Formation and Evolution of BHs in Star Clusters

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Outline

1. My research in a nutshell

2. The BH mass spectrum (**single** stellar evolution)

3. The BH mass spectrum (**binary** stellar evolution)

4. Conclusions

Overview of my research

AIM

To study the formation pathways of **compact-object binaries** that merge within a Hubble time

FINAL GOAL

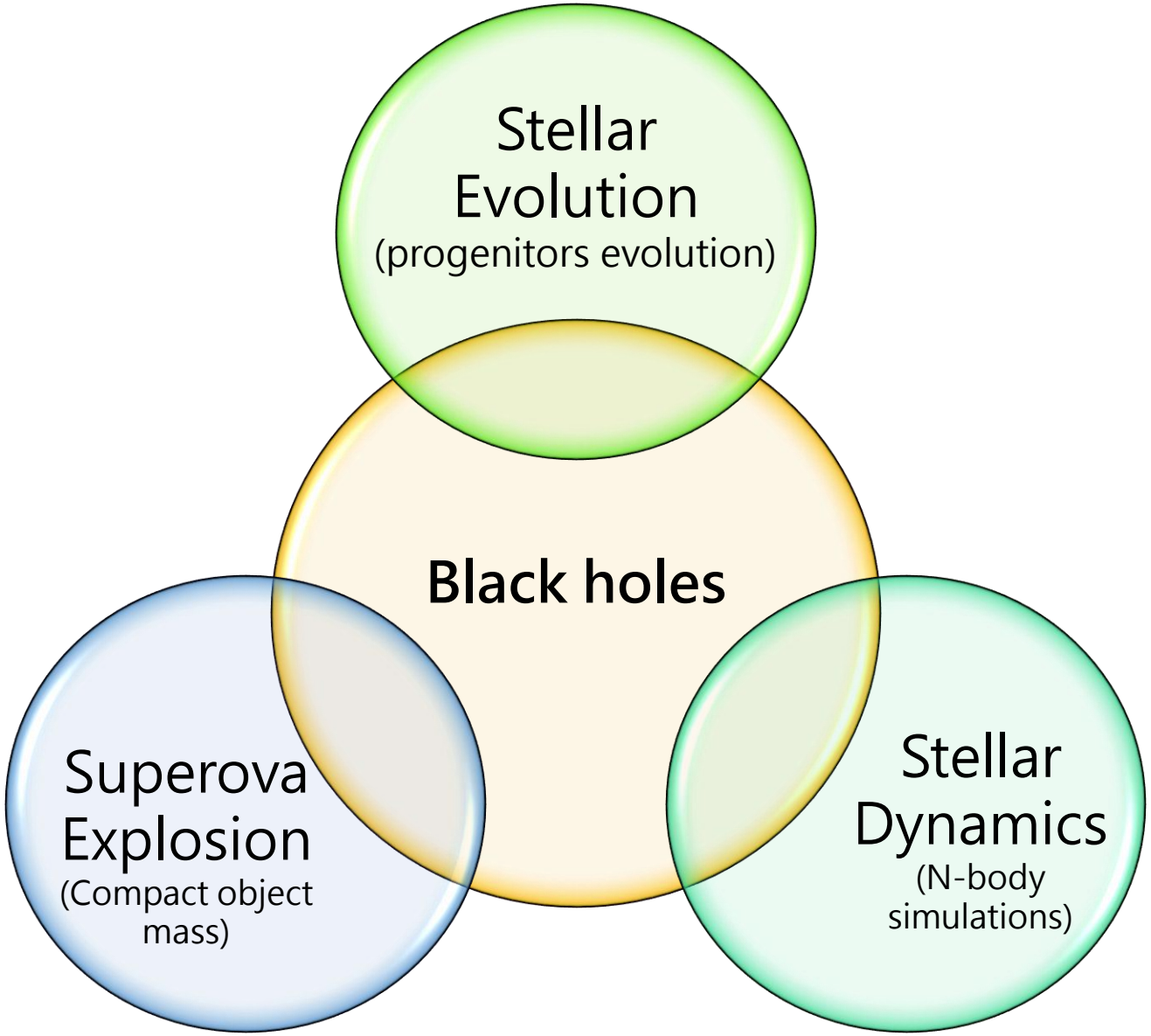
To provide theoretical models to **interpret present and forthcoming GW sources**

MOTIVATION

The formation and evolution of (merging) compact-object binaries is **very uncertain**

How/where massive stellar BHs ($\gtrsim 25 M_{\odot}$) form?

