Binary black hole mergers formed through isolated binary stars with all the stellar metallicities

Genesis symposium, April 29 2022

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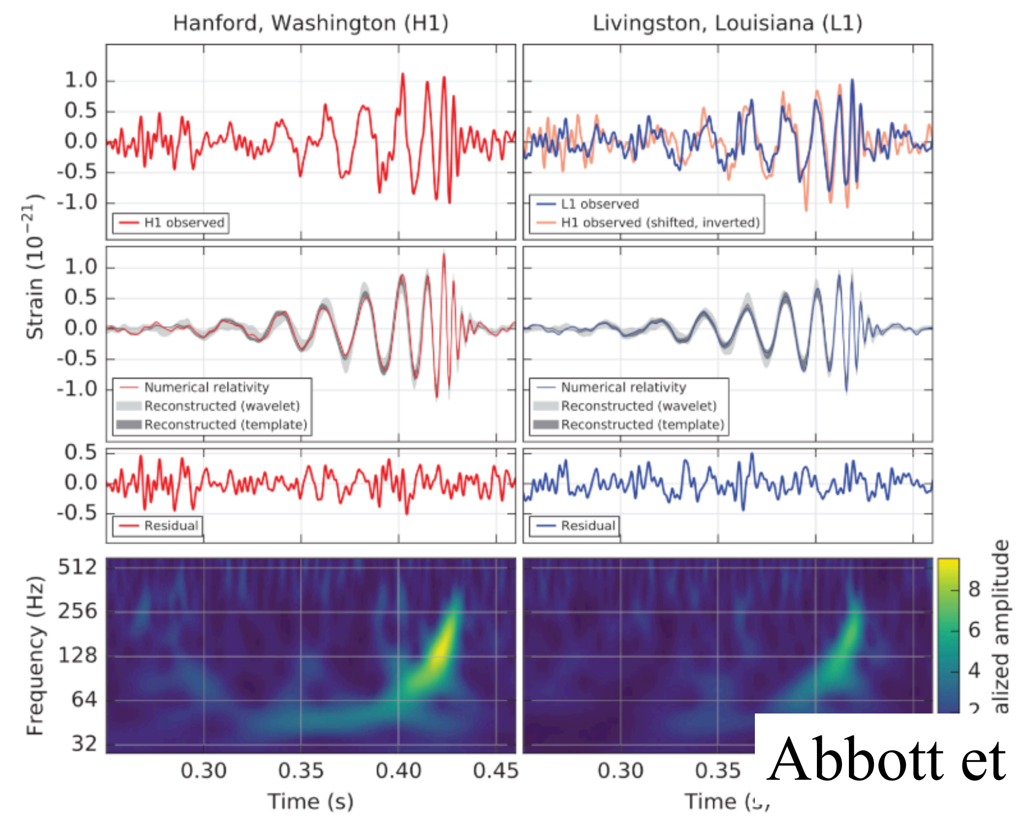
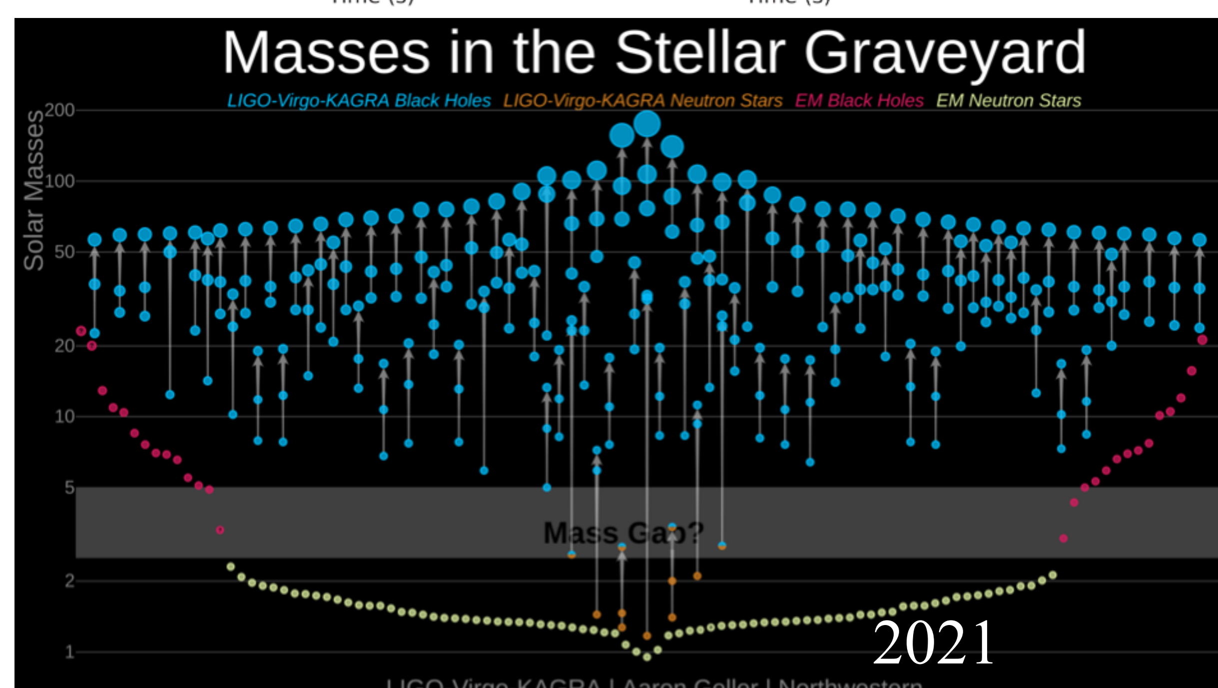
Tanikawa, Yoshida, Kinugawa, Trani, Hosokawa, Susa, Omukai (2022, ApJ, 926, 83)
Tanikawa, Moriya, Tominaga, Yoshida (2022, arXiv:2204.09402)

Discovery of BH mergers

- Rapid growth of the number of BH mergers discovered by GW observations
- Origin(s) of binary BHs
  - Isolated binary stars
  - Dense star clusters
  - Primordial BHs
- Clues for the origin(s)
  - Statistics
  - Peculiar events

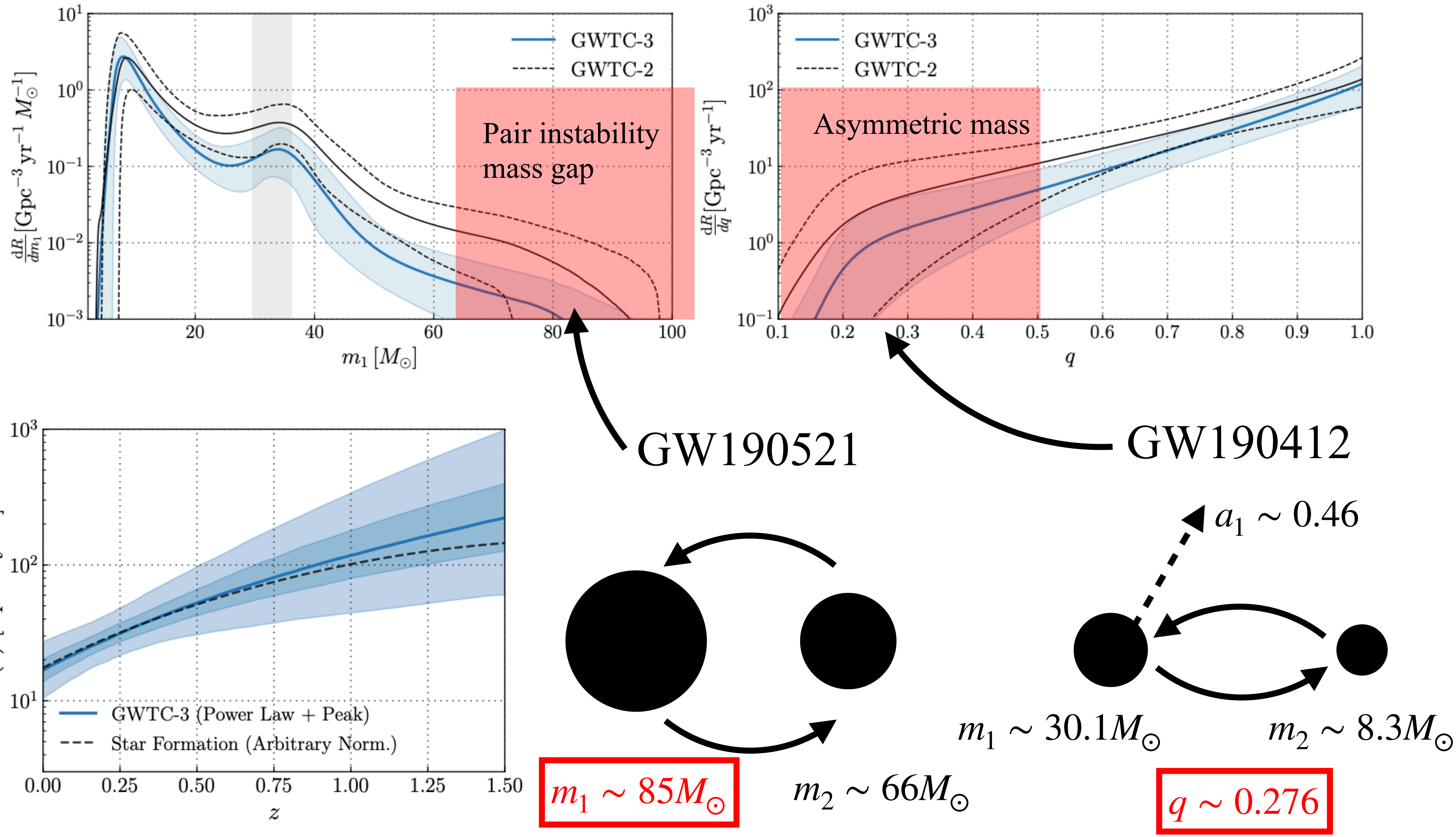


Abbott et al. (2016)



