The mass spectrum of compact remnants from the PARSEC stellar evolution tracks

Mario Spera[1], Michela Mapelli[1], Alessandro Bressan[2]

1. INAF-Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, I-35122, Padova, Italy
2. Scuola Internazionale Superiore di Studi Avanzati (SISSA), Via Bonomea 265, I-34136, Trieste, Italy

ABSTRACT

The debate about the demographics of black holes (BHs) in star clusters (SCs) has always been controversial. The dearth of observations of BH X-Ray binaries in globular clusters (GCs) suggested that most BHs were ejected from their birthplace. Nevertheless, the recent discovery of several BH candidates in GCs deeply changed our perspective. On the theoretical side, the formation and dynamical evolution of BHs in GCs and in younger SCs is still poorly understood. To shed light on the enigma of BH formation and evolution in SCs, it is essential to perform high-accuracy N-Body simulations of stellar systems, and to link them with new stellar evolution recipes. In particular, our knowledge of stellar evolution and stellar winds at low metallicity was revolutionized in the last ten years. In this poster, I present a new public software environment that couples N-Body dynamics, advanced models of stellar evolution (from the Padova stellar evolution group) and new recipes for remnant formation. I used this code to investigate the formation of massive BHs ($\gtrsim 30M_{\odot}$) in metal-poor SCs ($< 0.3Z_{\odot}$).

INTRODUCTION

- ✓ Compact remnants (CRs), such as black holes (BHs) and neutron stars (NSs), represent the final stage of the evolution of massive stars. They are the engine of several astrophysical objects (X-ray binaries, ultraluminous X-ray sources), and might play a crucial role in emitting gravitational waves and in powering short gamma-ray bursts.

- ✓ **Matter of debate n.1**: formation of BHs and NSs
  - ✓ What is the impact of SN explosion on the CR mass? → **Importance of updated models for supernovae (SNe) explosions**;
  - ✓ What is the importance of stellar evolution (at different metallicity) on the CR mass? → **Importance of updated stellar evolution recipes**.

- ✓ **Matter of debate n.2**: BHs in star clusters (SCs)
  - ✓ Theoretical prediction: 100 – 1000 BHs in SCs with mass $\gtrsim 10^4 M_{\odot}$
  - ✓ Observations: only few BHs in SCs → BHs ejected by birth kicks and/or strong dynamical interactions? → **Importance of high-precision N-body simulations**.

We combined
high-precision N-body dynamics +
(latest) stellar evolution recipes (PARSEC code, *Bressan A. et al., 2012, MNRAS, 427, 127*) +
(latest) SN explosion models (*Fryer C. L. et al., 2012, ApJ, 749,91 [FRY2012]*)
to shed light on the enigma of the presence of CRs in SCs

- ✓ **PARSEC**: pre-MS evolution + input physics deeply revisited especially for what concerns massive stars ($M > 20M_{\odot}$) whose models have not been updated for two decades.

- ✓ We present here the CRs mass spectrum obtained using our new tool, with particular attention to its dependence on metallicity *(details in Spera M., et al., 2015, in preparation).*

THE MASS SPECTRUM OF COMPACT REMNANTS

➢ **Fig. 1** shows the evolution of the mass of a star ($M_{ZAMS} = 100M_{\odot}, Z = 2\times10^{-3}$) obtained using our tool in comparison with the SSE stellar evolution code (*Hurley et al., 2000, MNRAS, 315, 543*);
Final mass (PARSEC) ≅ **50M$_{\odot}$** Final mass (SSE) ≅ **13M$_{\odot}$**

➢ **Fig. 2** shows the remnant as a function of the zero age main sequence (ZAMS) mass of the progenitor, at different metallicities.
- SN explosion model: delayed *[FRY2012]*;
- The heaviest BH we obtain lies in the range $M^{(max)}_{remnant} \in [25; 135]\, M_{\odot}$ depending on the metallicity (the higher the metallicity the lower the masses of the BHs, as expected);

