THE UNIVERSITY OF TOKYO

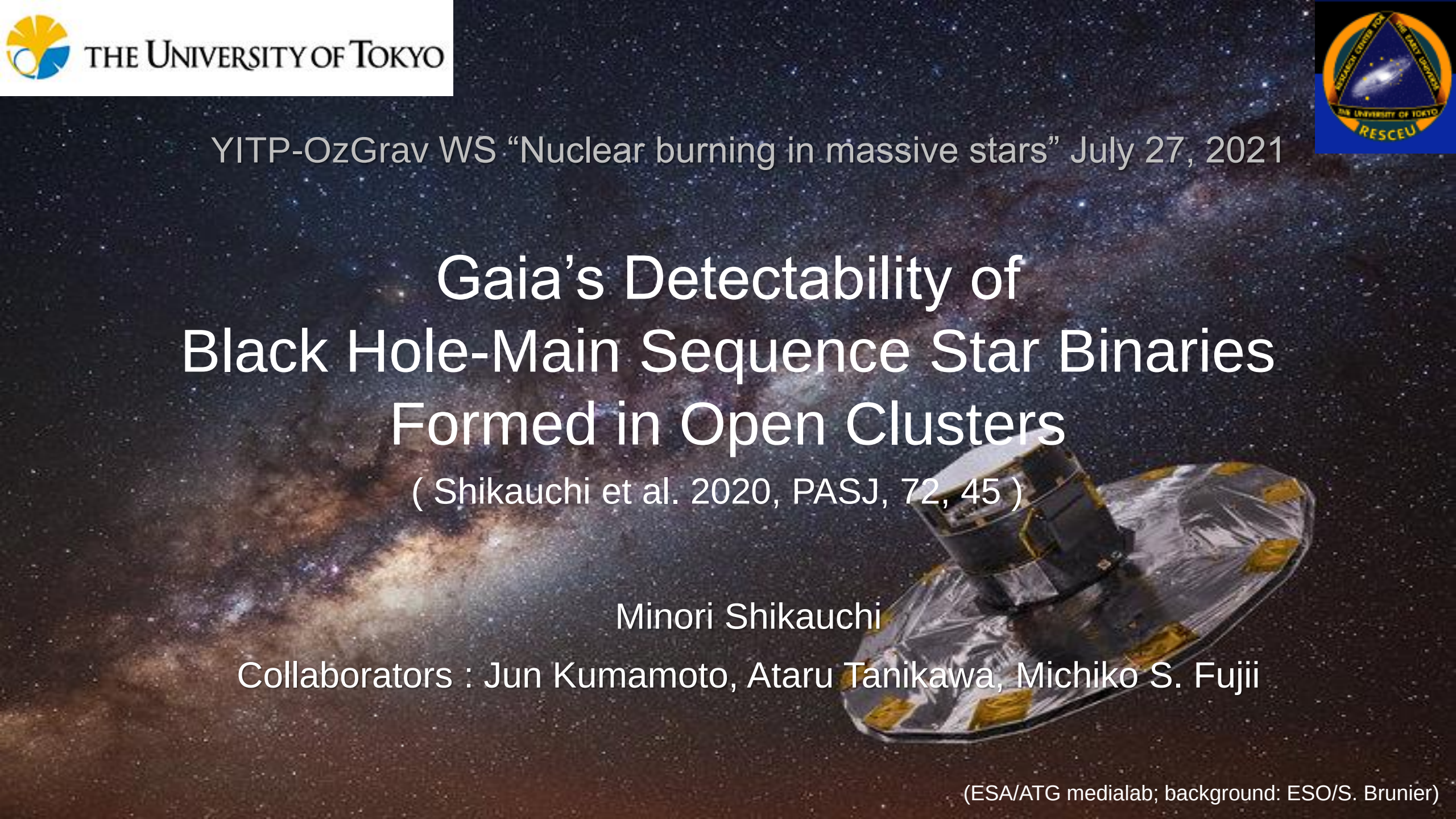
YITP-OzGrav WS “Nuclear burning in massive stars” July 27, 2021

Gaia’s Detectability of Black Hole-Main Sequence Star Binaries Formed in Open Clusters

(Shikauchi et al. 2020, PASJ, 72, 45)

Minori Shikauchi

Collaborators : Jun Kumamoto, Ataru Tanikawa, Michiko S. Fujii



(ESA/ATG medialab; background: ESO/S. Brunier)