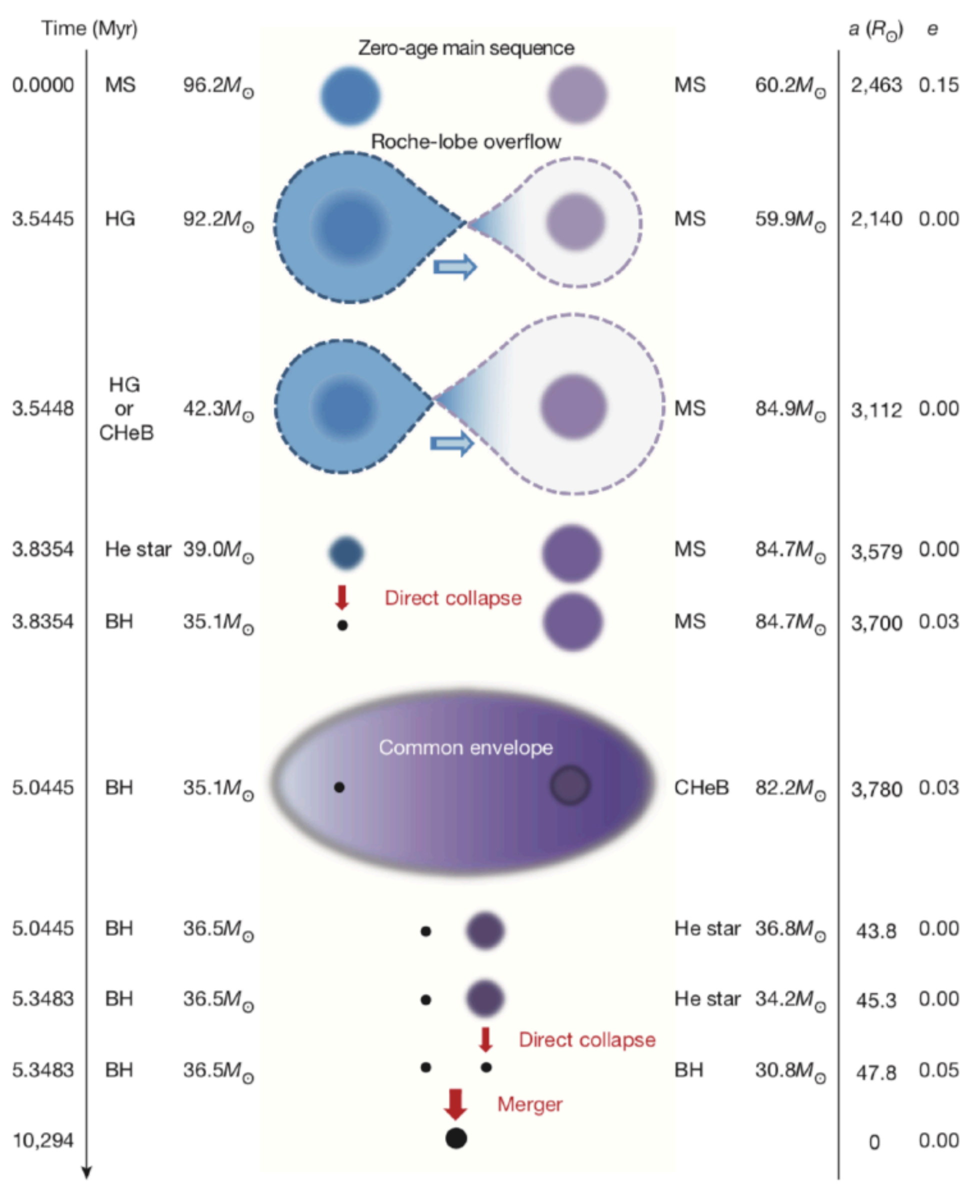
2021

GWTC-3

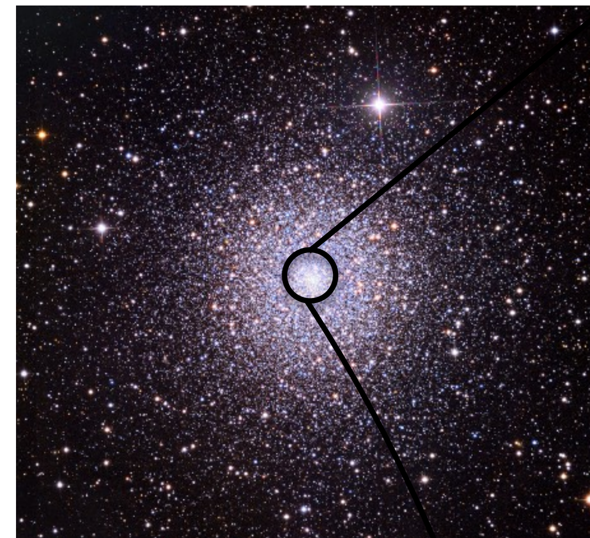


GWTC-3
GWTC-2
Pair instability mass gap
m_1 $[M_\odot]$
$\frac{dR}{dm_1}$ [Gpc^{-3} yr^{-1} $M_\odot^{-1}$]
Asymmetric mass
q
$\frac{dR}{dq}$ [Gpc^{-3} yr^{-1}]
GW190521
GW190412
$R(z)$ [Gpc^{-3} yr^{-1}]
z
GWTC-3 (Power Law + Peak)
Star Formation (Arbitrary Norm.)
$a_1 \sim 0.46$
$m_1 \sim 85M_\odot$
$m_2 \sim 66M_\odot$
$m_1 \sim 30.1M_\odot$
$m_2 \sim 8.3M_\odot$
$q \sim 0.276$

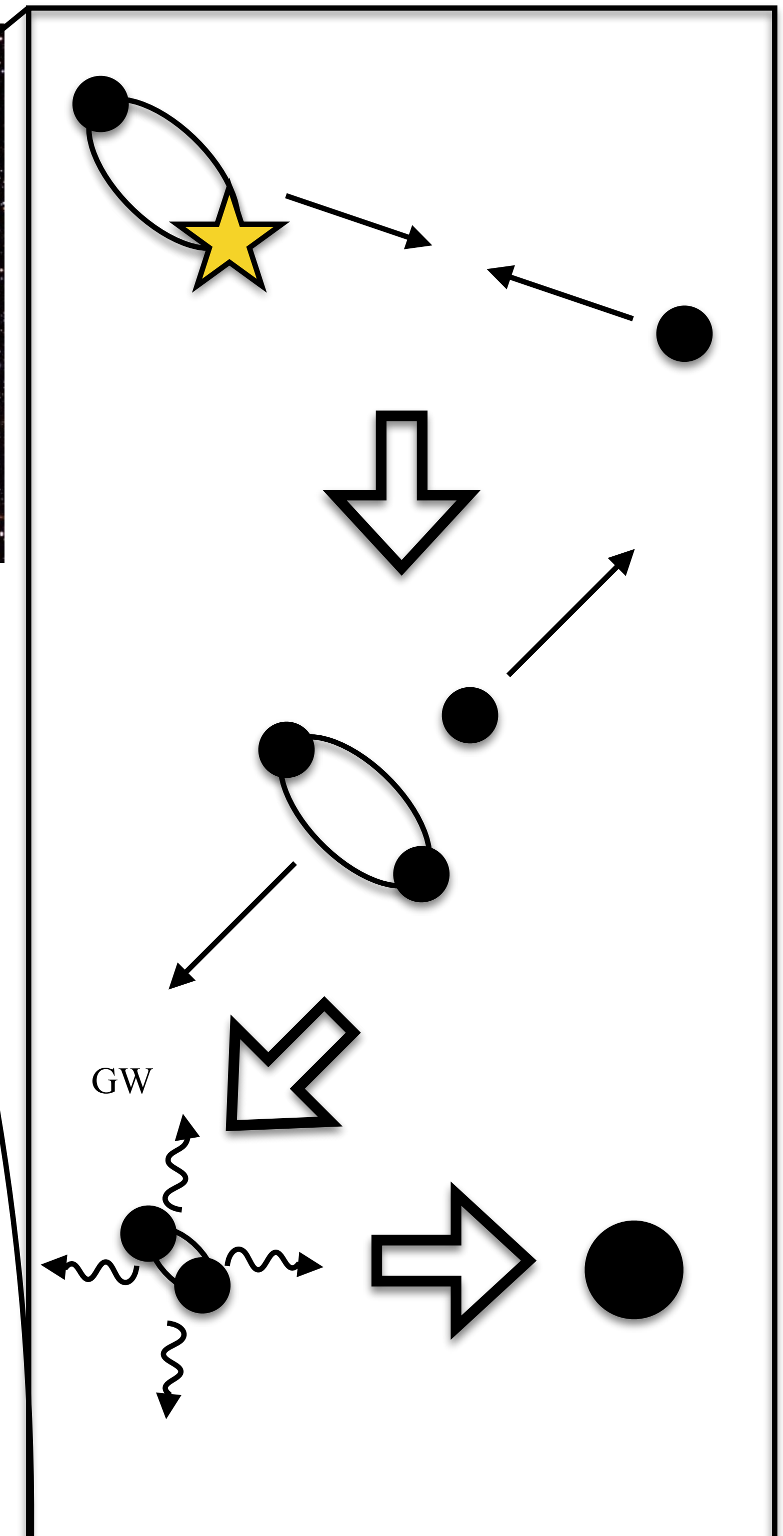
Binary stars and clusters



Belczynski et al.; Eldridge et al.; Giacobbo et al.; Kinugawa et al.; Kruckow et al.; Stevenson et al.; Tanikawa et al.;



- Open clusters (Kumamoto et al.; Di Carlo et al.)
- Globular clusters (Rodrigeuz et al.; Askar+Giersz et al.; Wang et al.)
- AGN disks (Tagawa et al.)