Understanding black holes: ingredients



BH mass spectrum: physical processes

Stellar evolution → stellar winds

Stars lose mass

(Vink+ 2001, 2005, 2011, Bressan+ 2012, Tang, Bressan+ 2014, Chen, Bressan+ 2015)

- ✓ Mass-loss depends on **mass** and **metallicity**

$$\frac{dM}{dt} \propto Z^{0.85}$$

- ✓ The amount of mass-loss for massive stars can be conspicuous

Supernova explosion

BHs form after supernovae

(Fryer+ 1999, 2001, 2012, Heger+ 2003, Mapelli+ 2009, 2010)

- ✓ Very **complex and uncertain**. It depends on: final mass of the star, fallback, compactness…

✓ $M_{\rm final} \gtrsim 30 M_\odot$: the SN explosion may fail → **direct collapse** → massive black hole

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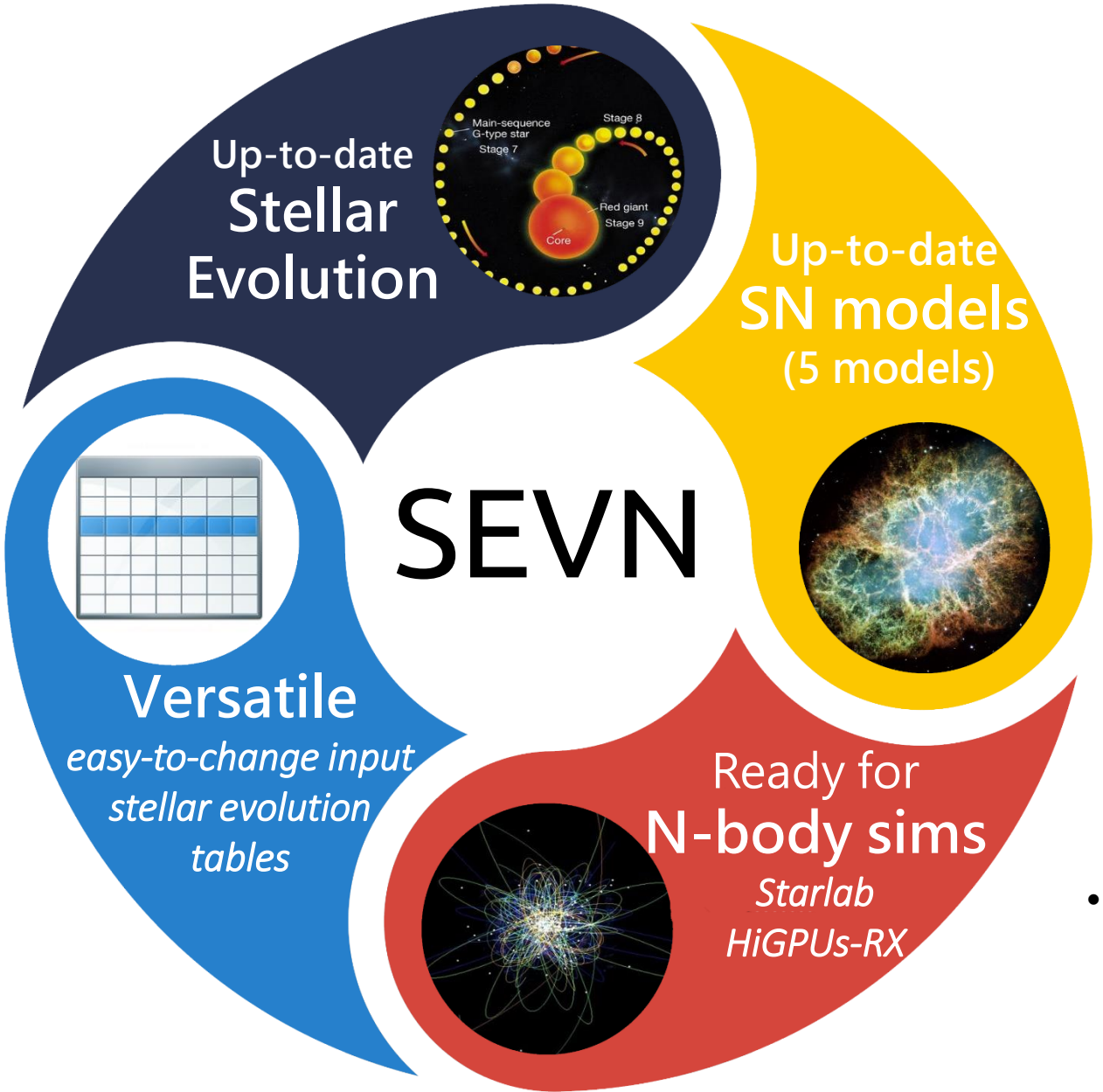
The SEVN code

