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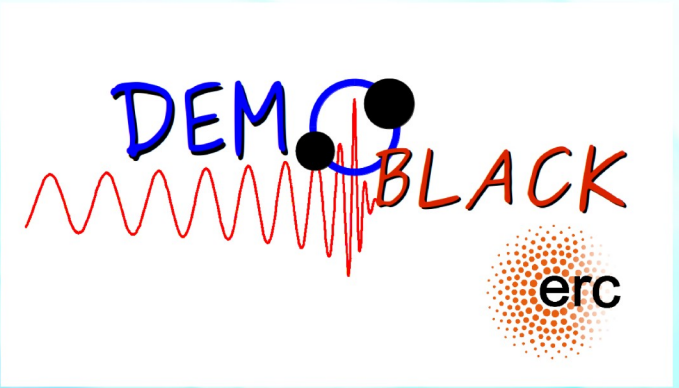


Dynamics of Black Holes in Young Star Clusters

Collaborators: Ugo N. Di Carlo, Nicola Giacobbo, Sara Rastello, M. Celeste Artale, Alessandro Ballone, Yann Bouffanais, Mario Spera, Long Wang, Mario Pasquato, Filippo Santoliquido, Davide Gerosa, Emanuele Berti, Vishal Baibhav, Francesco Haardt

KITP, Santa Barbara, 24 – 28 June 2019

1. Why BHs in young star clusters?

Massive stars (= BH progenitors) form mostly in star clusters

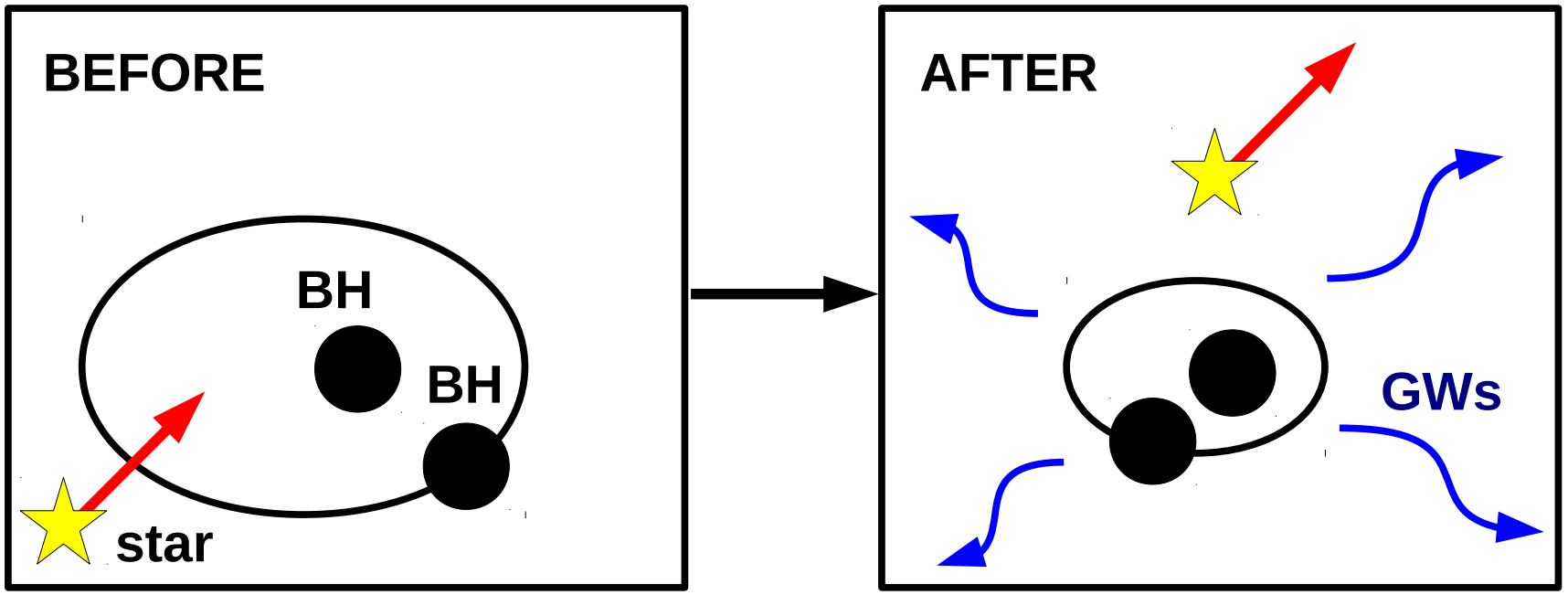
(Lada & Lada 2003; Weidner & Kroupa 2006; Weidner, Kroupa & Bonnell 2010; Gvaramadze et al. 2012; see Portegies Zwart+ 2010 for a review)

BHs and BH progenitors share the dynamics of star clusters at least for few Myr

R136 in the LMC

2. What dynamical processes affect BHs?

DYNAMICAL HARDENING via 3 – body encounters



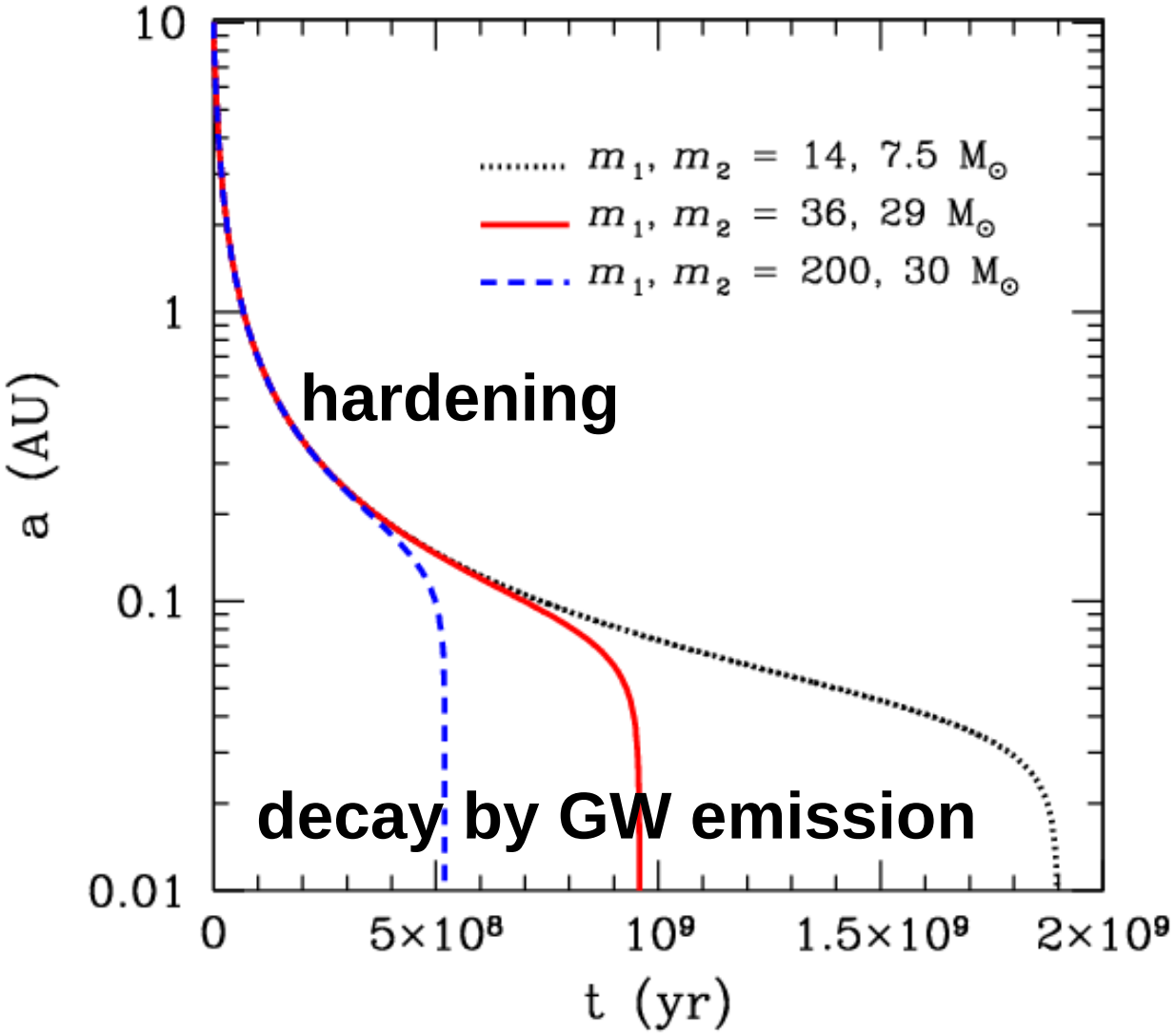
After 3-body encounters, the semi-major axis shrinks
→ BH binary might enter the GW regime