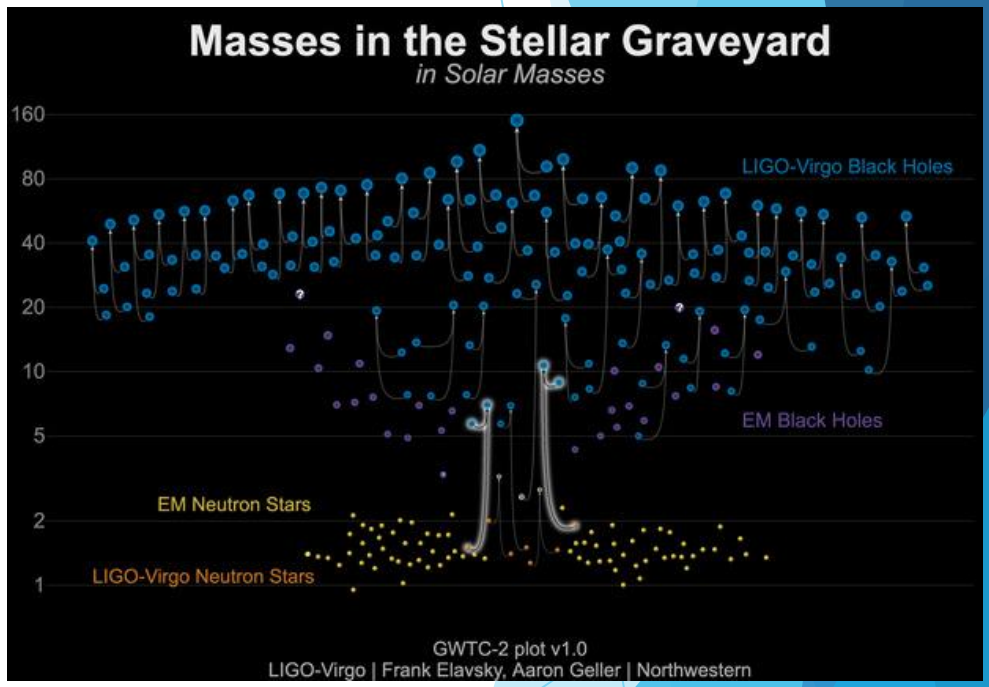
Detecting Stellar Mass BHs with Gaia

- $\lesssim$ 100 BHs in X-ray binaries in the MW
- $\gtrsim$ 60 BBHs/NSBHs as GW transients
- periods of BH binaries: hours – days

⇒ biased to shorter period binaries

possibility of unseen binaries in X-ray

(Yungelson+ 2006)

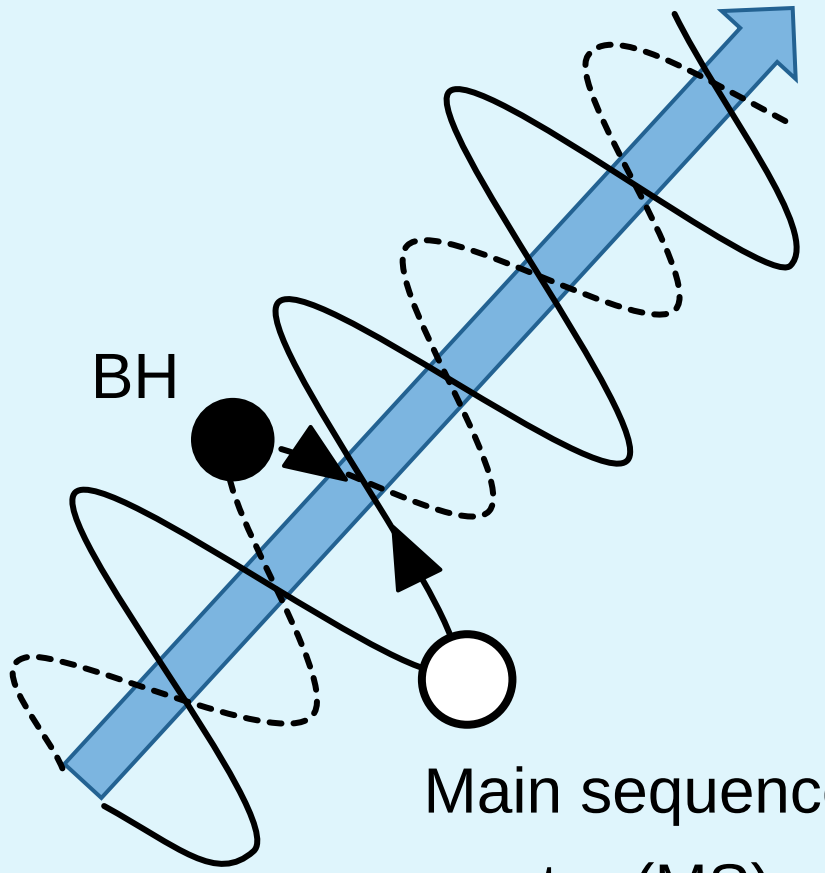


(https://www.ligo.caltech.edu/image/ligo20210629b)

How can such binaries be observed?

Detecting Stellar Mass BHs with Gaia

motion of astrometric binary

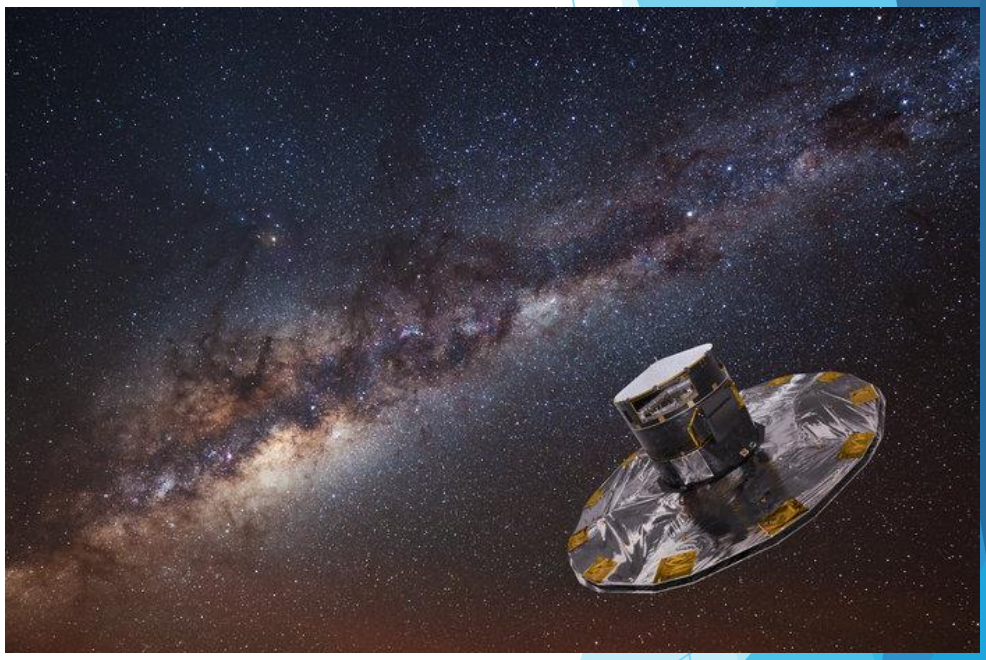


- observe the motion of MSs
  → confirm the existence of BHs

Detecting Stellar Mass BHs with Gaia

- astrometric satellite : Gaia
- future data release in 2022
  - Including the data of five-year observation from 2013
  - binaries with periods of days – years

⇒ X-ray and astrometric observations are complementary!



