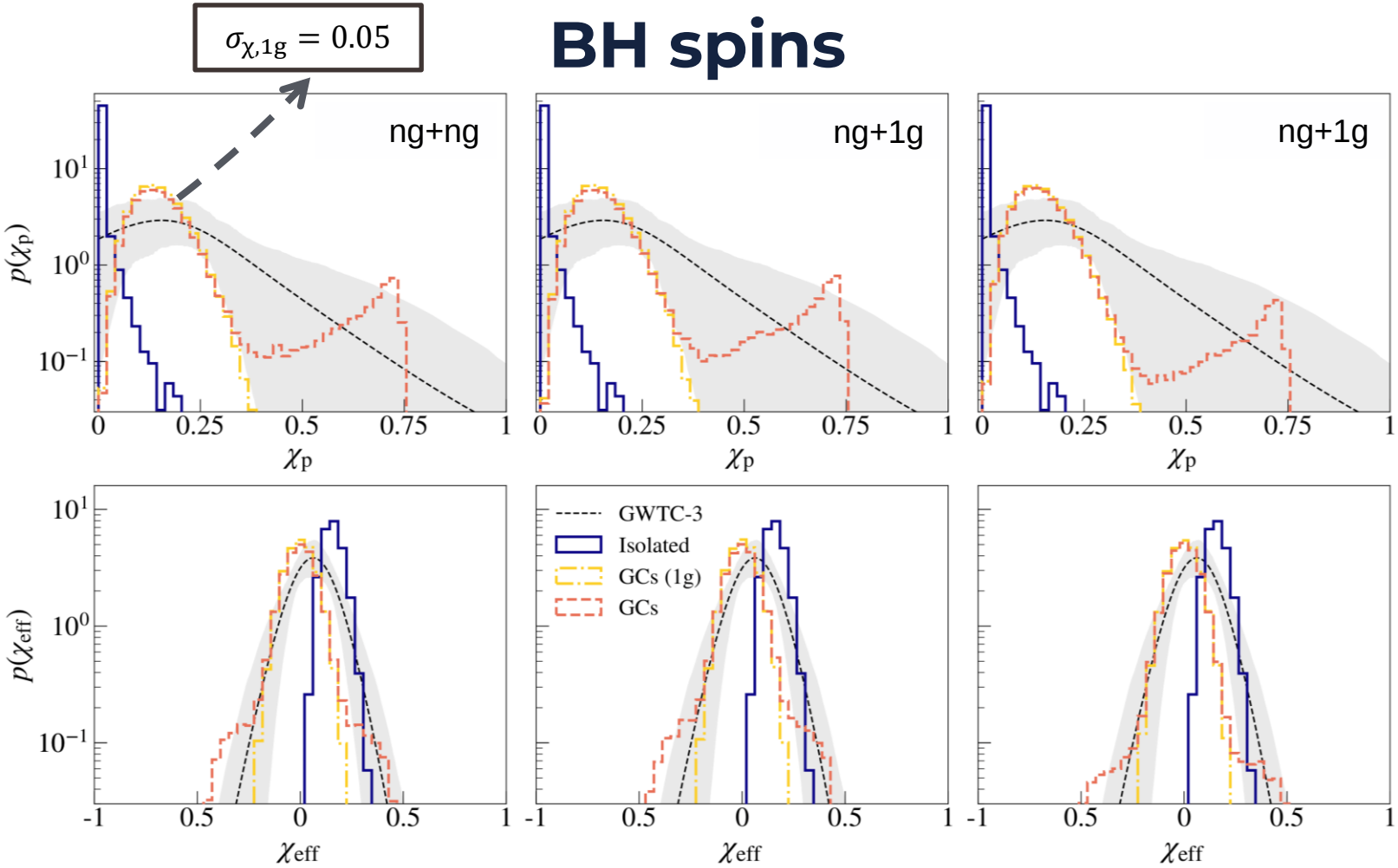
BH sampling

Mapelli+ 2021, 2022

Antonini+ 2023

Torniamenti+ in prep.

BH spins



Torniamenti+ in prep.

Summary

Star-star collisions

In dynamically-active YSCs: $\sim$10% BBH mergers with m_1 in the pair-instability mass gap.

In GCs: repeated collisions less efficient due to long relaxation timescales.

GC dissolution

GC dissolution strongly quenches hierarchical mergers after second generation.

Hierarchical mergers in GCs

Essential to explain the primary mass distribution above 60 $\mathrm{M}_{\odot}$. At lower masses: dependence on mass sampling assumptions.

Explain high-spin distribution? More information required.