DYNAMICAL EJECTION:

3 – body encounters cause RECOIL kicks
which might eject BH binaries and BHs from clusters

2. What dynamical processes affect BHs?

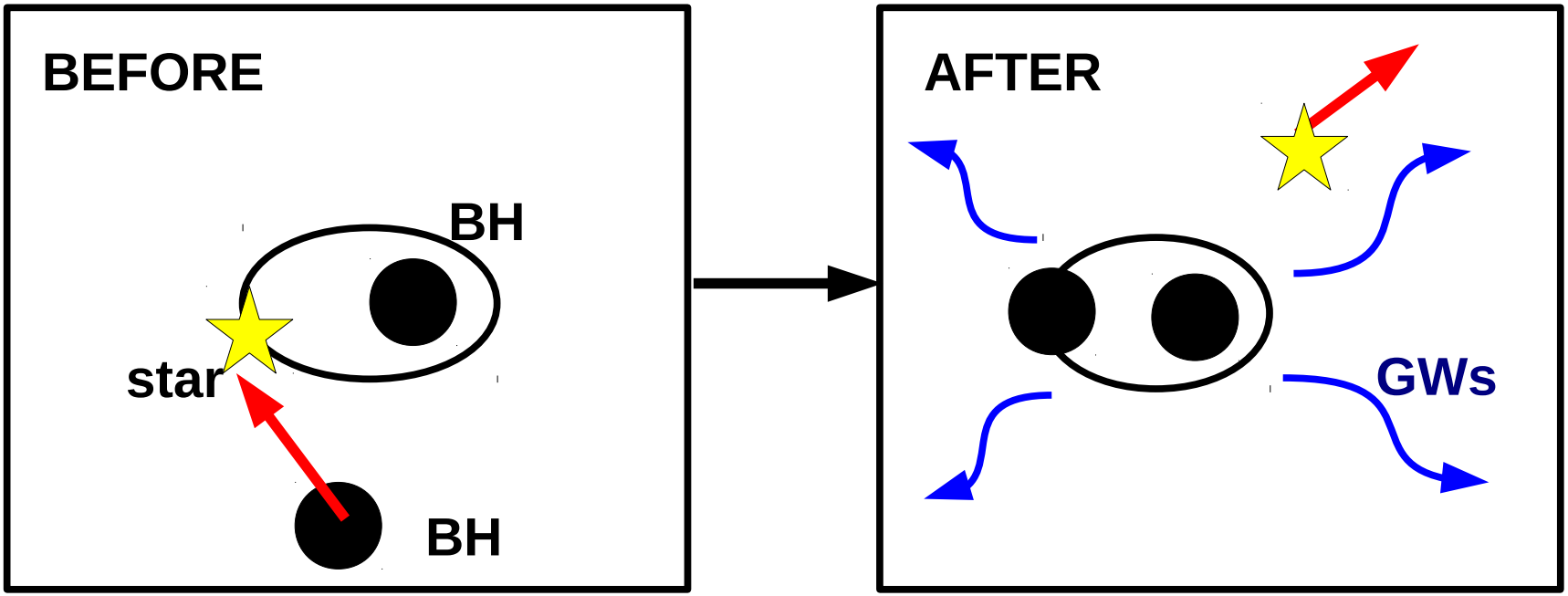
DYNAMICAL HARDENING via 3 – body encounters



by simple analytic integration, see MM 2018, arxiv1807.07944

2. What dynamical processes affect BHs?

DYNAMICAL EXCHANGES



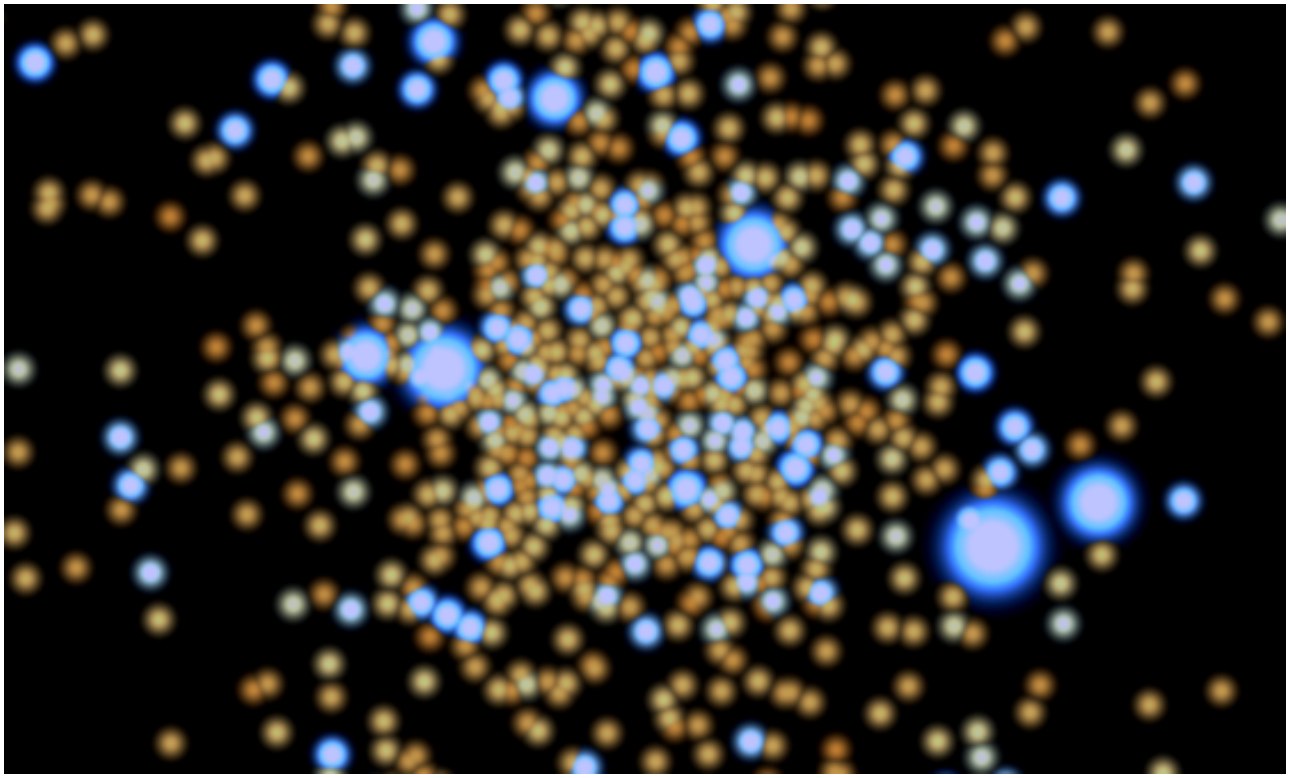
>90% BH-BH binaries in young star clusters form by exchange
(Ziosi, MM+ 2014; MM 2016)

EXCHANGES FAVOUR THE FORMATION of BH-BH BINARIES WITH

- *** THE MOST MASSIVE BHs**
- *** HIGH ECCENTRICITY**
- *** MISALIGNED BH SPINS**

3. BH binaries from dynamical simulations of young star clusters

MOBSE + Nbody6++GPU (Di Carlo, Giacobbo, MM+ 2019)