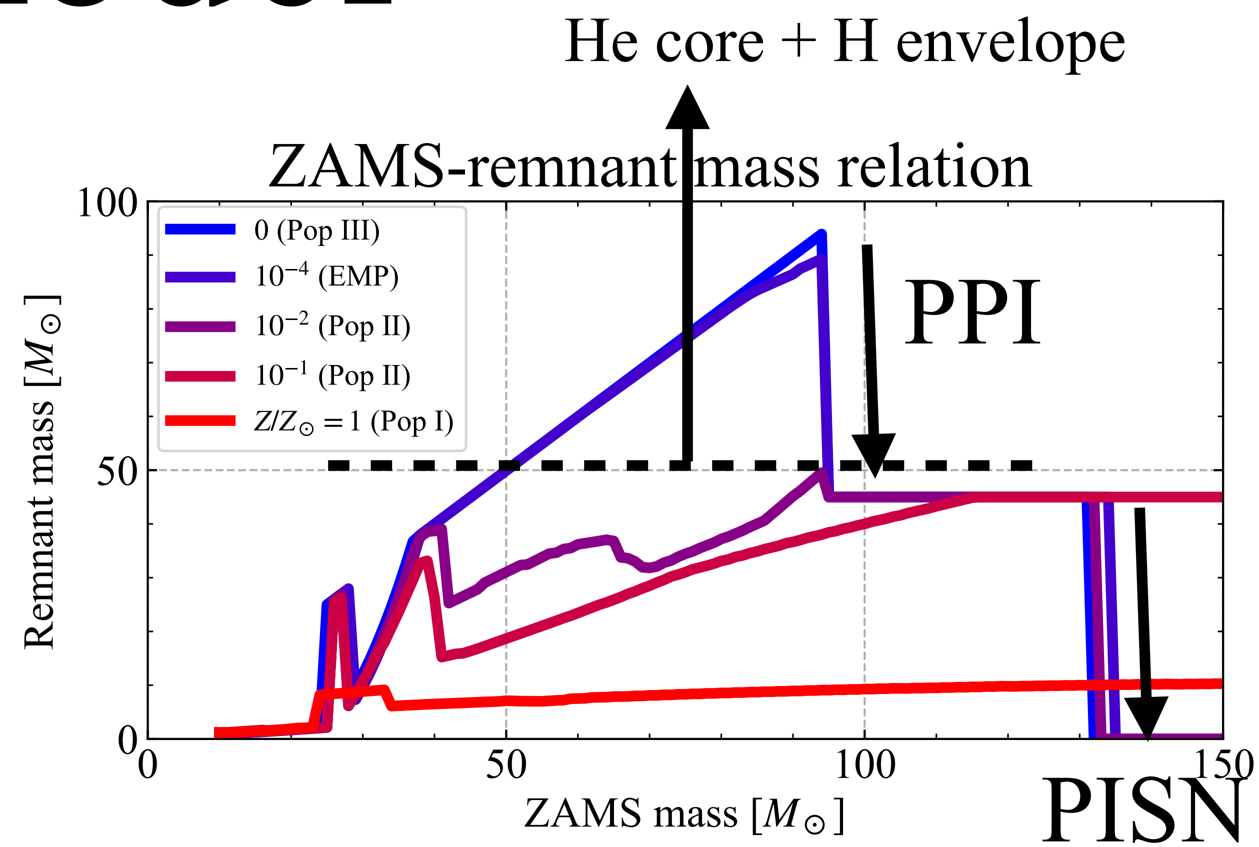


Our work

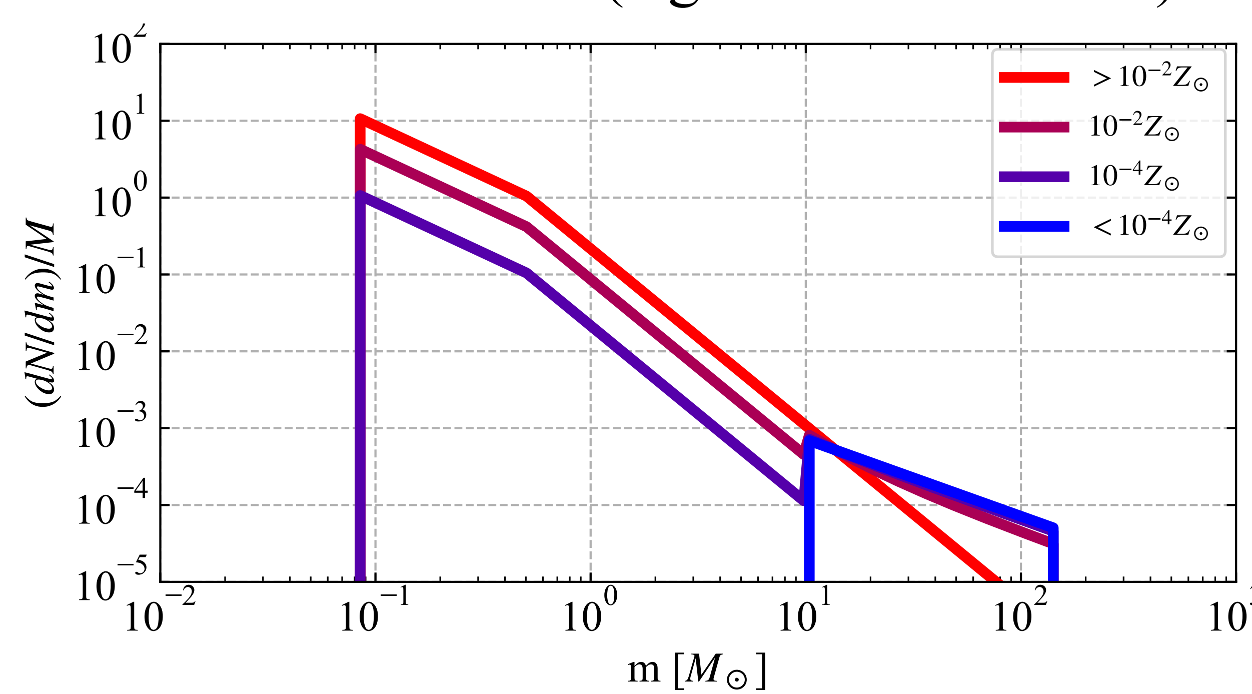
- Binary population synthesis for all stellar metallicities
- Contribution of extremely metal-poor stars ($Z \lesssim 10^{-4} Z_\odot$), especially Pop III stars ($Z = 0 Z_\odot$)

Our model

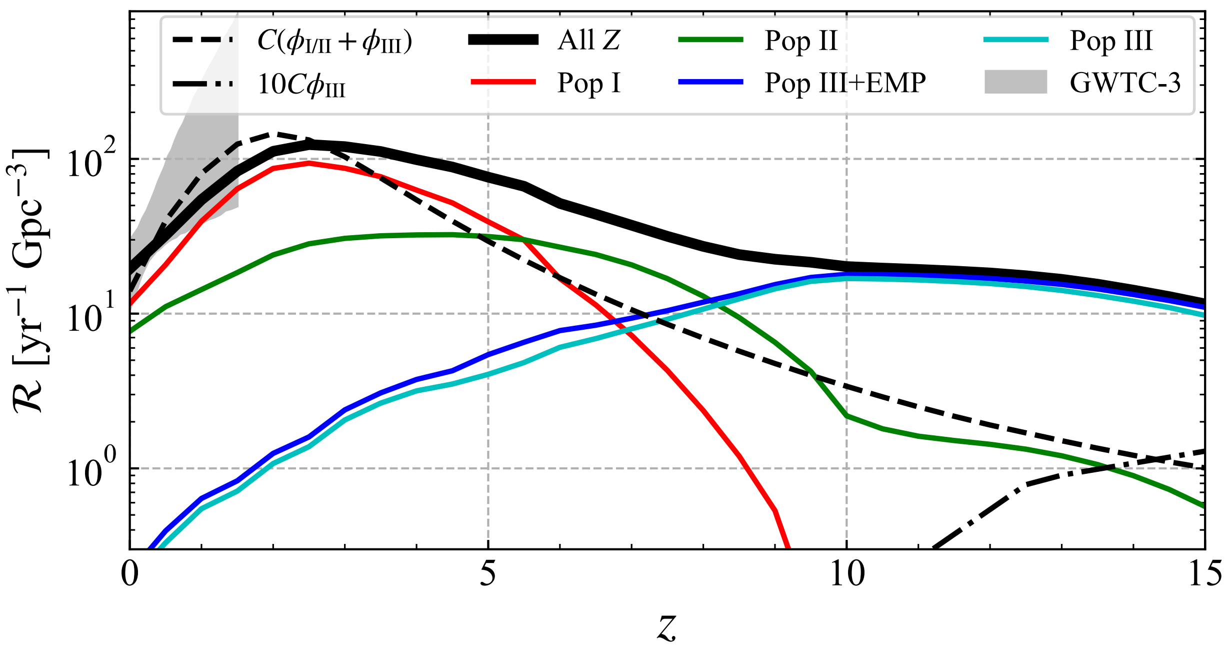
- Single star evolution
  - $0 - 0.1Z_{\odot}$: Tanikawa's model
  - $0.1 - 1Z_{\odot}$: Hurley's model
- Metallicity-dependent stellar winds
- Fryer's rapid supernova model
- Leung's strong pair instability (PI) model
- Hobbs's fallback natal kick model
- Hurley's binary evolution model

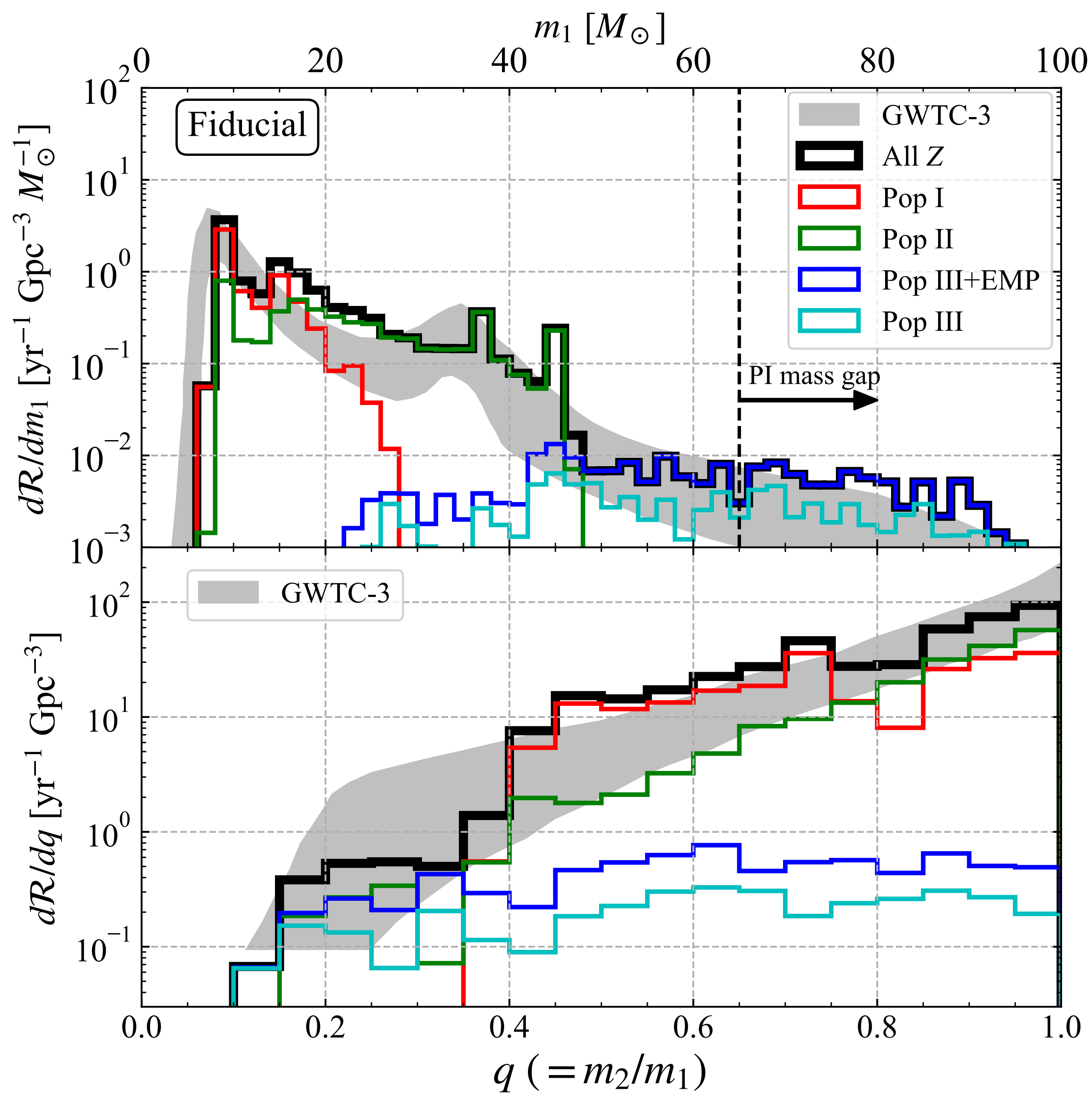


Transitional IMF (e.g. Chon et al. 2021)



