Toward understanding of binary black hole formation

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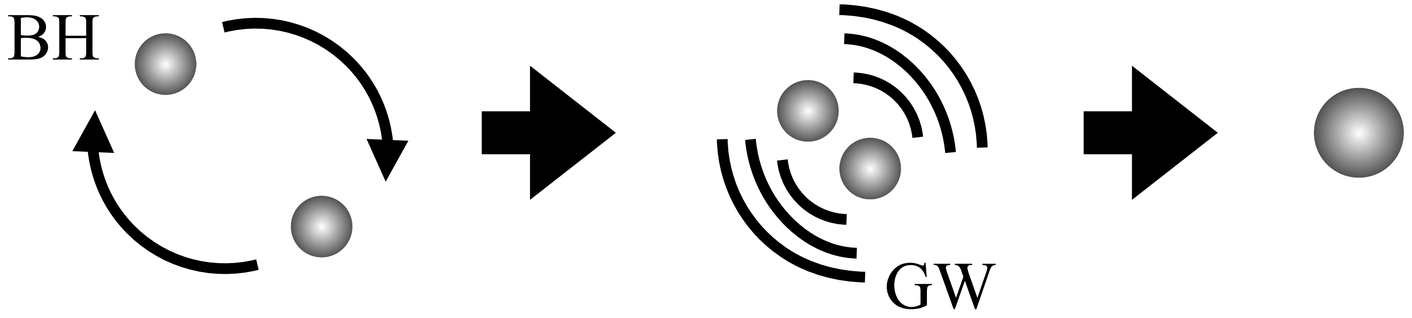
(Fukui Prefectural University)

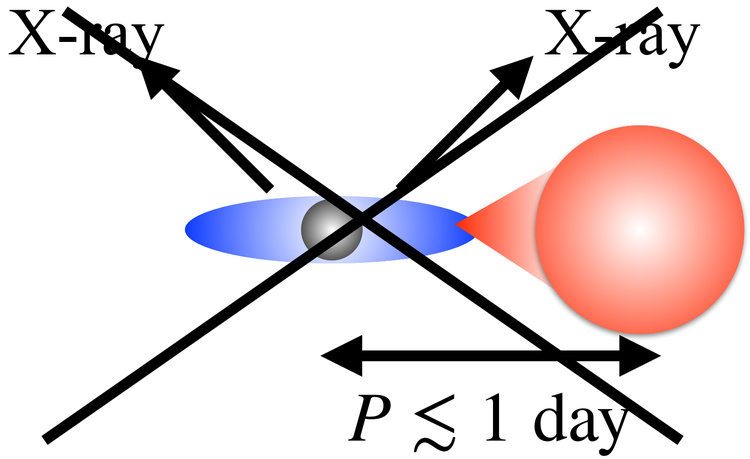
II SYNERGIES AT NEW FRONTIERS
Kashiwa, 25th March 2024

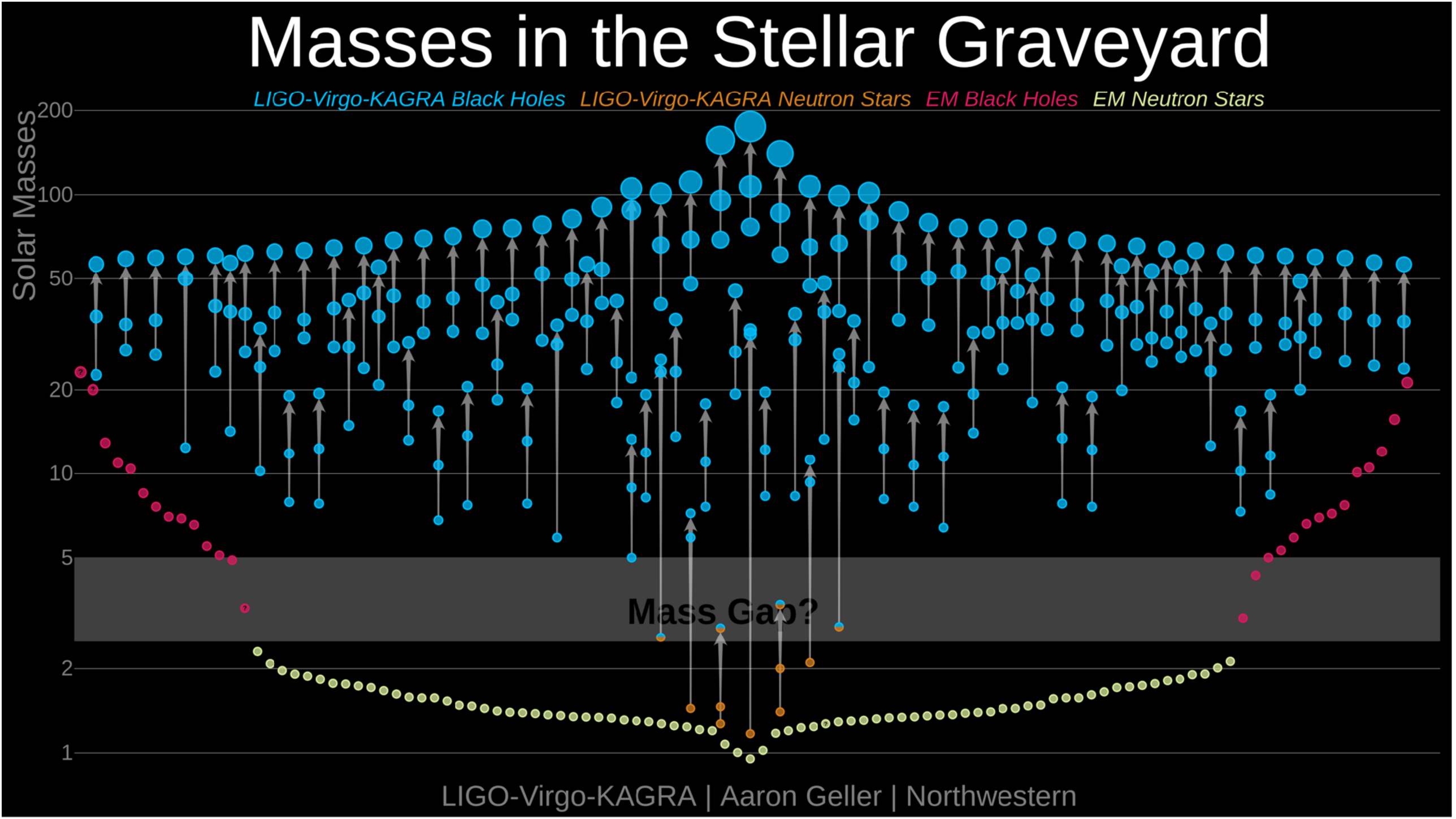
Contents

- Binary black holes as gravitational wave sources



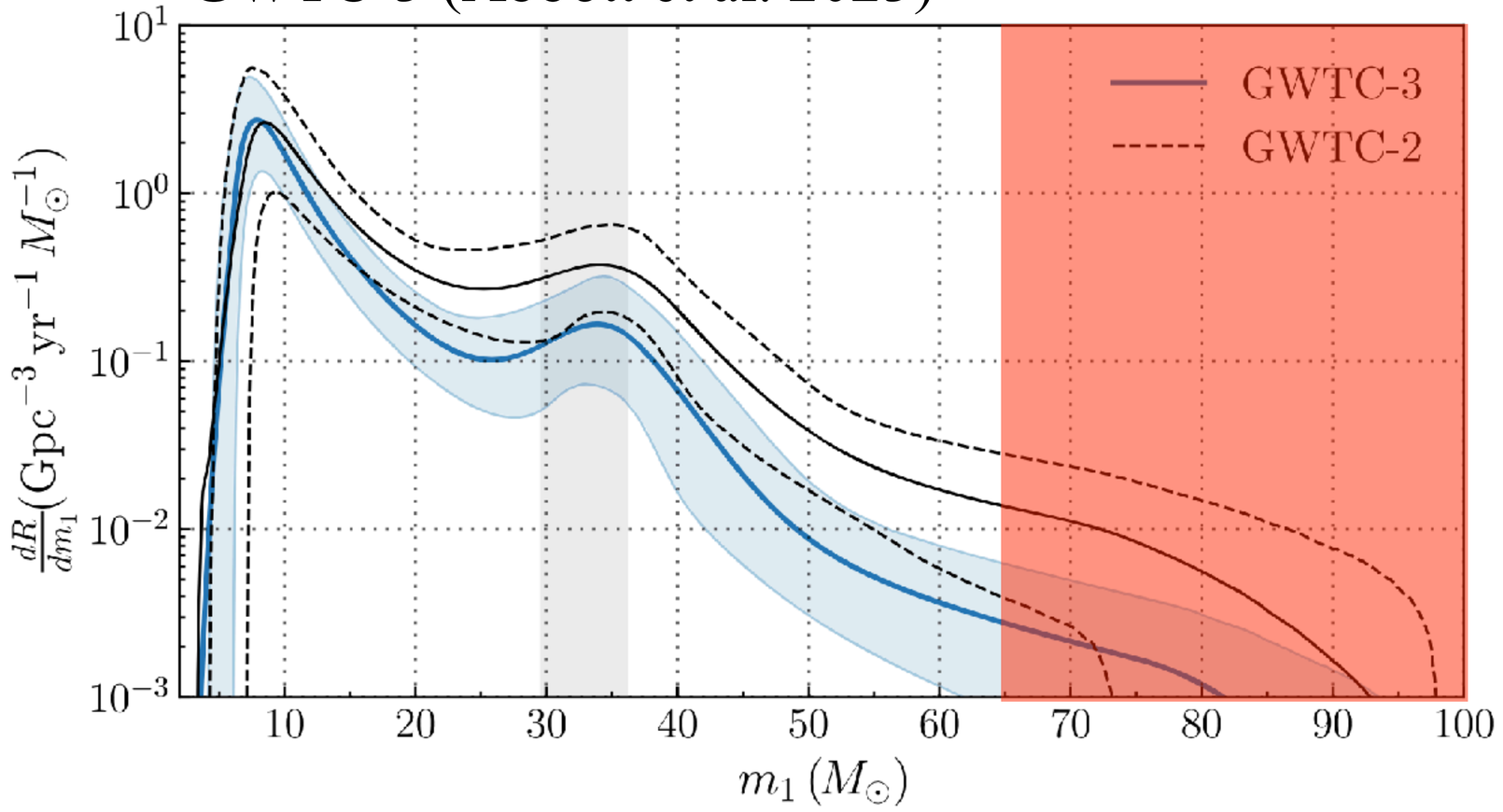
- Search for black holes in binary stars in the Milky Way