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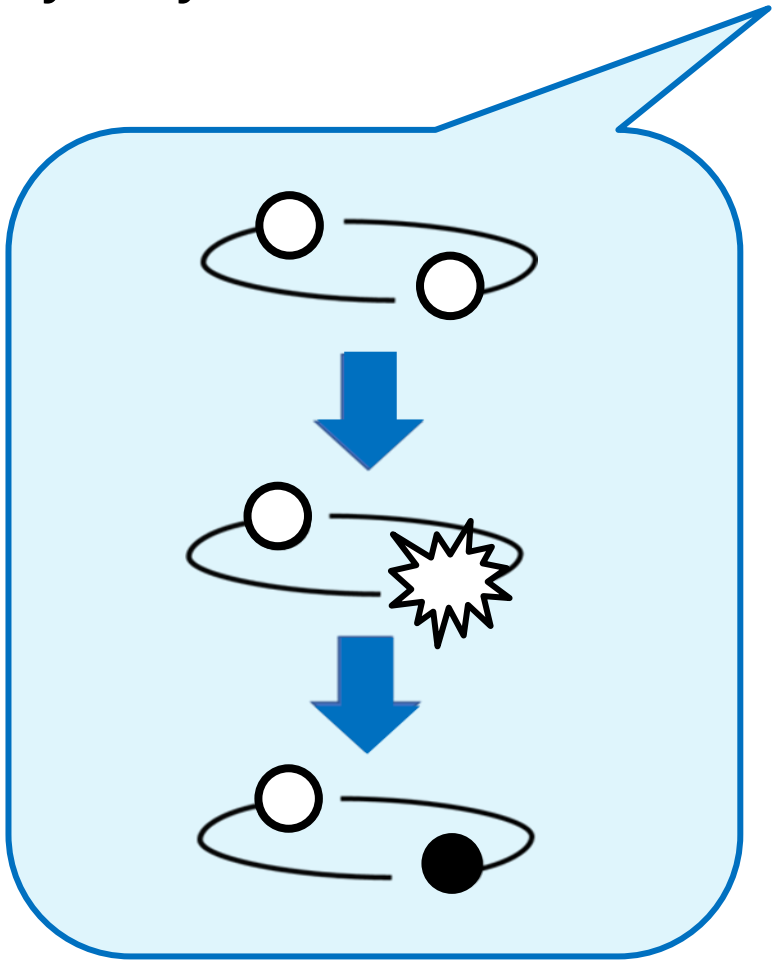
How many BH-MS binaries will be detected with Gaia?

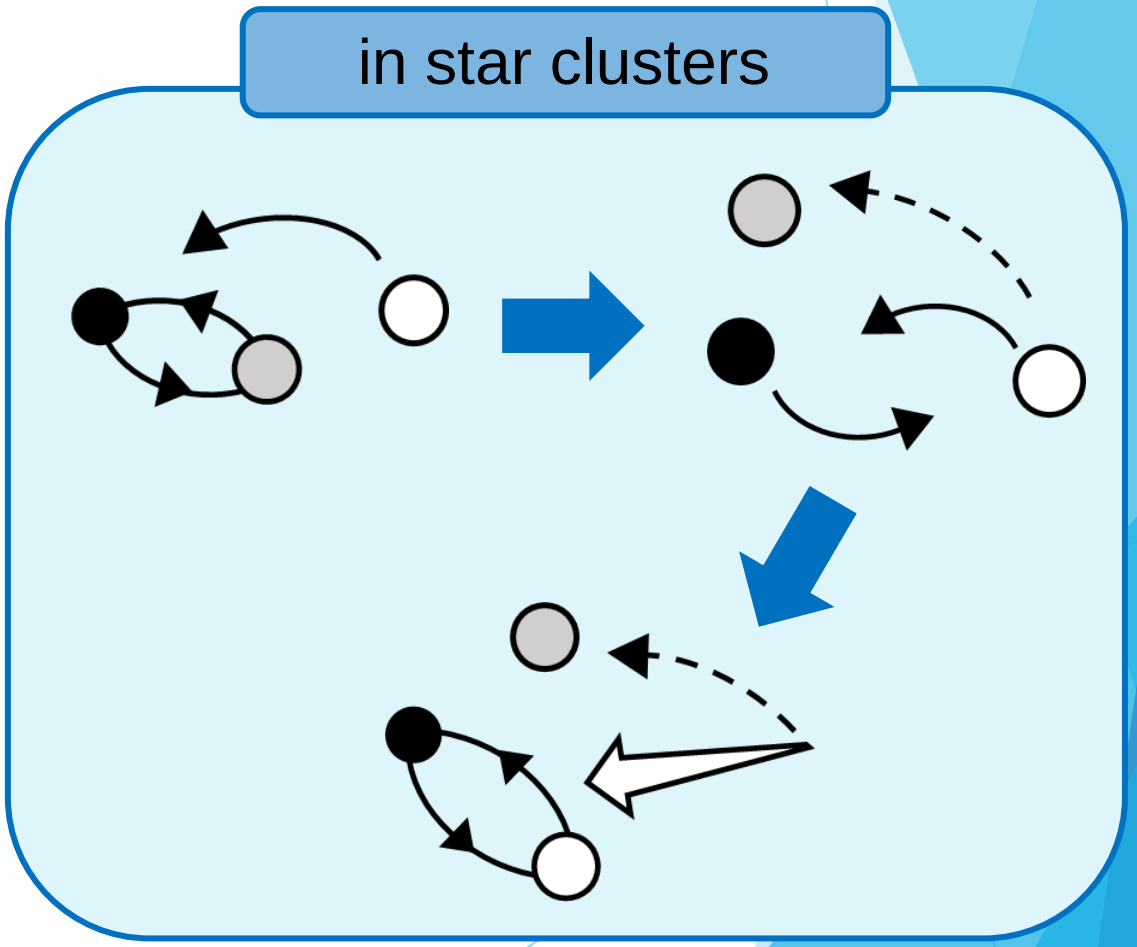
(Mashian & Loeb 2017, Breivik+ 2017, Yamaguchi+ 2018, …)