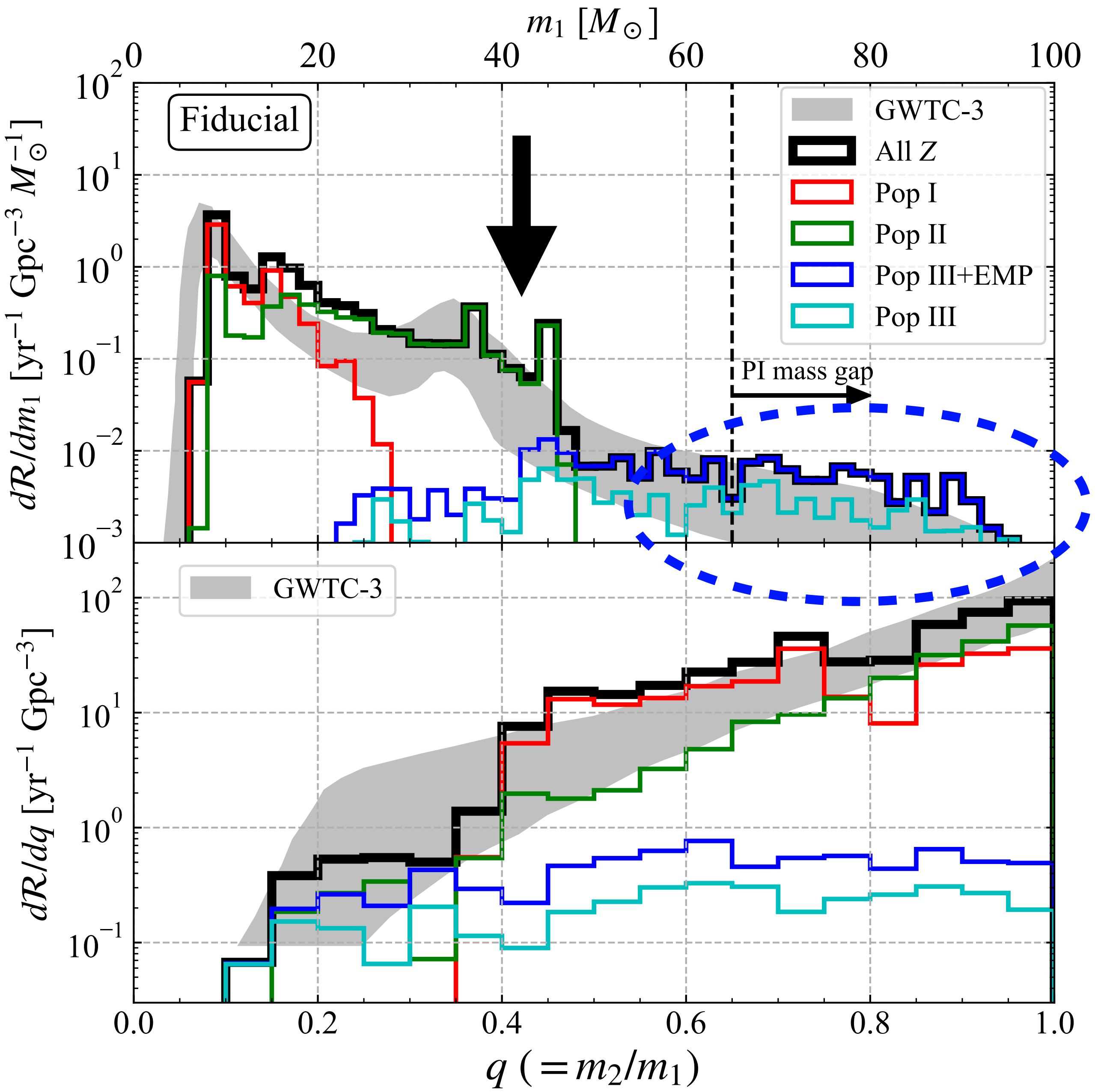
Statistics





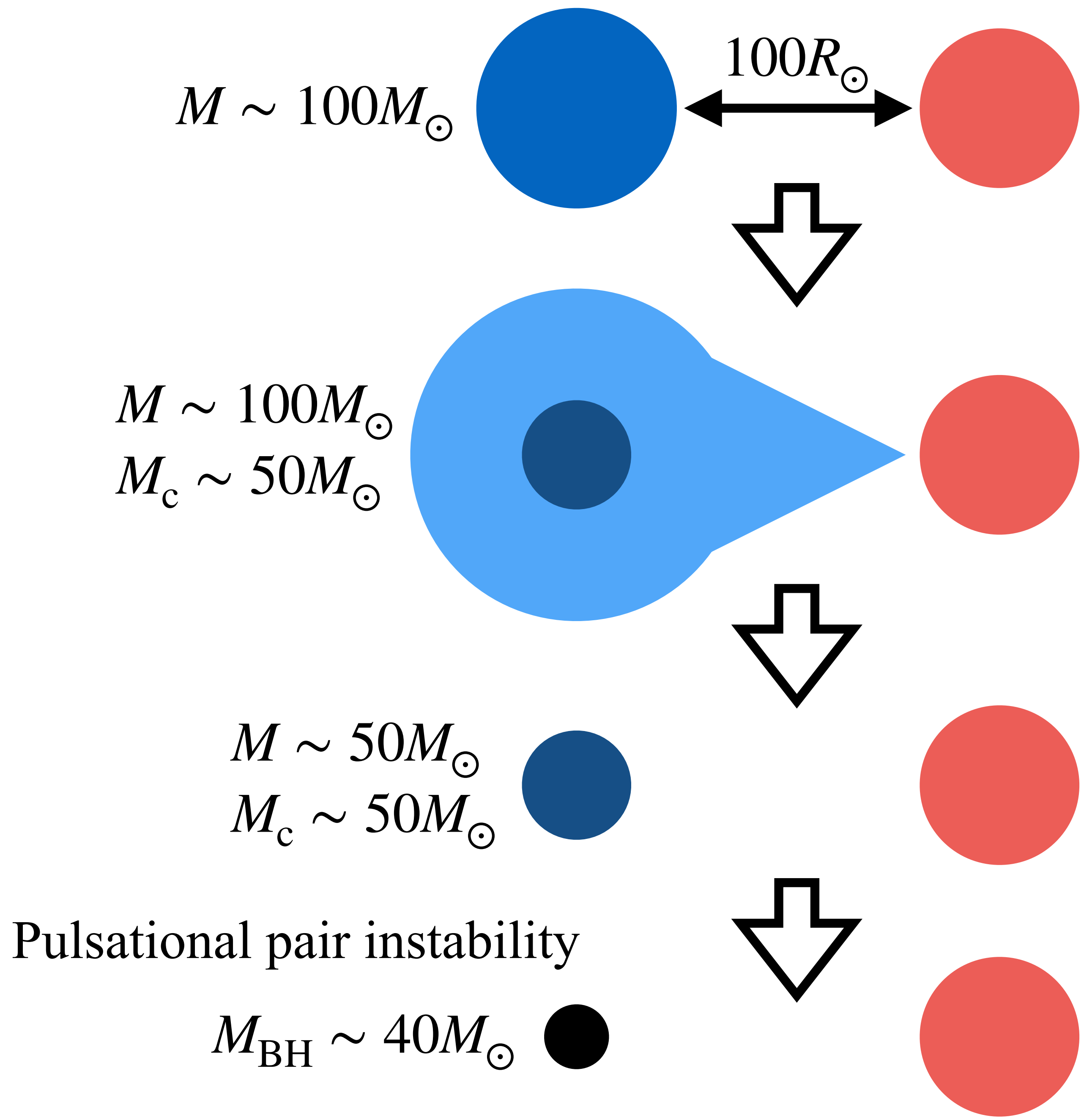
- Merger rate and mass distribution consistent with GWTC-3
- Peculiar events → Pop III+EMP?
  - PI mass gap events
  - Low-q (high-a_1) events

GW190521: PI mass gap

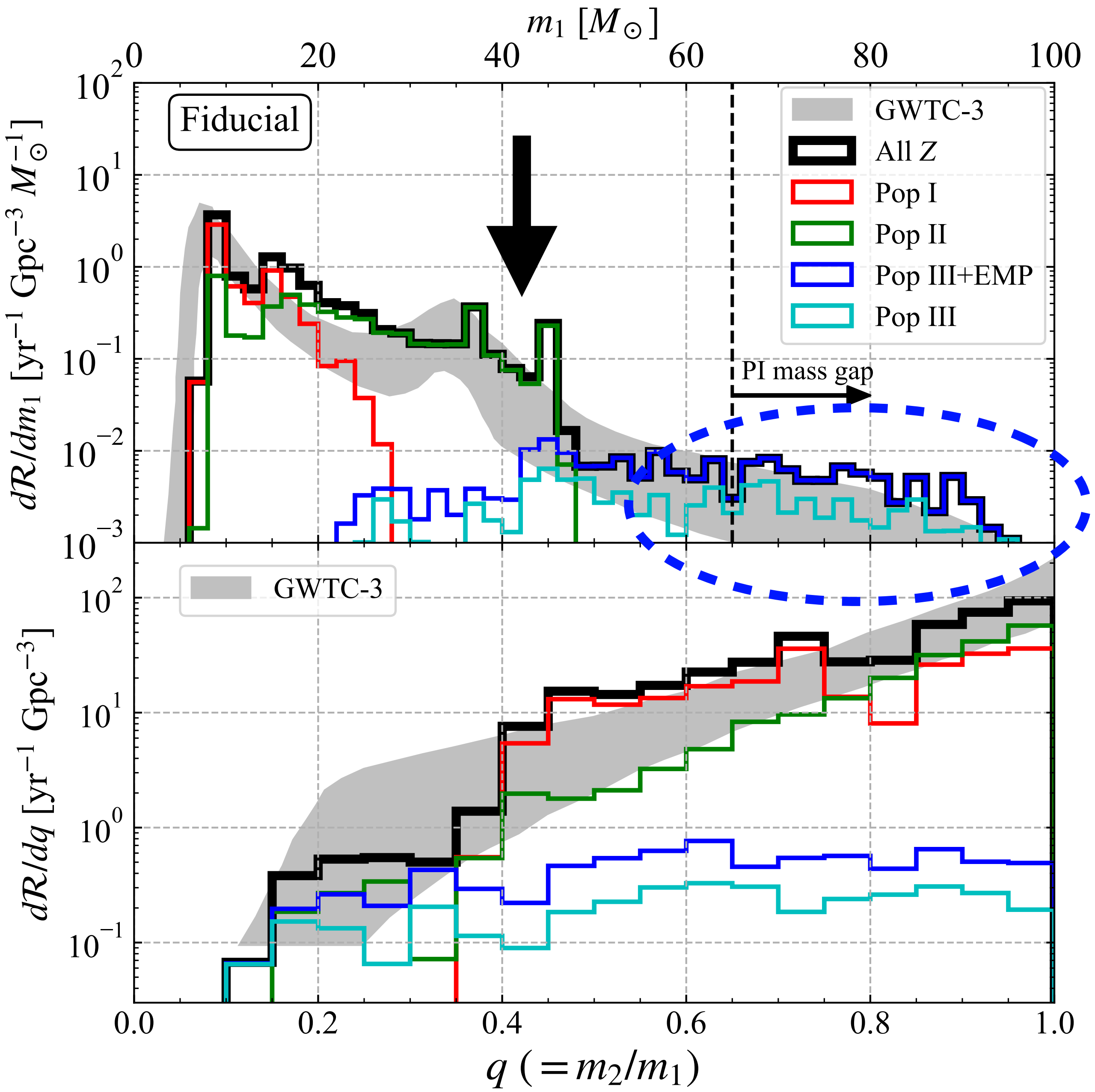


Tanikawa et al. (2022, ApJ, 926, 83)

Pop II case ($M \gtrsim 90M_\odot$)