Stellar EVolution for N-body



- *MS, Mapelli, Bressan, 2015, MNRAS, 451, 4086*
- *MS & Mapelli, 2017, MNRAS, 470, 4739*
- ***MS +, 2018, in preparation***

- Stellar evolution through **look-up tables**.
  a. Versatile approach.
  b. Default: tables from the PARSEC code (Bressan+ 2012, Chen+ 2015)

- Several up-to-date **SN explosion** models
  a. CO-based criteria
  b. Compactness-based criteria

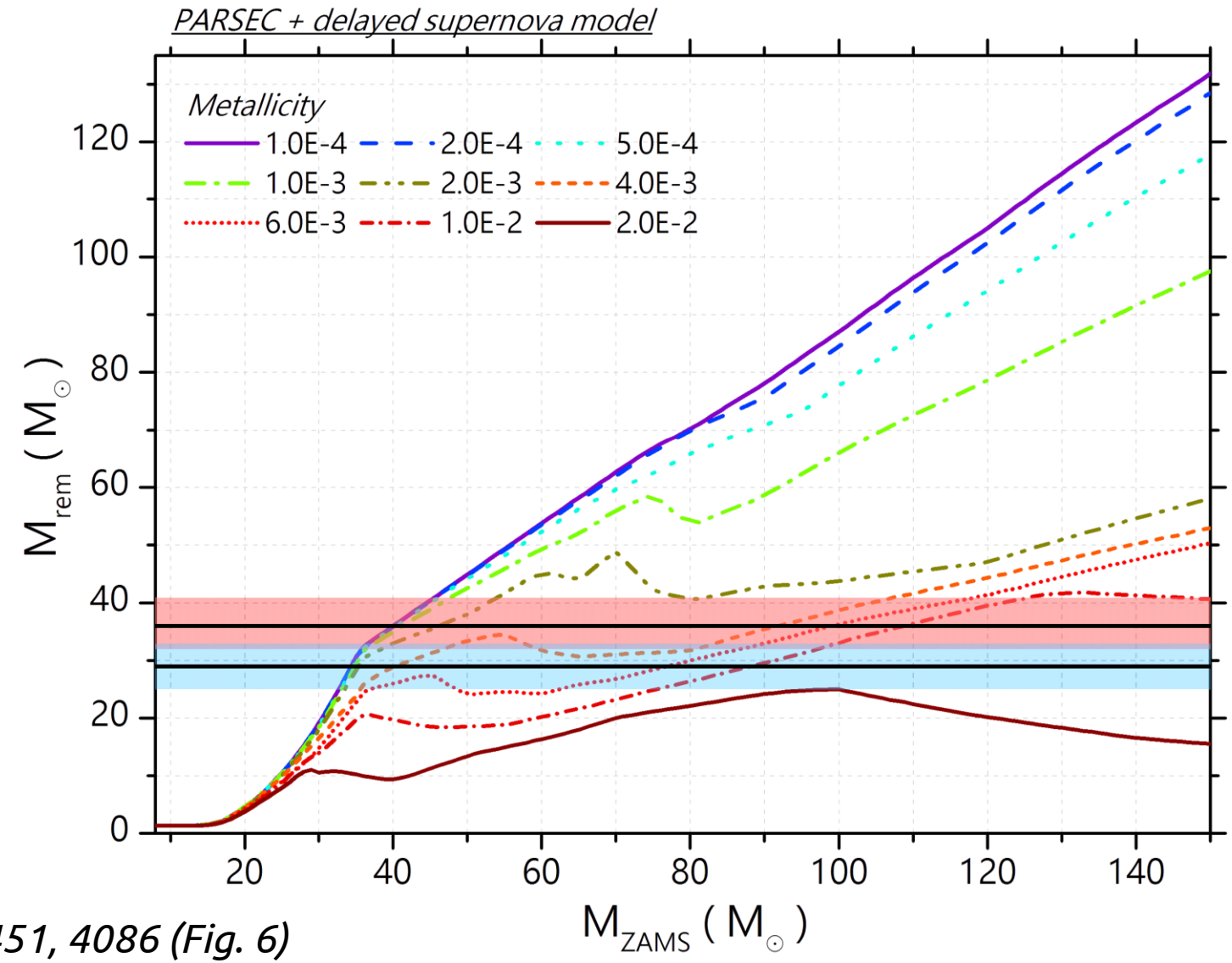
- Already coupled with some **N-body codes**

