Formation rate of LB-1 like systems through dynamical interactions

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Innovative Area Gravitational Wave Physics and Astronomy: Genesis
The Third Annual Area Symposium
Konan University, Kobe, Japan, 11th Feb. 2020

Binary evolution and star cluster in A03 group

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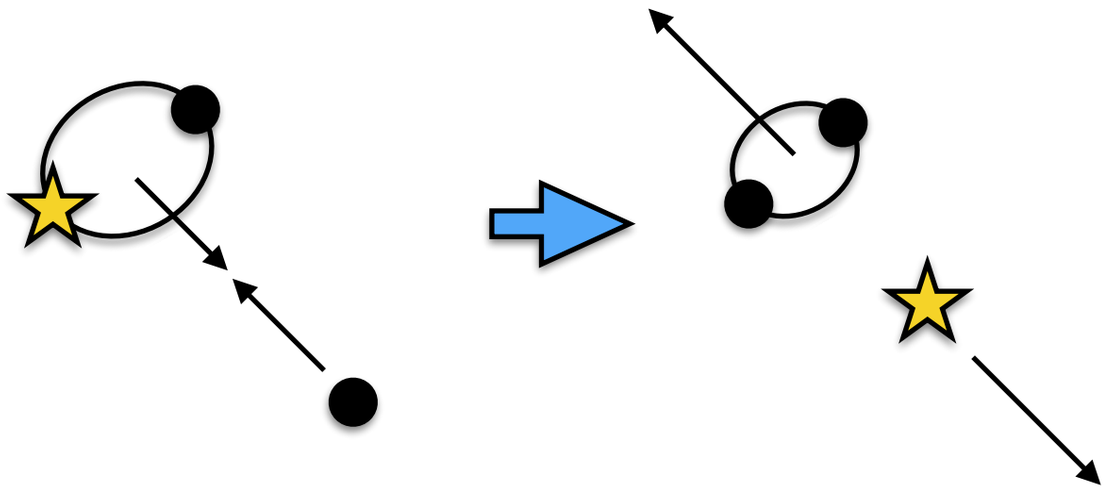
- Formation of LB-1 (Tanikawa et al. 2019) Open cluster
- Stellar evolution tracks (Tanikawa et al. 2019)

