

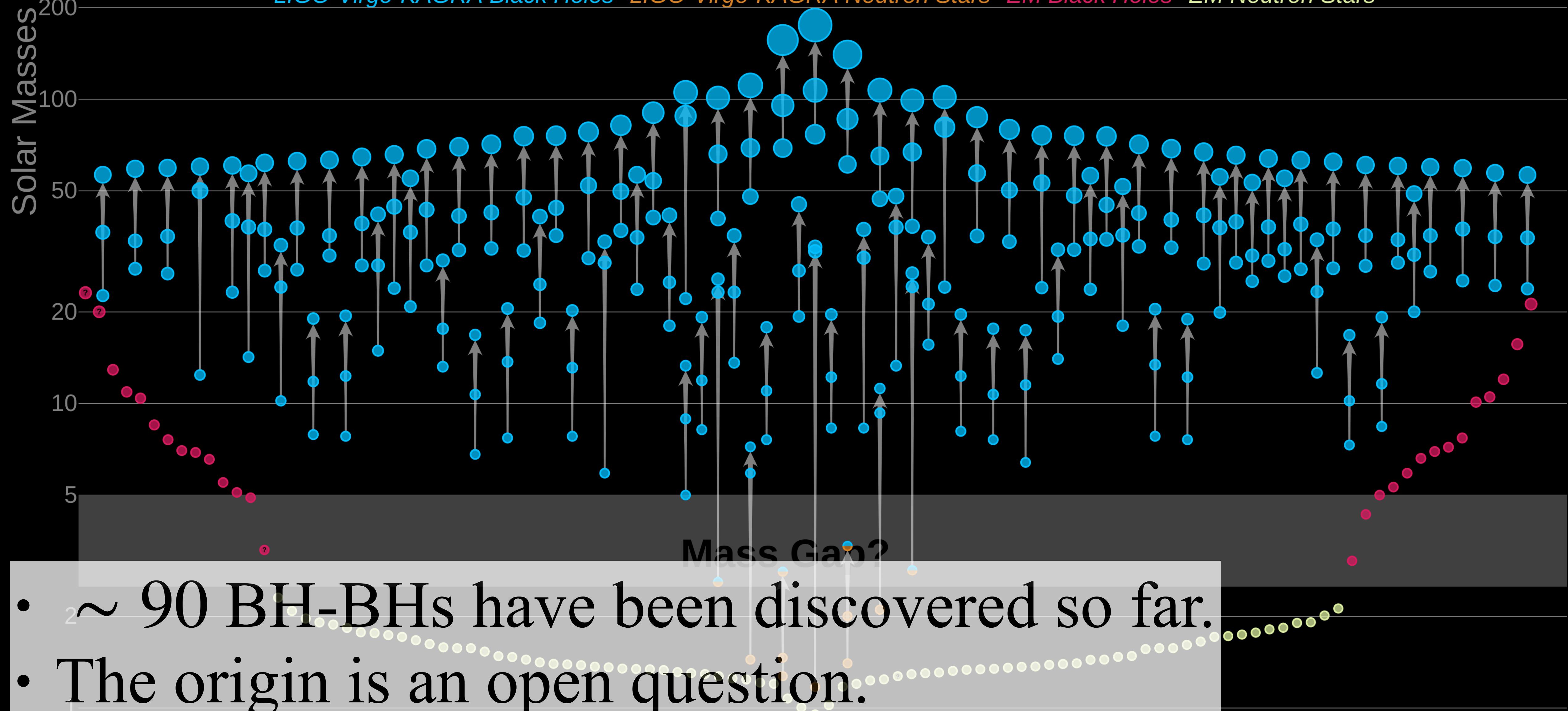
# Formation machanisms of GW190521-like and GW190412-like events from Population III binary stars

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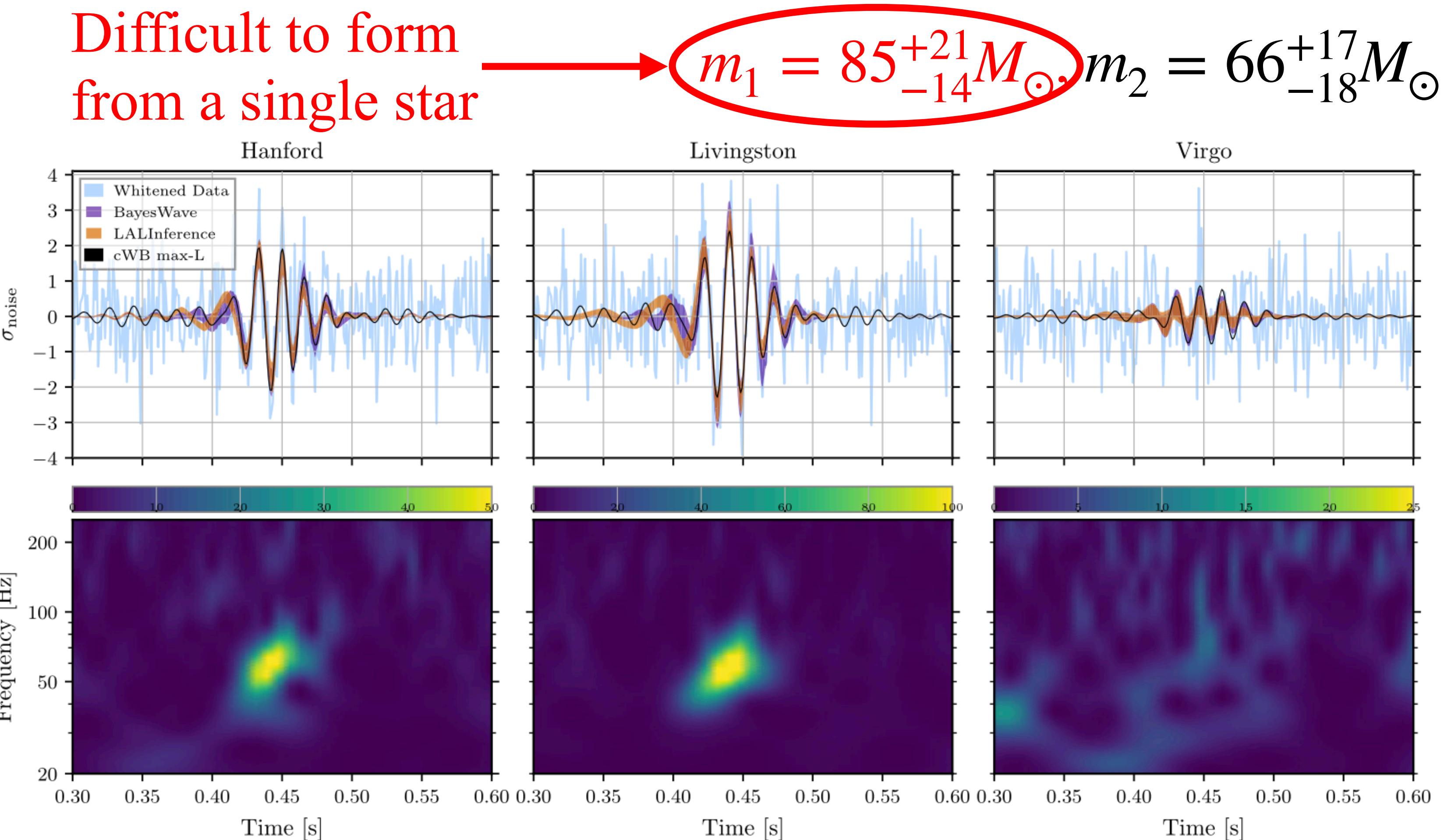
# Masses in the Stellar Graveyard