Previous Researches Predicted it, but…

- they only considered isolated field binaries.



never exchange companions



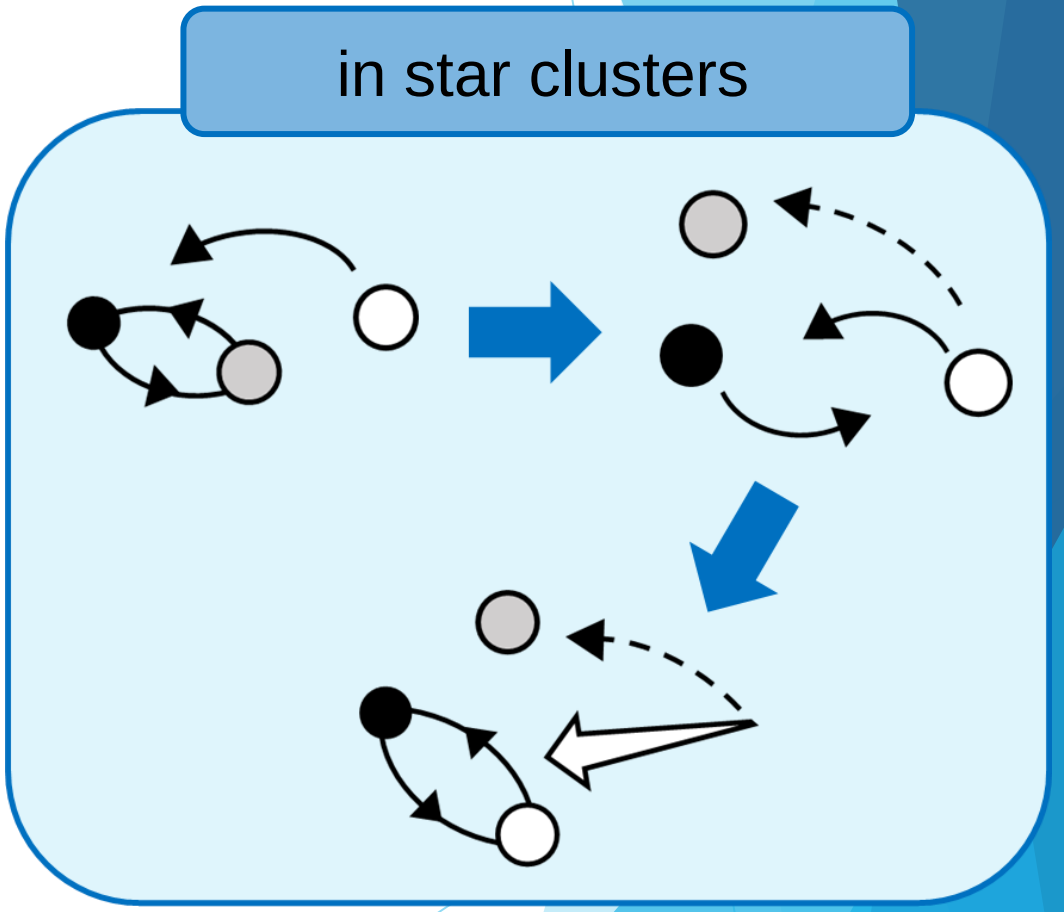
dynamically interact

(Mashian & Loeb 2017, Breivik+ 2017, Yamaguchi+ 2018, …)

Previous Researches Predicted it, but…

- in a dense stellar region,
  stellar number density is higher than
  in isolated fields.

⇒ more binaries can be formed
and kicked out from cluster!



How much do they contribute to the detectability?

Can we find the difference of formation process?