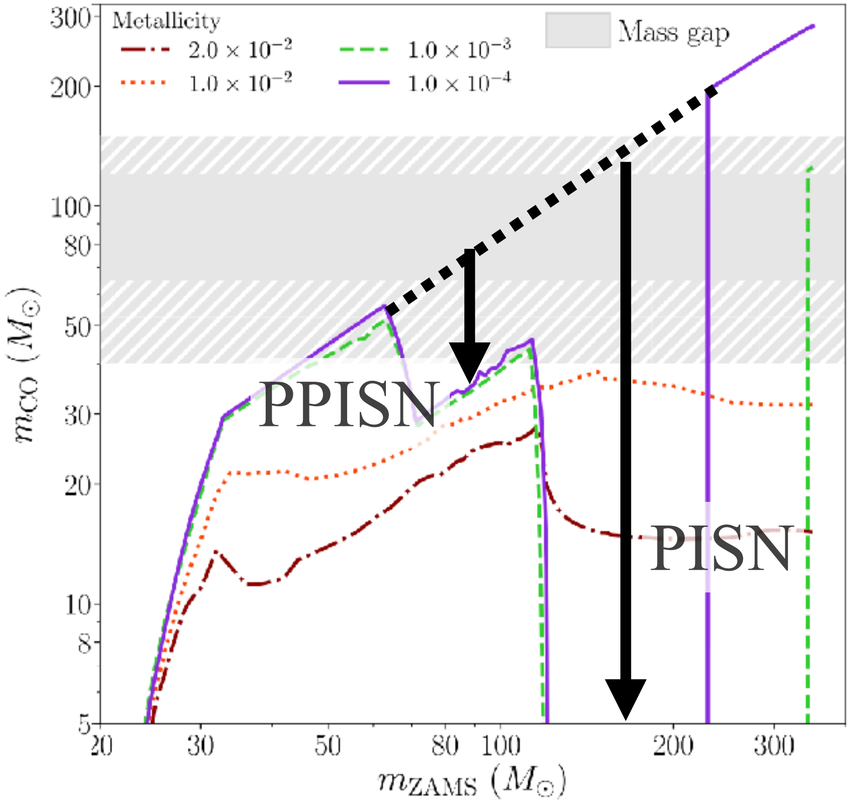

Masses in the Stellar Graveyard
LIGO-Virgo-KAGRA Black Holes
LIGO-Virgo-KAGRA Neutron Stars
EM Black Holes
EM Neutron Stars
Solar Masses
200
100
50
20
10
5
2
1
Mass Gap?
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

Pair instability mass gap

GWTC-3 (Abbott et al. 2023)



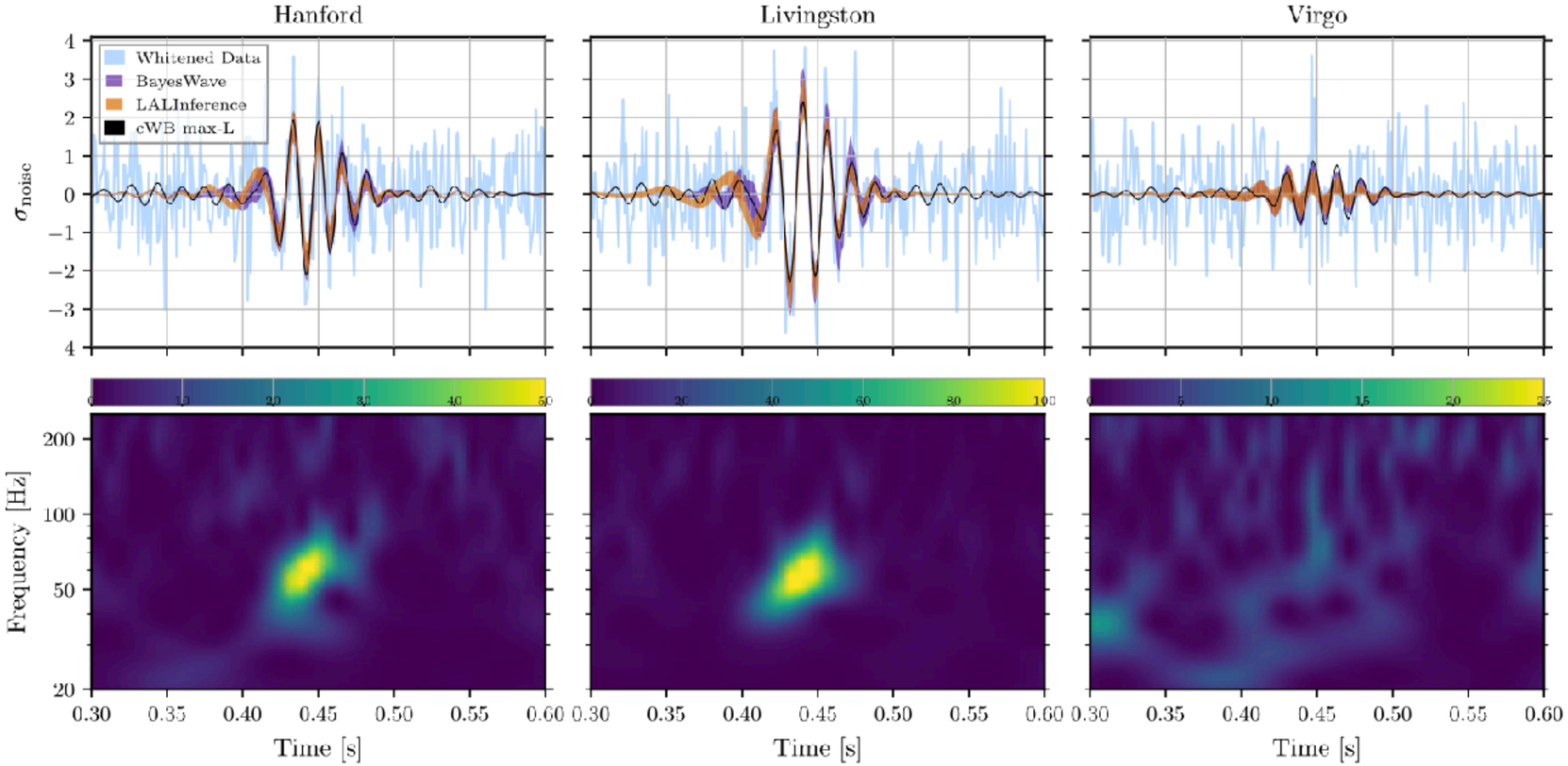
Abbott et al. (2020)



GW190521: Pair instability mass gap

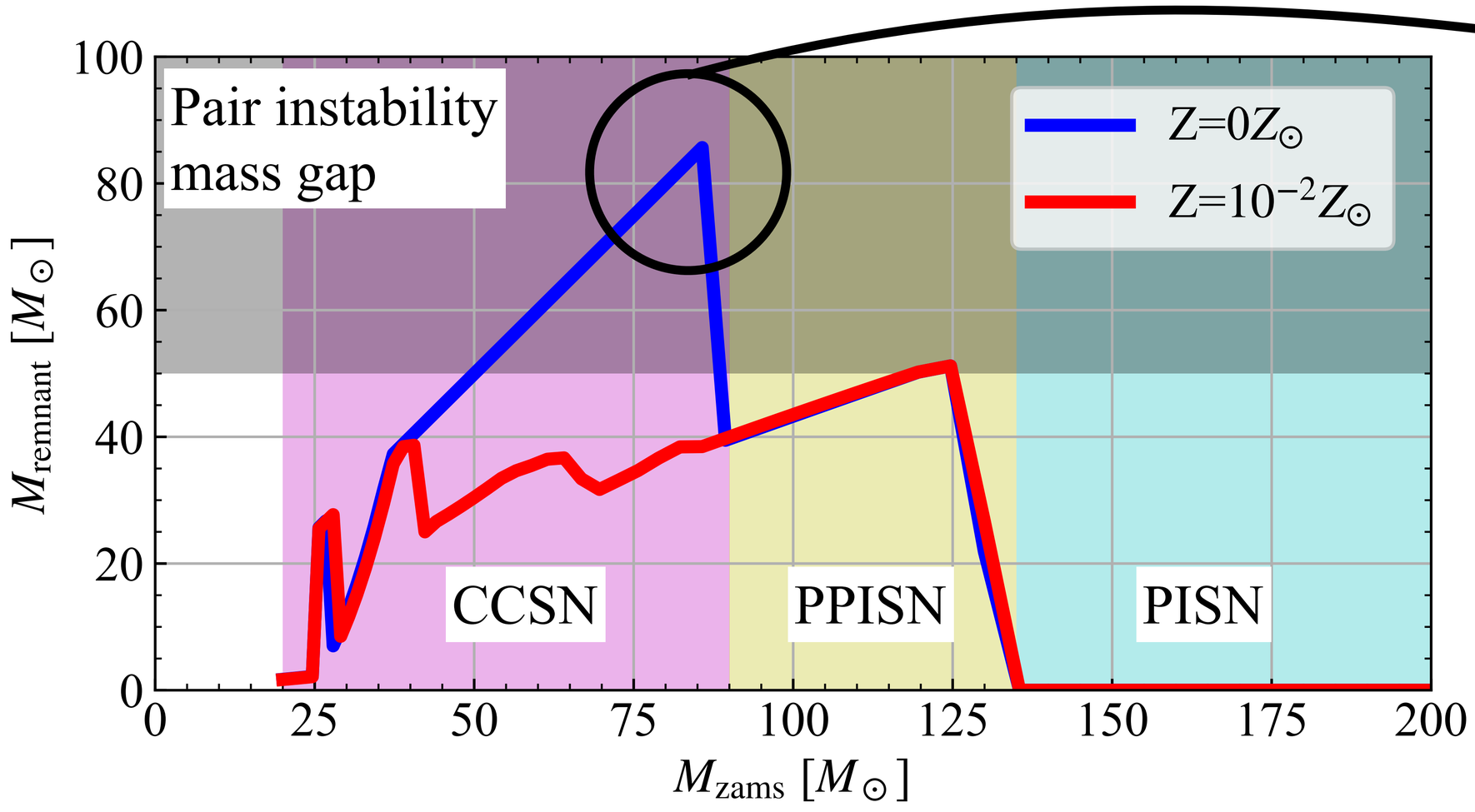
- Dense star cluster (Rodriguez et al. 2019; Di Carlo et al. 2020; Tagawa et al. 2021)
- Actually, a “straddling” event (Fishbach, Holz 2020; Nitz, Capano 2021)
- Uncertainty in $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ (Farmer et al. 2020; Costa et al. 2021; see also Takahashi 2018)
- Pop III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