*LIGO-Virgo-KAGRA Black Holes* *LIGO-Virgo-KAGRA Neutron Stars* *EM Black Holes* *EM Neutron Stars*



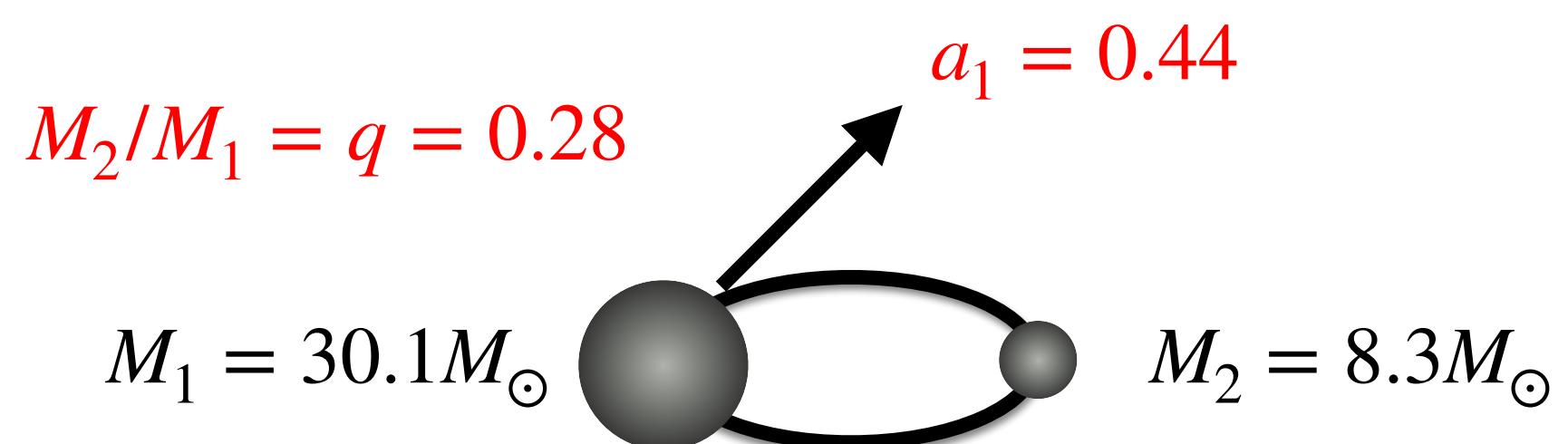
# GW190521: Pair instability mass gap

- Dense star cluster (Rodriguez et al. 2019; Di Carlo et al. 2020; Tagawa et al. 2021)
- Actually, a “straddling” event (Fishbach, Holz 2020; Nitz, Capano 2021)
- Uncertainty in  $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$  (Farmer et al. 2020; Costa et al. 2021; see also Takahashi 2018)
- Pop III binary stars (Kinugawa et al. 2021; Tanikawa et al. 2021, MNRAS, 505, 2170; 2022, ApJ, 926, 83)

