Outline

- **Metallicity dependence of BH+MS binaries detectable with Gaia**

  My work

- **Rate of ultra-stripped supernovae and binary evolution leading to double NS**

  My student (Hijikawa)'s work.

  But, he is ill with influenza.

  I will present in place of him.

Metallicity dependence of BH+MS binaries detectable with Gaia

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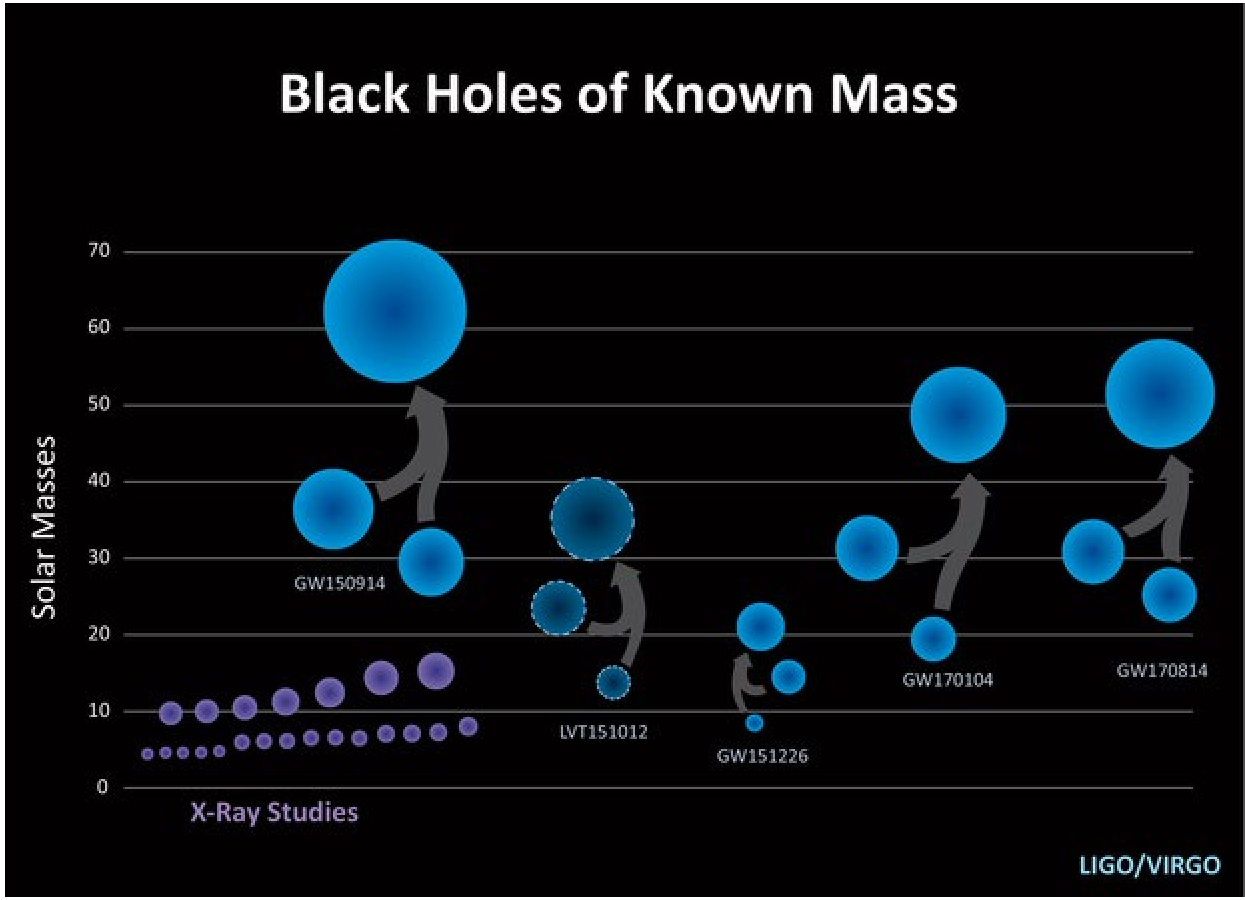
arXiv:1810.09721

Massive BHs observed by LIGO

- Extremely metal poor stars or first stars are the candidate of the origin of these massive BHs

- But, BH do not have the information of metal.



Our target : BH+MS binaries (Z=Zsun, 0.1Zsun)

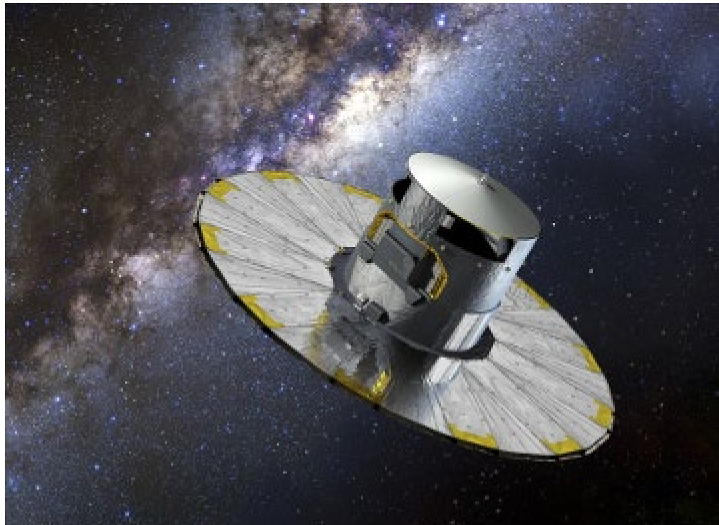
- GAIA possibly detects BH+MS binaries.
  Dmax: ~1.4 kpc (~1Msun), ~10kpc (~10Msun)
- The MS companion has the information of metallicity.
- Using the spectroscopic observation with 4-m class telescopes such as Anglo-Australian Telescope, Mayall telescope, and Kyoto university 3.8m telescope, we can check the metallicity of BH-MSs