Binary evolution and star cluster

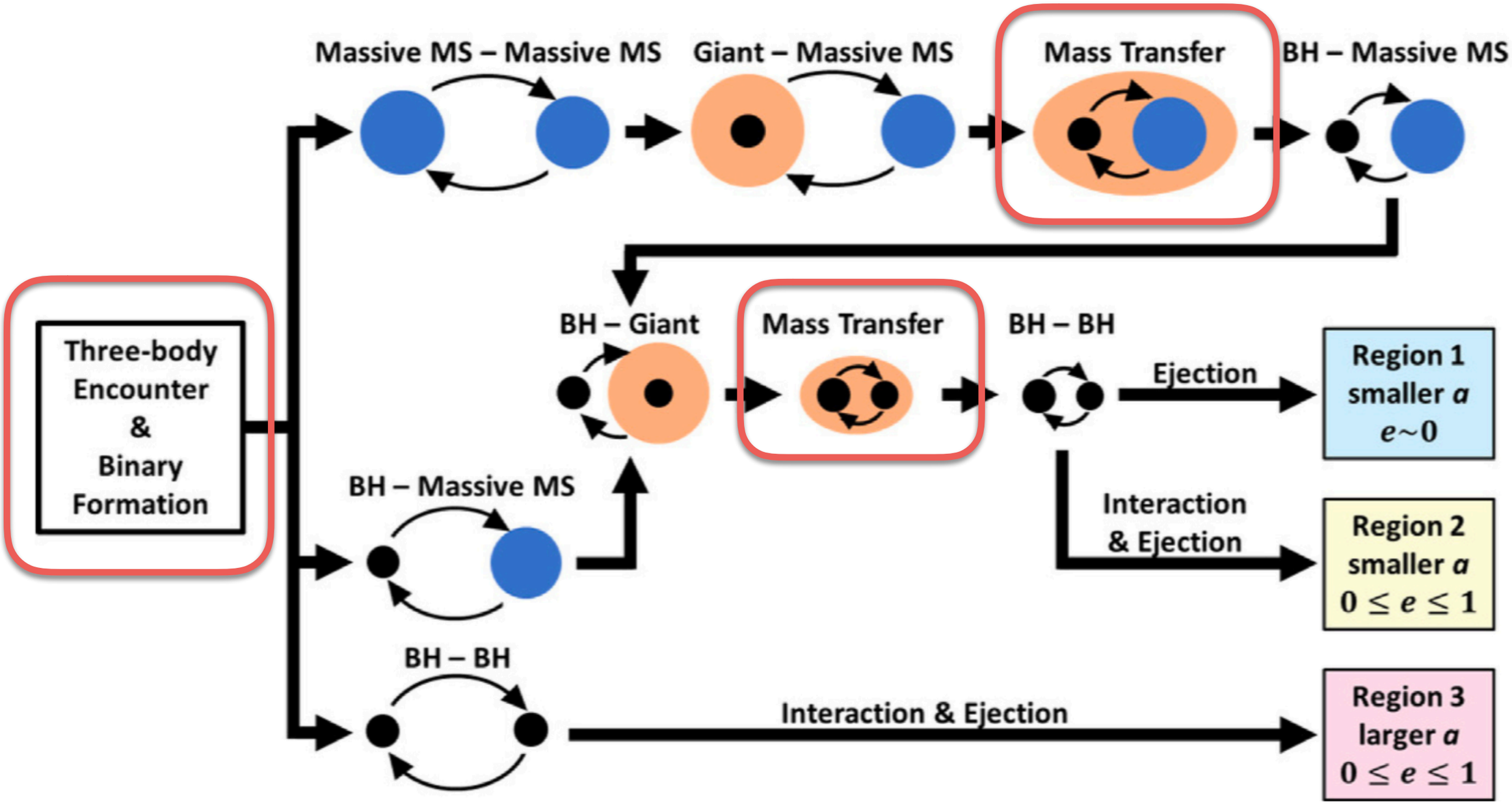
Open clusters

- Dense stellar clusters
  - $M_{\rm oc} \sim 10 - 10^4 M_\odot$
  - $\rho_{\rm oc} \sim 1 - 10^4 M_\odot {\rm pc}^{-3}$
  - $\rho_{\rm disk,solar} \sim 0.1 M_\odot {\rm pc}^{-3}$


Pleiades (© NASA, ESA, AURA/Caltech Palomar Obsevatory)