GW190521: PI mass gap



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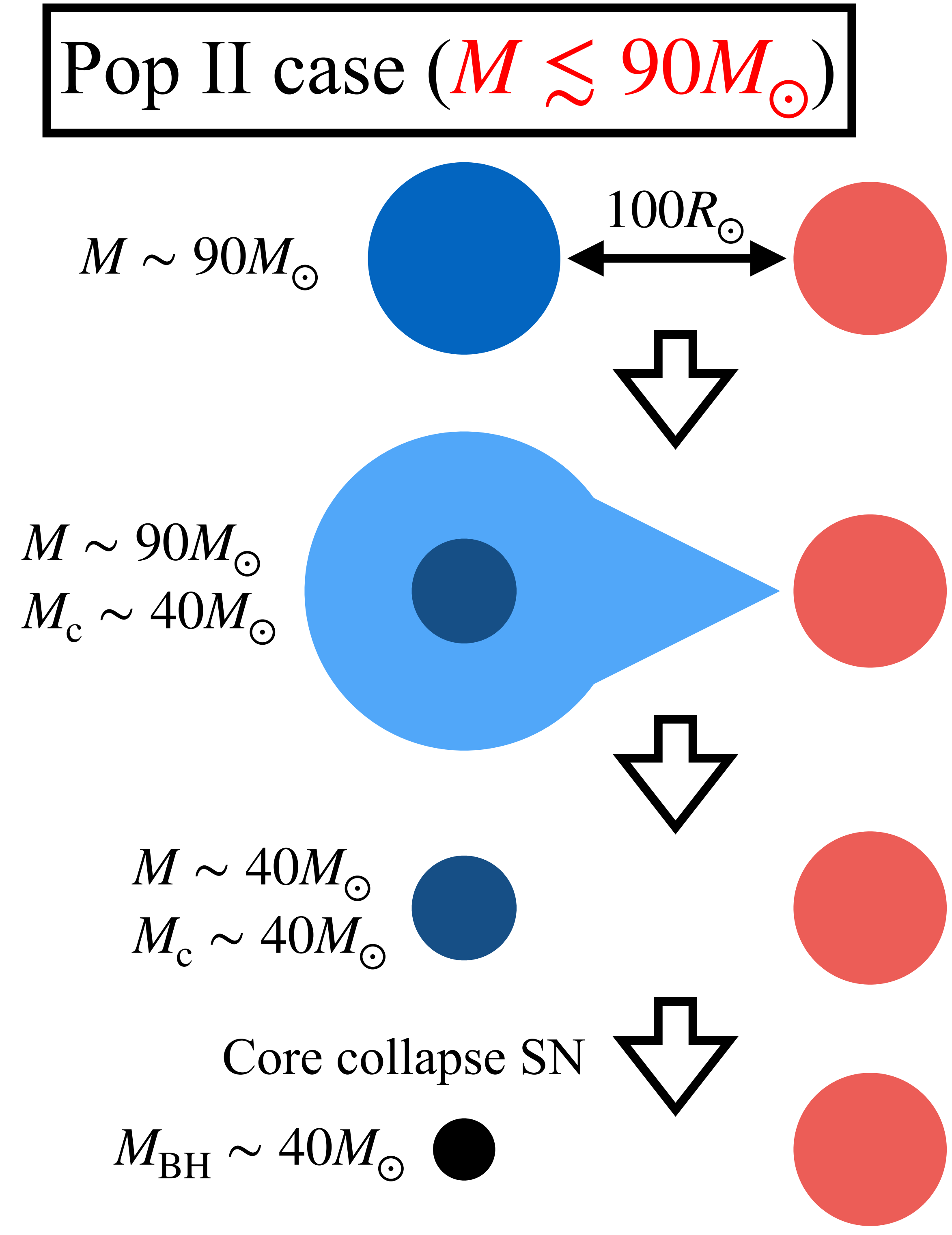
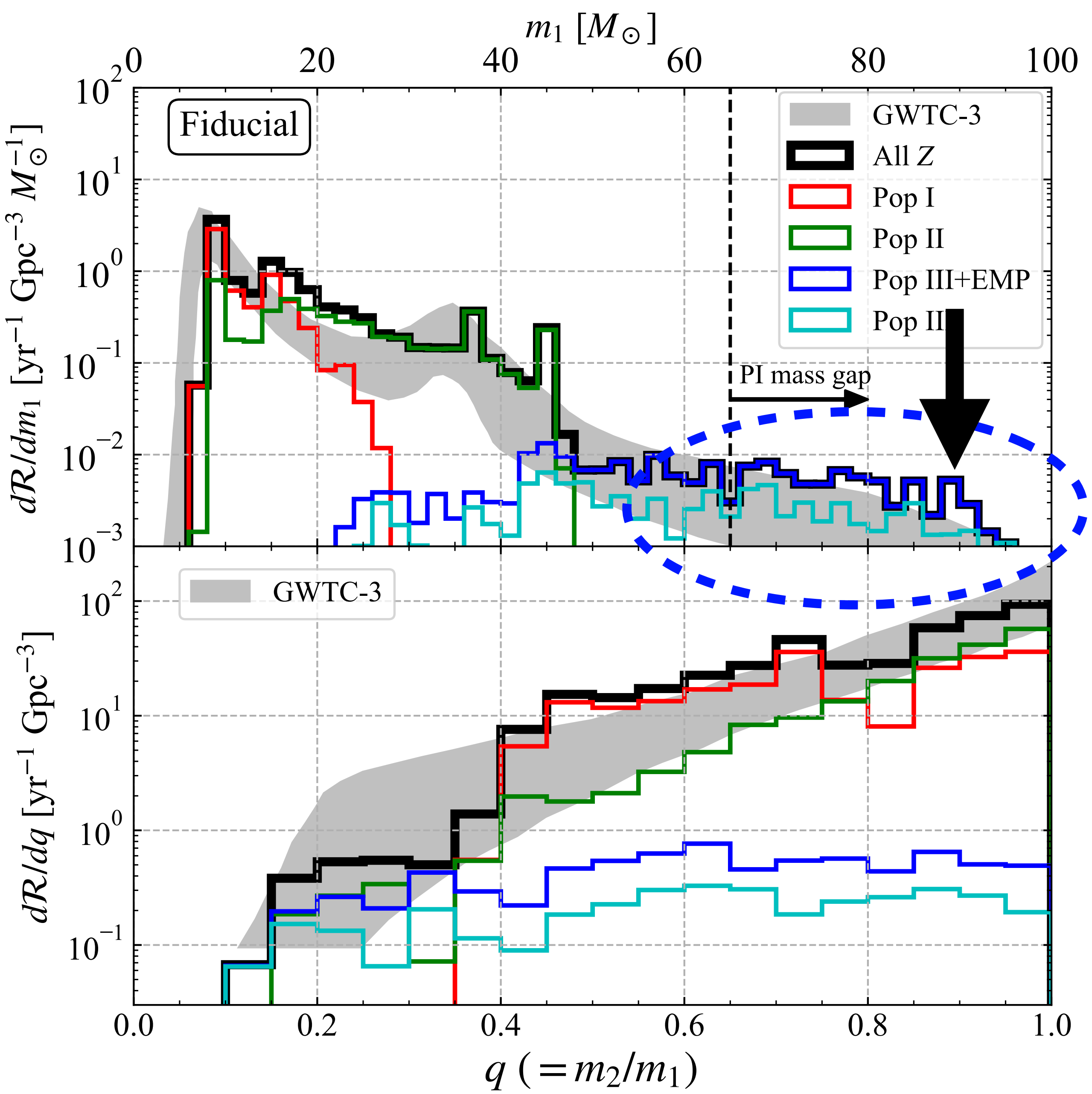
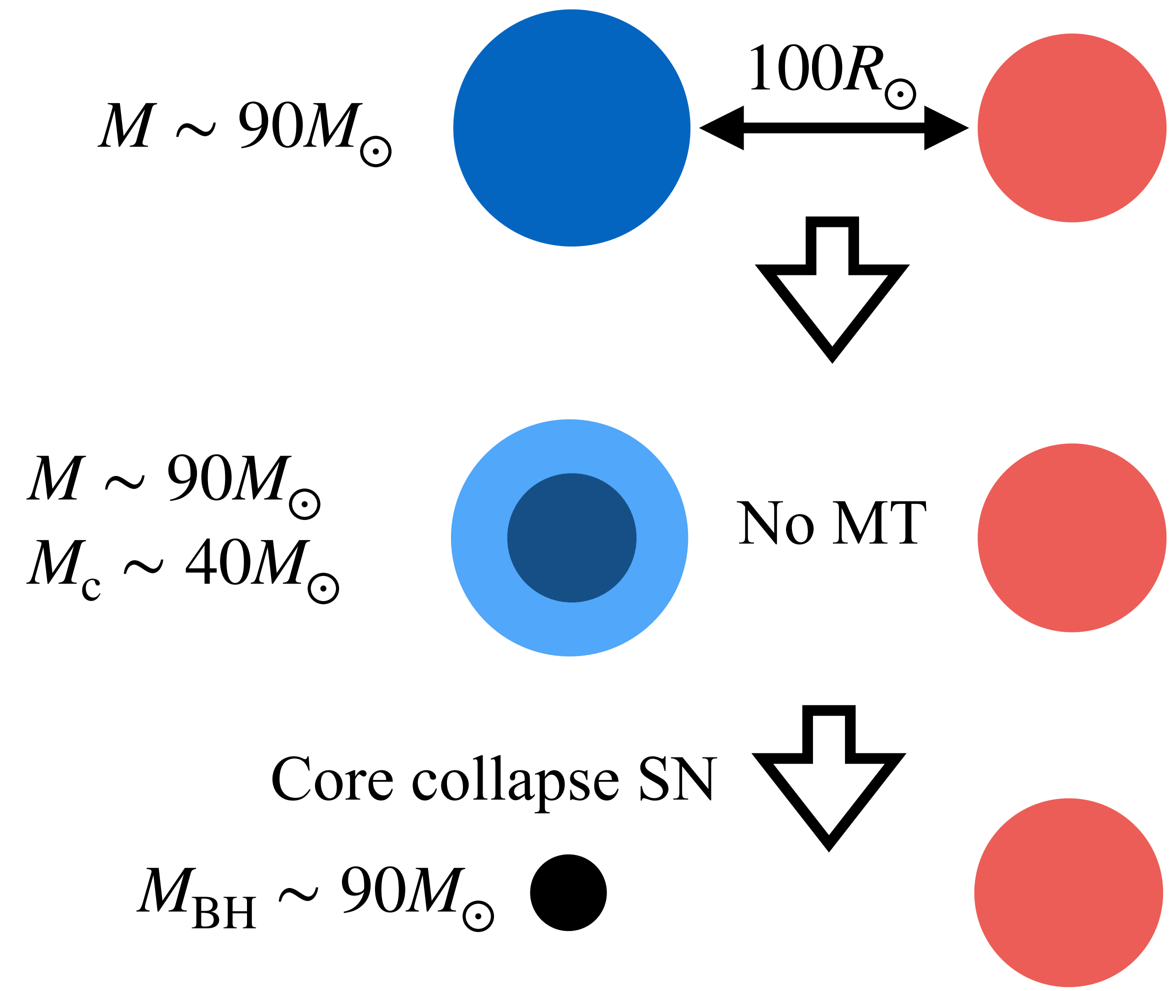