performed *N*-body simulations of open cluster models

Setup of *N*-body Simulations

open cluster models

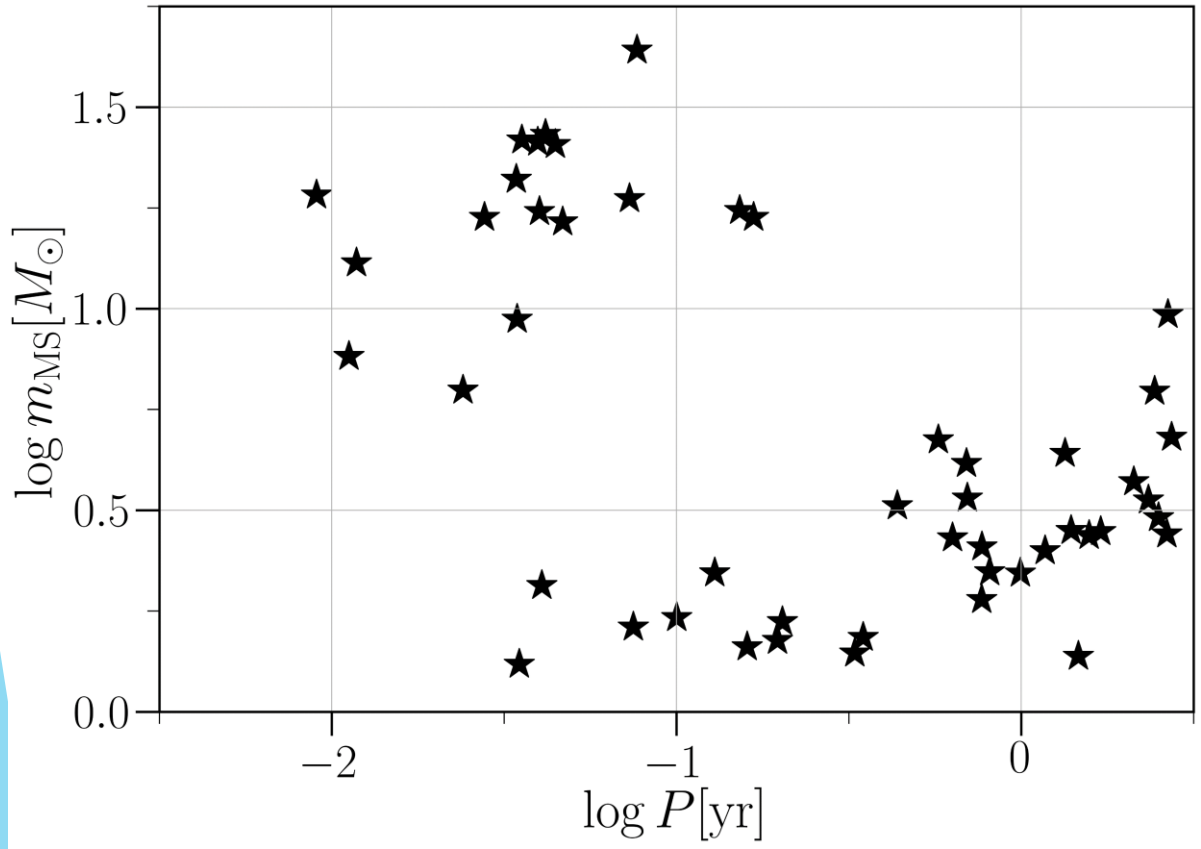
metallicity : solar metallicity

mass of each cluster $M_{\rm ini}$: $2500 M_{\odot}$, Plummer profile

Kroupa IMF (range : $0.08 M_{\odot} - 150 M_{\odot}$)

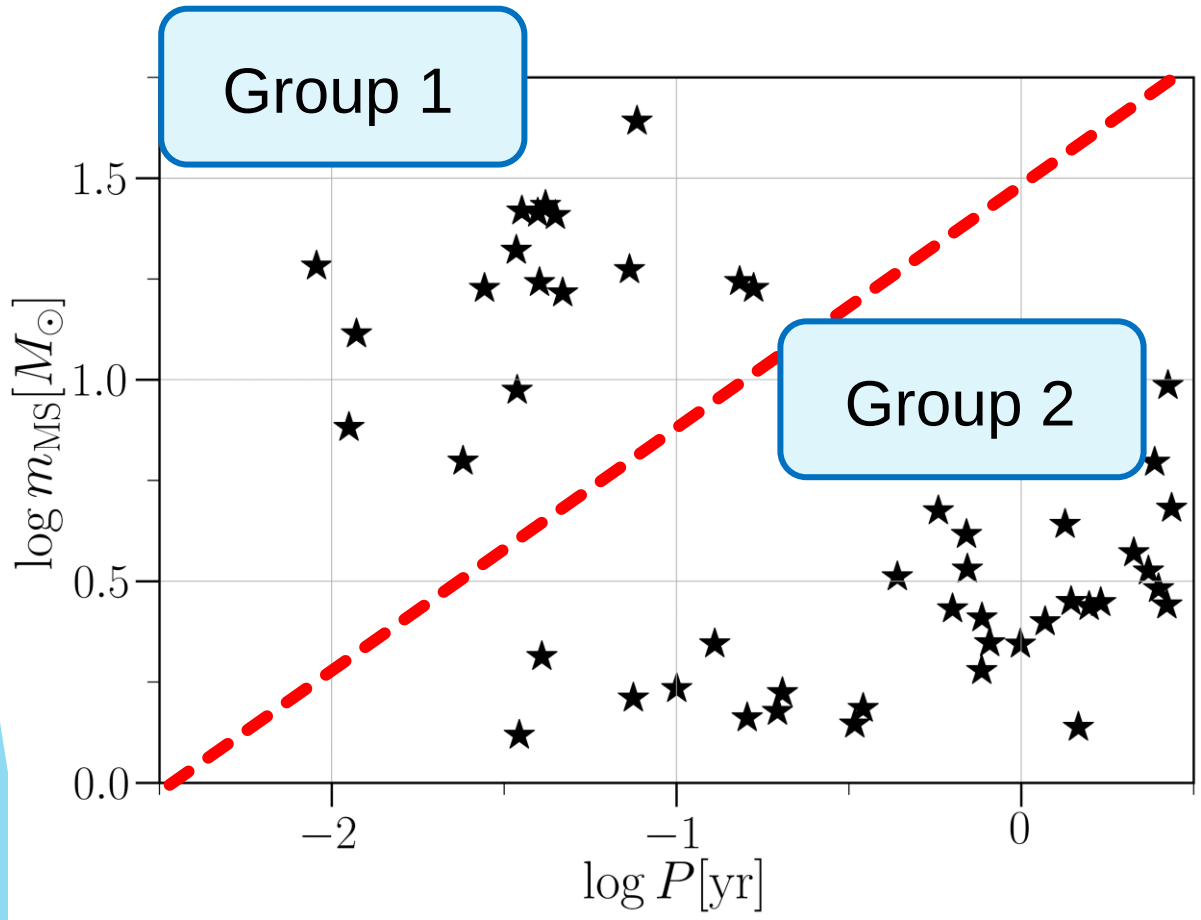
- single / binary stellar evolution
- common envelope phase, stellar wind mass loss
- no BH natal kicks (Not important for detectability, cf. Breivik+ 2017)
- 1000 different realizations with NBODY6++GPU

Results and Classification of Binaries



- obtained 49 BH-MS binaries escaping from open clusters with orbital periods of $\lesssim$ 3 years.
- divide them into two groups