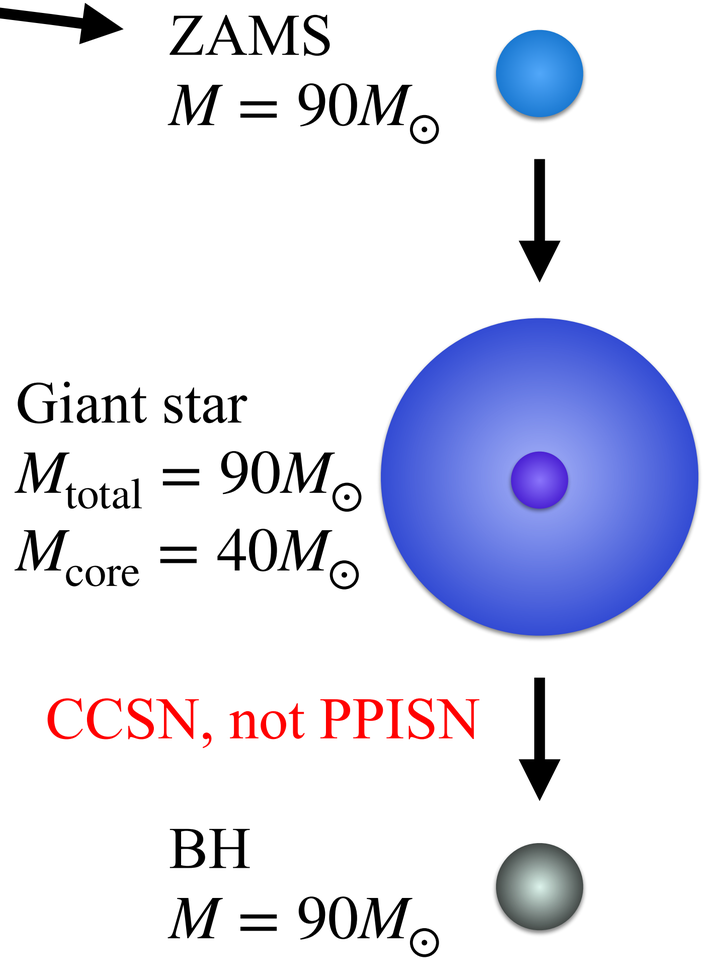
Difficult to form from a single star → $m_1 = 85^{+21}_{-14}M_\odot$, $m_2 = 66^{+17}_{-18}M_\odot$



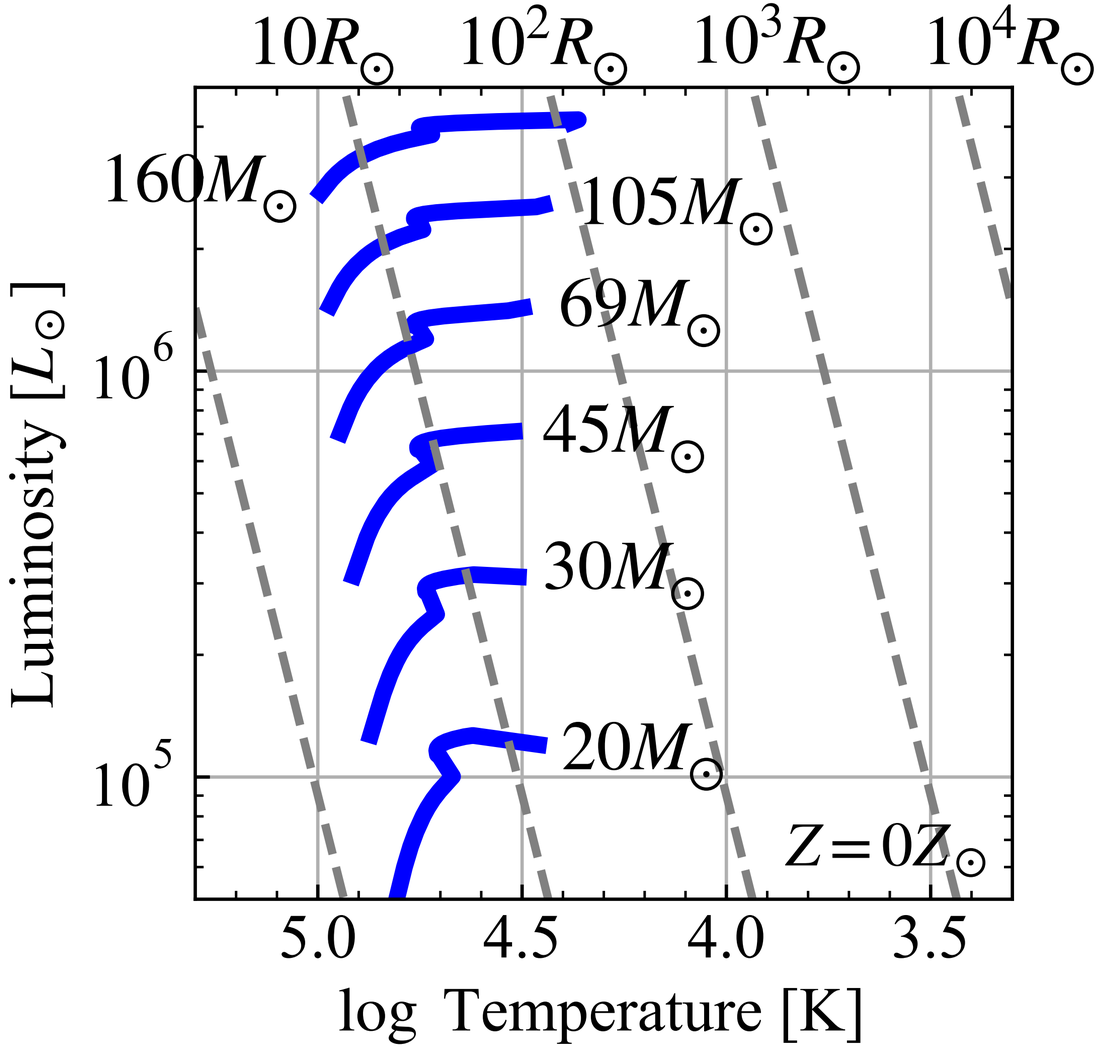
Abbott et al. (2020, PRL, 125, 101102)