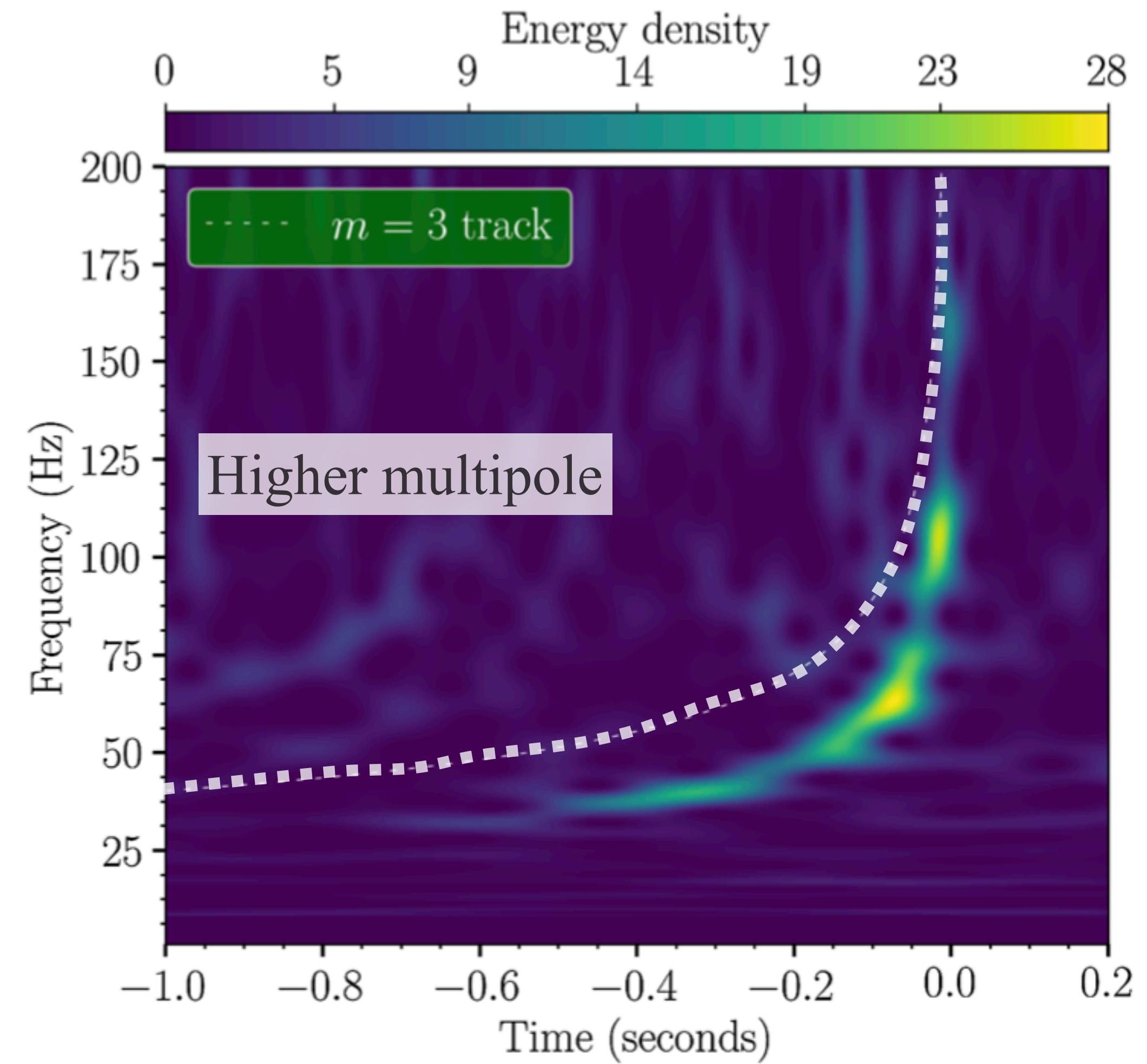


# GW190412: Asymmetric merger

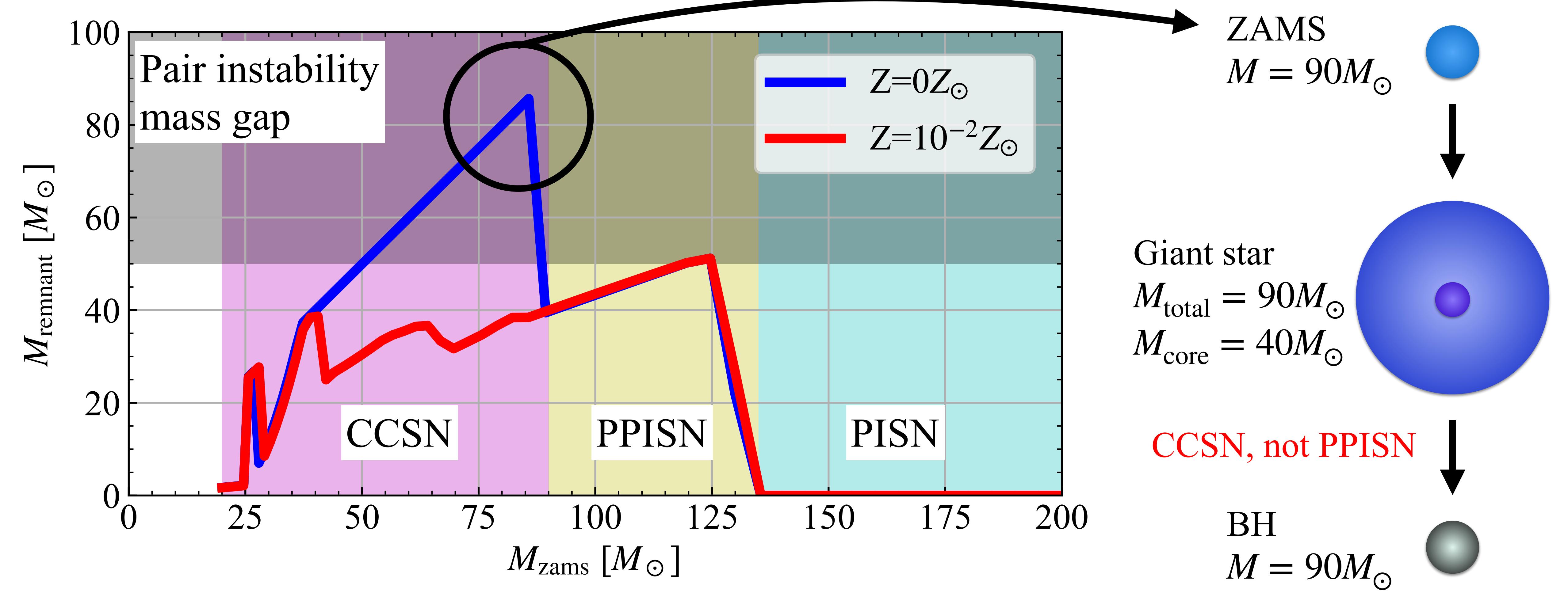
- Dense star clusters (Rodriguez et al. 2020; Tagawa et al. 2020)
- “Mass reversal” (Olejak et al. 2021; Mould et al. 2022; Zevin, Bavera 2022)
- Pop III binary stars (Tanikawa et al. in prep.)