Results and Classification of Binaries

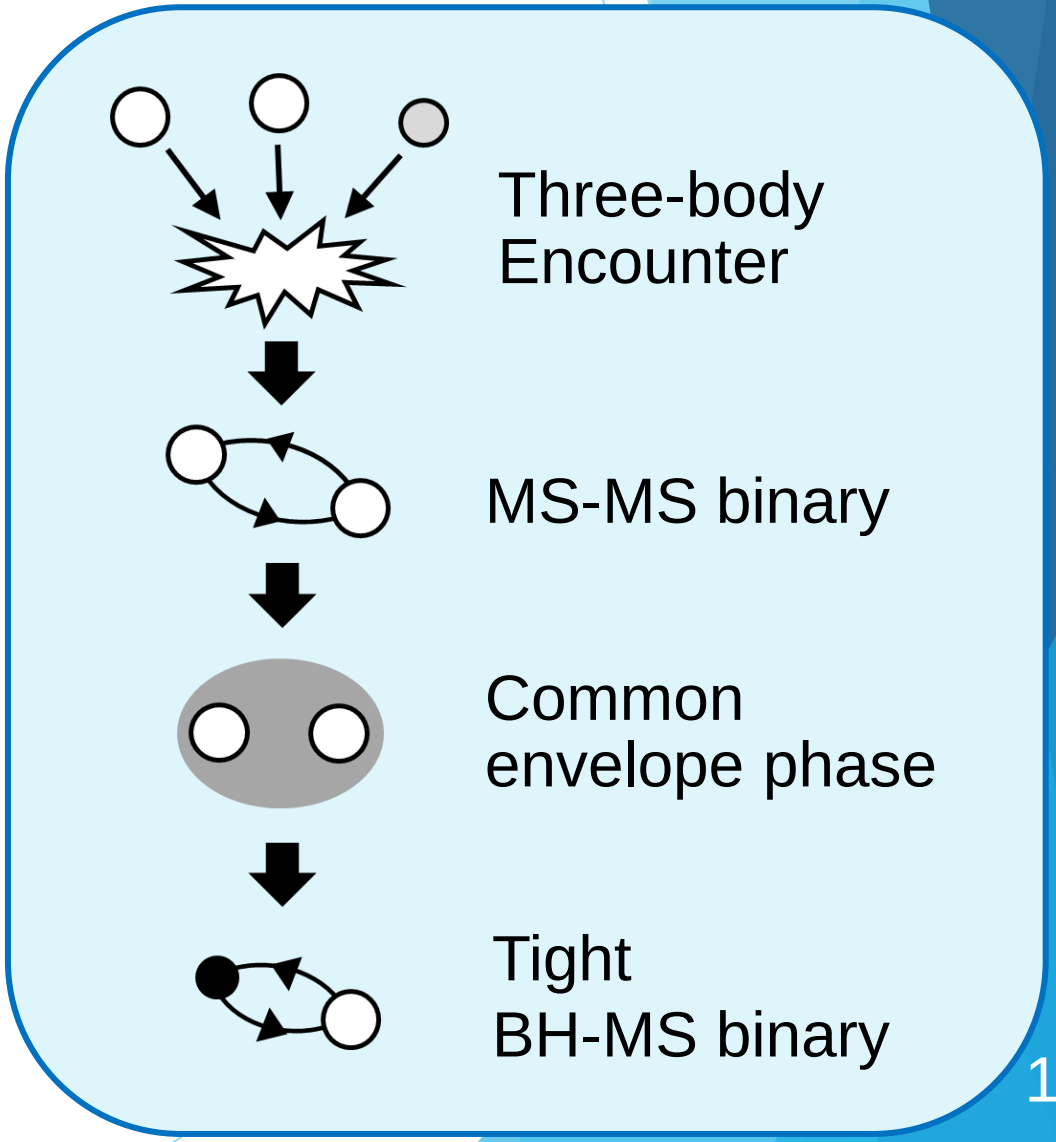


- obtained 49 BH-MS binaries escaping from open clusters with orbital periods of $\lesssim$ 3 years.
- divide them into two groups
  - Group 1 : tight with massive MSs
  - Group 2 : less tight and less massive MSs

Formation Process of Group 1 Binaries

- short periods ($P \lesssim 0.1$ year)
- massive MSs ($m_{\rm MS} \gtrsim 5.6 M_\odot$)
- dynamically formed MS-MS binary experiencing common envelope phase

  → tight BH-MS binaries
  (a kind of isolated field binaries)