SMALL STAR CLUSTERS with FRACTAL INITIAL CONDITIONS
> 6000 star clusters

Di Carlo, Giacobbo, MM et al., 2019

see also Ziosi+ 2014; MM 2016; Kimpson+ 2016

3. BH binaries from dynamical simulations of young star clusters

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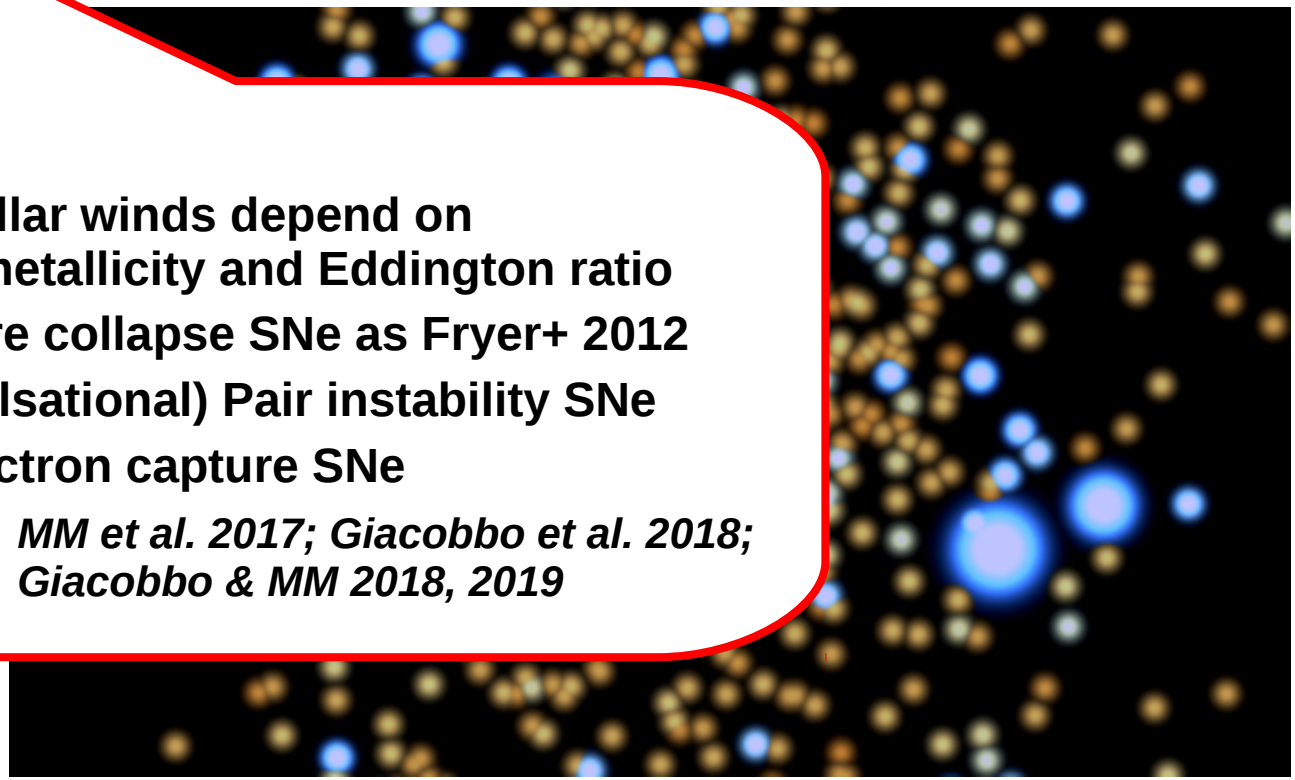

* Stellar winds depend on metallicity and Eddington ratio
* Core collapse SNe as Fryer+ 2012
* (Pulsational) Pair instability SNe
* Electron capture SNe

MM et al. 2017; Giacobbo et al. 2018; Giacobbo & MM 2018, 2019

SMALL STAR CLUSTERS with FRACTAL INITIAL CONDITIONS
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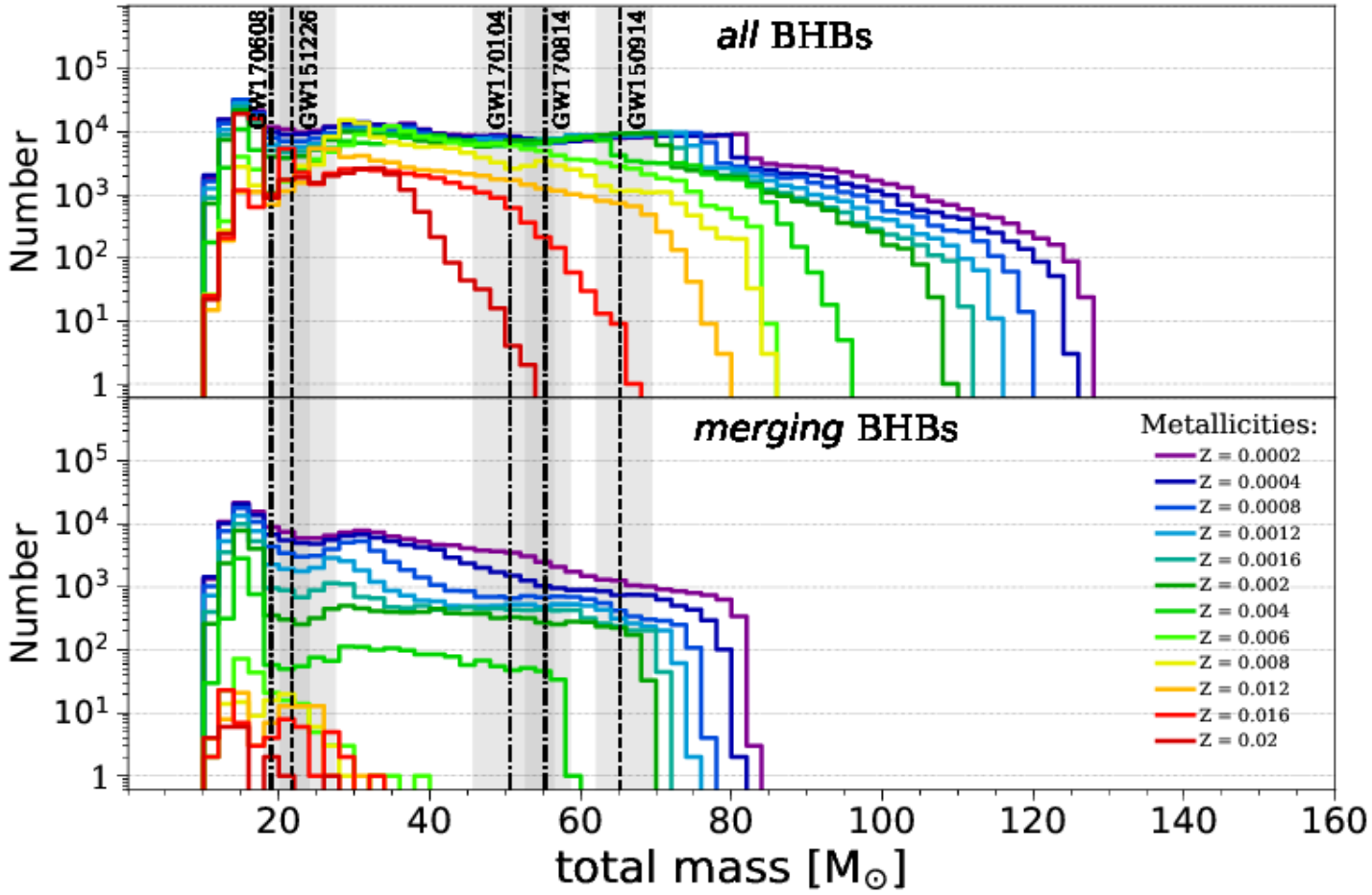
Di Carlo, Giacobbo, MM et al., 2019

see also Ziosi+ 2014; MM 2016; Kimpson+ 2016

3. MOBSE population synthesis

DISTRIBUTION of BH mass from ISOLATED BINARY EVOLUTION:



*** Mass and number of BH binaries depend on metallicity (Z)**

*** BHs with mass ≤ 60 $M_\odot$ form, but only BHs with mass ≤ 40 $M_\odot$ merge**

Giacobbo, MM & Spera 2018; see also MM+ 2017;
Giacobbo & MM 2018a, 2018b; MM & Giacobbo 2018

3. BH binaries from dynamical simulations of young star clusters

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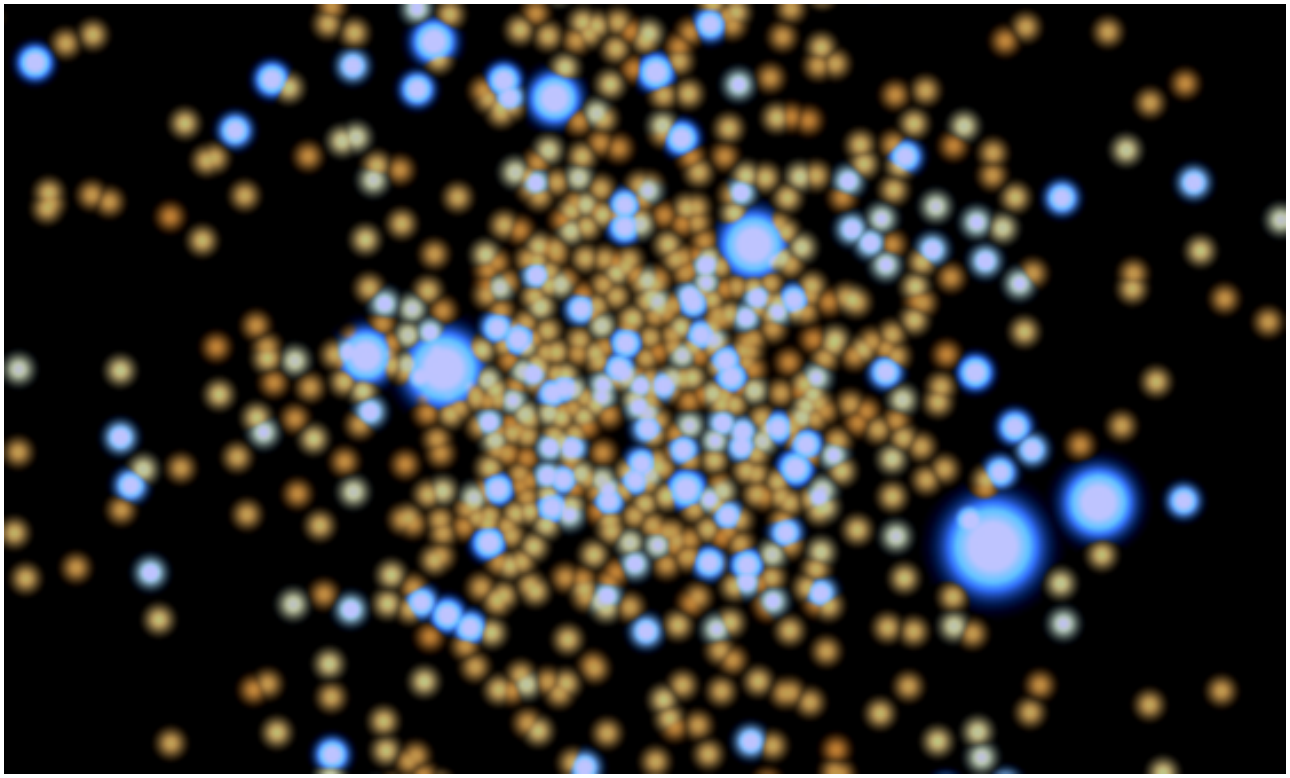


SMALL STAR CLUSTERS with FRACTAL INITIAL CONDITIONS
> 6000 star clusters

Di Carlo, Giacobbo, MM et al., 2019

see also Ziosi+ 2014; MM 2016; Kimpson+ 2016

3. BH binaries from dynamical simulations of young star clusters

Why fractal initial conditions?

* Star forming regions very asymmetric

* Gas distribution important in young star clusters, but it is too expensive run hydro. simulations

Large initial binary fraction: 40 %

Star cluster mass distribution:

$$\frac{dN}{dM_{\rm cl}} \propto M_{\rm cl}^{-2}$$

where $M_{cl} \in [10^3, 10^5]$ Msun

to mimic realistic Milky Way population (Lada & Lada 2003)

IMF	Kroupa (2001)
m_{min}	0.1 Msun
m_{max}	150 Msun
Z	0.0002, 0.002, 0.02
D	2.3, 1.6
r_h	Marks & Kroupa
Q_{vir}	0.5
f_{bin}	0.4

Di Carlo, Giacobbo, MM et al., 2019

3. BH binaries from dynamical simulations of young star clusters

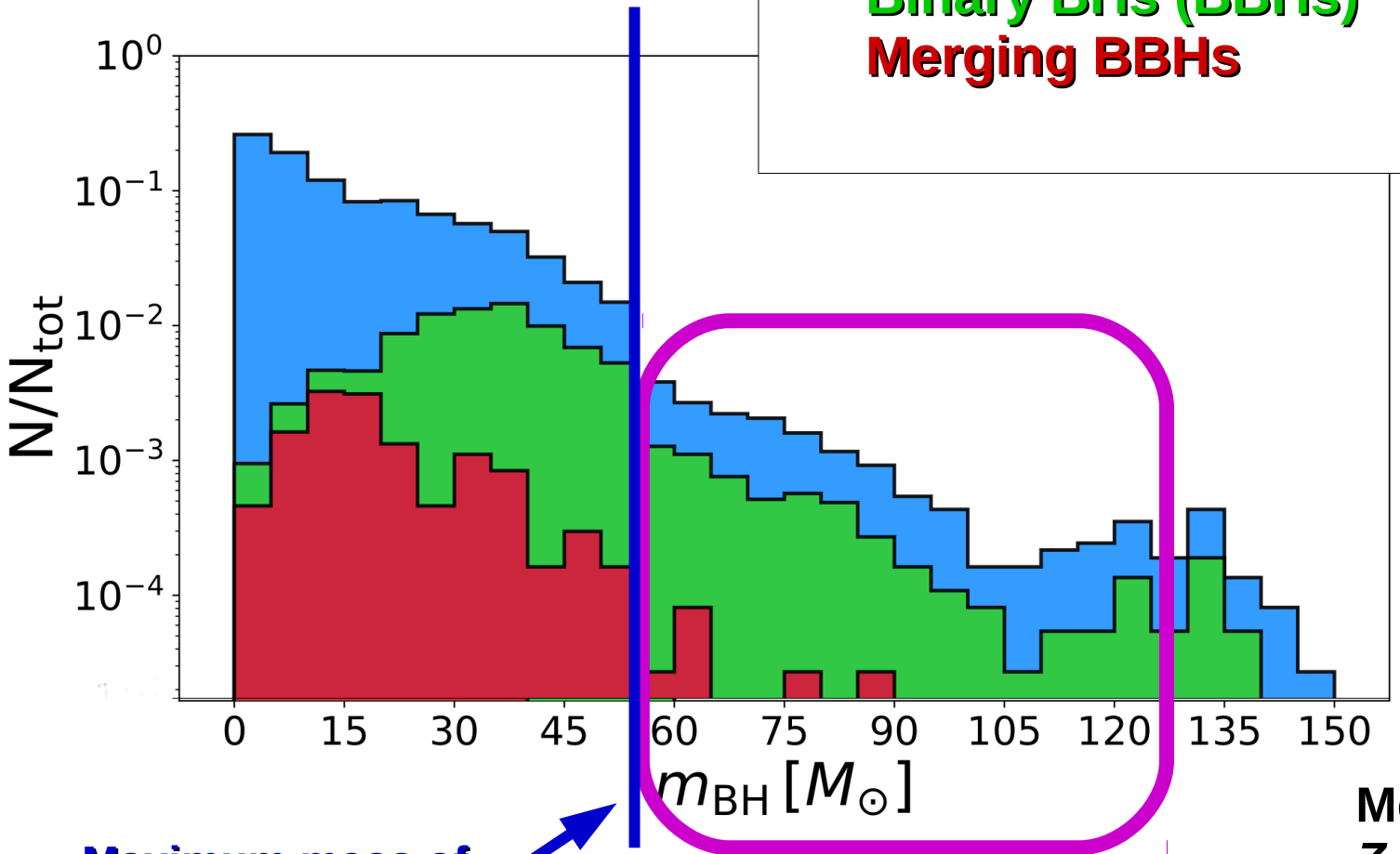
BHs in clusters

BH Mass Distribution:

All BHs

Binary BHs (BBHs)

Merging BBHs



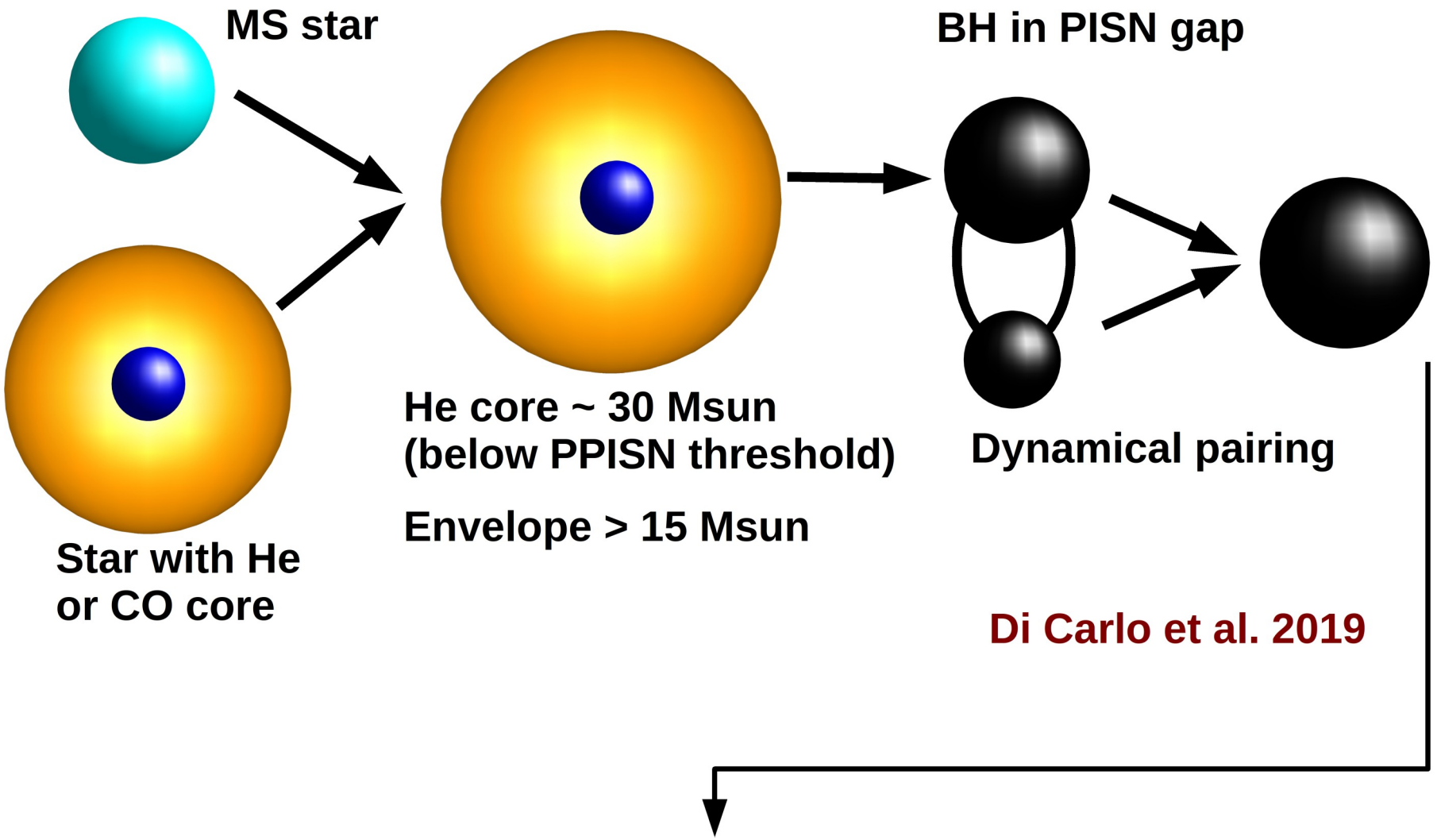
Maximum mass of BHs from single stars at Z = 0.1 Z⊙

BHs in PISN MASS GAP

Metallicity
Z = 0.1 Z⊙

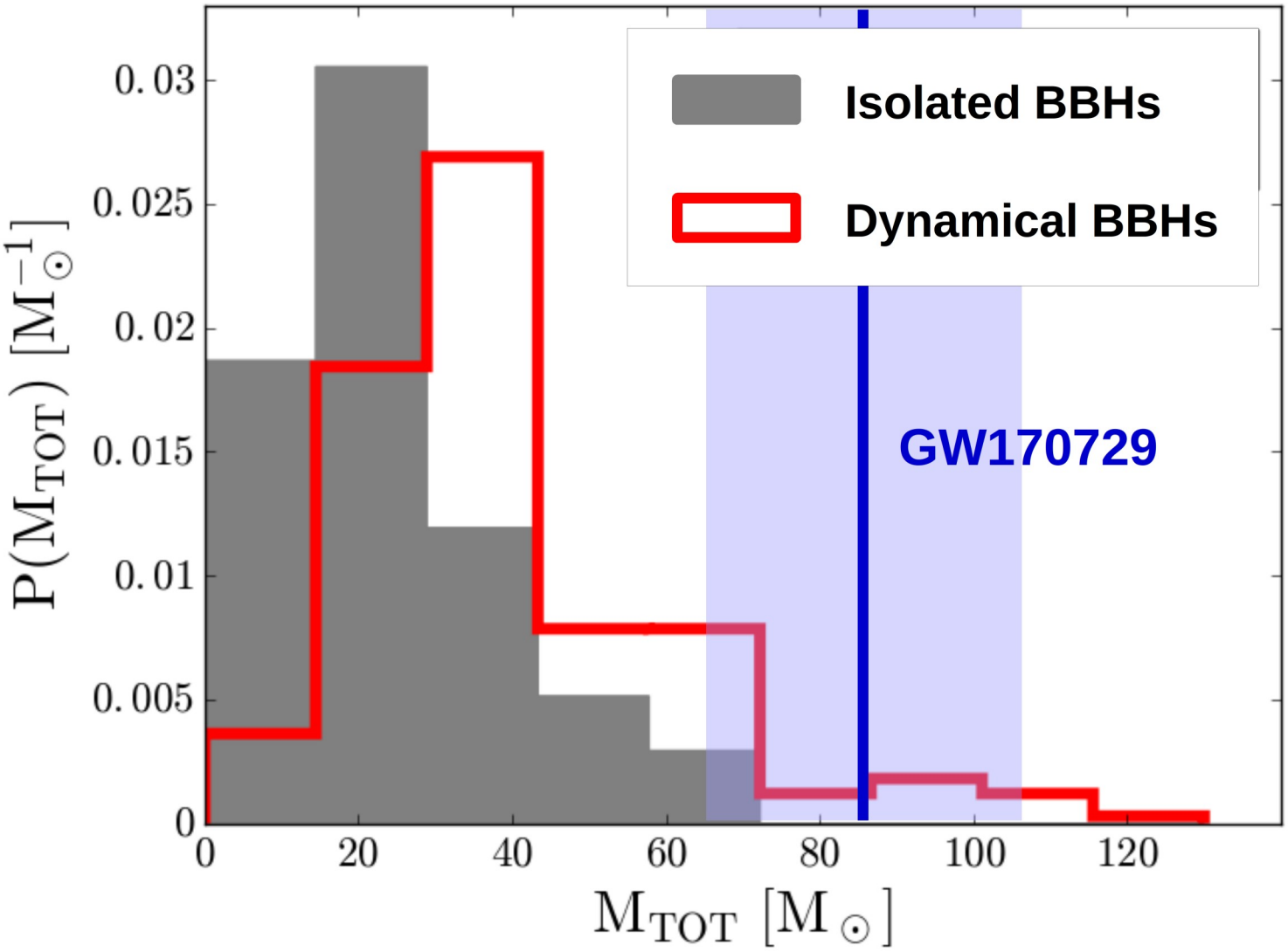
Di Carlo, Giacobbo, MM et al., 2019

3. BH binaries from dynamical simulations of young star clusters



RARE EVENT: ~ 2 % of BBH mergers in star clusters (Di Carlo et al. 2019)