- SEVN is **publicly available**
  - http://web.pd.astro.it/mapelli/SEVN.tar.gz

The BH mass spectrum

Massive ($> 30 M_\odot$) stellar black holes:

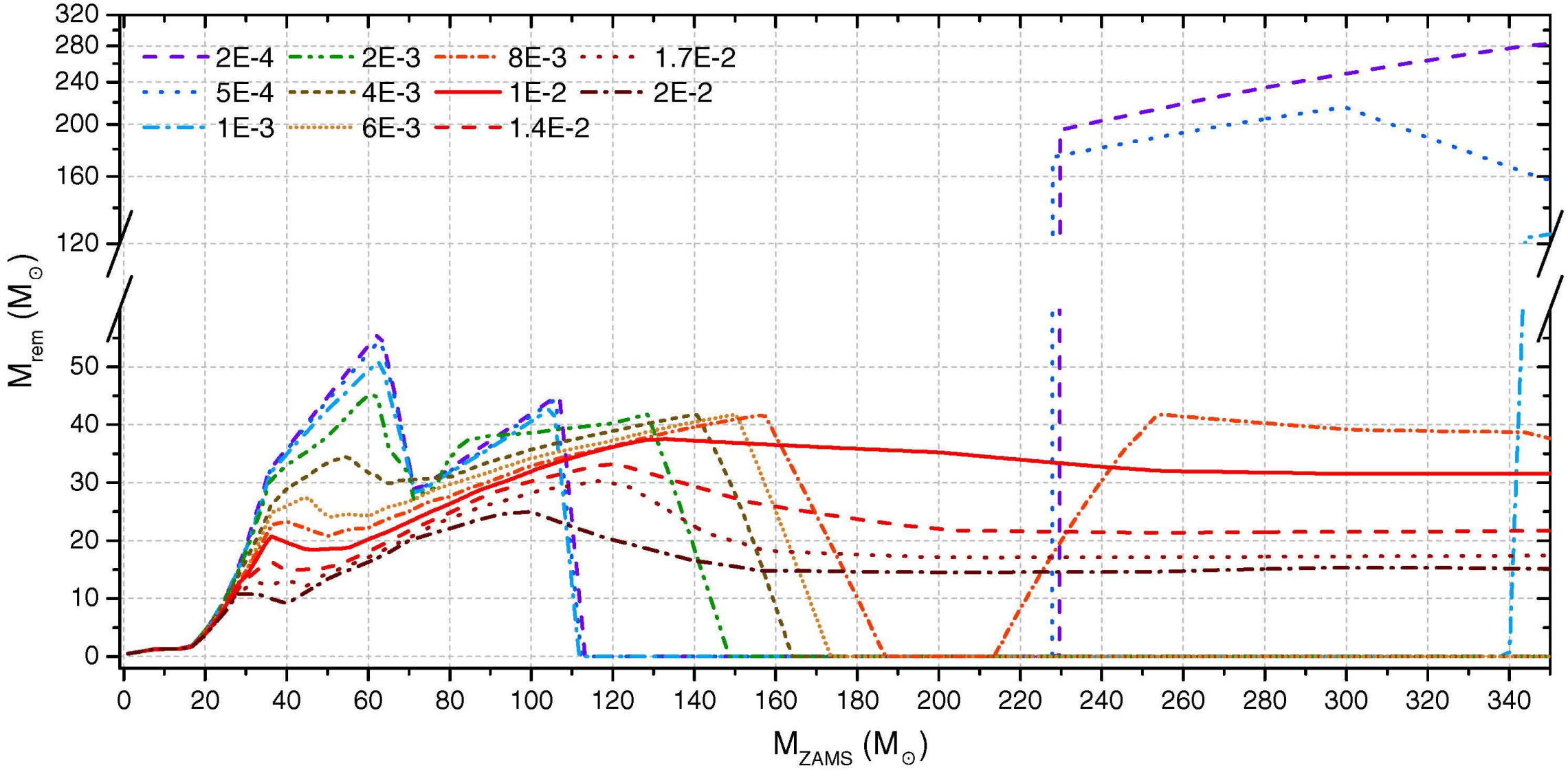
Low metallicity
+
direct collapse



- *MS, Mapelli, Bressan, 2015, MNRAS, 451, 4086 (Fig. 6)*
- *Abbott+ 2016 ApJL, 818, L22 (Fig. 1)*