➢ **Fig. 3** reports a comparison of the CRs mass spectrum obtained with our tool with other codes, at $Z = 2\times10^{-3}$:
- **Codes: SSE** and a modified version of **STARLAB** (*Mapelli et al., 2013, MNRAS, 429, 2298);*
- For $M_{ZAMS} \gtrsim 30M_{\odot}$, our tool predicts a factor 1.5 - 3 heavier BHs than SSE and STARLAB;

$M^{(max)}_{BH} = 60M_{\odot}$ **OUR TOOL** $M^{(max)}_{BH} = 40M_{\odot}$ **STARLAB**
$M^{(max)}_{BH} = 20M_{\odot}$ **SSE**

Fig. 1

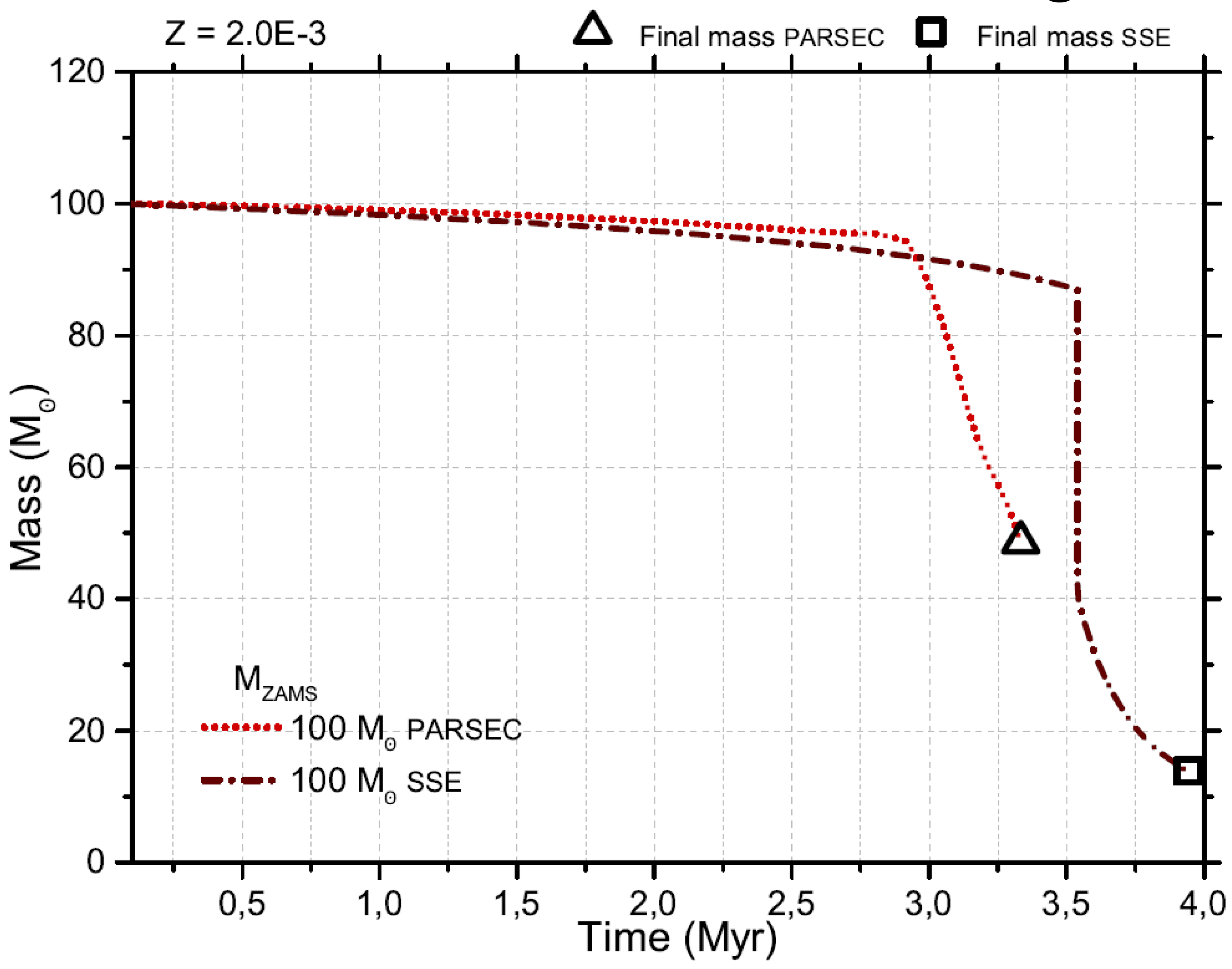


Fig. 2

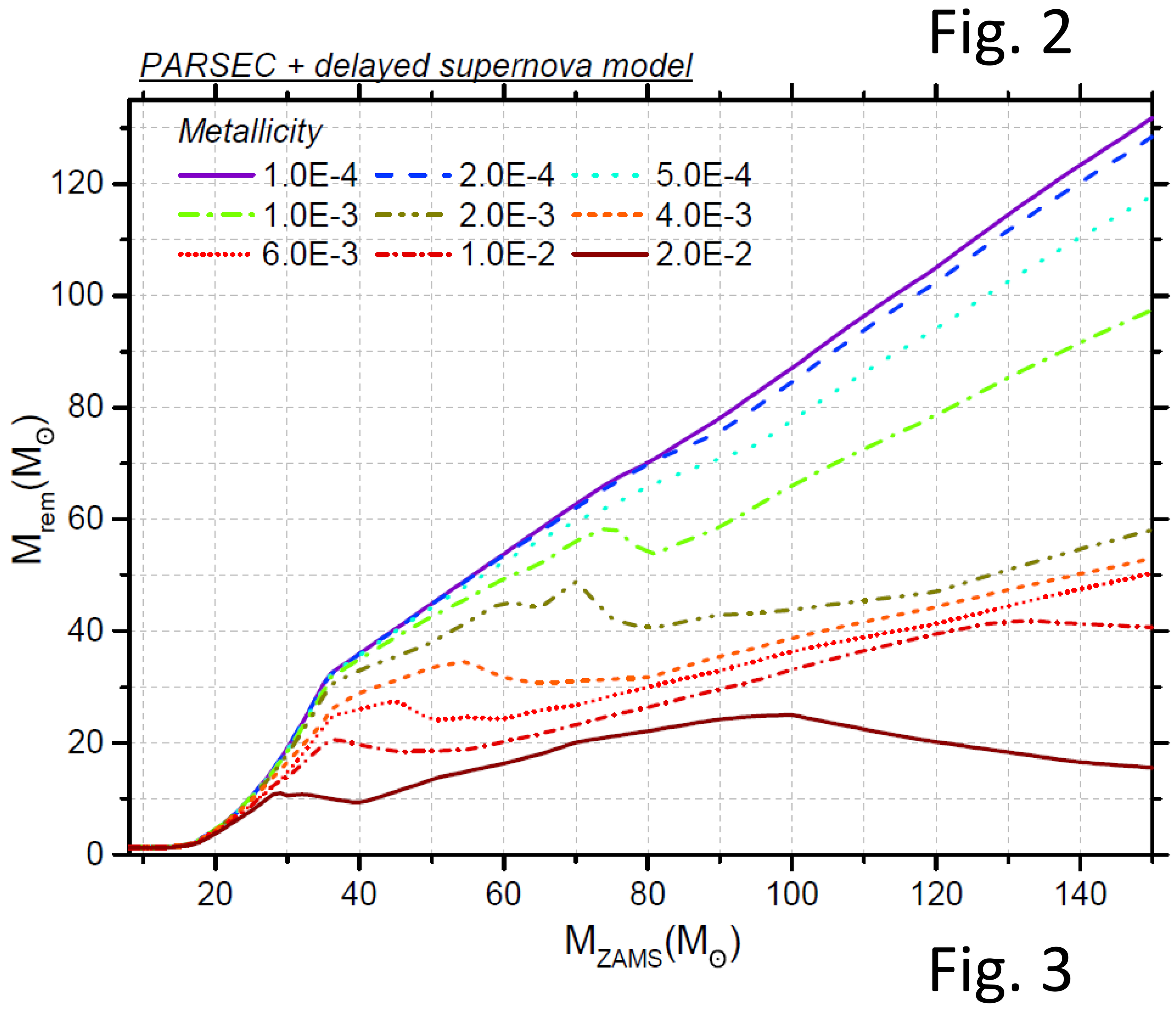