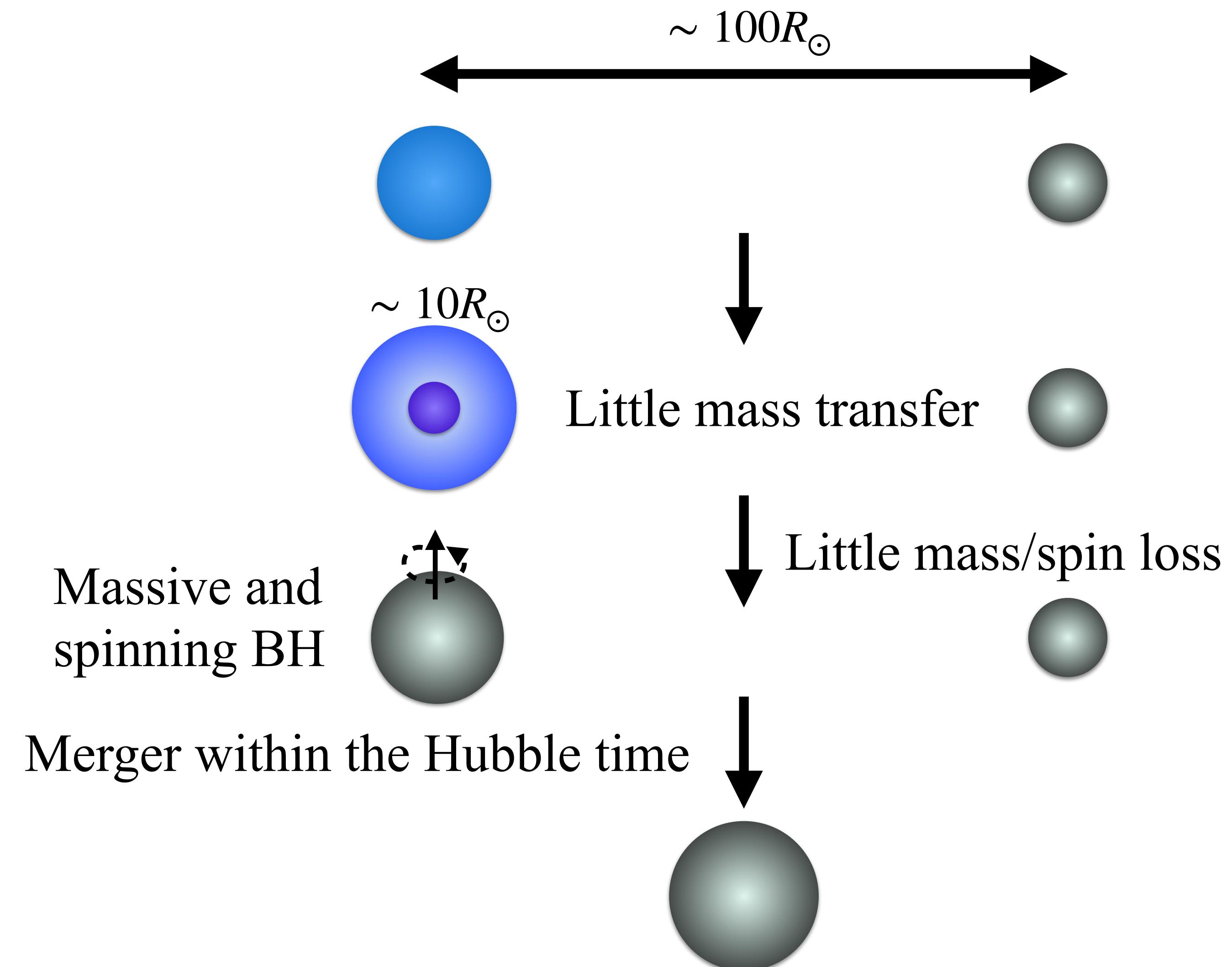
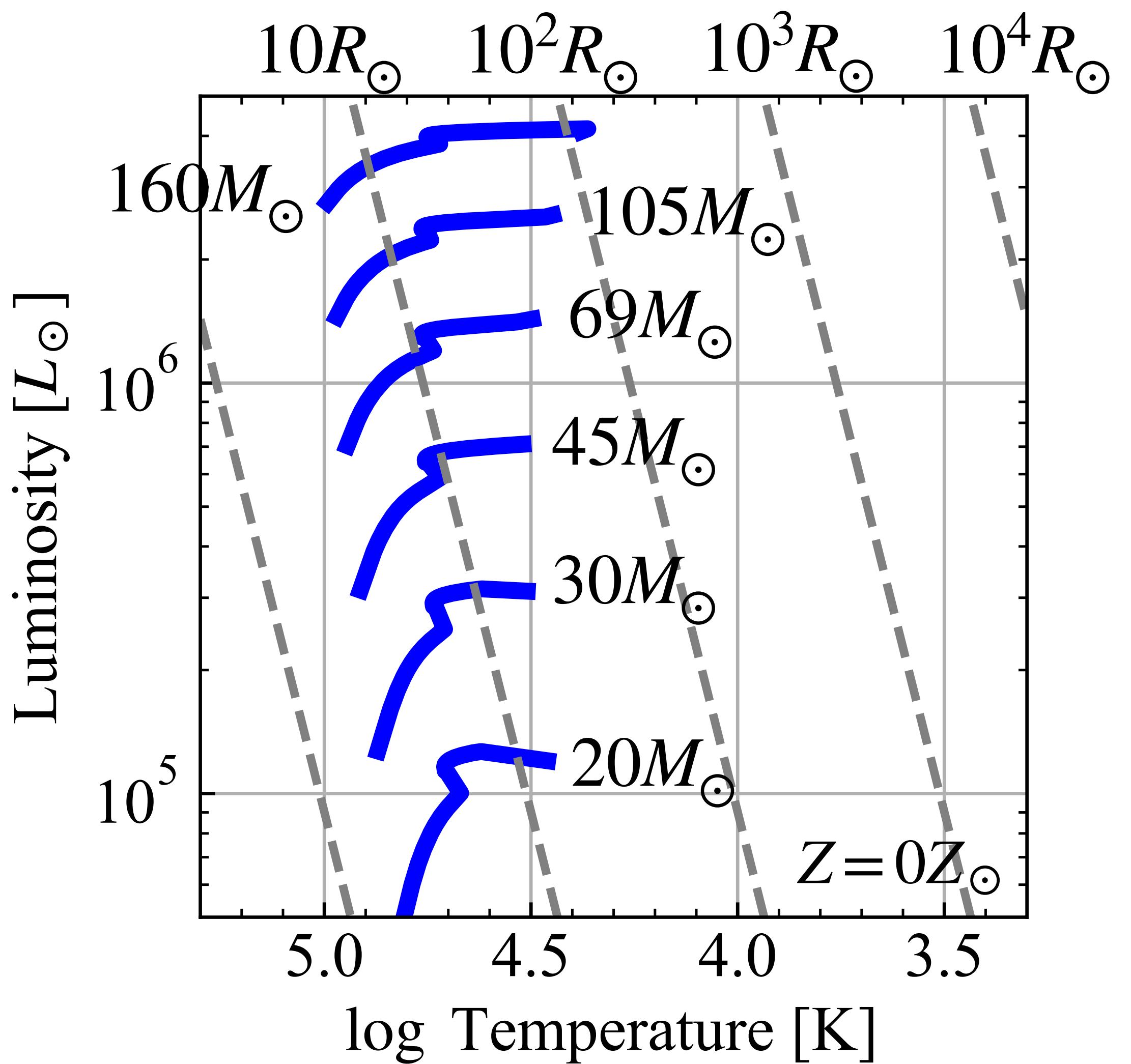
Abbott et al. (2020, PRD, 102, 043015)