The effect of pair-instability SNe

Pulsational- and pair-instability SNe are missing in most population-synthesis codes



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What about black-hole binaries?

MS+, 2018, in preparation

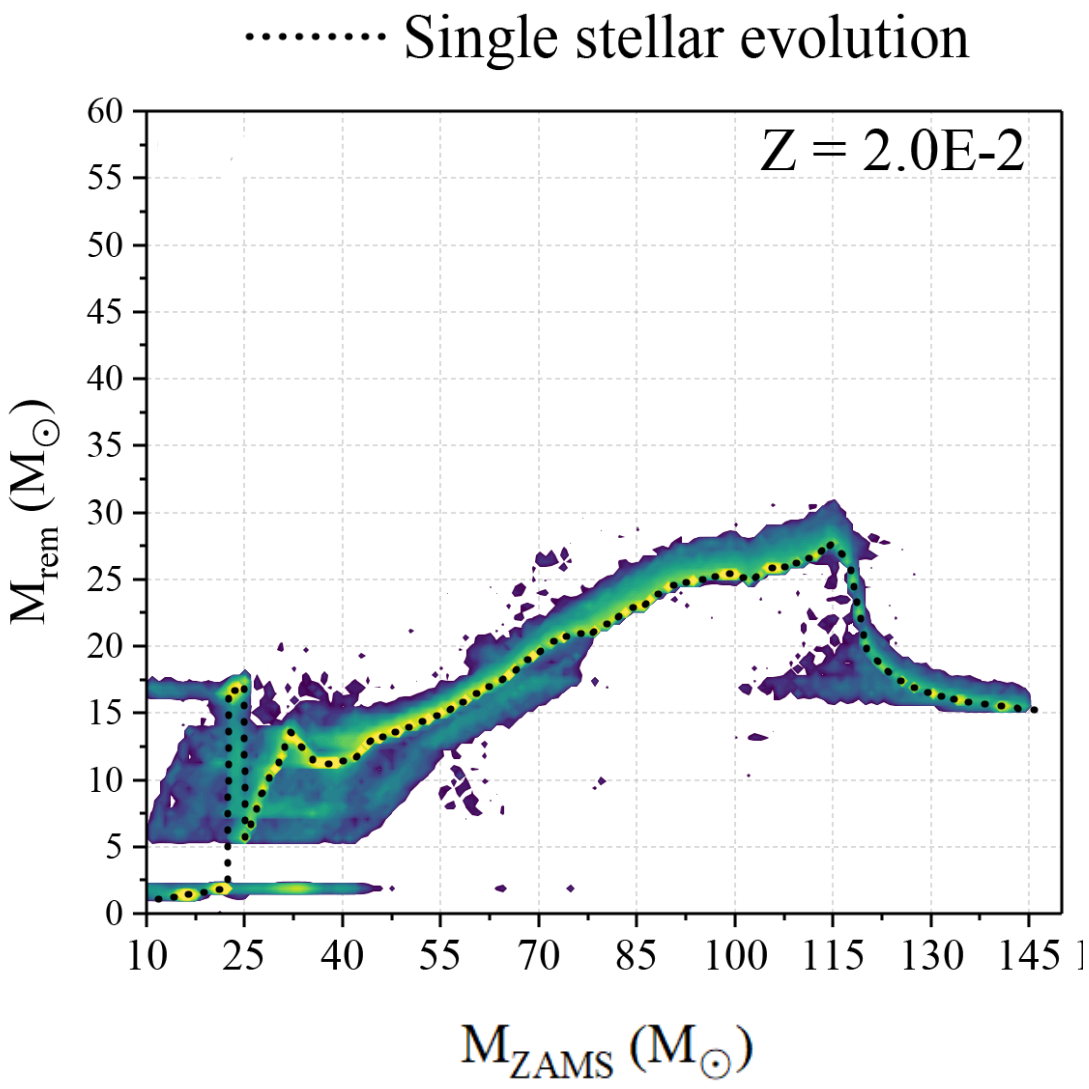
- **Major upgrade to the SEVN code: binary stellar evolution**