BH-BH formation

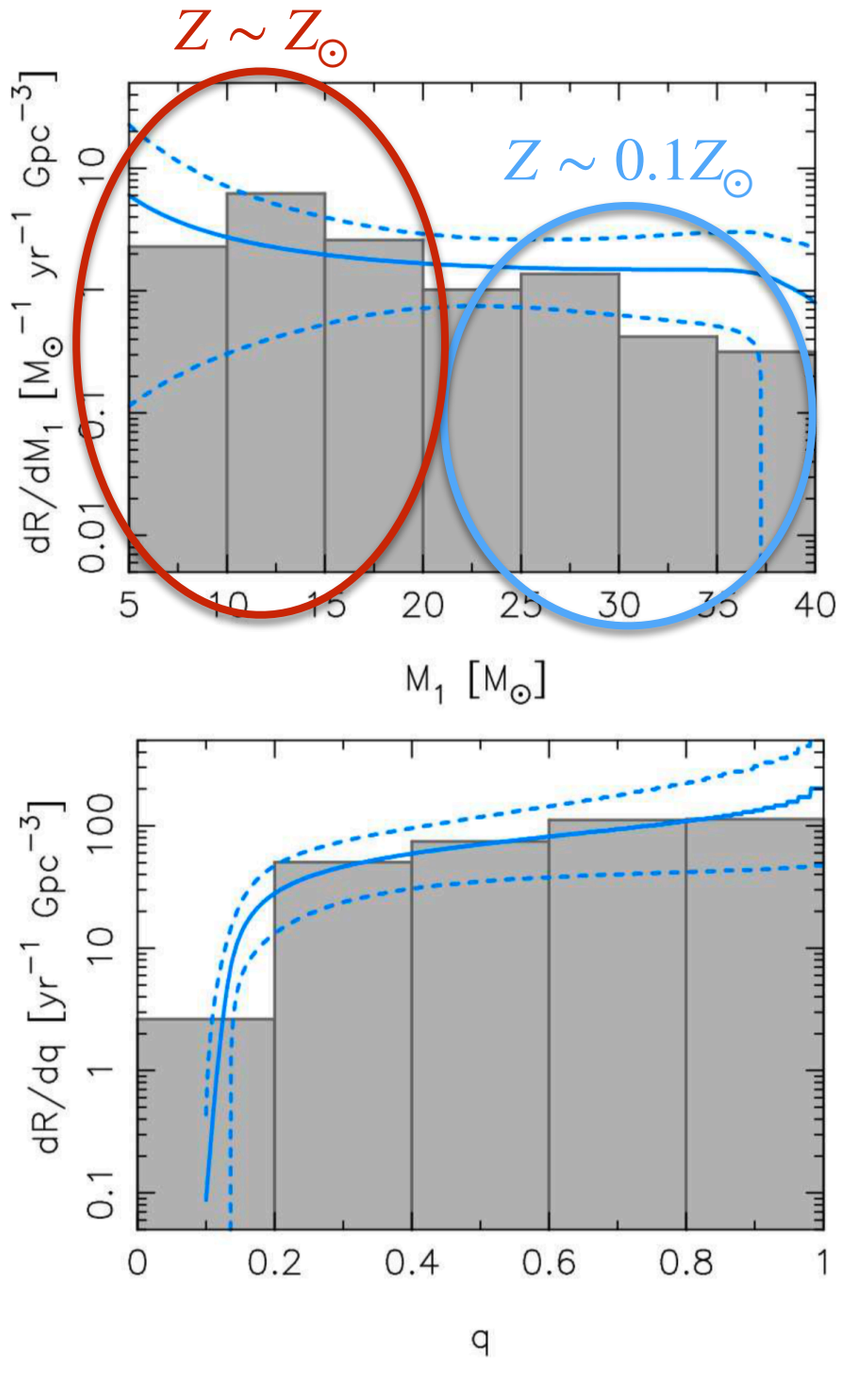


Kumamoto et al. (2018, MNRAS, 486, 3942),

(see also Di Carlo, Giacobbo, Mapelli et al. 2019, MNRAS, 487, 2947)

Mass distribution

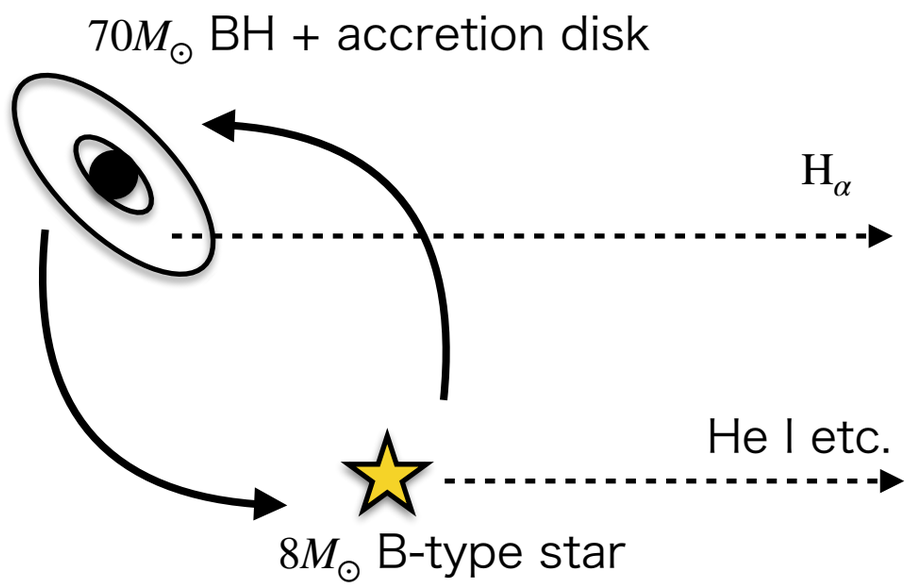
- The M_1 and q distributions are consistent with LIGO/ Virgo observations.
- $Z \sim Z_\odot$ stars contribute to low-mass mergers ($M_1 \sim 10 M_\odot$) .
- High-mass mergers ($M_1 \sim 30 M_\odot$) come from $Z \sim 0.1 Z_\odot$ stars formed at the present day.