3. BH binaries from dynamical simulations of young star clusters

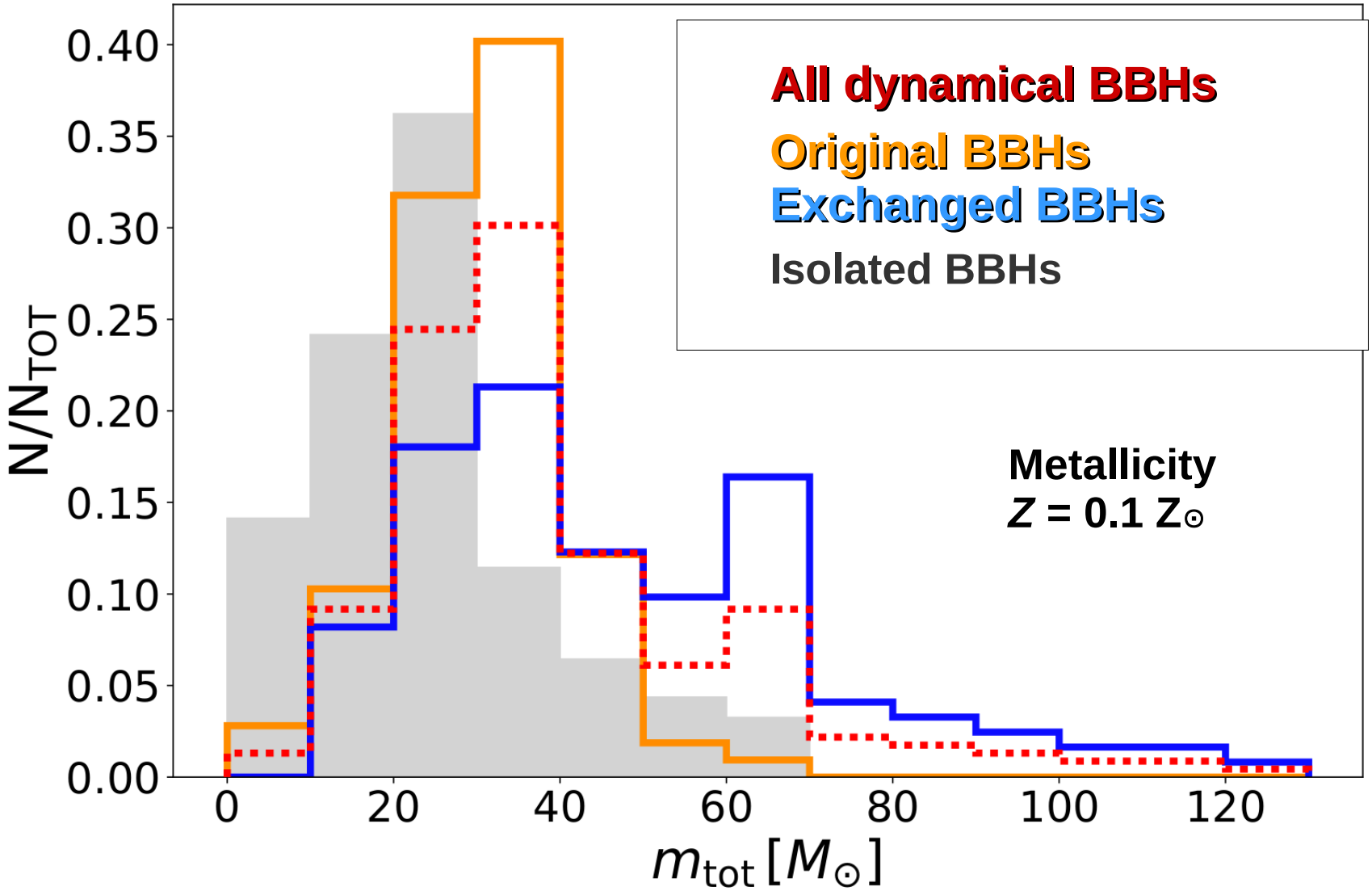


*** Dynamical binaries more massive than primordial**

*** Three merging systems with total mass >> 80 Msun**

Di Carlo, Giacobbo, MM et al., 2019

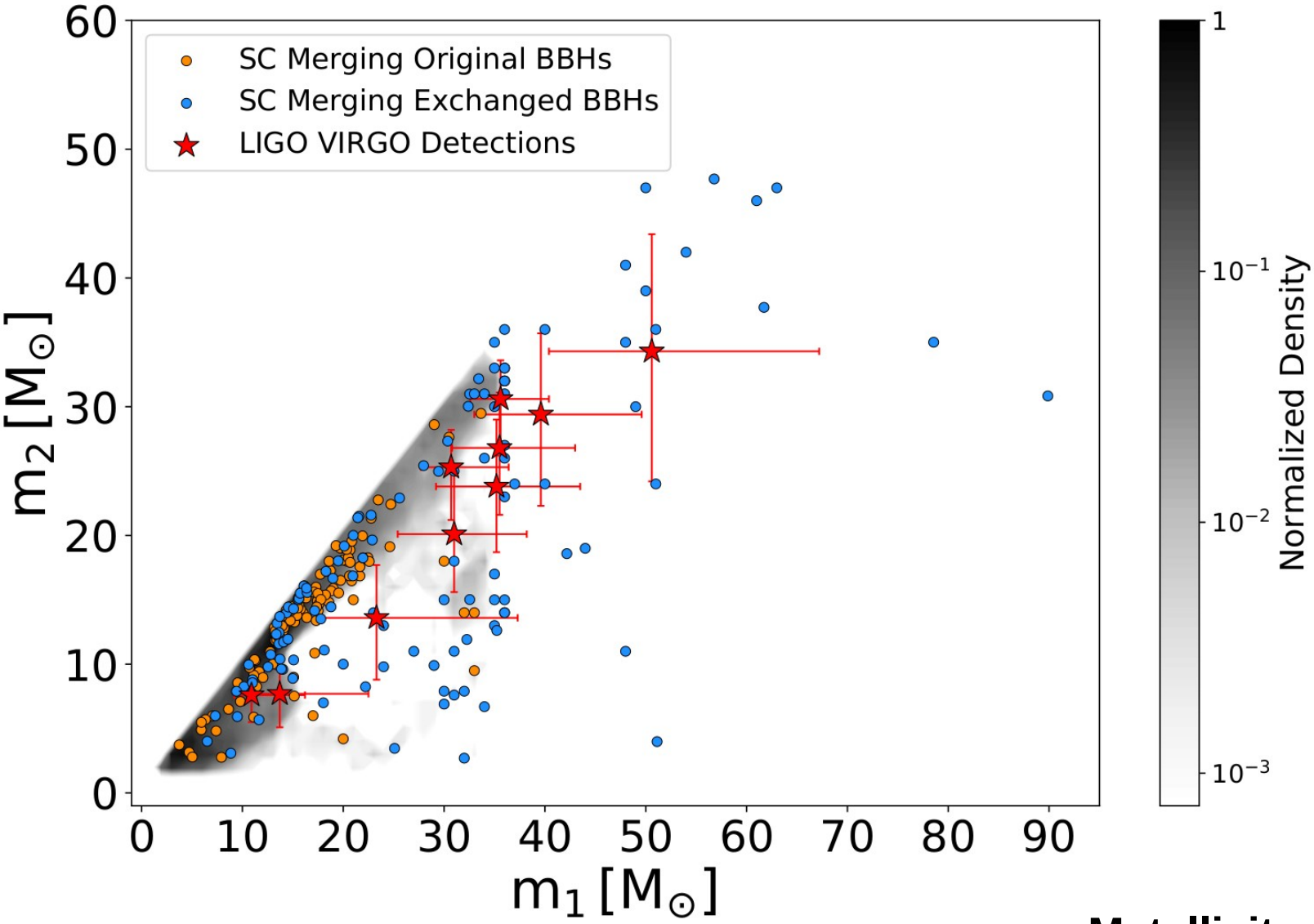
3. BH binaries from dynamical simulations of young star clusters