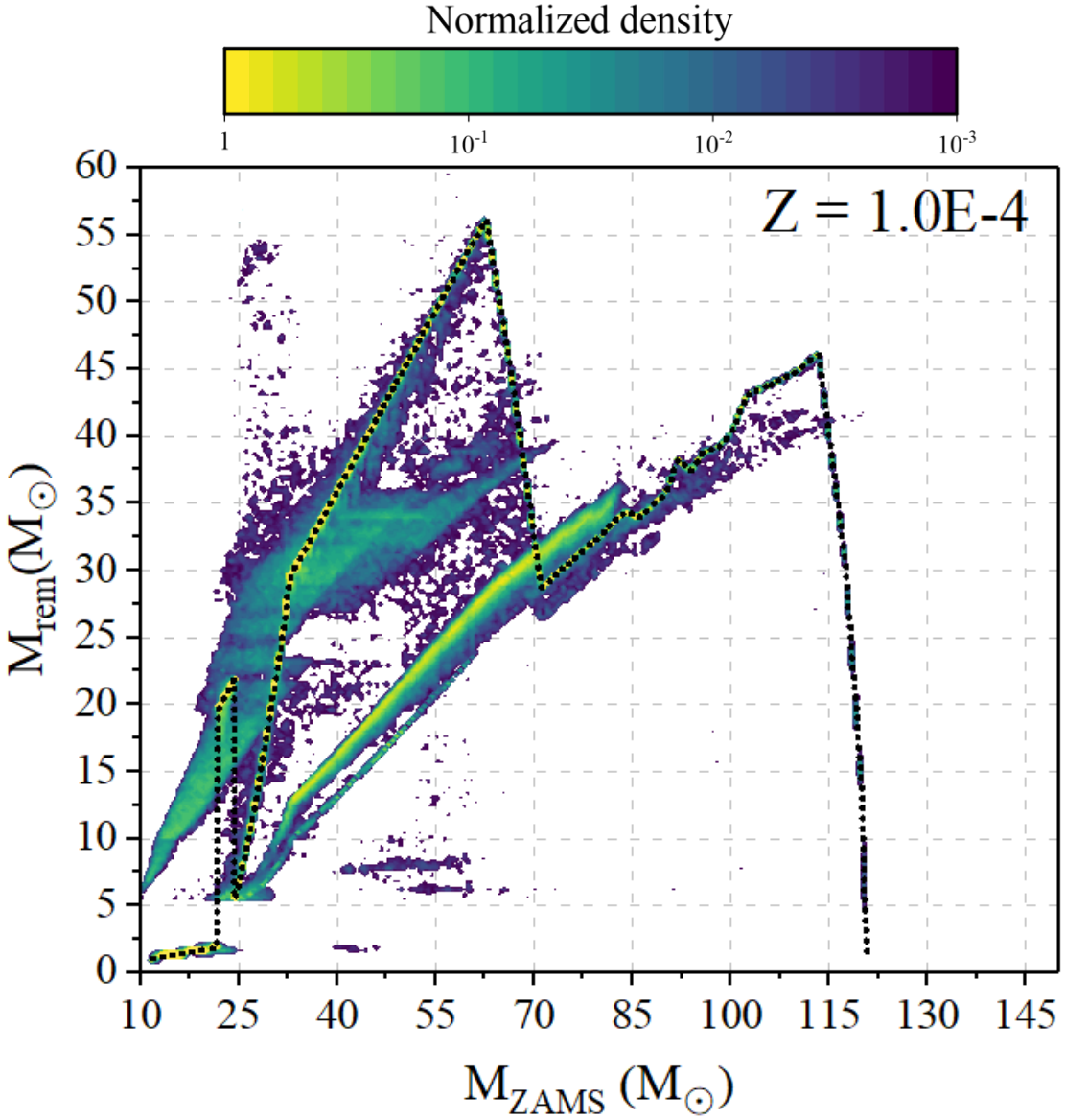
- We follow the BSE prescriptions (Hurley+ 2002), with few important updates.