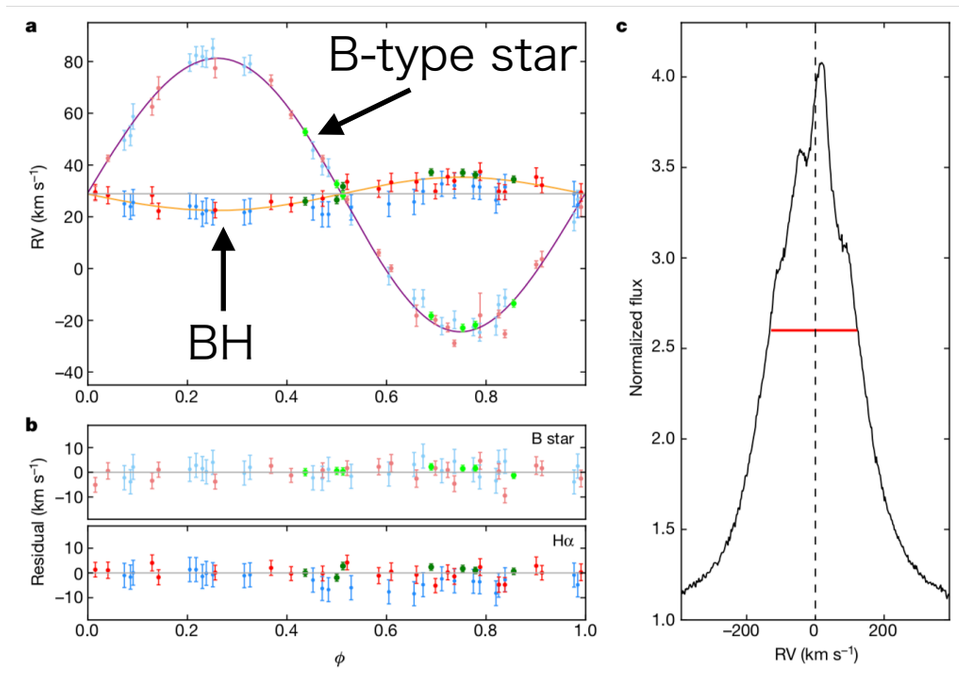


Kumamoto et al. (2020, arXiv:2001.10690)

LB-1 system

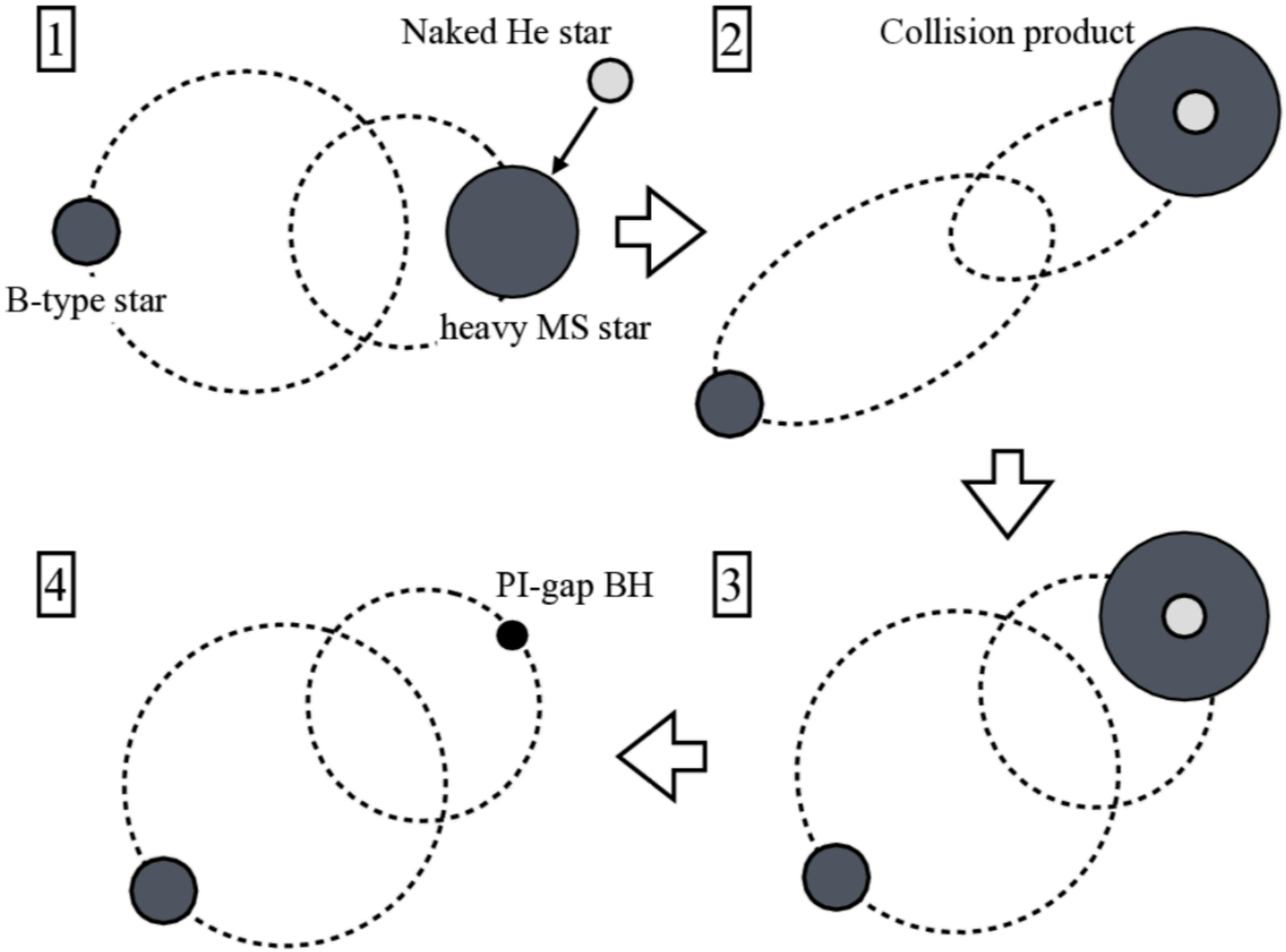
- $8M_\odot$ B-type star - $70M_\odot$ BH
- $a \sim 1$ au, $e \sim 0.03$, $Z \sim Z_\odot$
- But, many studies have raised doubts on the presence (e.g. Eldridge et al. 2019; Adbul-Masih et al. 2019; Safarzadeh et al. 2019; El-Badry, Quataert 2020; Irrgang et al. 2020).