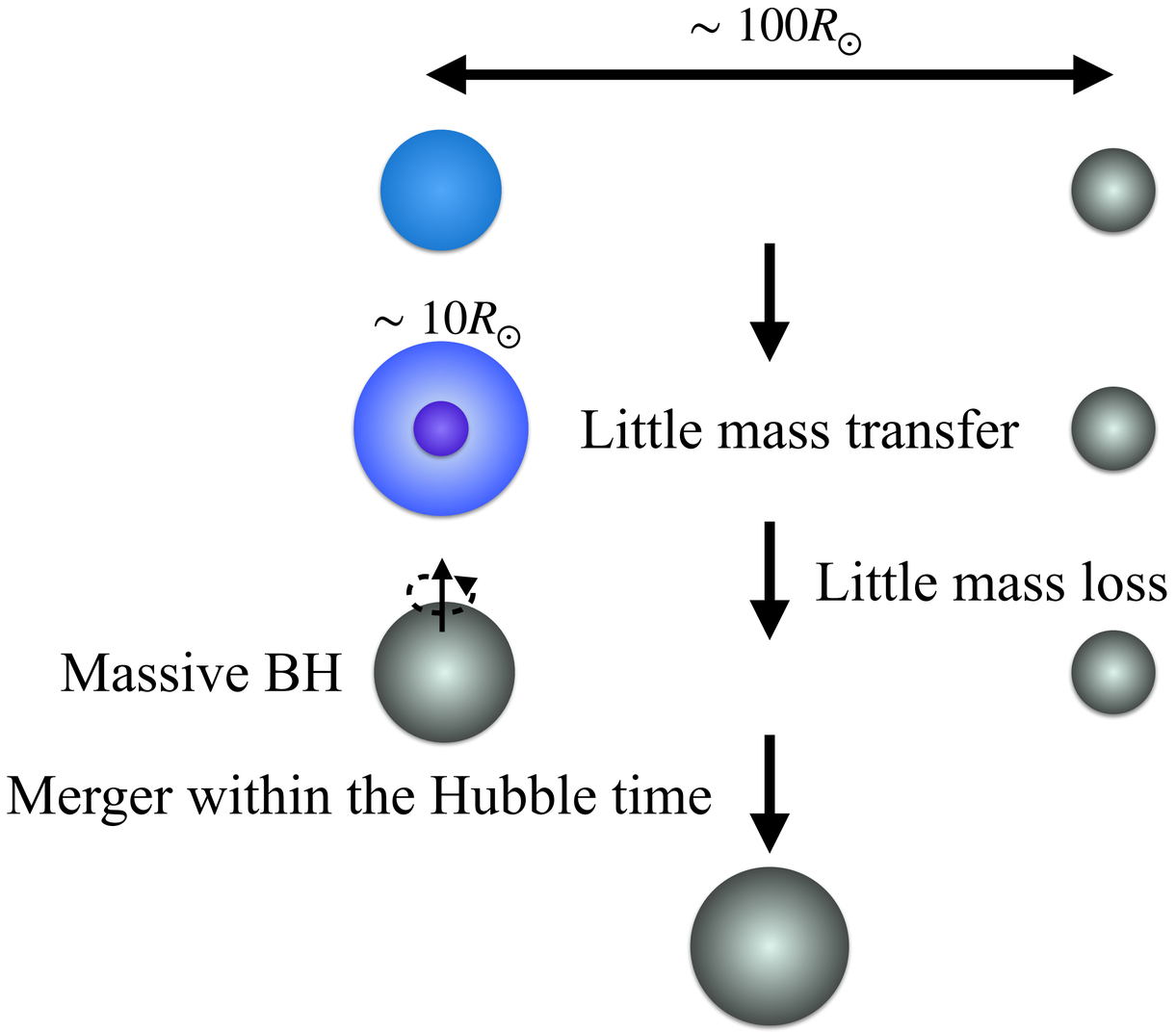
Population III remnant mass





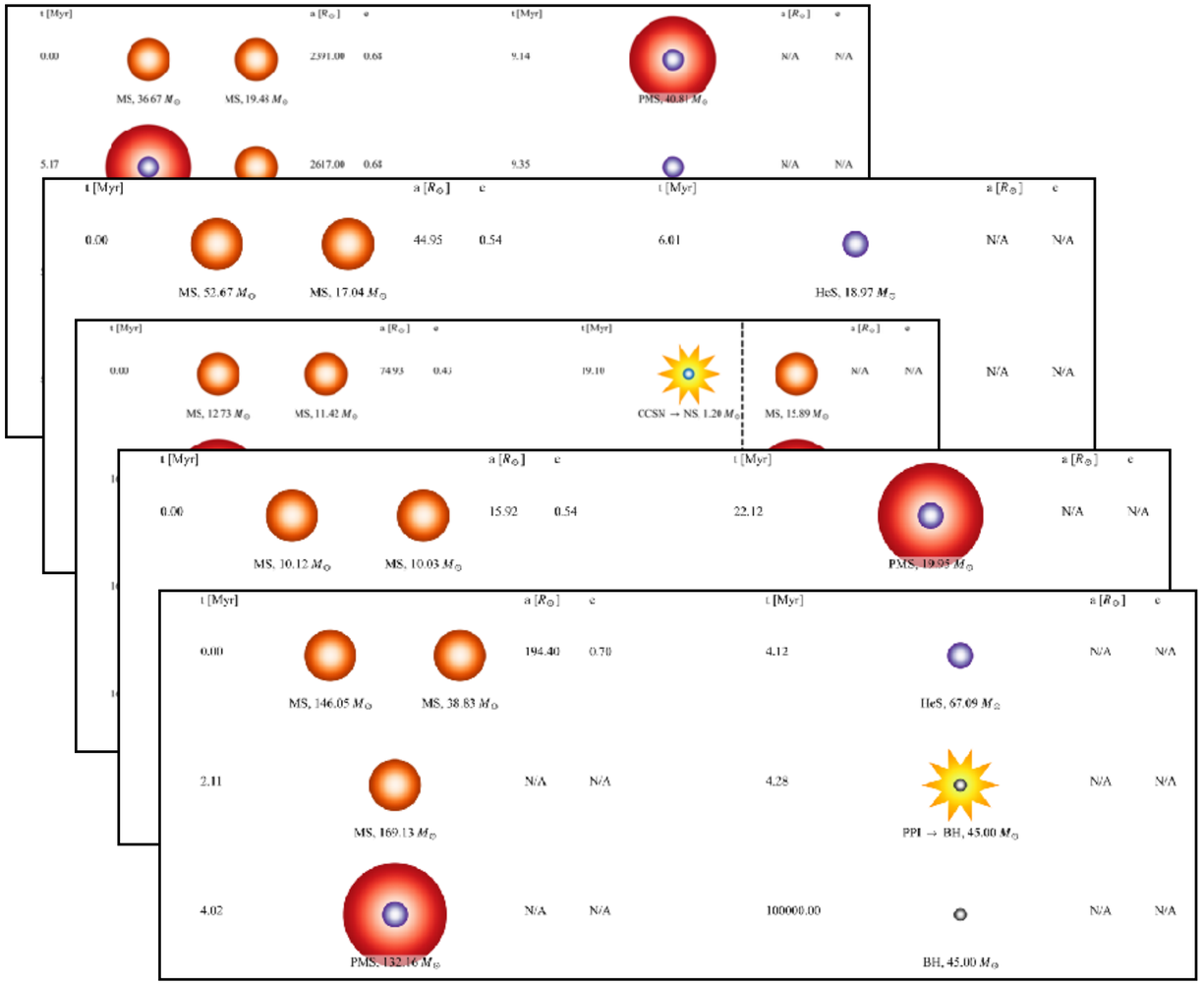
Population III stellar radius





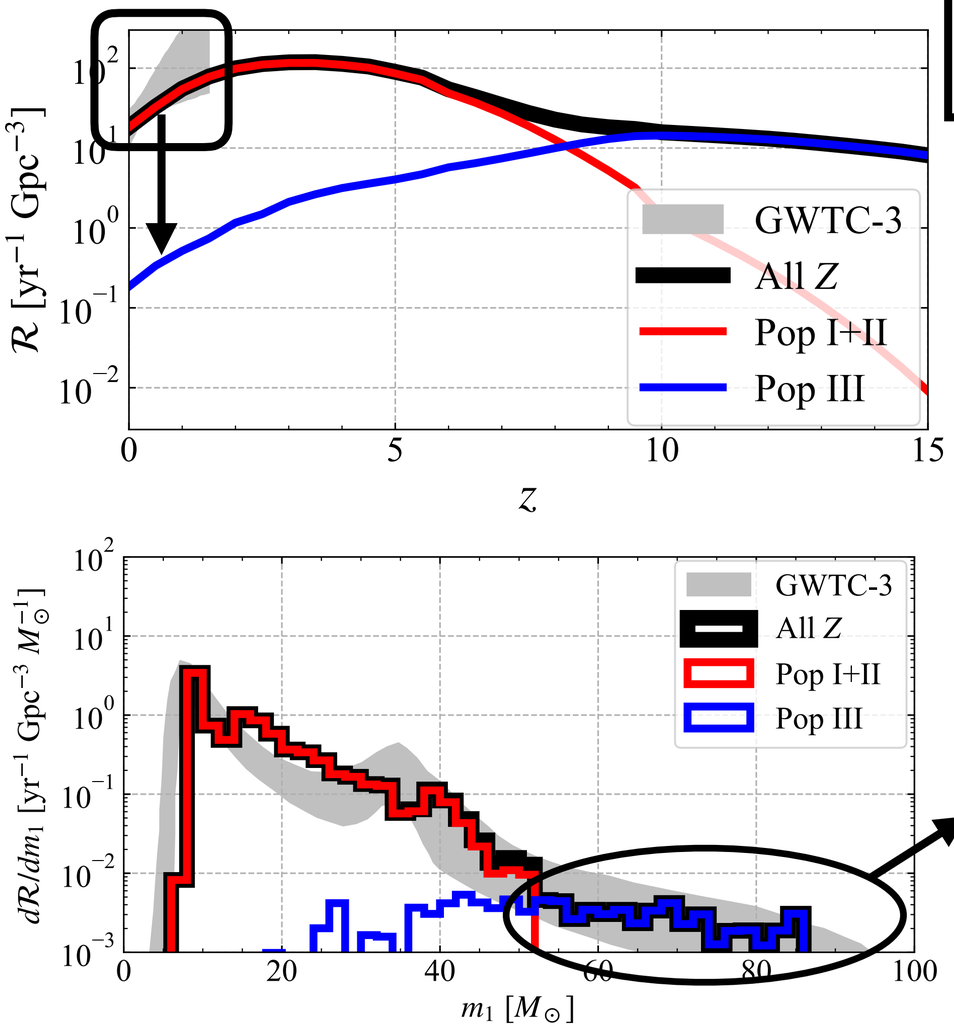
Binary population synthesis

- BSEEMP: https://github.com/atrtnkw/bseemp
- Metallicity: $0 - 1Z_{\odot}$ (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)

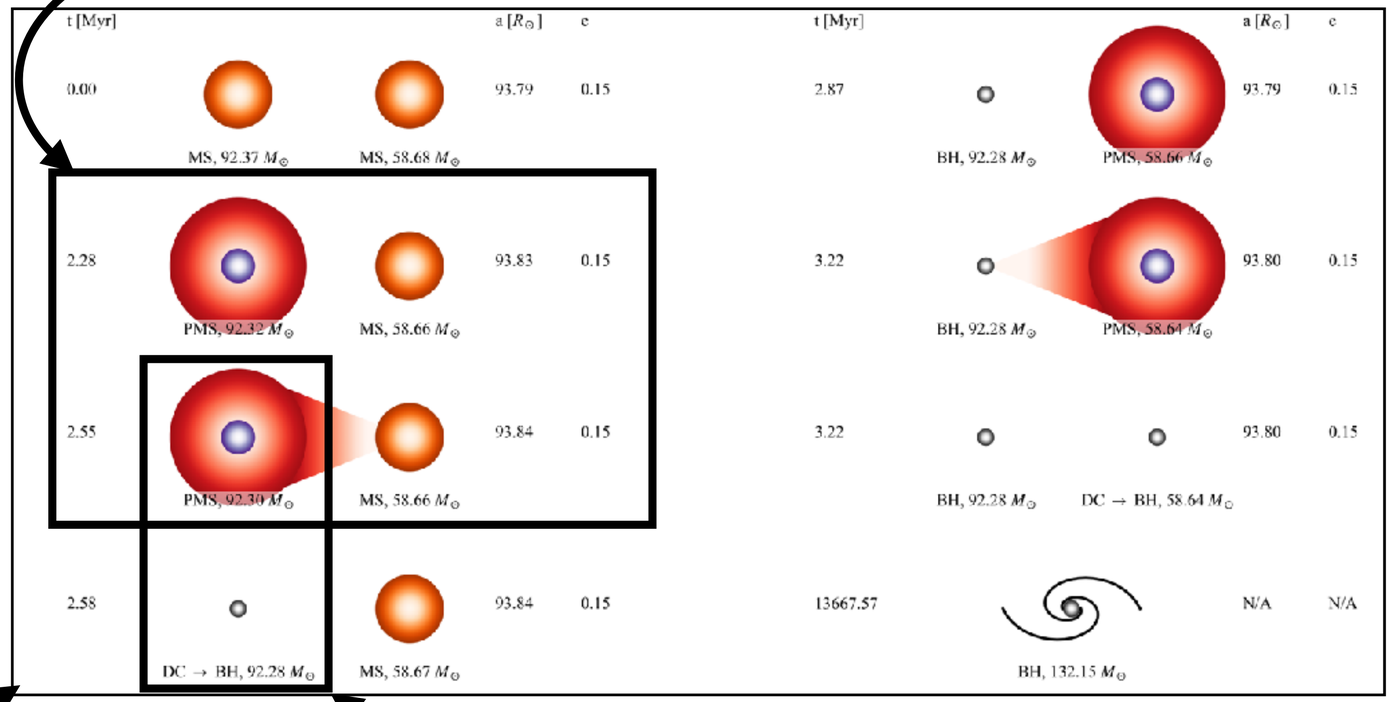


Visualization tool of BSEEMP (to be published…)