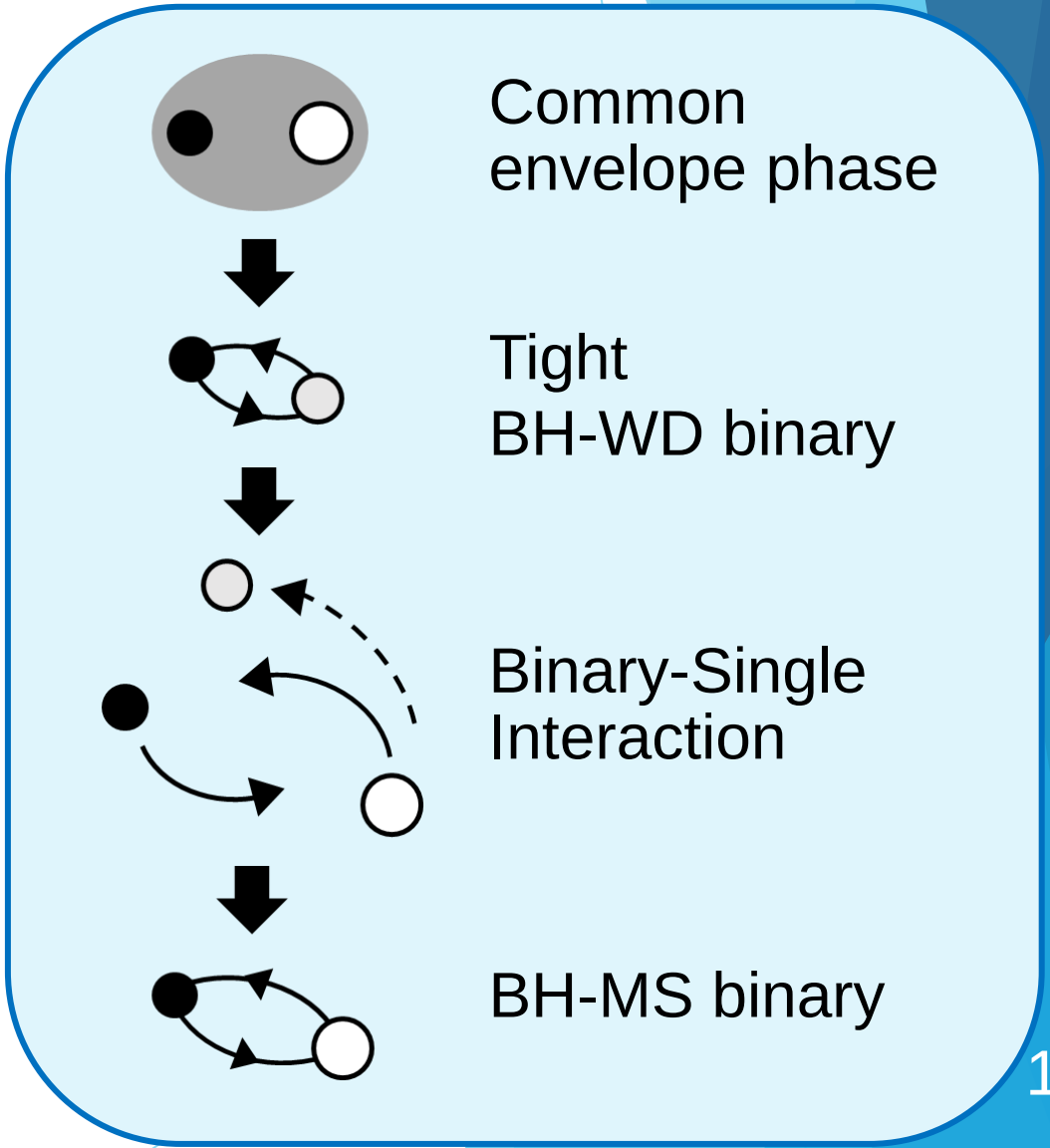


Formation Process of Group 2 Binaries

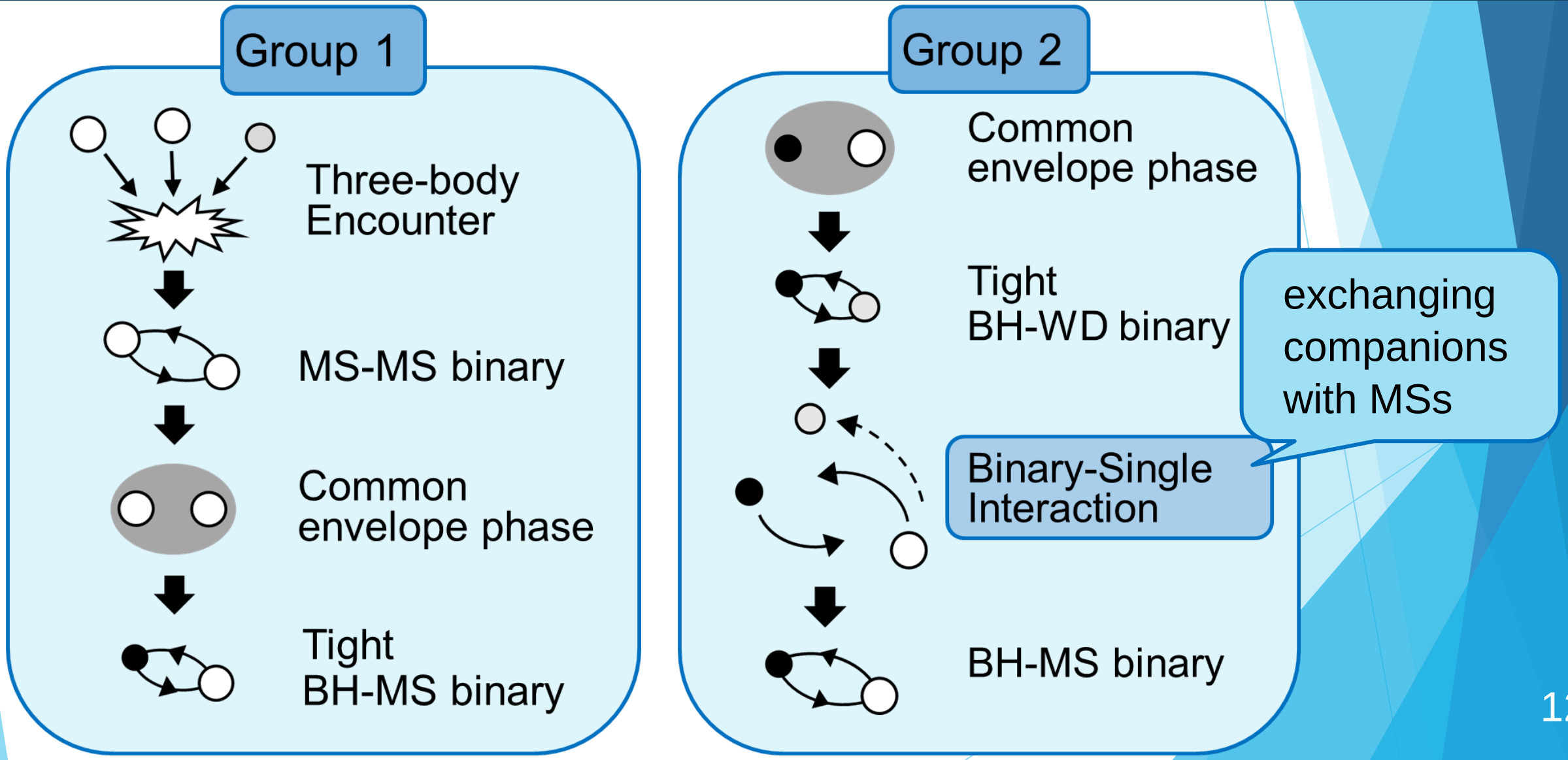
- long periods ($P \gtrsim 0.1$ year)
- less massive MSs ($m_{\rm MS} \lesssim 5.6 M_\odot$)
- dynamically formed BH-MS binaries experiencing common envelope phase