Liu et al. (2019)

Formation scenario



Tanikawa et al. (2019, arXiv:1912.04509)

Formation rate

- Formation rate:

$$N_{\rm LB1} \sim 0.1 \left(\frac{\dot{N}_{\rm coll}}{3\times10^{-8}{\rm yr}^{-1}}\right)\left(\frac{P_{\rm surv}}{0.1}\right)\left(\frac{T_{\rm B}}{40{\rm Myr}}\right)$$

- Collision rate:

$$\dot{N}_{\rm coll} = \dot{N}_{\rm PIgap}\frac{\Gamma_{\rm nHe}}{\Gamma_{\rm eHe}} \sim 3\times10^{-8}\ [{\rm yr}^{-1}]$$

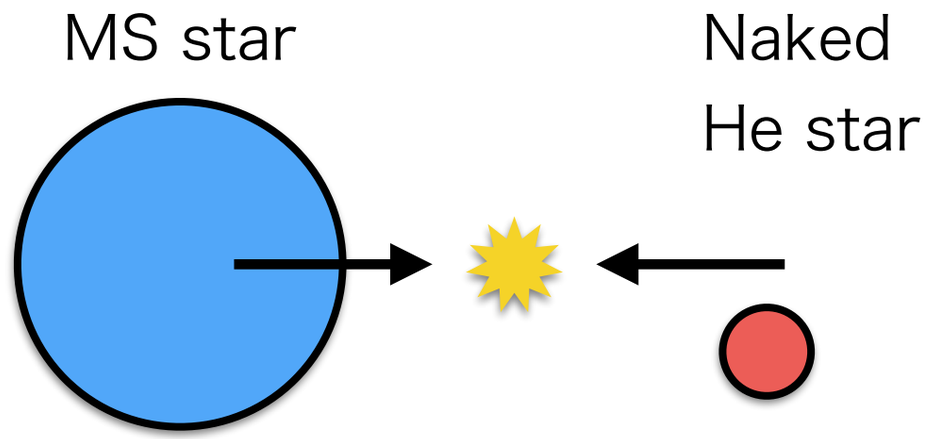
  - $$\dot{N}_{\rm PIgap} \sim 2\times10^{-6}\left(\frac{f_{\rm PIgap}}{0.002}\right)\left(\frac{\rho_{\rm oc}}{10^4 M_\odot {\rm pc}^{-3}}\right)\left(\frac{\eta_{20}}{0.003 M_\odot^{-1}}\right)\left(\frac{f_{\rm oc}}{0.2}\right)\left(\frac{\dot{M}_{\rm mw}}{2M_\odot {\rm yr}^{-1}}\right)\ [{\rm yr}]$$