# Population III remnant mass

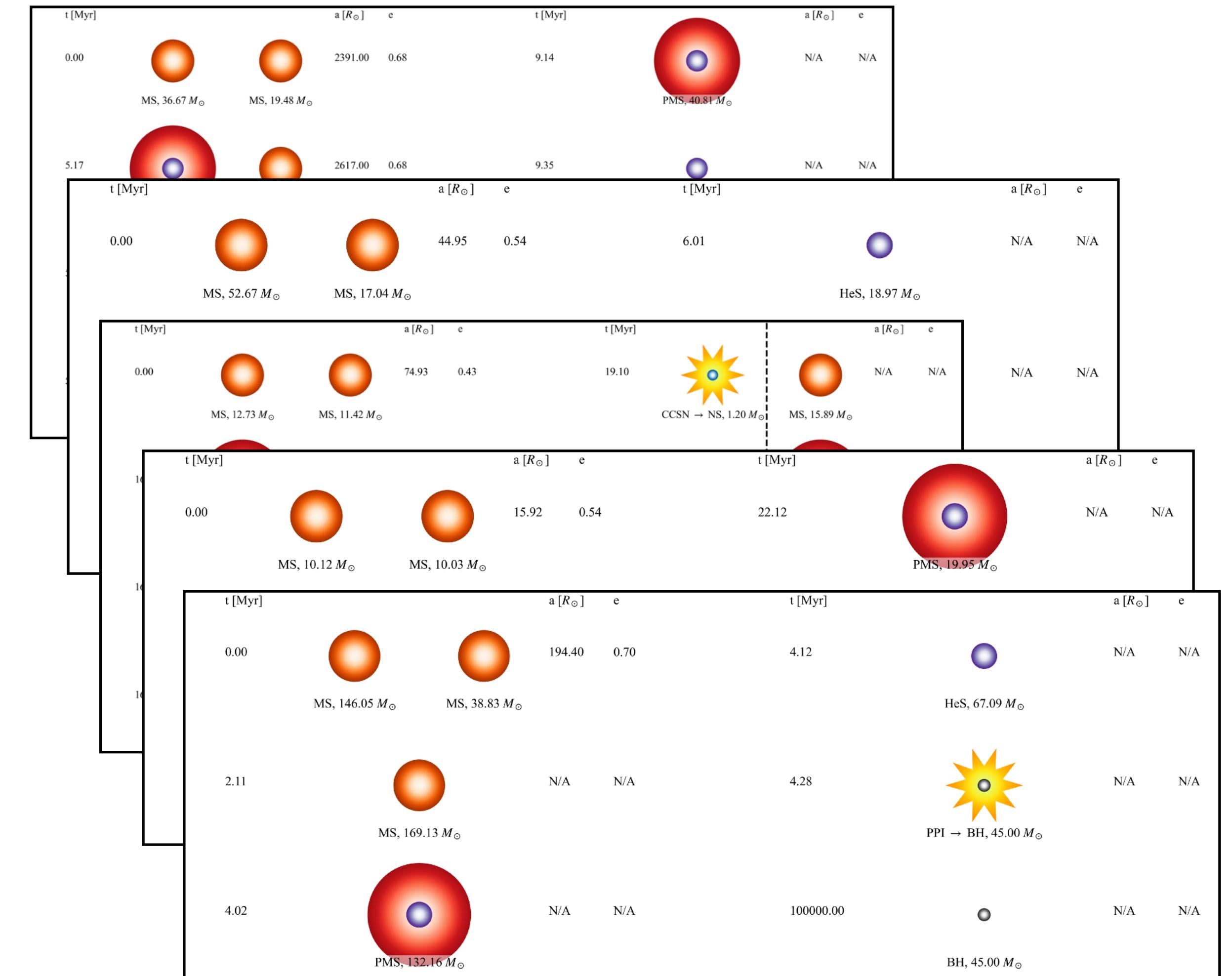


# Population III stellar radius



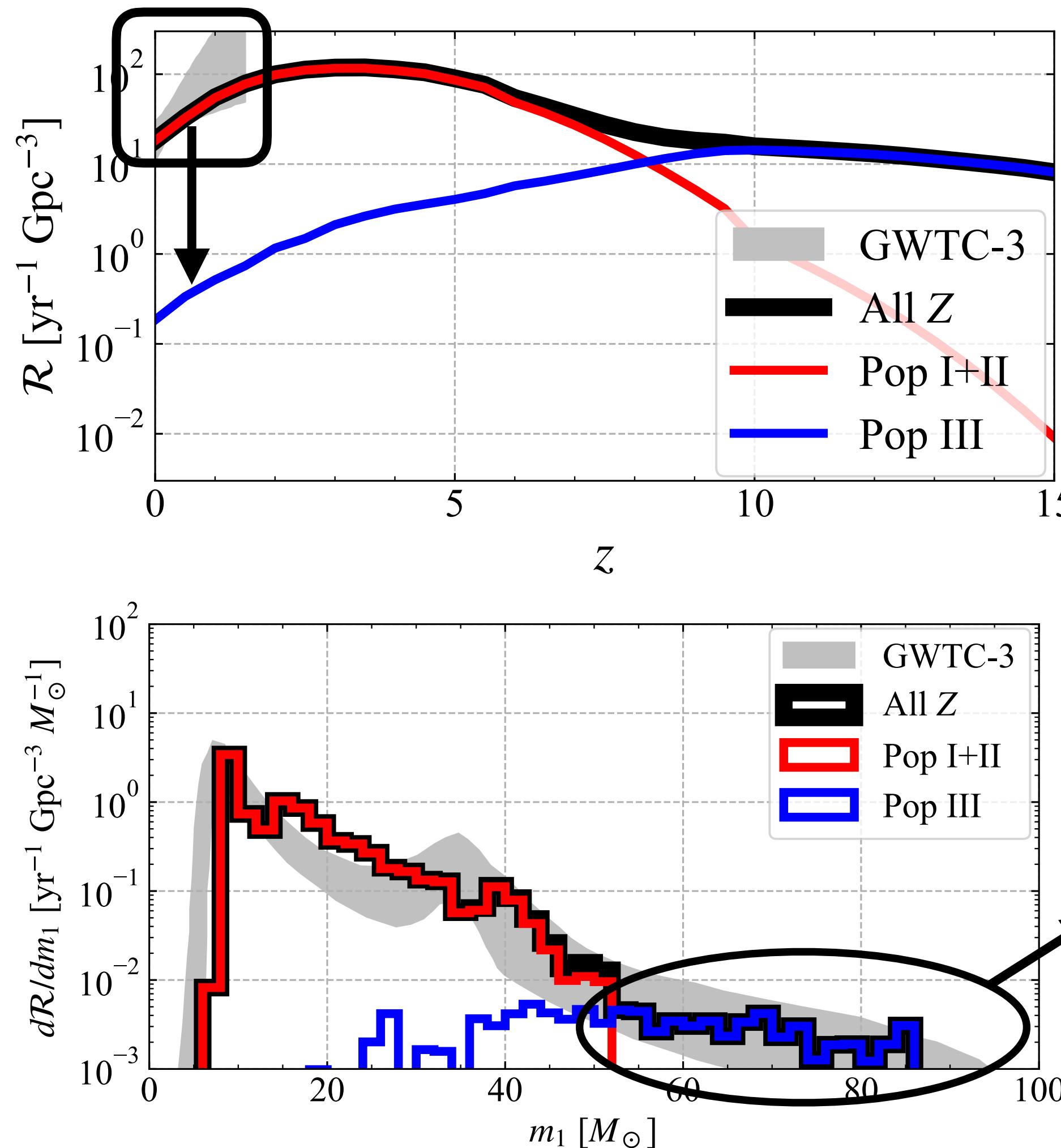
# Binary population synthesis

- BSEEMP: <https://github.com/atrtnkw/bseemp>
- Metallicity:  $0 - 1 Z_{\odot}$  (Tanikawa et al. 2020, MNRAS, 495, 4170; 2021, MNRAS, 505, 2170)
- Stellar wind mass loss (Belczynski et al. 2010)
- Core-collapse supernova model (Fryer et al. 2012) with PISN model (Belczynski et al. 2020)