- Preliminary results: population synthesis simulations of 10^7 binary systems at:
  - different metallicity $z \in [10^{-4}; 6 \times 10^{-2}]$;
  - different initial a and e (Sana+, 2012);
  - Kroupa IMF $[10; 150]\ M_\odot$

The BH mass spectrum

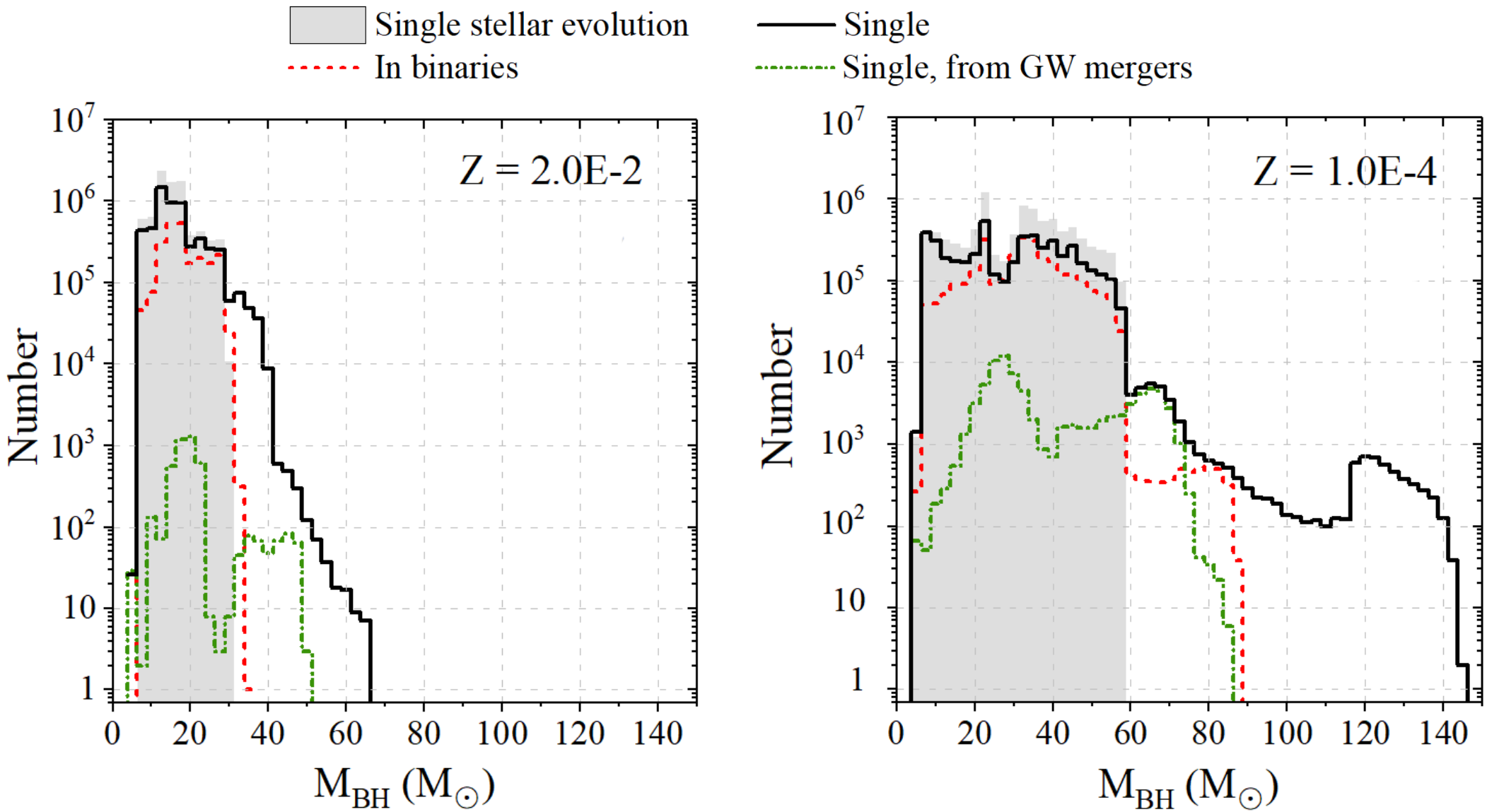
MS+, 2018, in preparation





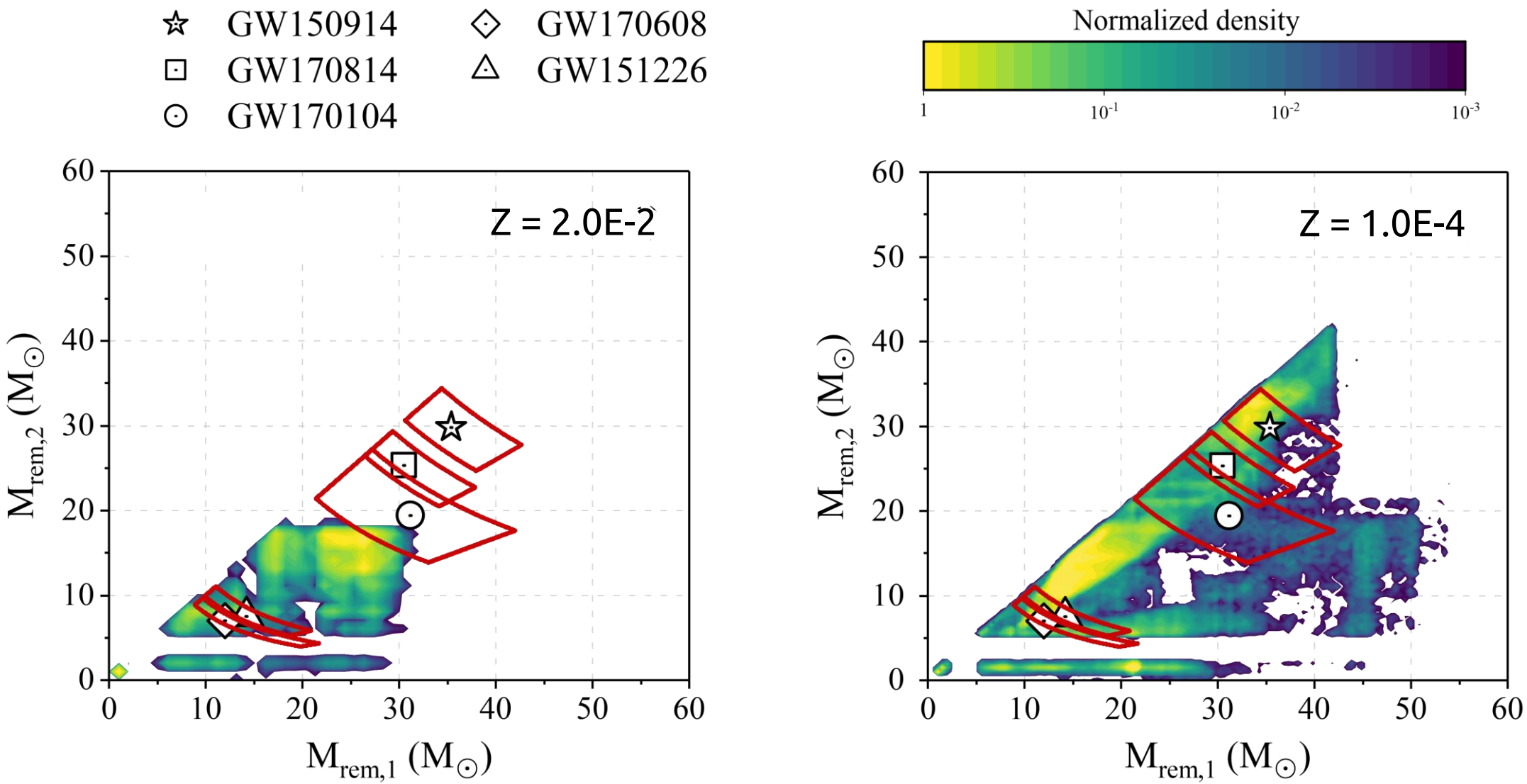
The distribution of BH masses

MS+, 2018, in preparation



Merging BH binaries

MS+, 2018, in preparation



Conclusions

1. Massive stellar BHs can form at low metallicity via direct collapse

2. **Major upgrade of the SEVN code** (binary stellar evolution):

    1. The mass distributions of double BHs from single and binary stellar evolution calculations are remarkably similar;

    2. Massive ($\gtrsim \boldsymbol{60 M_{\odot}}$) single BHs can form at all metallicities;

    3. BH binaries with massive BHs ($\gtrsim \boldsymbol{40 M_{\odot}}$) do form in our simulations but they **do not merge**.