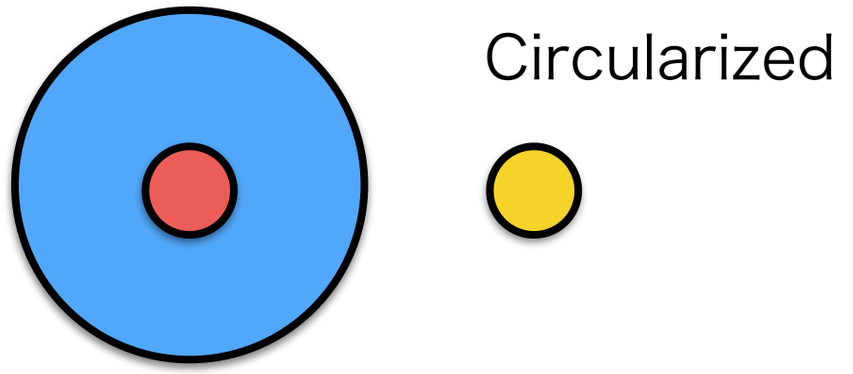
  - $$\frac{\Gamma_{\rm nHe}}{\Gamma_{\rm eHe}} \sim 10^{-2}\left(\frac{N_{1,\rm nHe}/N_{1,\rm eHe}}{2}\right)\left(\frac{M_{12,\rm nHe}/M_{12,\rm eHe}}{2}\right)\left(\frac{R_{12,\rm nHe}/R_{12,\rm eHe}}{0.01}\right)$$

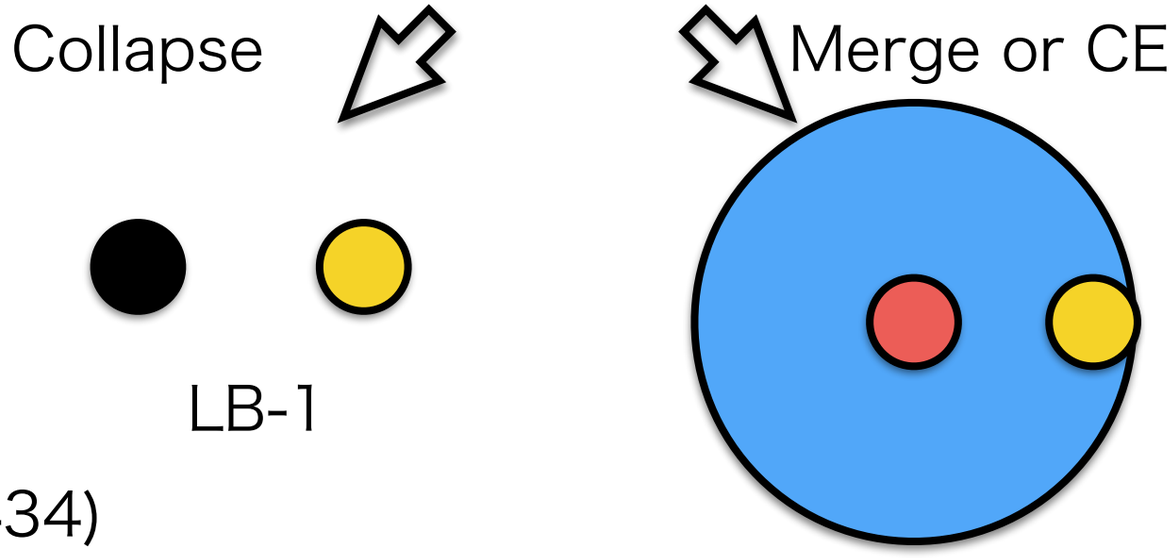
- Surviving rate:

$$P_{\rm surv} = t_{\rm KH}/t_{\rm coll,life,max} \sim 0.1\left(\frac{t_{\rm coll,life,max}}{0.2{\rm Myr}}\right)^{-1}$$

  - $$t_{\rm KH} \sim 2\times10^4\left(\frac{M_{\rm coll}}{70M_\odot}\right)^2\left(\frac{R_{\rm coll}}{100R_\odot}\right)^{-1}\left(\frac{L_{\rm coll}}{10^5 L_\odot}\right)^{-1}\ [{\rm yr}]$$