  → tight BH-white dwarf (WD) binaries

  → exchanging WD with MS



The Difference of Formation Process

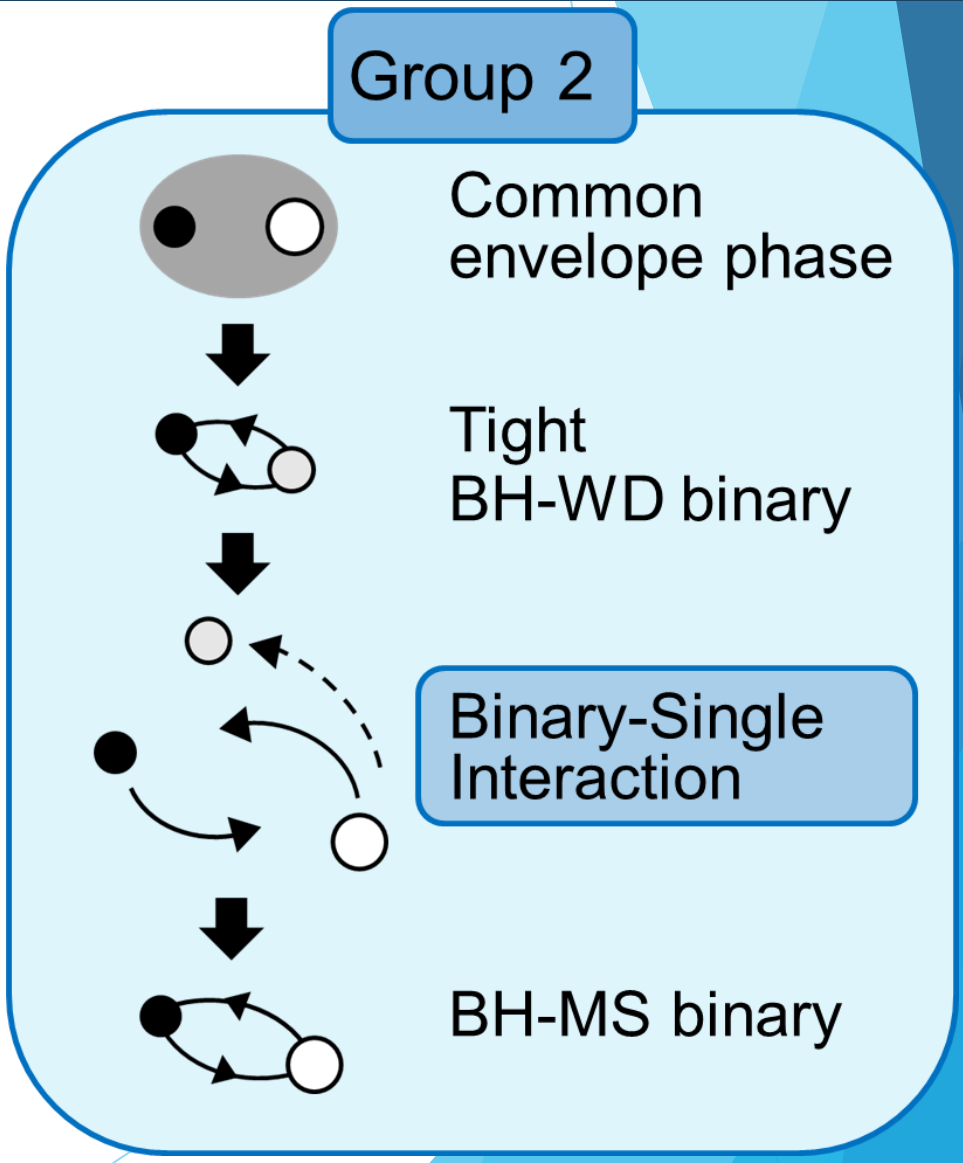


The Difference of Formation Process

- Group 2 binaries exchange MSs after CE phases

⇒ MSs of Group 2 binaries are not polluted by outflows of the BH progenitors

companion MSs with normal chemical abundance patterns can exist!



Detectability : The Number of BH-MS Binaries

- constraints for realistic observation (following Yamaguchi et al. 2018)
  - interstellar extinction
  - Gaia's detection limit : parallaxes and orbital separations

	Total
our result	8.9
isolated field binaries (Yamaguchi et al. 2018)	200 - 1000

⇒ ~ 1 – 5 % contribution to the total detectability

Detectability : Main Contribution of Group 2

- constraints for realistic observation (following Yamaguchi et al. 2018)
  - interstellar extinction
  - Gaia's detection limit : parallaxes and orbital separations

	Total	**Group 1**	**Group 2**
our result	8.9	5.6×10^{-4}	8.9
isolated field binaries (Yamaguchi et al. 2018)	200 - 1000	~ 0	~ 0

Group 1 binaries are hardly observed because of their tight separation.

Detectability : Main Contribution of Group 2

	Total	Group 1	Group 2
our result	8.9	5.6×10^{-4}	8.9
isolated field binaries (Yamaguchi et al. 2018)	200 - 1000	~ 0	~ 0

the formation process of Group 2 binaries is
a characteristic of cluster-origins.

chemical abundance patterns of MSs can be
a clue to identify the origin of BH-MS binaries!

Summary

- predicted Gaia's detectability of cluster-origin BH-MS binaries
- ~ 10 binaries can be detected considering interstellar extinction

  - 1 – 5% contribution to the detectability
  - Group 2 are dominant

  → chemical abundance patterns of MSs will be a characteristic of cluster-origin binaries