- BH natal kick model (Hobbs et al. 2005; Fryer et al. 2012)
- Binary evolution model (Hurley et al. 2002) with correction of tidal interaction model (Kinugawa et al. 2020)
- IMF: Metal-rich (Kroupa 2001), Metal-poor (Susa et al. 2014; Hirano et al. 2014; Chon et al. 2021)
- Binary initial conditions (Sana et al. 2012)
- Pop I/II star formation history (Harikane et al. 2022), Pop III star formation history (Skinner, Wise 2020)

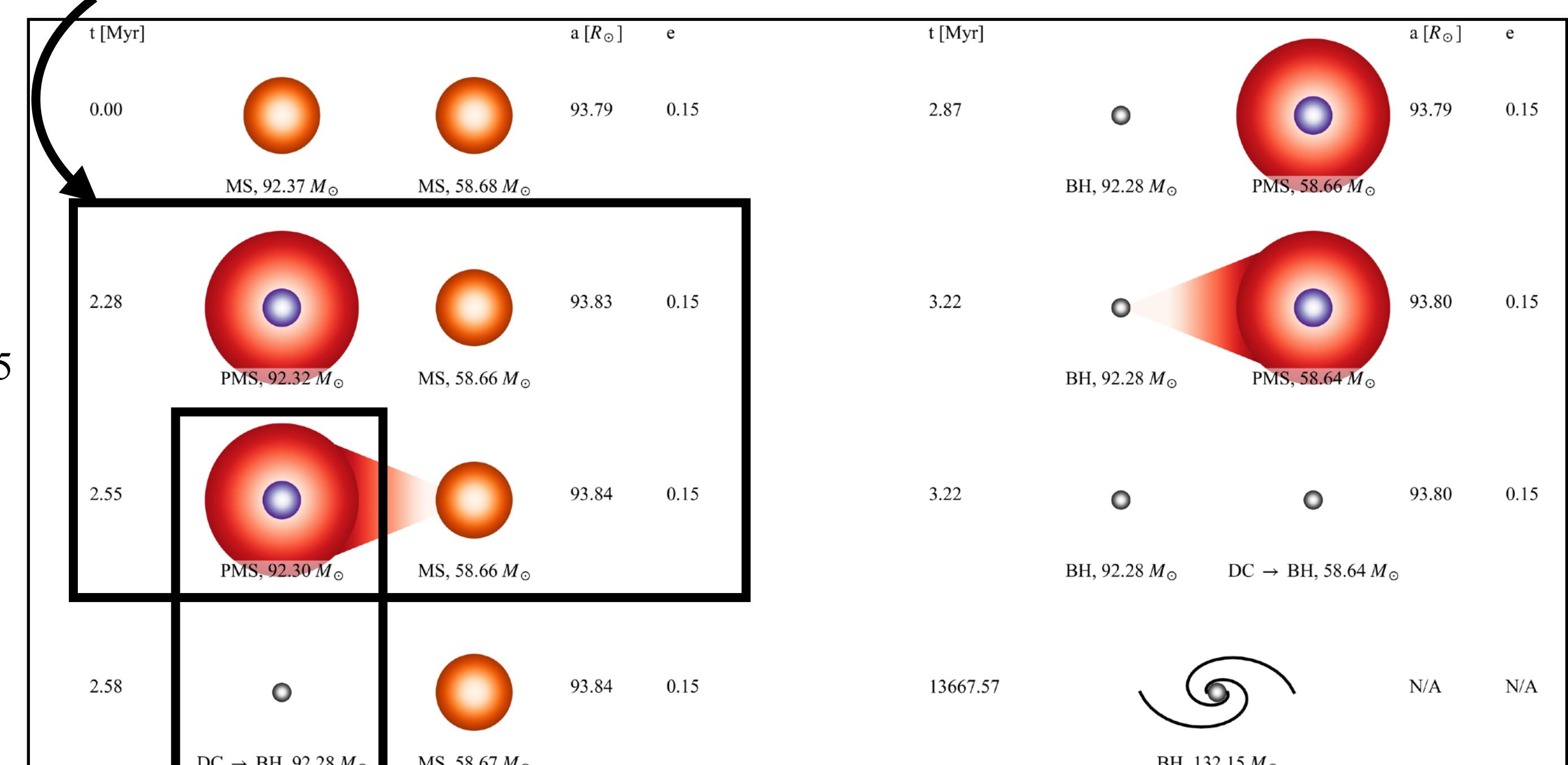


Visualization tool of BSEEMP (to be published...)