Di Carlo, Mapelli et al. (2019, arXiv:1911.01434)

Stellar evolution track

Binary evolution

MS MS

He star MS

Naked He star MS

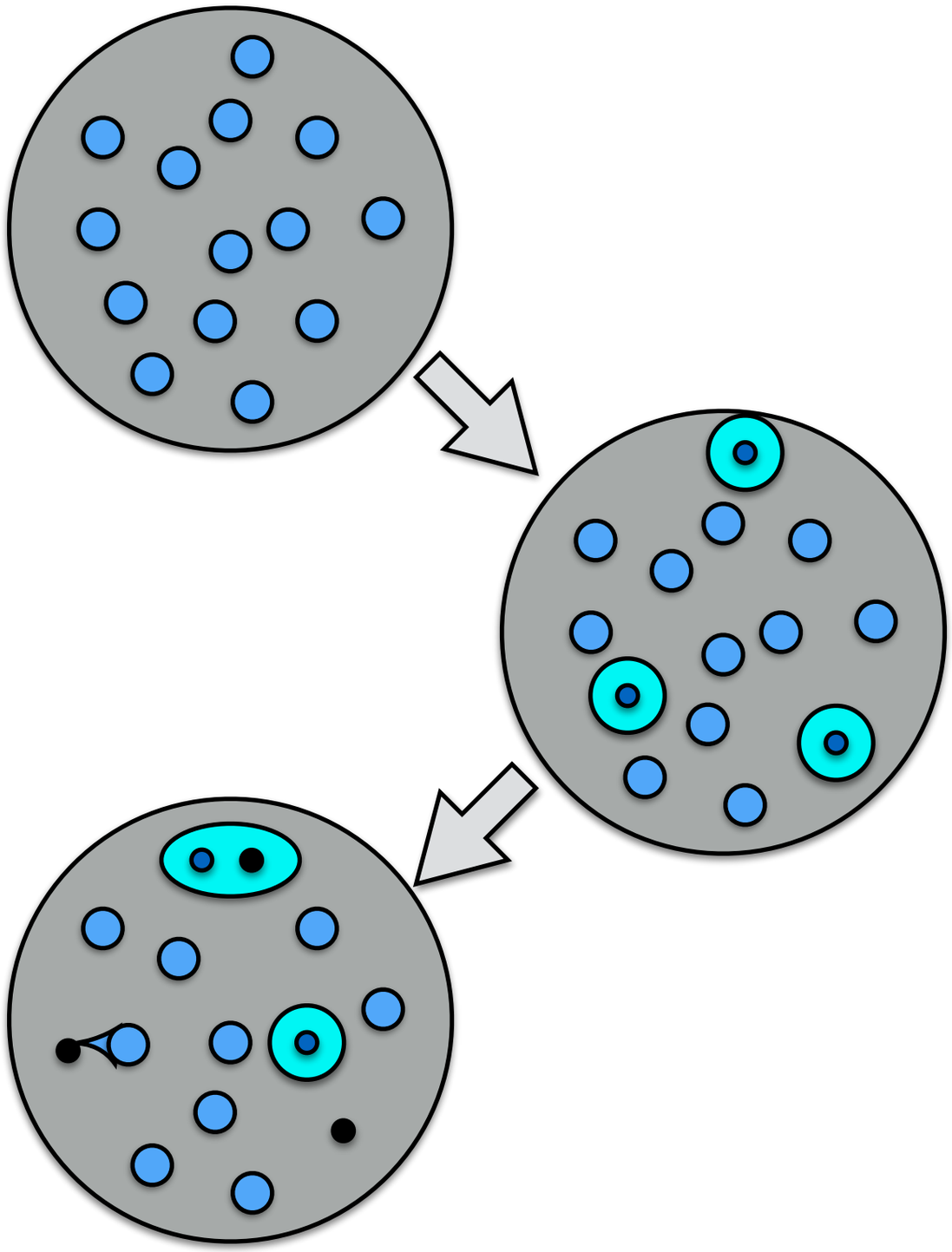
BH MS

BH He star

BH BH

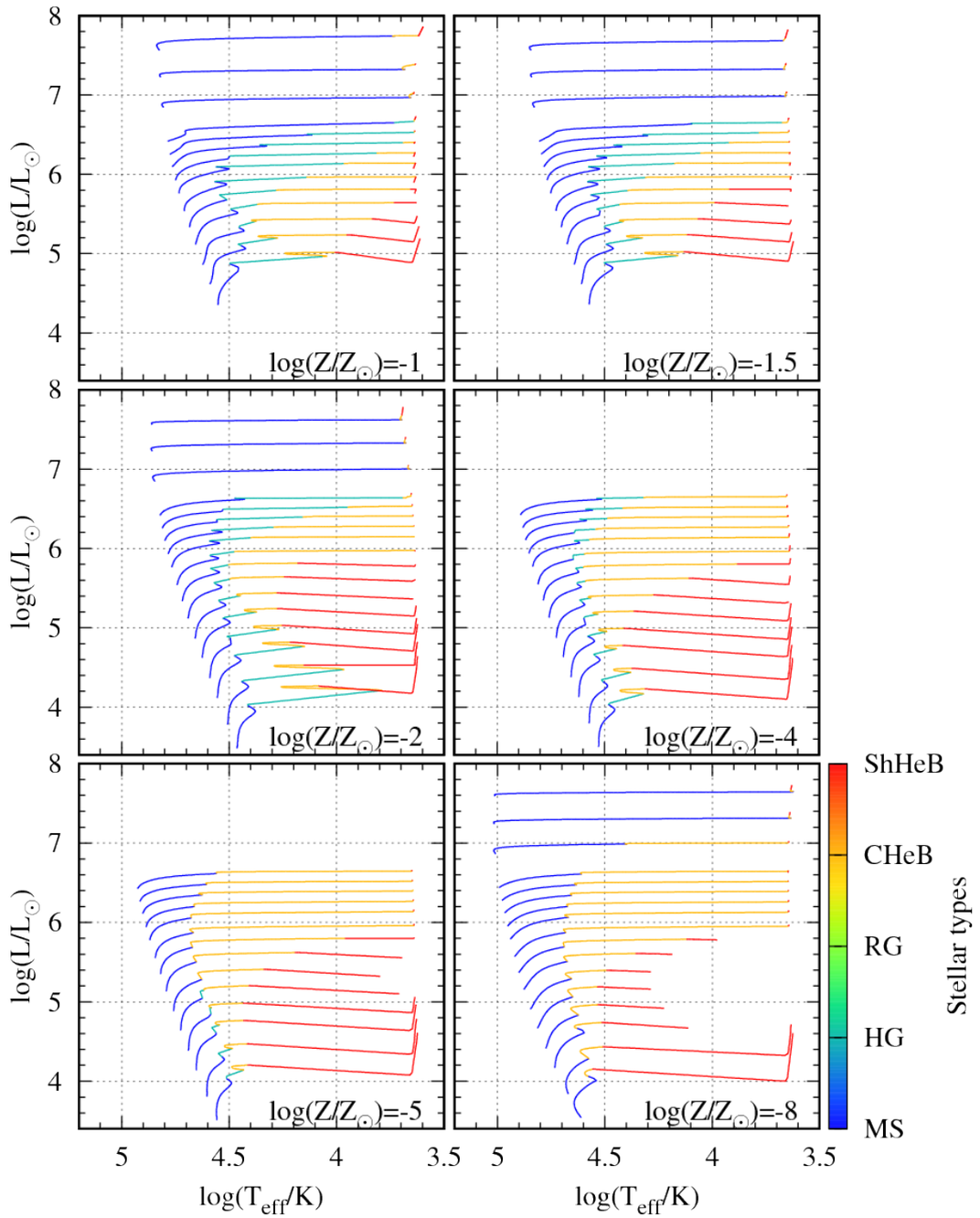
BH BH

Dense stellar cluster



Fitting formulae

- Fitting formulae
  - Based on the Bonn model
  - Coupled with SSE, BSE, and NBODY
- Support for
  - Extreme metal poor stars down to $\log(Z/Z_\odot) = -8$
  - Massive stars up to $M \sim 1300 M_\odot$
- To be open sources within this year



Tanikawa et al. (2019, arXiv:1906.06641)

Summary

- Open clusters are one of promising formation sites of merging BH-BHs (Kumamoto et al. 2019, MNRAS, 486, 3942; 2020, arXiv:2001.10690)

- The LB-1 system cannot be formed in open clusters (Tanikawa et al. 2019, arXiv:1912.04509).

- Evolution tracks for massive or EMP stars will be soon available on SSE, BSE, and NBODY codes (Tanikawa et al. 2019, arXiv:1906.06641).