Formation of GW190512-like events



Little wind mass loss
Little mass transfer mass loss



No pair instability because of small He core

Tanikawa et al. (2021, MNRAS, 505, 2170; 2022, ApJ, 926, 83)

Contents

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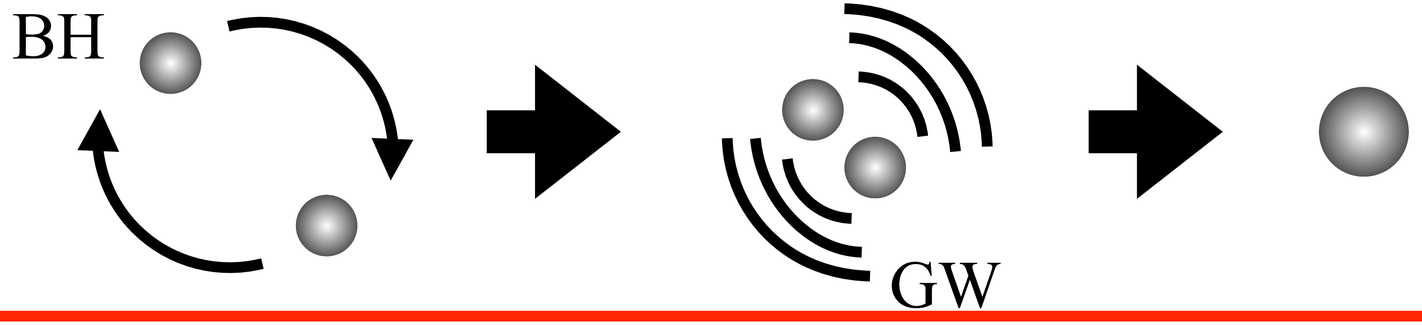
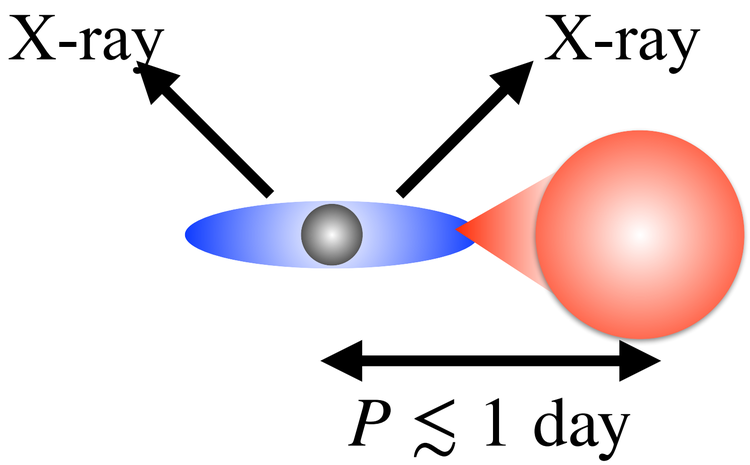
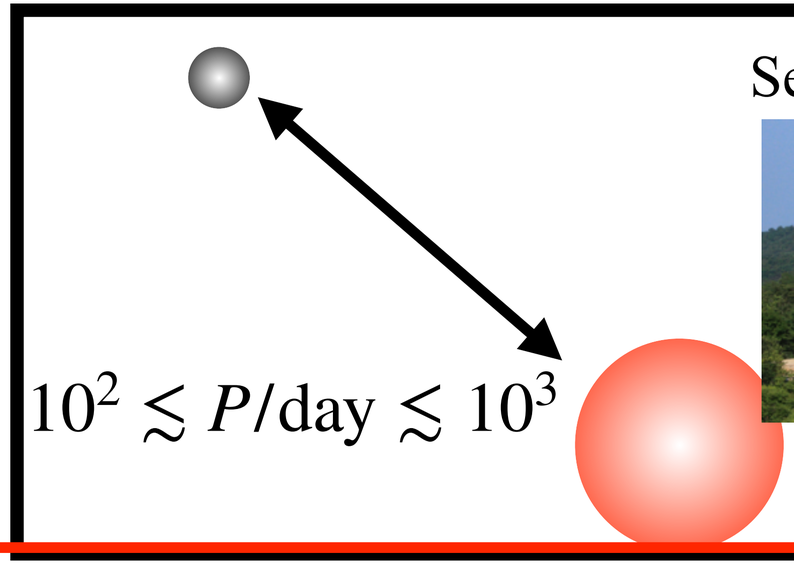


- Search for black holes in binary stars in the Milky Way

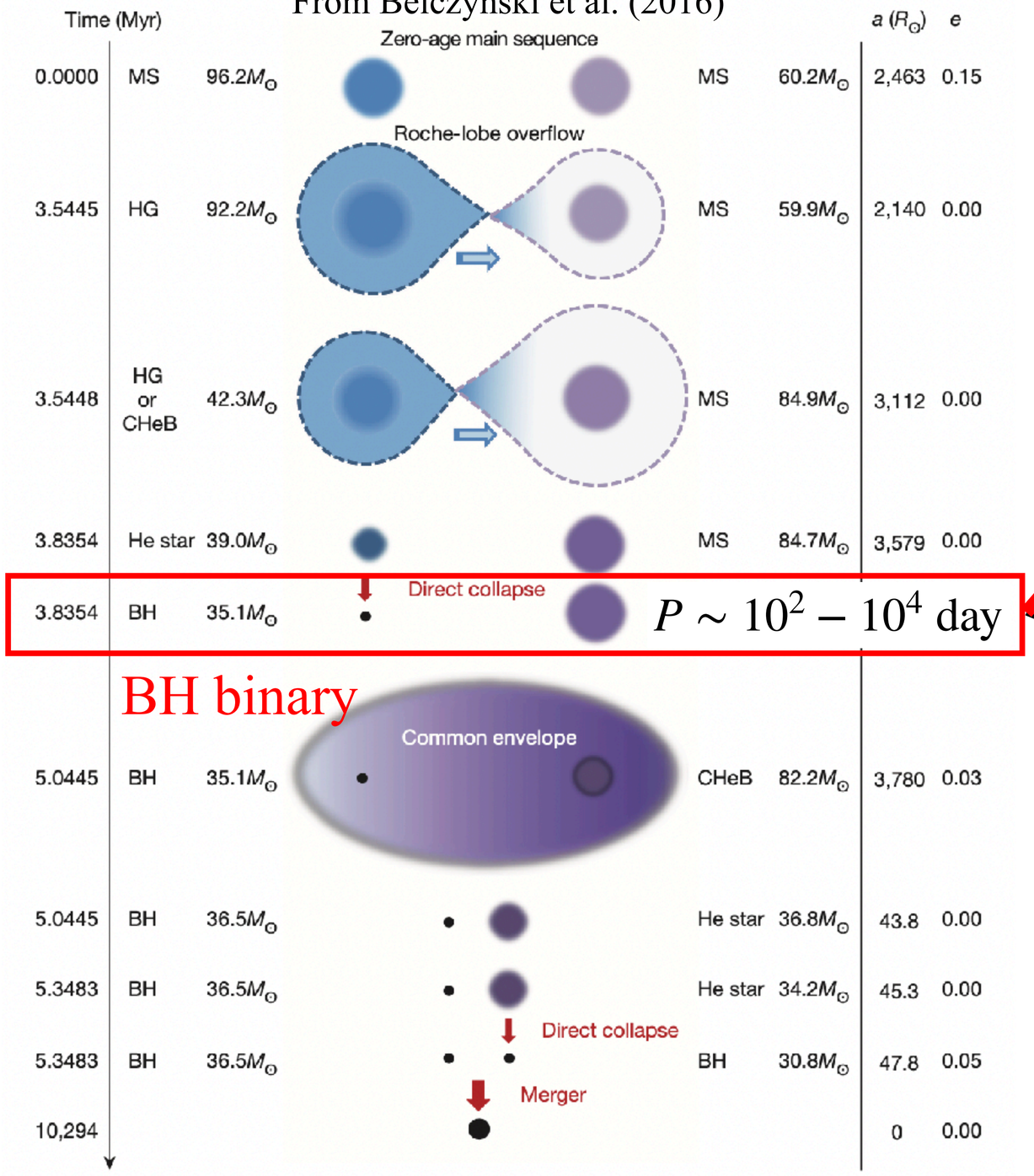




Seimei GAOES-RV

NAYUTA MALLS

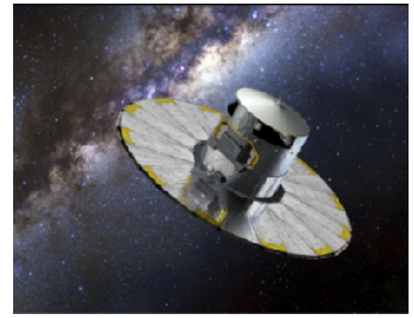
From Belczynski et al. (2016)