*** Dynamical BBHs come from original (~50%) and exchanged binaries (~ 50%)**

Di Carlo, Giacobbo, MM et al., 2019

3. BH binaries from dynamical simulations of young star clusters

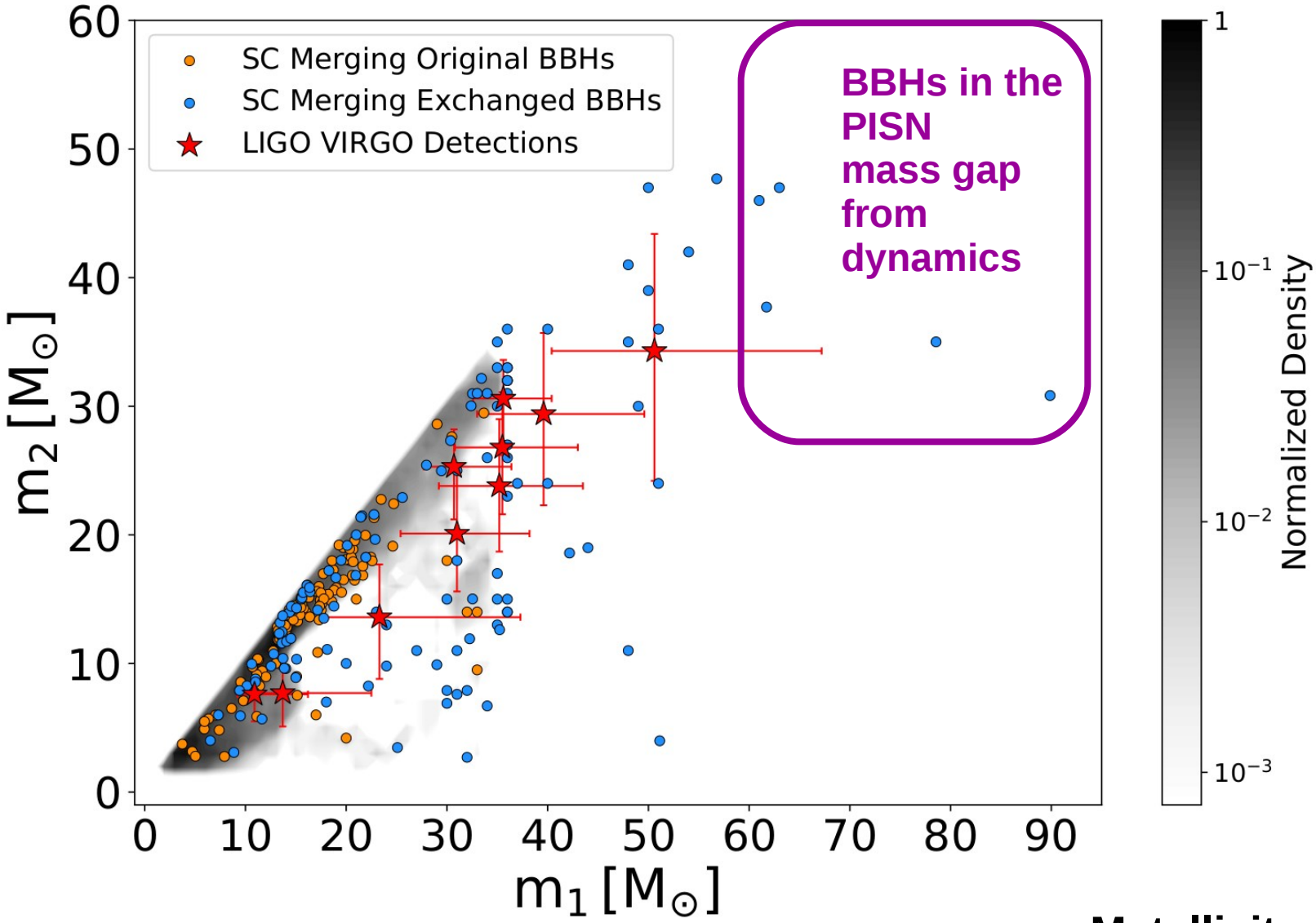


*** Exchanges match GW170729**

Metallicity
$Z = 0.1\ Z_\odot$

Di Carlo, Giacobbo, MM et al., 2019

3. BH binaries from dynamical simulations of young star clusters



*** Exchanges match GW170729**

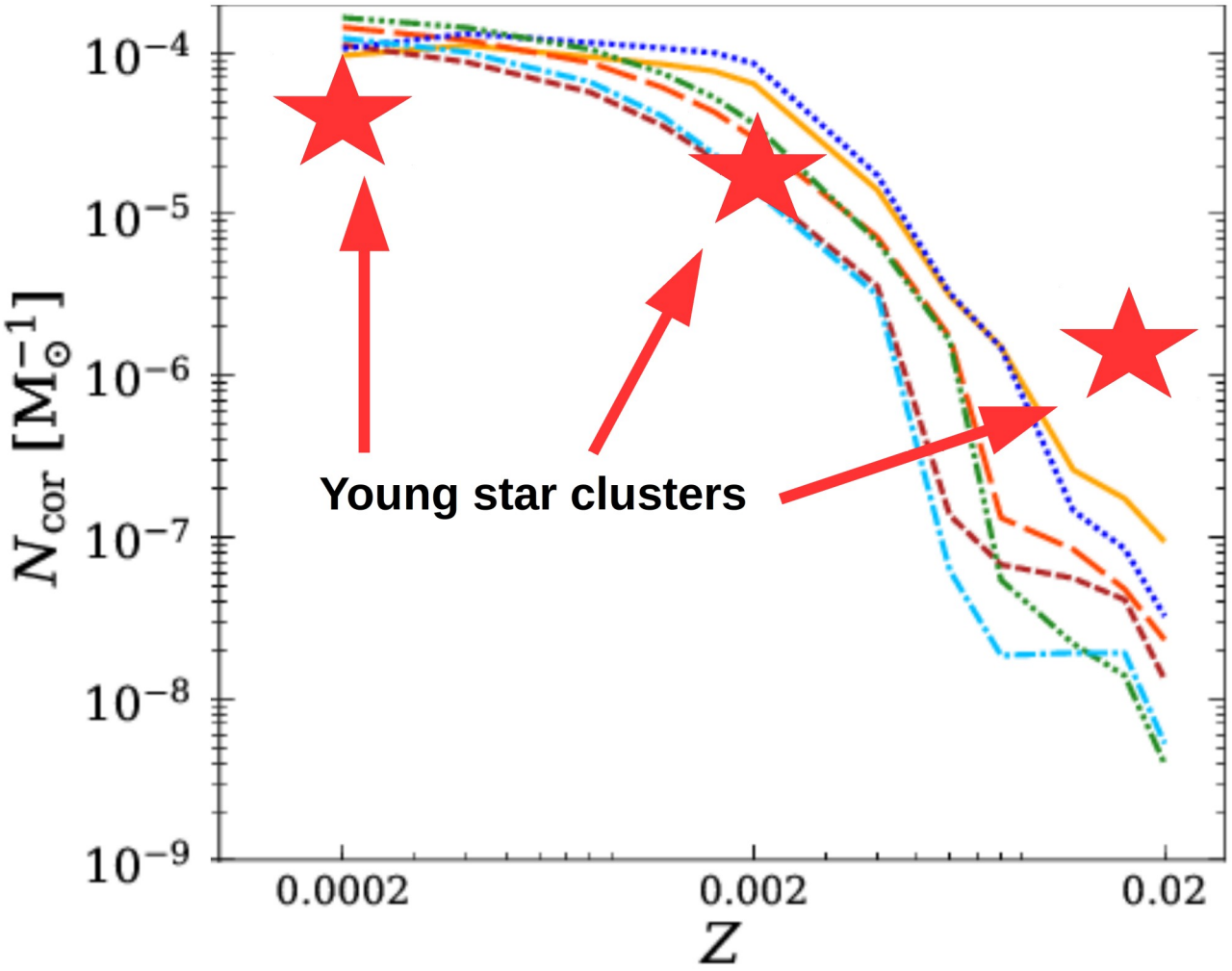
*** ~ 2% merging BBHs in the pair instability (PISN) mass gap**

Metallicity
$Z = 0.1\ Z_\odot$

Di Carlo, Giacobbo, MM et al., 2019

3. BH binaries from dynamical simulations of young star clusters

Number of BH mergers per unit stellar mass



Lines: isolated binaries from Giacobbo & Mapelli 2018

Stars: dynamical simulations Di Carlo et al., in prep.