GW190521: PI mass gap



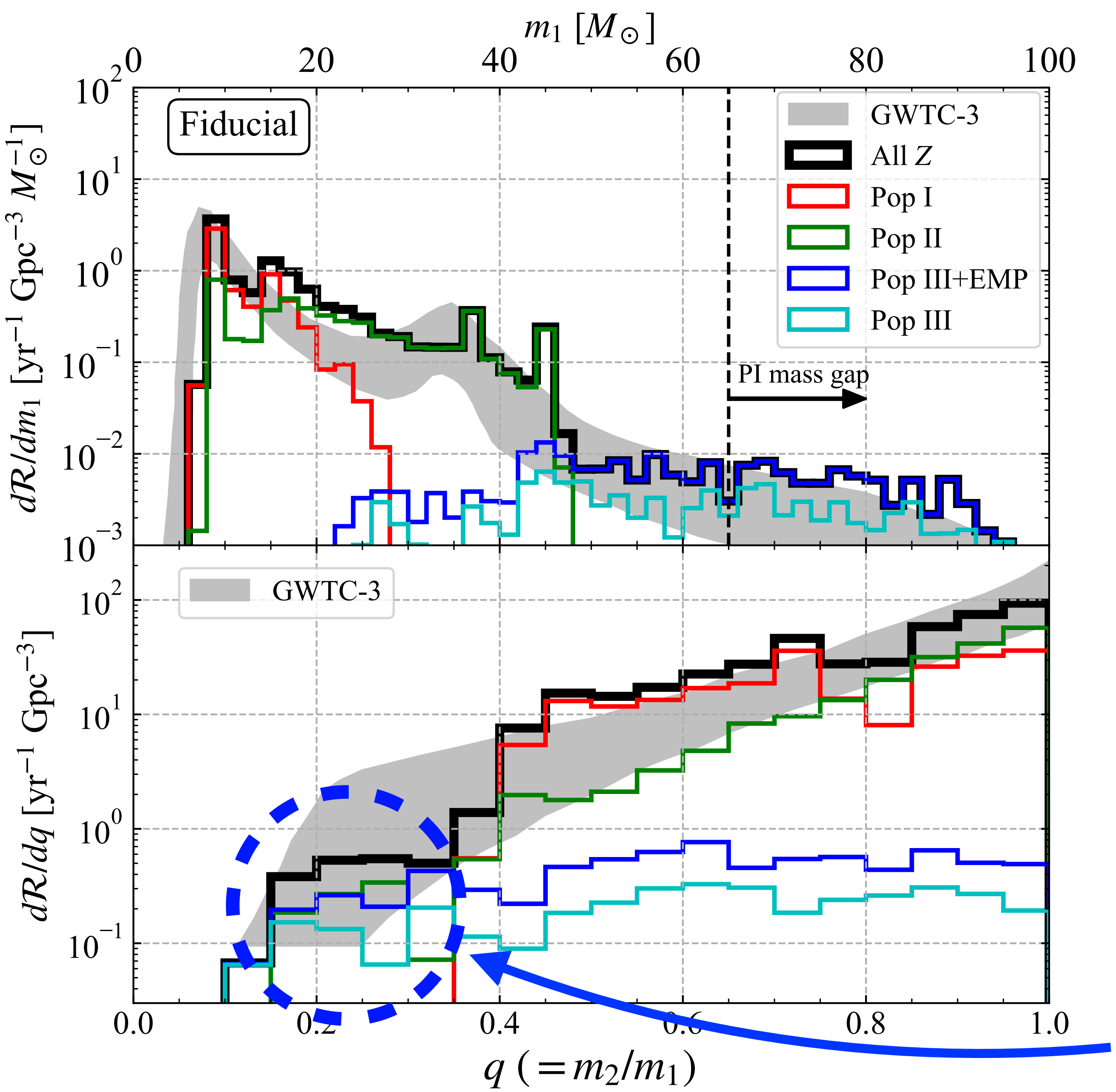
Tanikawa et al. (2022, ApJ, 926, 83)

Pop III case ($M \lesssim 90M_\odot$)



Tanikawa et al. (2021, MNRAS, 505, 2170)

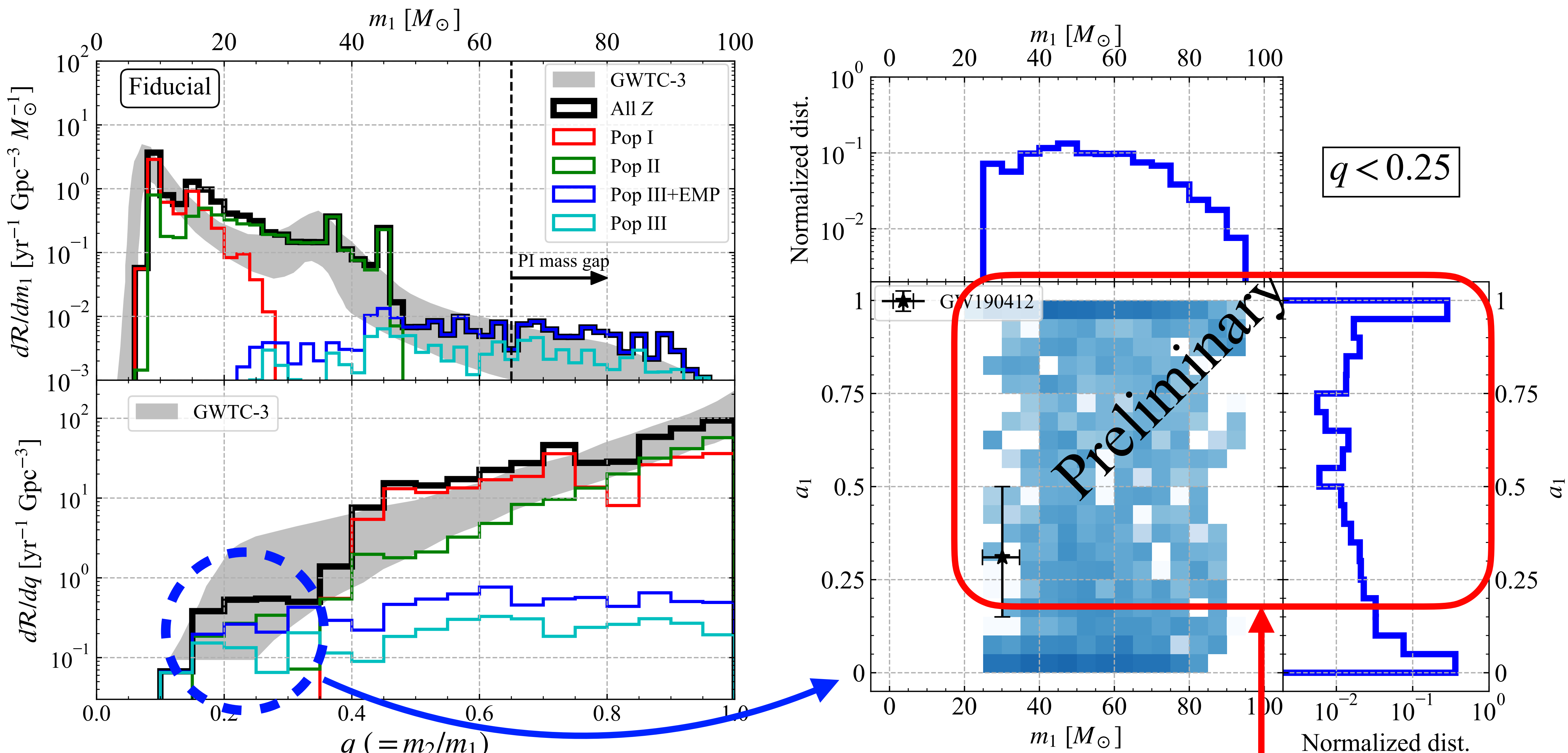
GW190412: low-q, high-a_1



Tanikawa et al. (2022, ApJ, 926, 83)

- High-q (~ 1), high-a_1
  - Chemically homogeneous evolution (Mandel, De Mink 2016; Marchant et al. 2016)
  - Double common envelope (Olejak, Belczynski 2021; Neijssel et al. 2019)
- Low-q, low-a_1 (but high-a_2)
  - Tidal spin up of BH-WRs (Kushnir et al. 2017; Hotokezaka, Piran 2017)
- How about Pop III binary stars?