# Formation of GW190512-like events



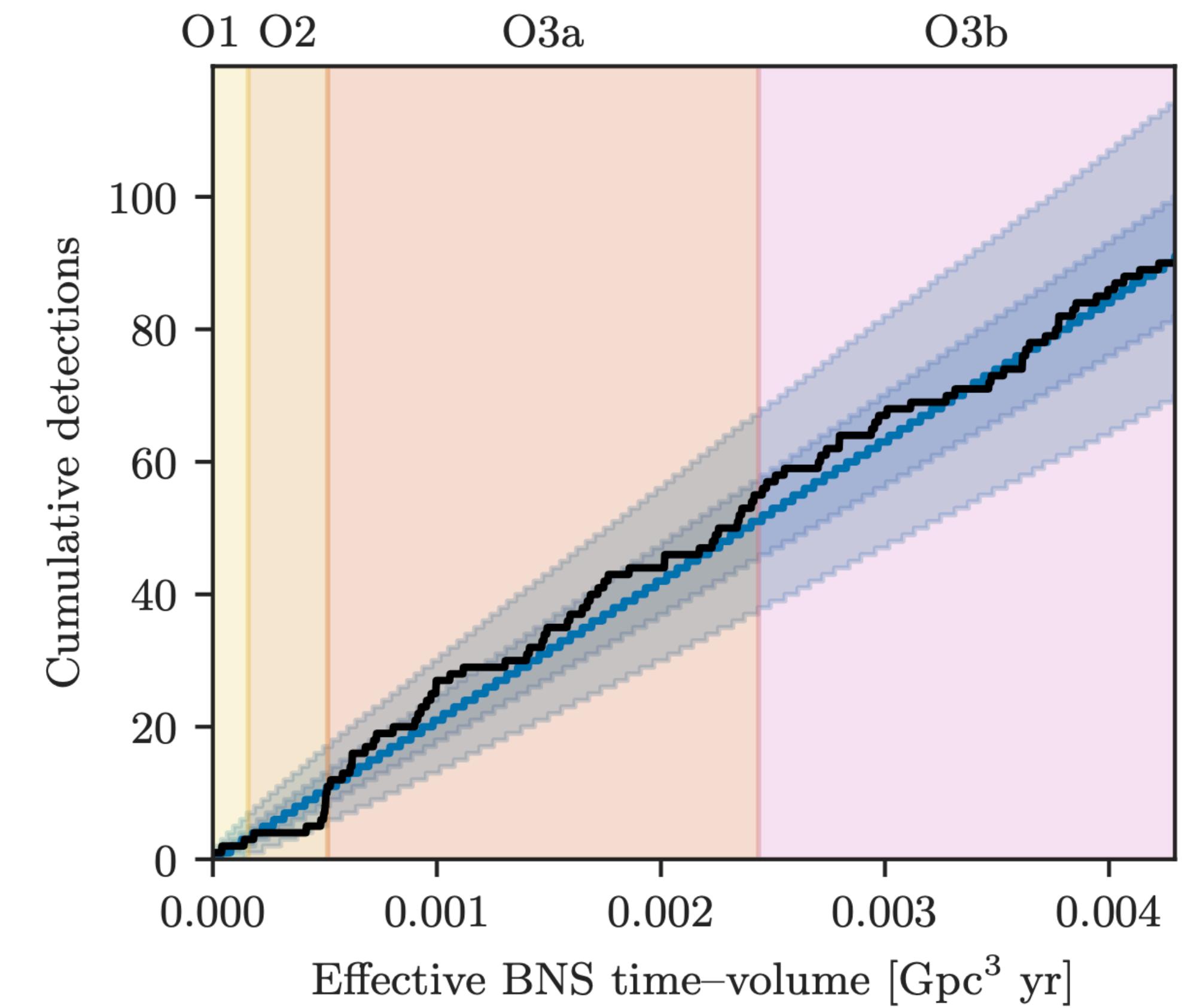
Little wind mass loss  
Little mass transfer mass loss