*** Dynamics in young star clusters washes out dependence of merger rate on progenitor's metallicity**

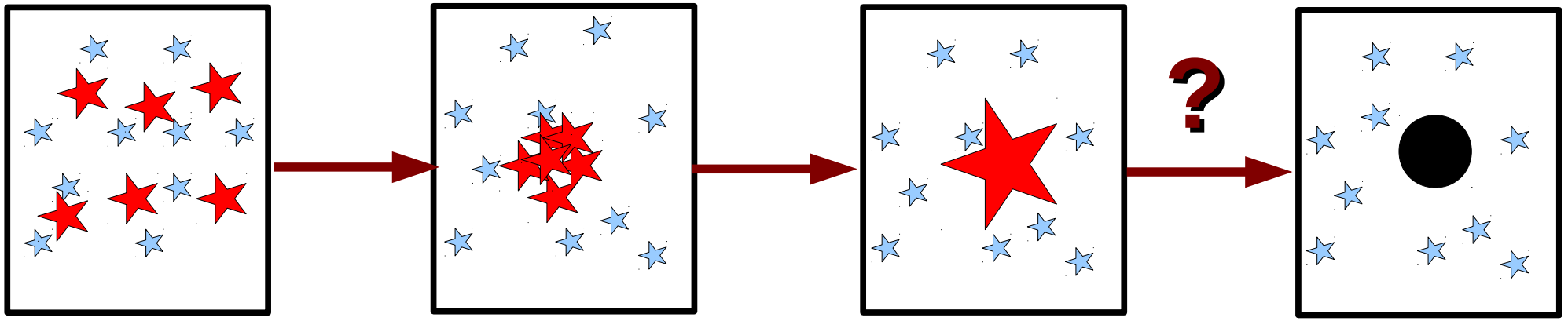
4. IMBHs from runaway collisions?

RUNAWAY COLLISIONS

Massive stars segregate to the centre of dense star clusters in few Myr

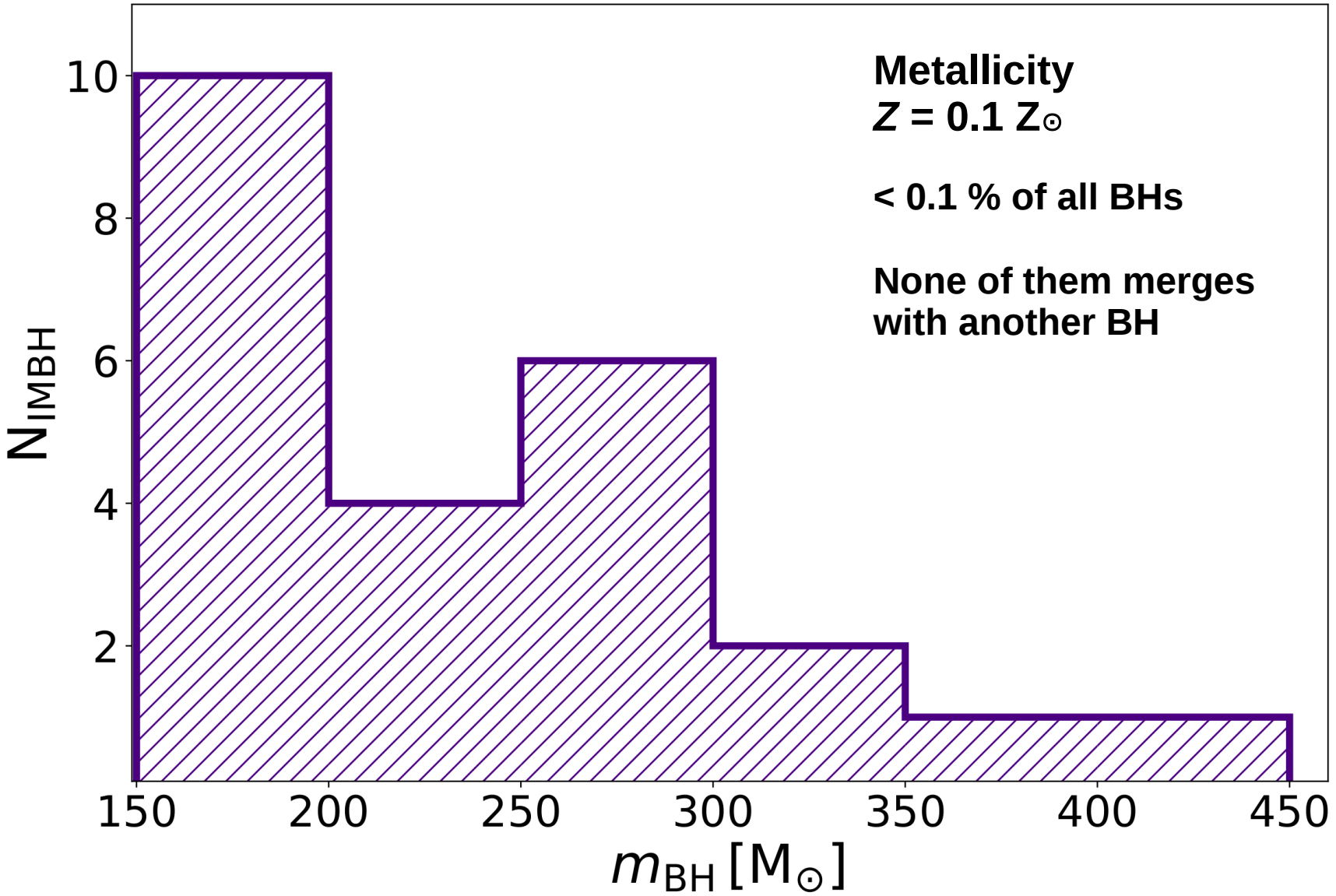
Massive super-star forms by collisions and possibly collapses to IMBH

Colgate 1967; Portegies Zwart+ 2004; Giersz+ 2015; MM 2016



What is the final mass of the collision product?

4. IMBHs from runaway collisions?



MM 2016; Di Carlo+ 2019

5. Conclusions

* **MOBSE: We have updated BSE (Hurley et al. 2000, 2002) to include new prescriptions for stellar winds and supernovae**
  (see Giacobbo+ 2018; MM+ 2017)

* **BH progenitors form in young star clusters and star cluster dynamics significantly affects BH binaries**
  (see MM 2018 for a review of BH dynamics)

* **Isolated BH binaries form with mass up to 130 M⊙ but merging BH binaries only up to 80 M⊙**
  (Giacobbo, MM, Spera 2018; Giacobbo & MM 2018a, 2018b)

* **Dynamics in young star clusters leads to more massive merging BHs and washes out dependence on progenitor's metallicity**
  (Ziosi + 2014; MM 2016; Kimpson + 2016; Di Carlo + 2019)

* **~ 2 % BBH mergers in the pair instability mass gap**
  (Di Carlo + 2019)