GW190412: low-q, high-a_1

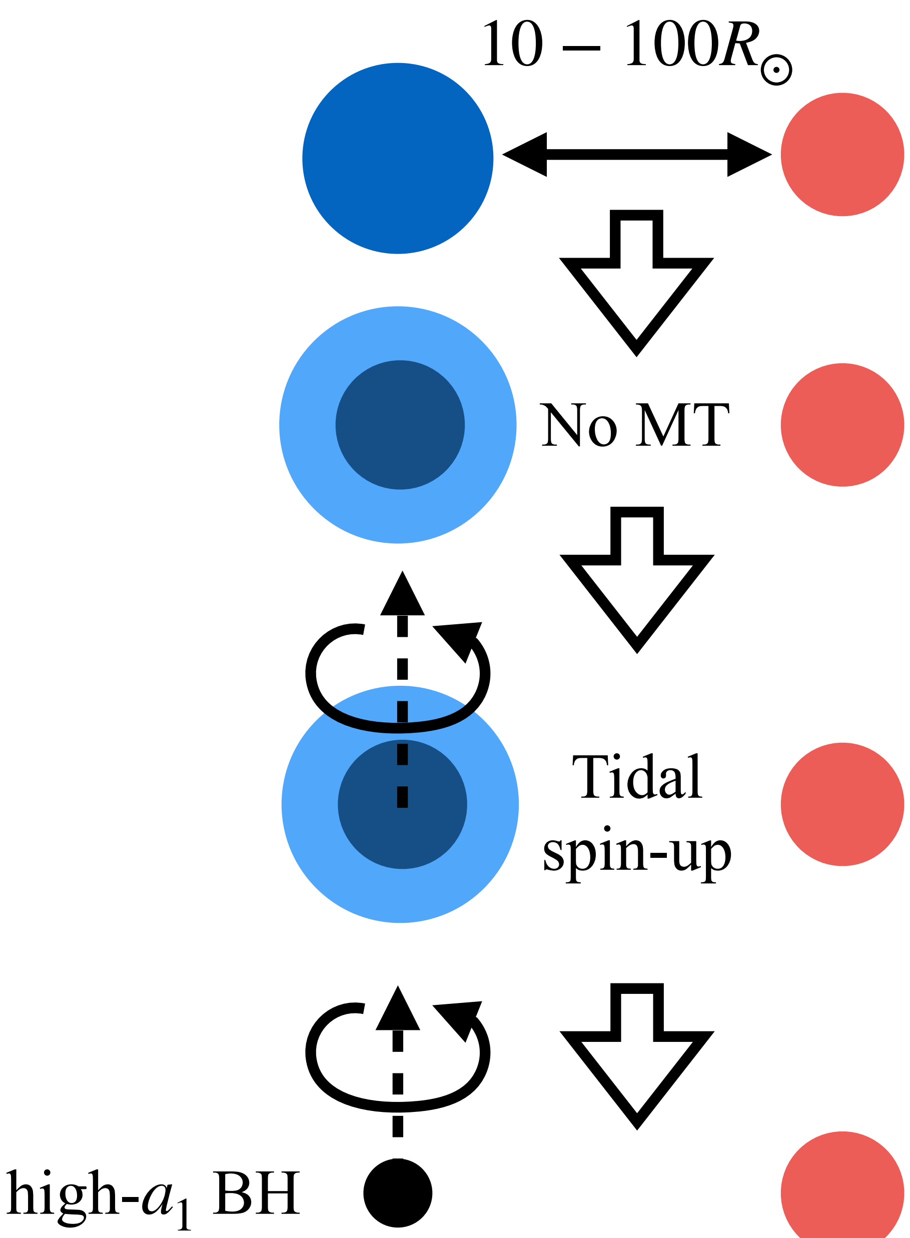


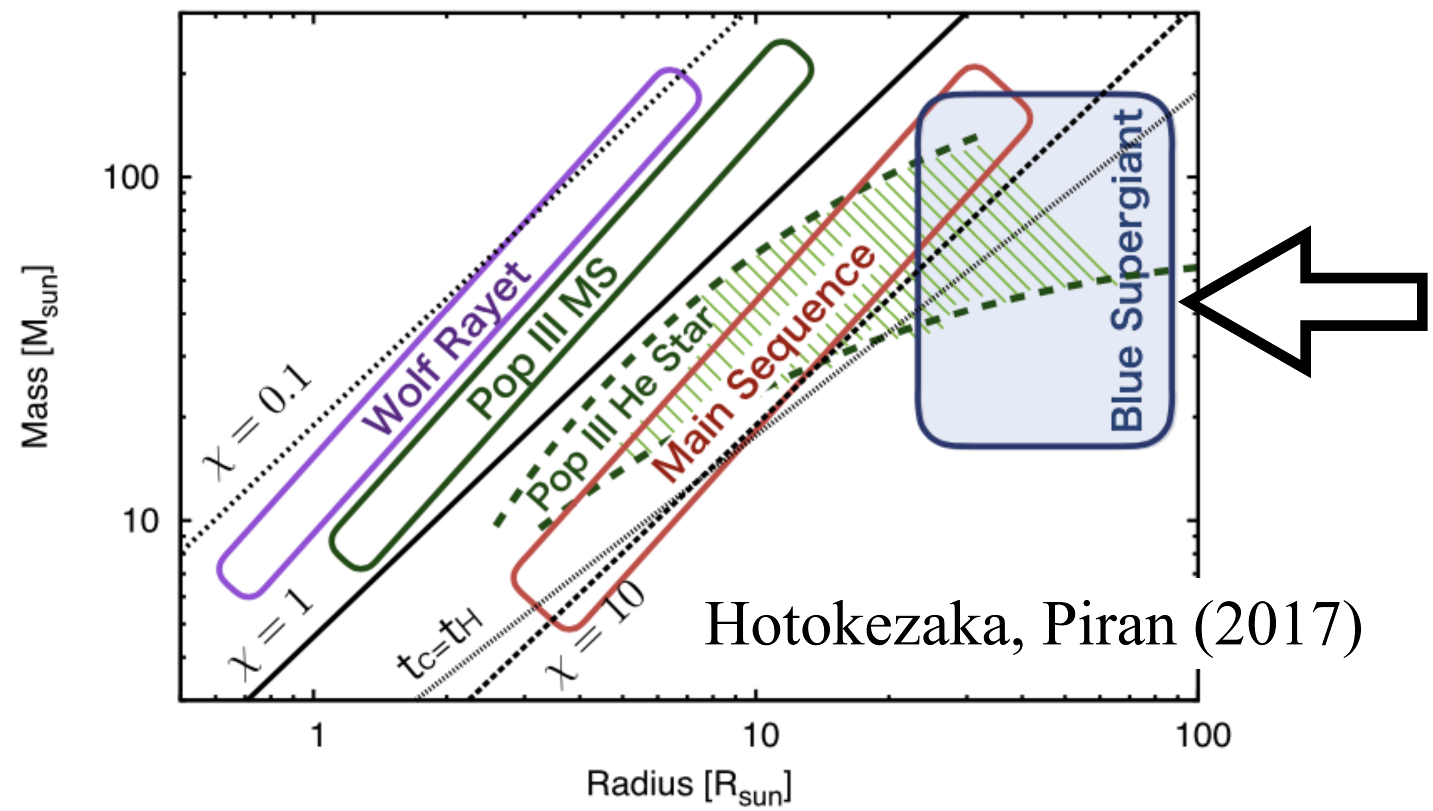
Tanikawa et al. (2022, ApJ, 926, 83)

Very high-a_1

GW190412: low-q, high-a_1

Pop III case

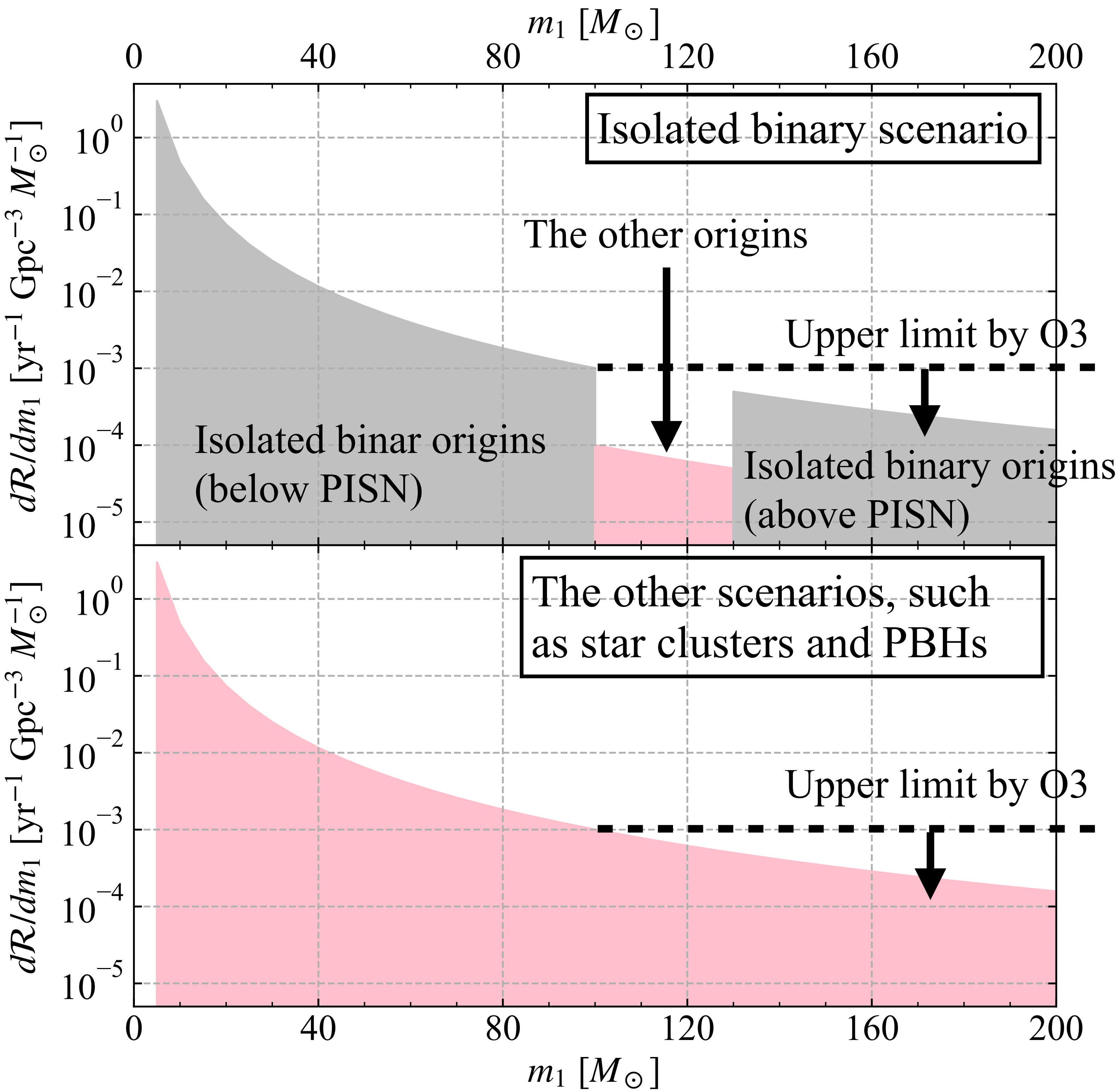




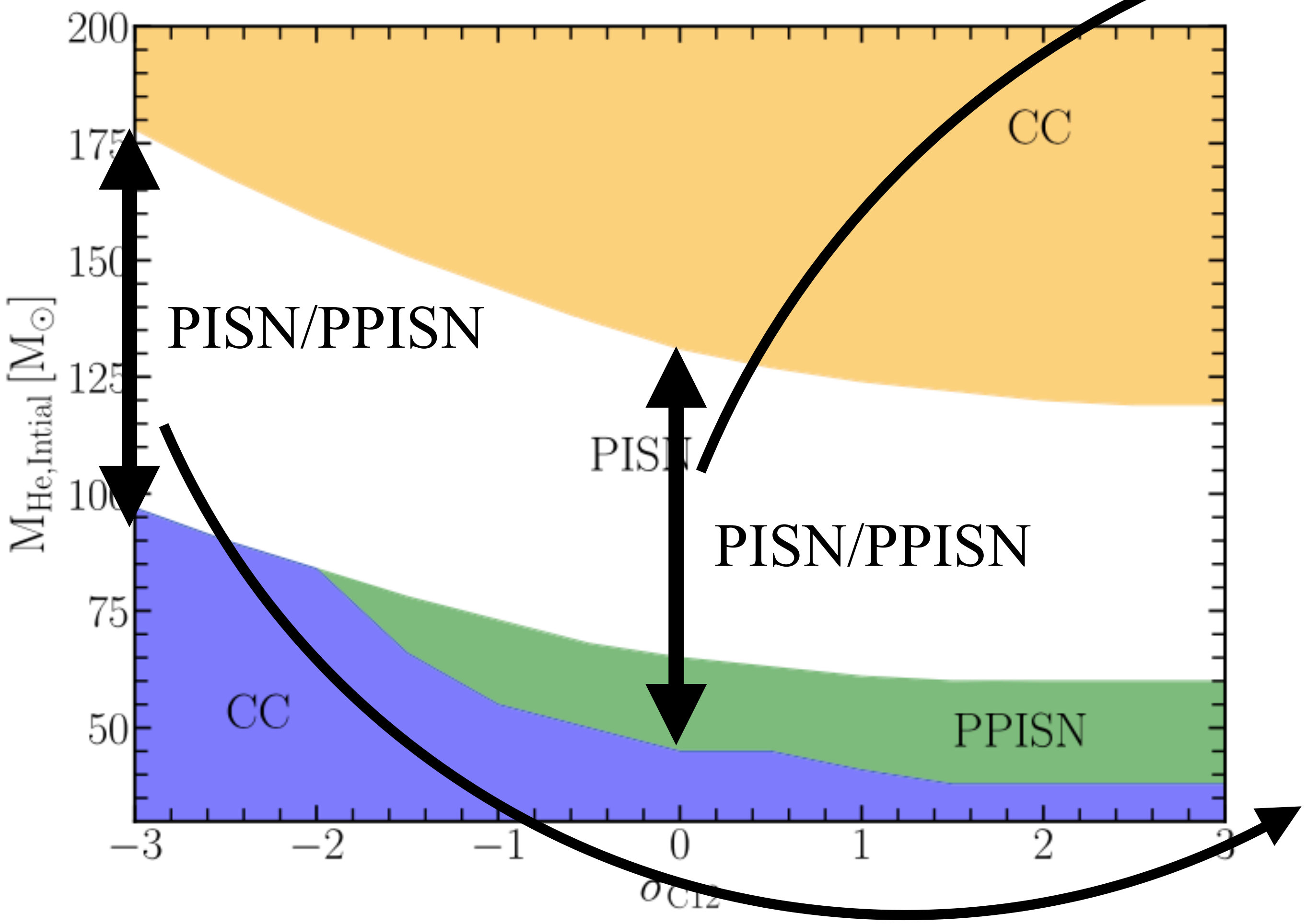
Hotokezaka, Piran (2017)

- GW190412 formation in isolated binary
  - Non-CE model (Olejak, Belczynski 2021)
  - Pop III model (Tanikawa et al. in prep.)