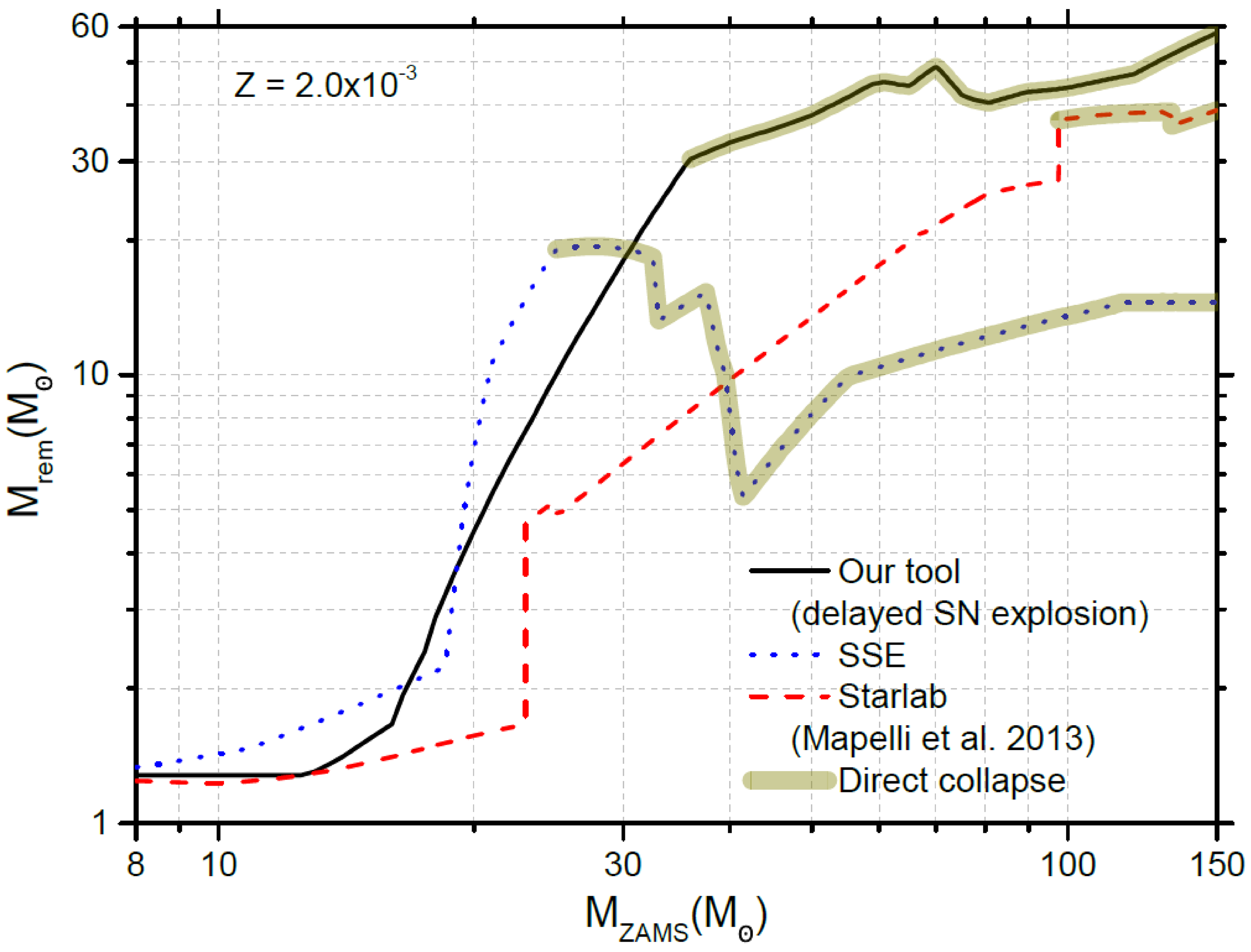


Fig. 3



CURRENT STUDY: the formation of BH binaries and the fraction of ejected BHs in young star clusters and their main implications for the observations of ultraluminous X-ray sources and gravitational waves.