No pair instability because of small He core

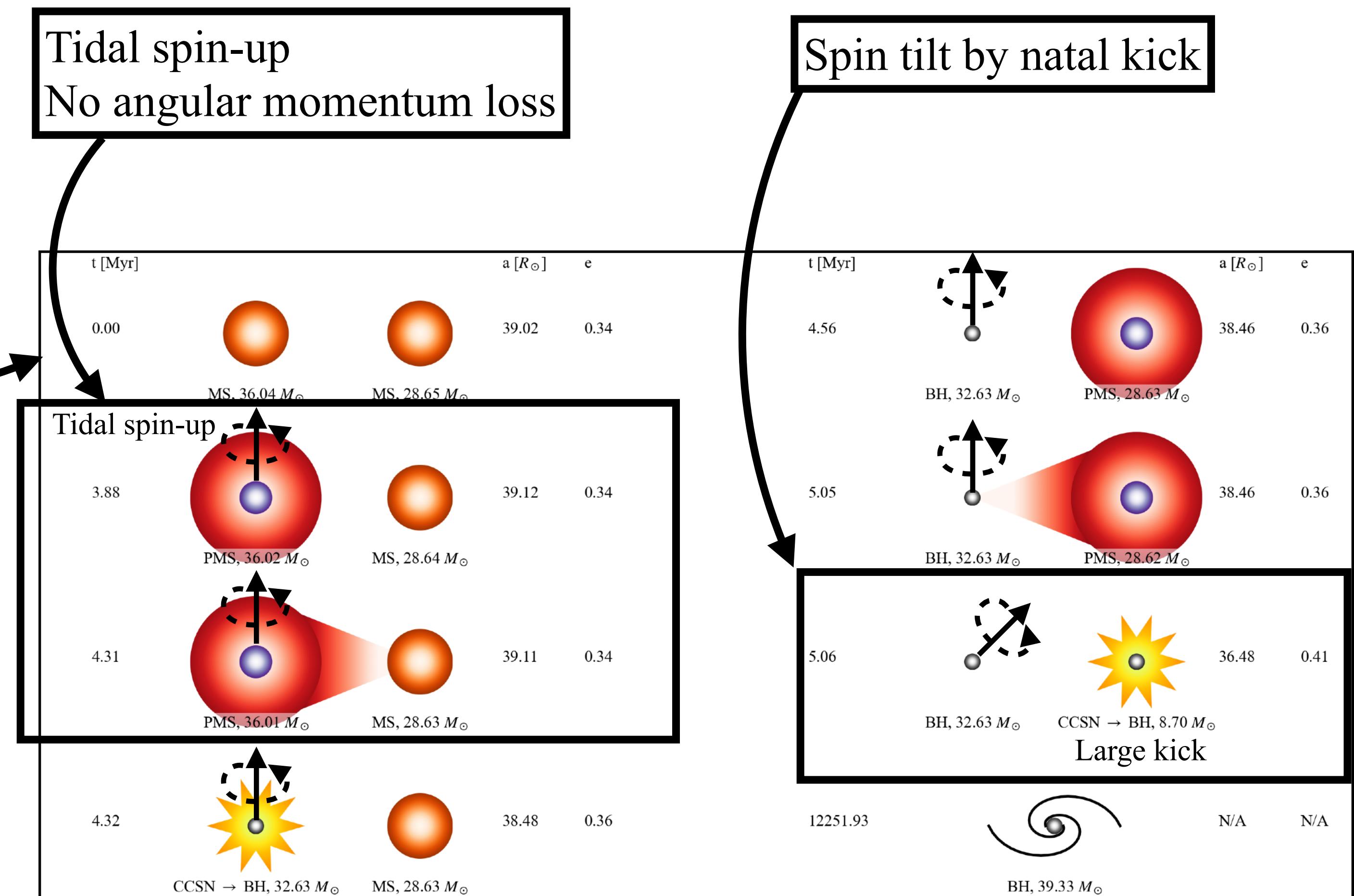
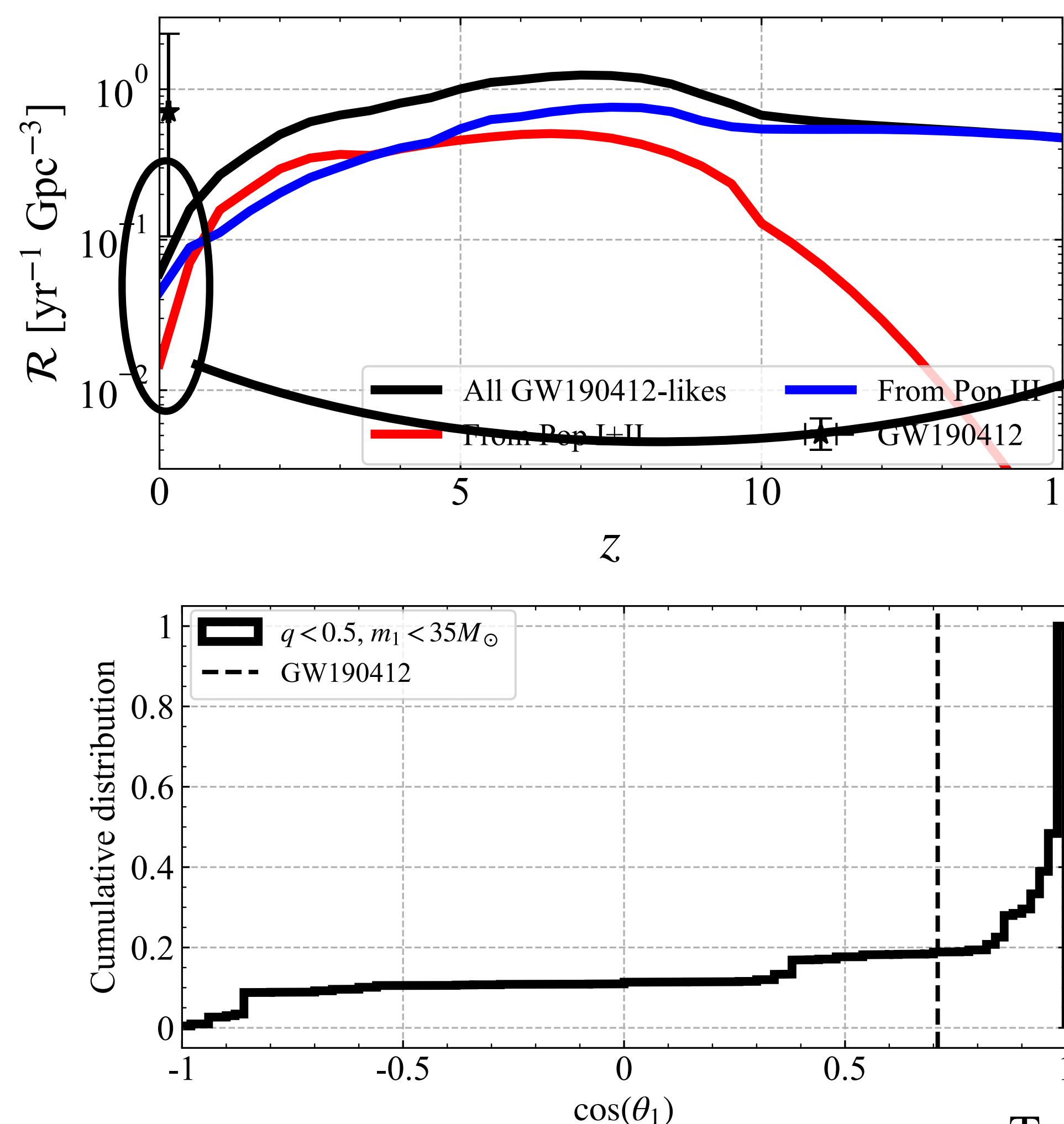
# GW190412-like event rate

- The number of GW190412-likes: only 1
  - Low mass ratio ( $q < 0.5$ )
  - High spin ( $\chi_{\text{eff}} > 0$  w/ 90% cl)
  - $R_{\text{GW190412}} \sim 0.75^{+1.77}_{-0.64} \text{ Gpc}^{-3} \text{ yr}^{-1}$  with 90% credible interval
  - $p(R | \text{GW190412}) \propto \sqrt{R \langle VT \rangle} \exp(-R \langle VT \rangle)$
  - $\langle VT \rangle \sim 1.57 \text{ Gpc}^3 \text{ yr} \left( \frac{\langle VT \rangle_{\text{DNS}}}{0.00425 \text{ Gpc}^3 \text{ yr}} \right) \left( \frac{m_c}{13.3 M_\odot} \right)^{5/2}$



Abbott et al. (2021, arXiv:2111.03606)

# Formation of GW190412-like events



# Summary

- Isolated binary stars seem difficult to explain the presence of peculiar events: GW190521 and GW190412.
- We show that Pop III binary stars can form these peculiar events.
- Pop III stars do not lose their mass nor spin angular momentum through stellar winds and mass transfer.
- No mass loss  $\implies$  GW190521-likes (Pair instability mass gap events)
- No spin angular momentum loss  $\implies$  GW190412-likes (Asymmetric merger events)