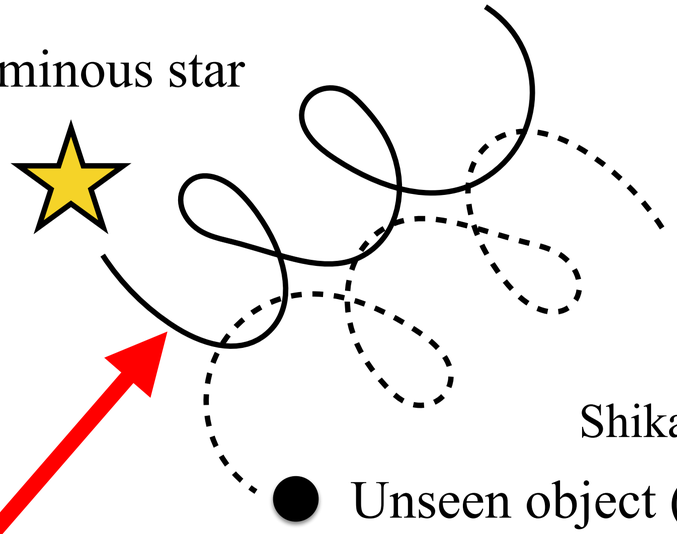
$P \sim 10^2 - 10^4$ day

Astrometric binary ($P \sim 10^2 - 10^3$ day)

Gaia satellite

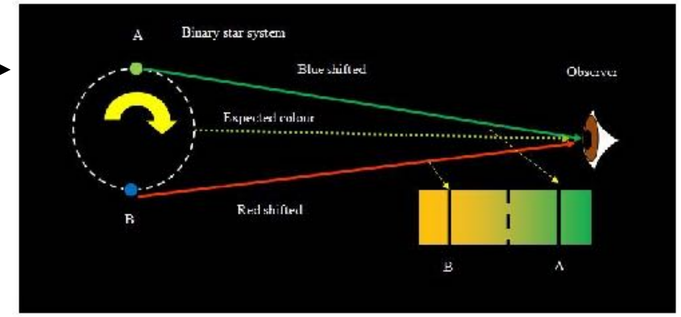


Luminous star

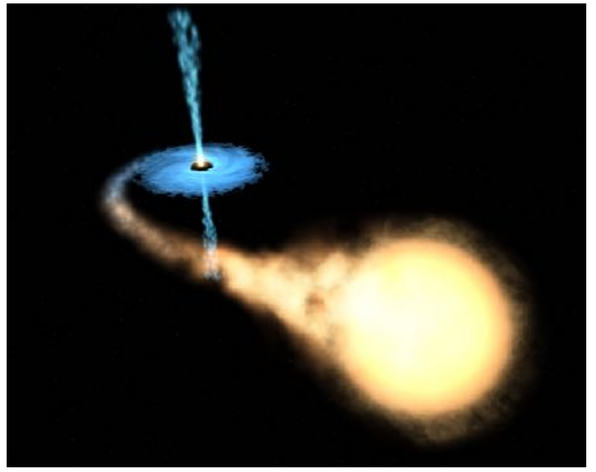


Shikauchi et al. (2020; 2022)

Unseen object (e.g. BH)

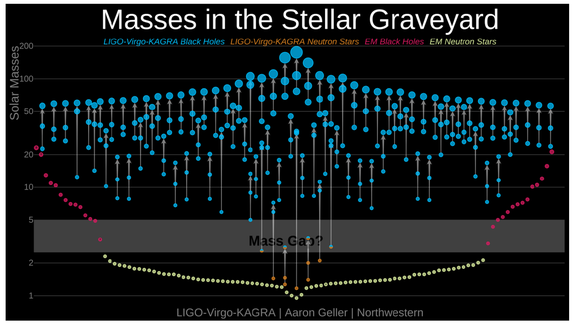


Spectroscopic binary
($P \sim 10 - 10^2$ day)

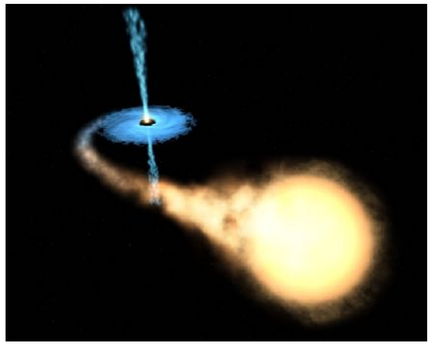


X-ray binary ($P \lesssim 1$ day)

Gravitational wave



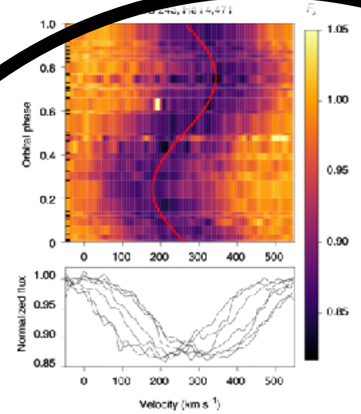
X-ray



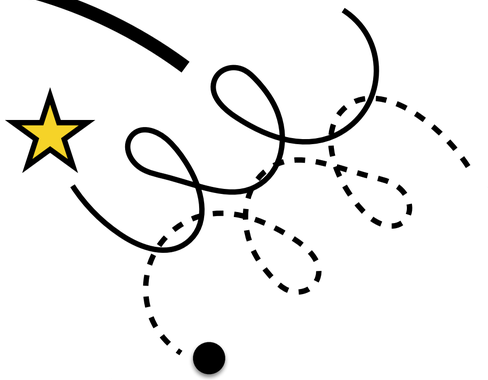
Massive companion ($\gtrsim 8M_\odot$)

Low-mass companion ($\lesssim 8M_\odot$)

No X-ray emission $\Longrightarrow$ Inert

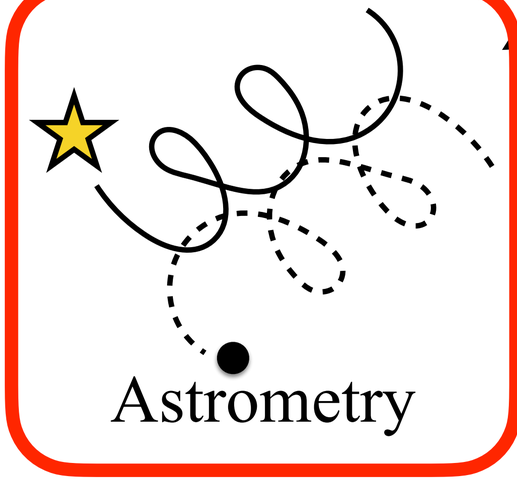


Spectroscopy



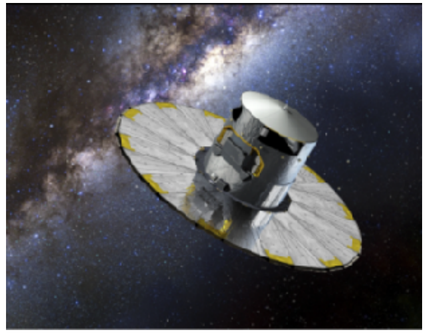
Astrometry

Discovered



Astrometry

Gaia mission



10^{-1} 1 10 10^2 10^3 10^4

Orbital period [day]

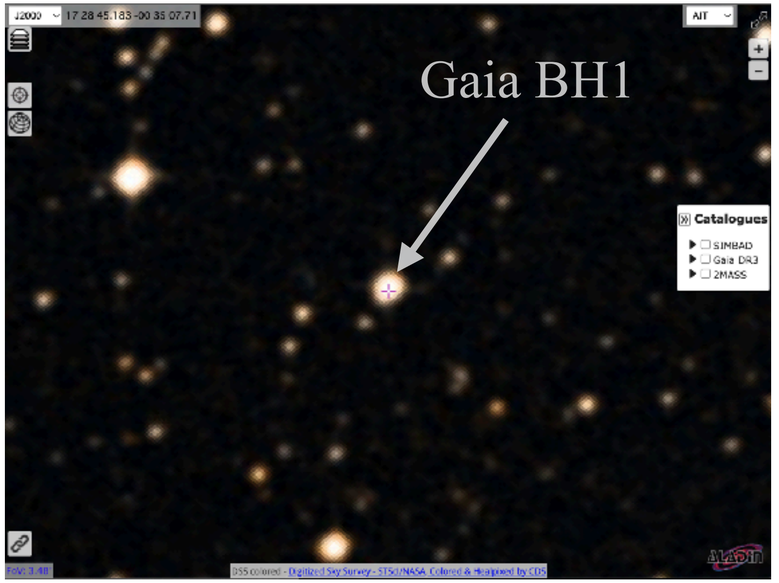
Gaia BH1

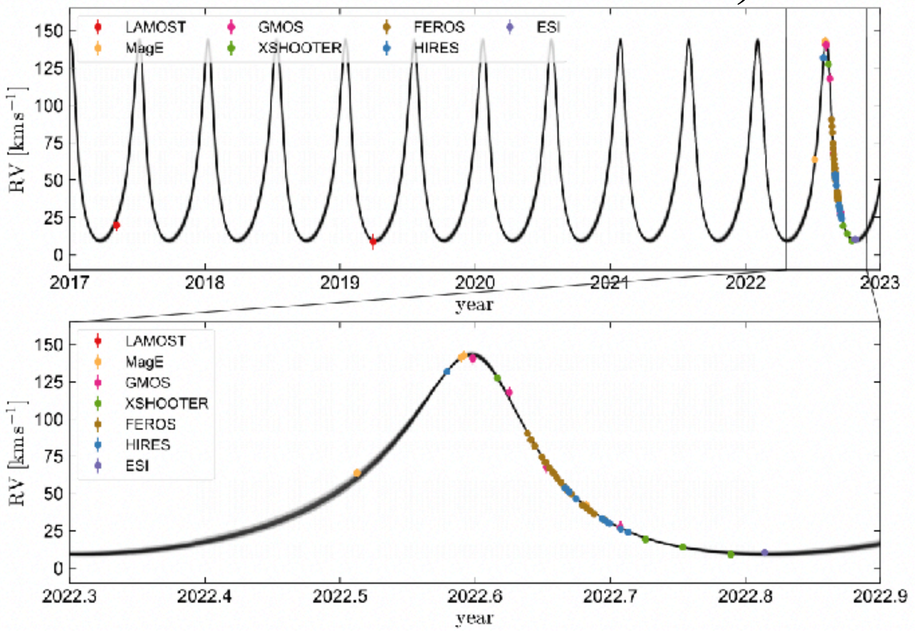
- $M_{\rm BH} = 9.62 M_\odot$
- $M_{\rm comp} = 0.93 M_\odot$
- $P = 185.59$ d
- $a = 1.40$ au
- $e = 0.451$
- [Fe/H] $= -0.2$