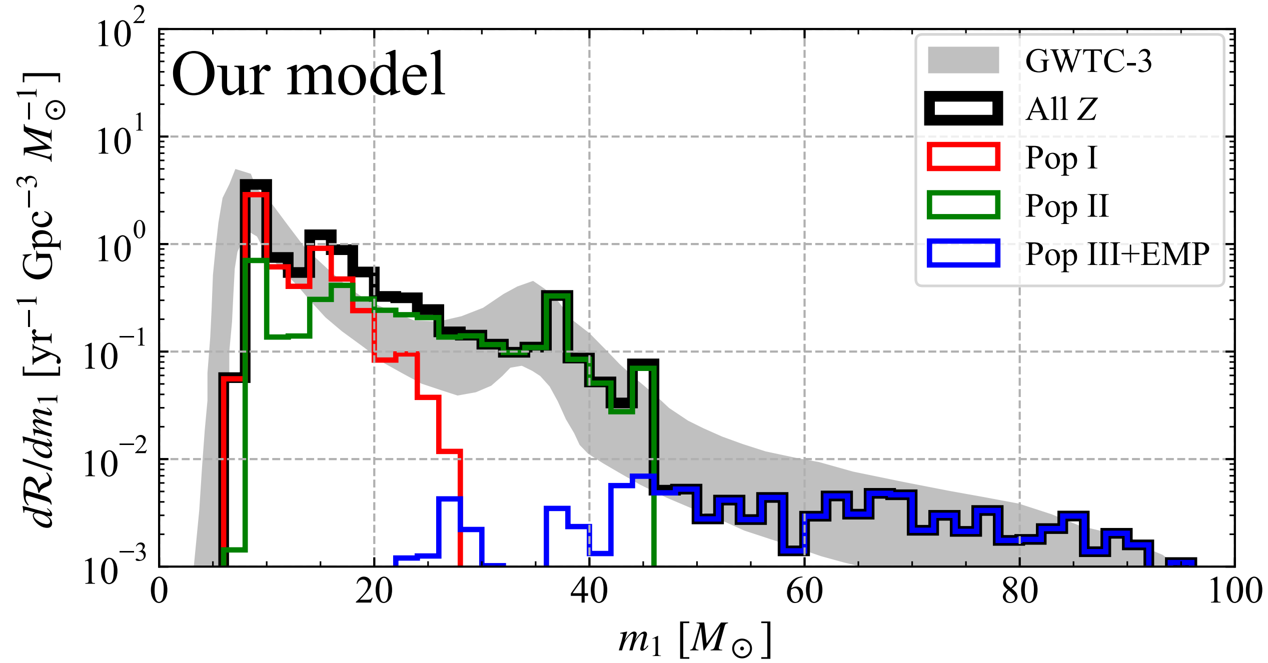
Consistency test by GW obs.

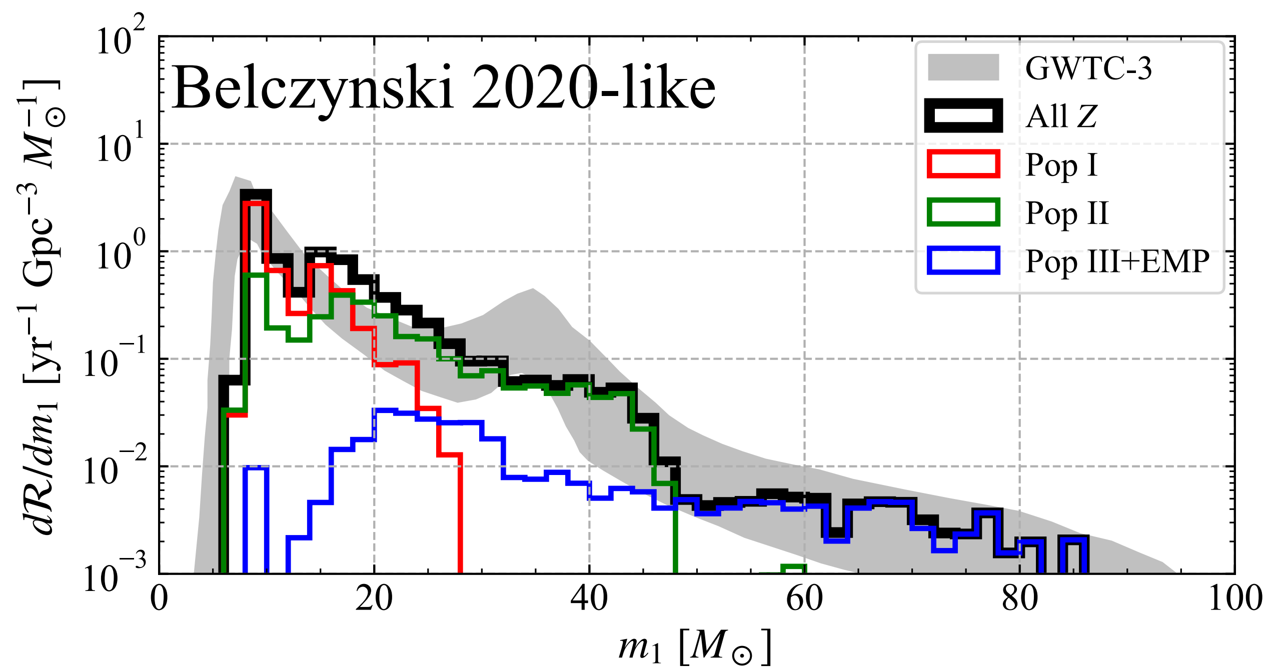


Consistency test by EM obs.

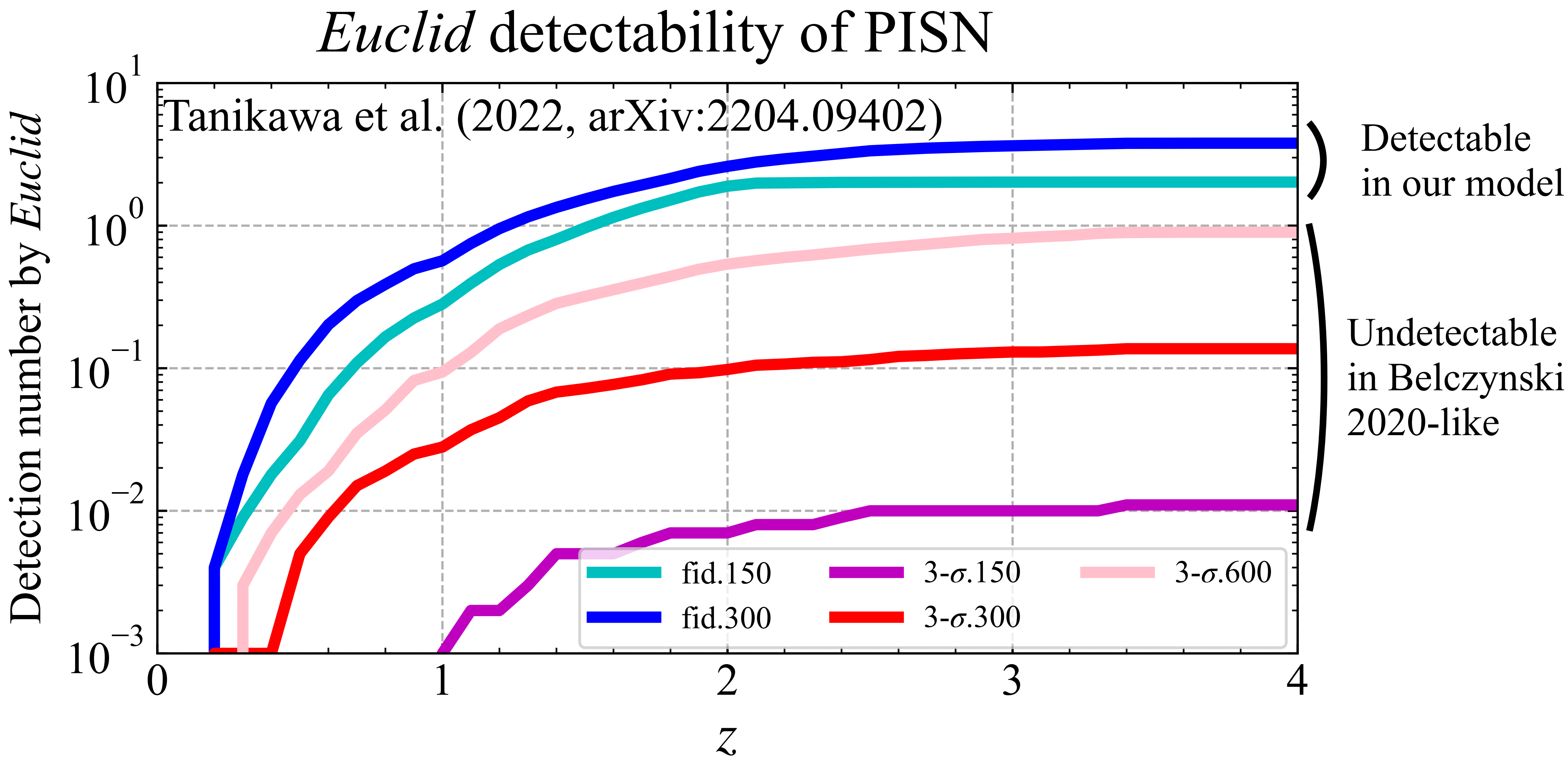


Farmer et al. (2020);
see also Costa et al. (2021)





Consistency test by EM obs.



- Pop I/II PISNe due to the detection horizon
- Hydrogen-poor (Type I) PISNe

Summary

- Binary population synthesis for merging binary BHs under all the metallicities
- Isolated binary scenario consistent with binary BHs observed by GWs
  - PI mass gap events like GW190521
  - Low-q, high-a_1 events like GW190412
- Future GWs: mass gap between $100 - 130 M_\odot$
- Future EMs: a few PISNs detectable by *Euclid*