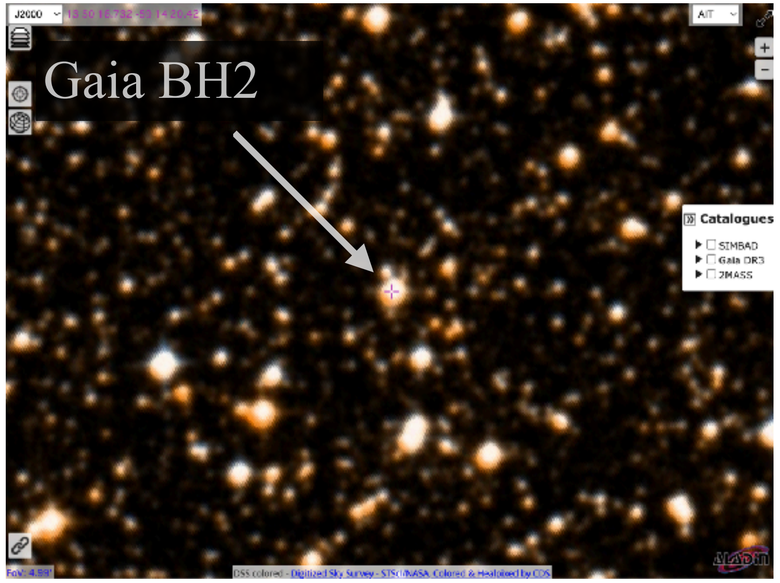
Gaia BH2

- $M_{\rm BH} = 8.94 M_\odot$
- $M_{\rm comp} = 1.07 M_\odot$
- $P = 1276.7$ d
- $a = 4.96$ au
- $e = 0.5176$
- [Fe/H] $= -0.22$

El-Badry et al. (2023; see also Chakrabarti et al. 2023)

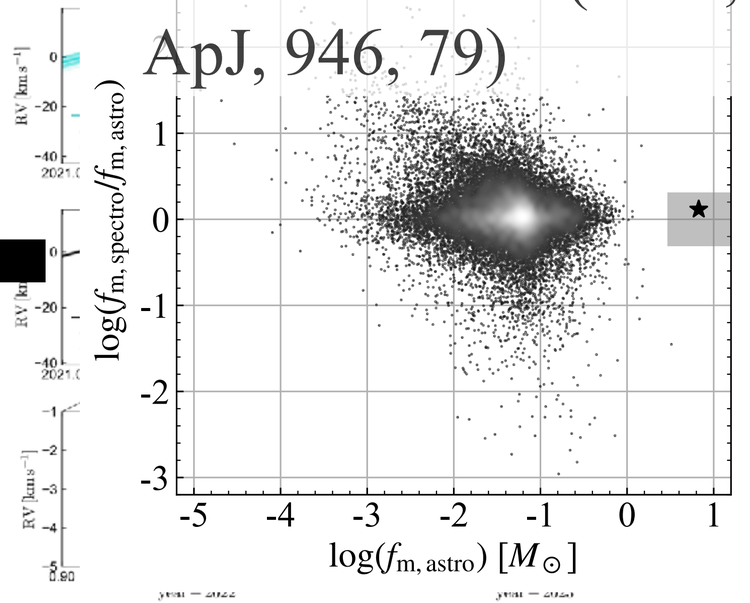


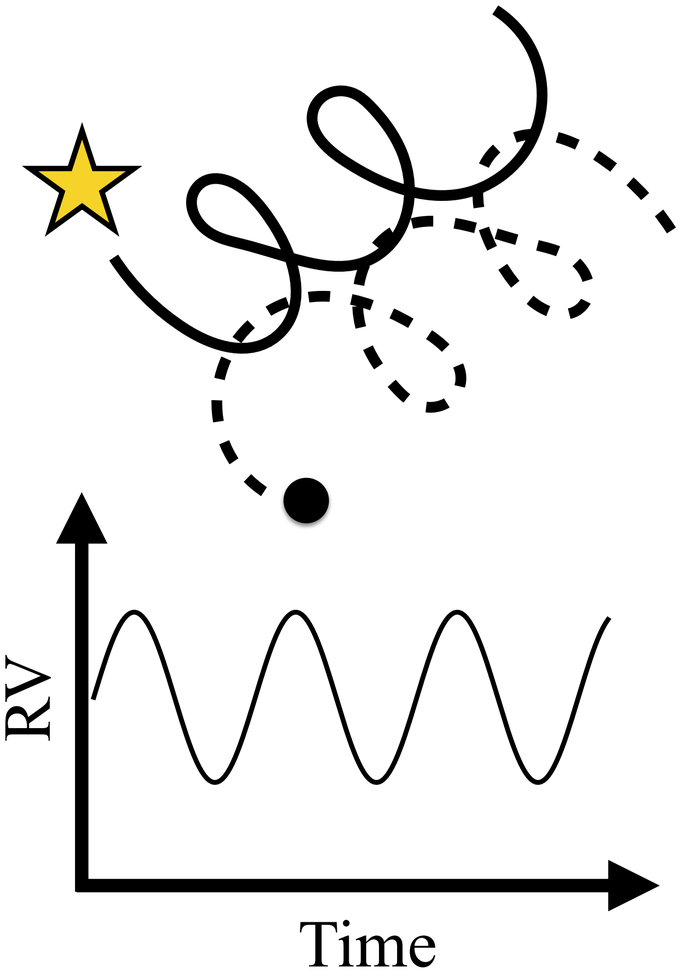




E

Tanikawa et al. (2023, ApJ, 946, 79)





$$\frac{m_2^3}{(m_1+m_2)^2} = 1 \left(\frac{\hat{a}}{\mathrm{mas}}\right)^3 \left(\frac{\varpi}{\mathrm{mas}}\right)^{-3} \left(\frac{P}{\mathrm{yr}}\right)^{-2} [M_\odot]$$

Astrometry

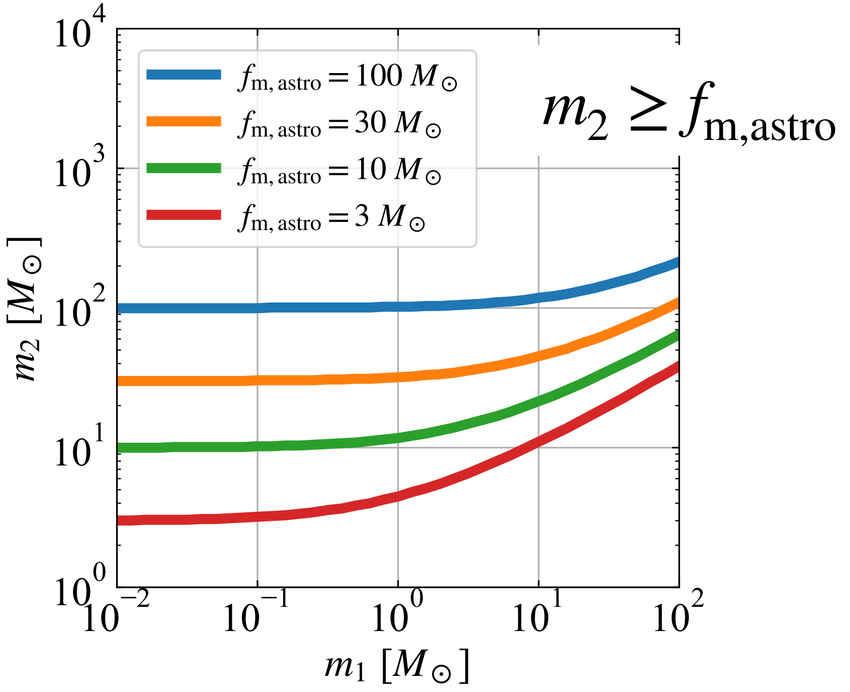
Orbit size — Parallax — Period

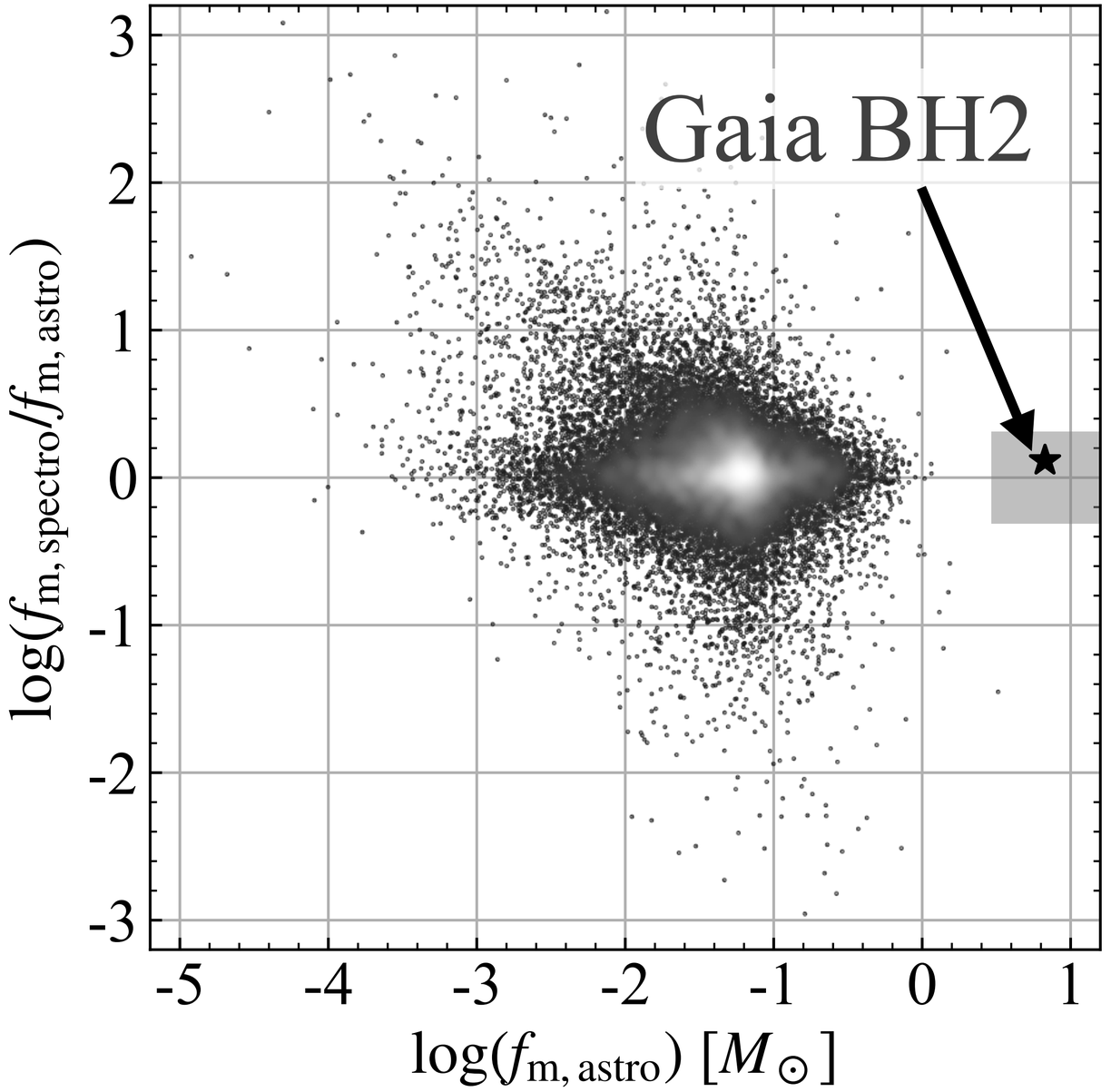
$$\frac{m_2^3}{(m_1+m_2)^2} = 1 \left(\frac{K_1}{30\mathrm{km\ s^{-1}}}\right)^3 \left(\frac{P}{\mathrm{yr}}\right) (1-e^2)^{3/2} \sin^{-3} i\ [M_\odot]$$

RV Semi-amplitude — Period — Eccentricity — Inclination

Spectroscopy

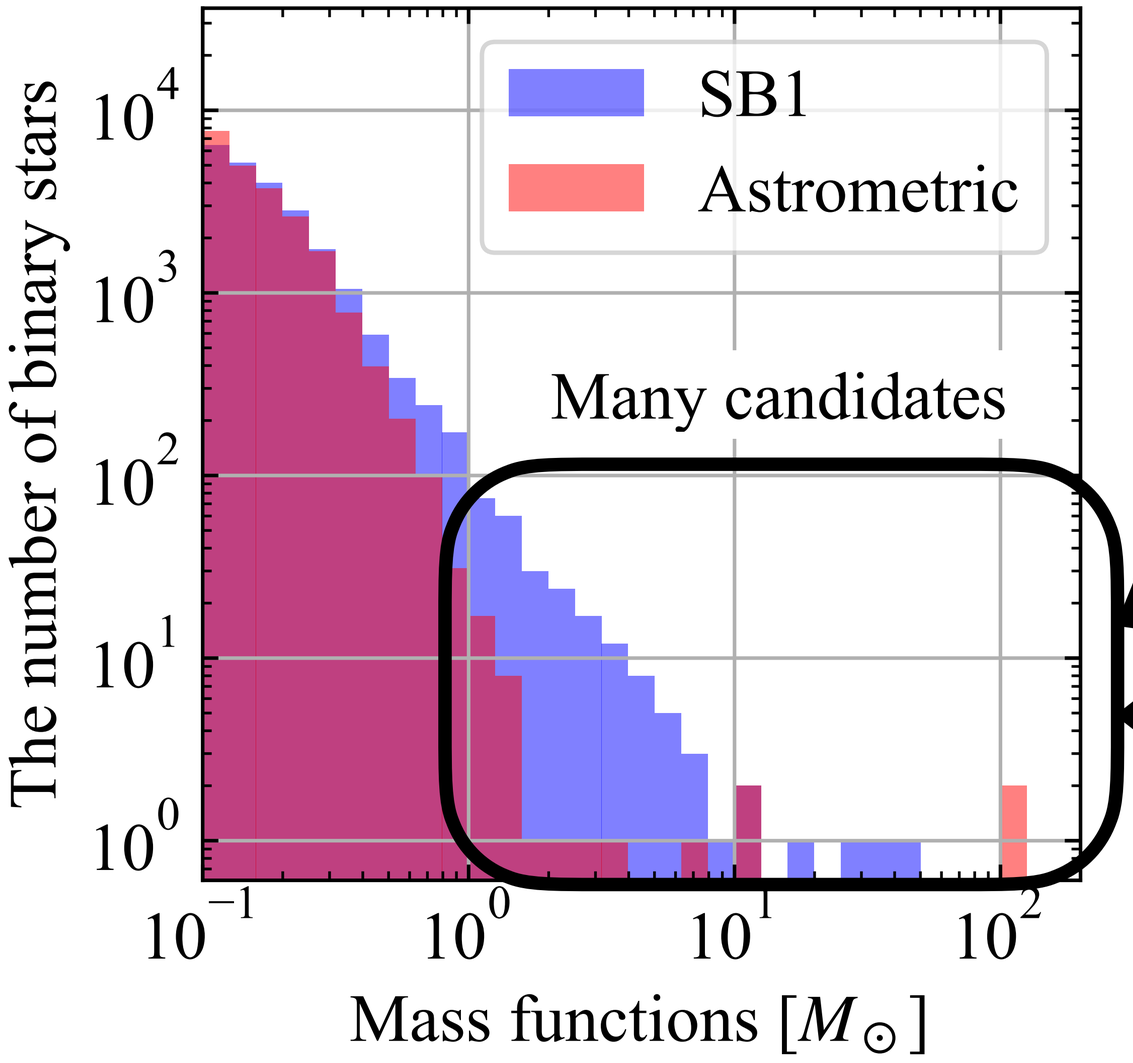
1. $f_{\mathrm{m,astro}} \sim f_{\mathrm{m,spectro}}$
2. $f_{\mathrm{m,astro}} \geq 3M_\odot$





Tanikawa et al. (2023, ApJ, 946, 79)

Another Gaia BHs or “Gaia NSs”



Seimei GAOES-RV

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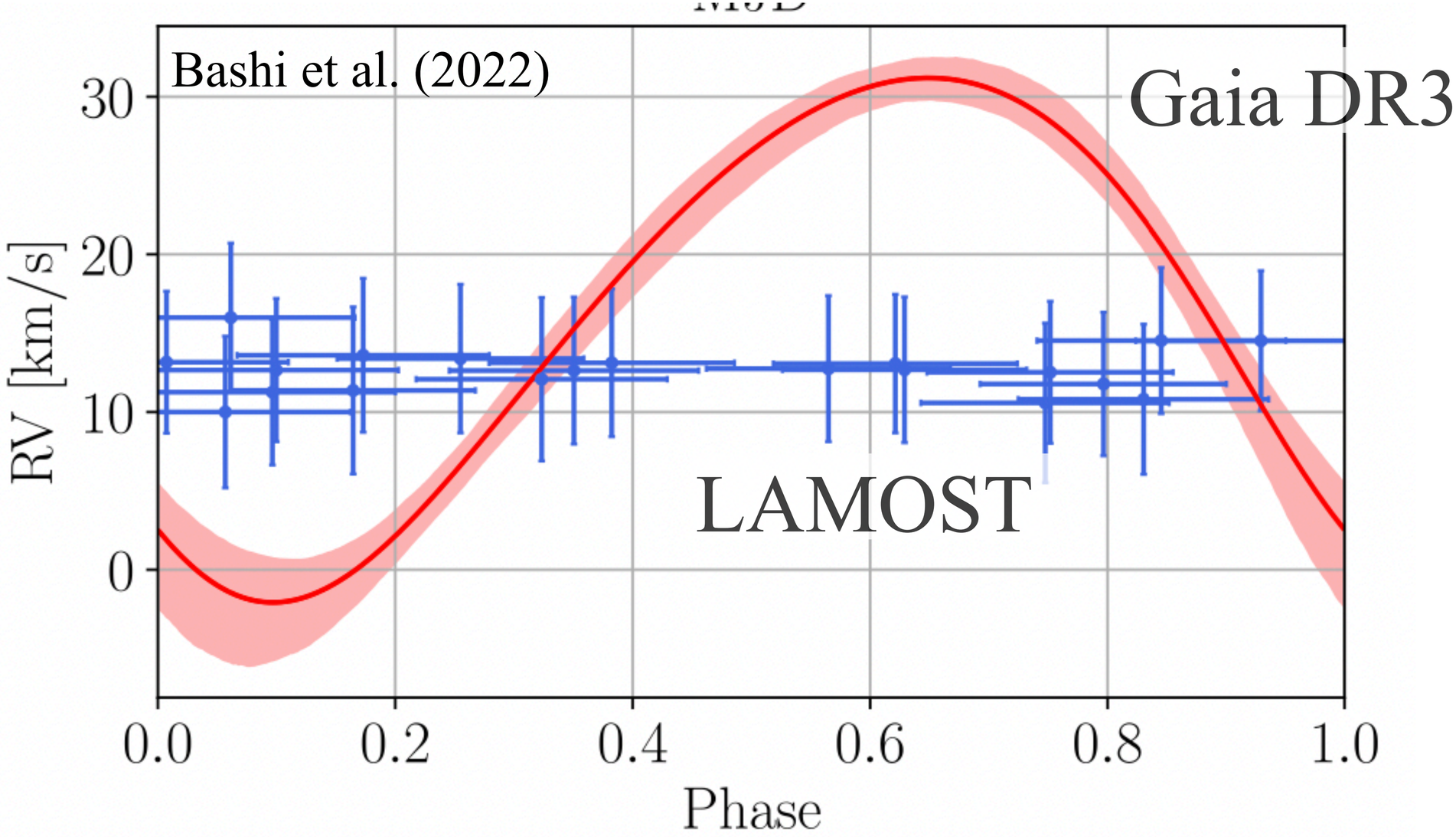
Follow-up RV observations

Needs for follow-up observations



Summary

- The origin of binary BHs is still unknown.
- The isolated binary scenario is promising if we include Pop III stars.
- In order to elucidate the origin of binary BHs, we search for inert BH binaries in the Milky Way.
- We have not yet discover any BH nor NS binaries.
- Our survey will add samples of inert BH or NS binaries as GW source progenitors.