↓

We can get the BH mass distribution for each metallicity.

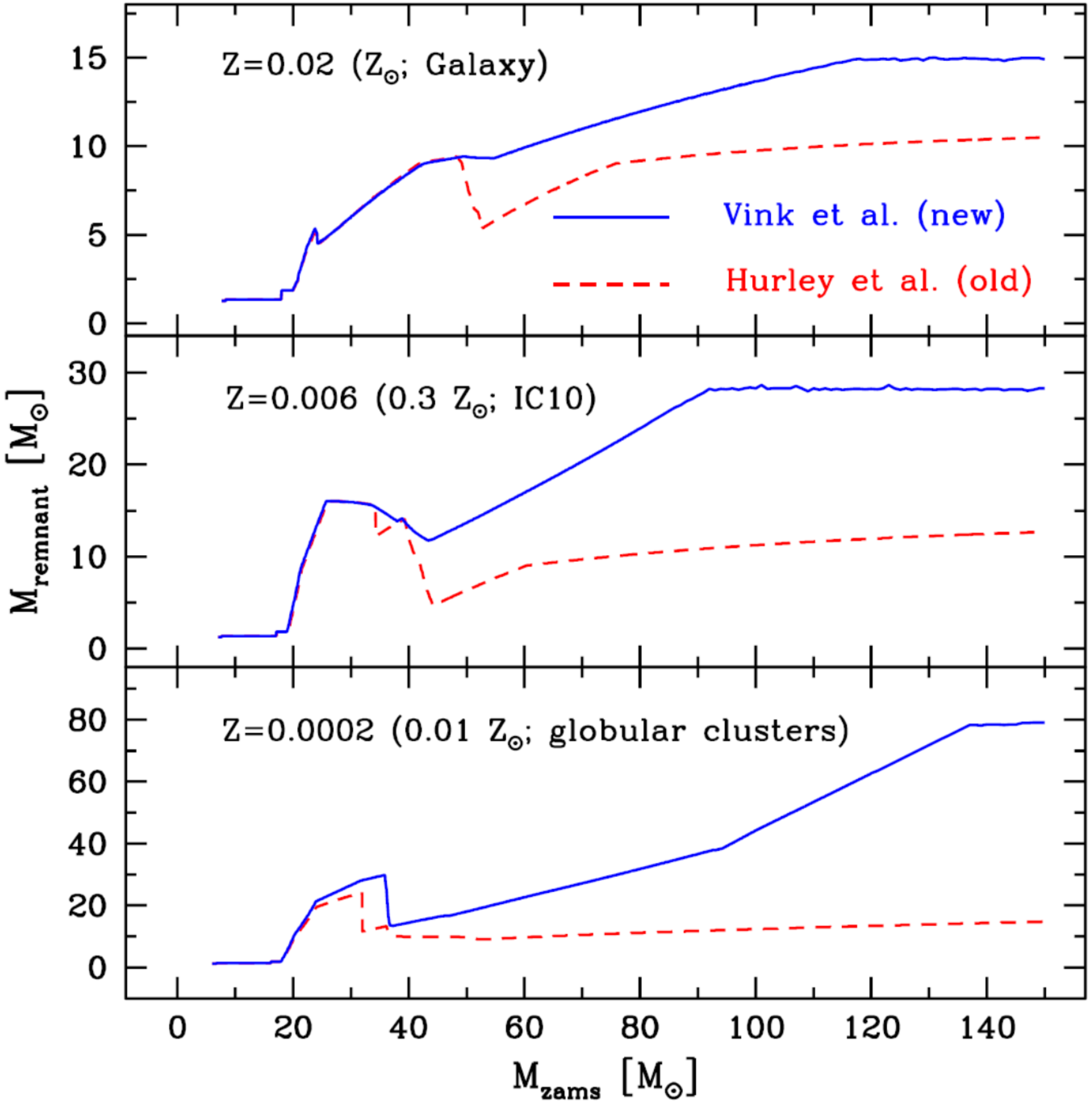
Gaia(Global Astrometric Interferometer for Astrophysics)

- Astrometry space observatory
- observation started at 25th/July/2014
- Mission lifetime: 5 yrs
- Gaia is expected to transform the field of astrometry by measuring the three dimensional spatial and velocity distribution of nearly ~1 billion stars brighter than magnitude G ~ 20 (Lindegren et al. 2016).



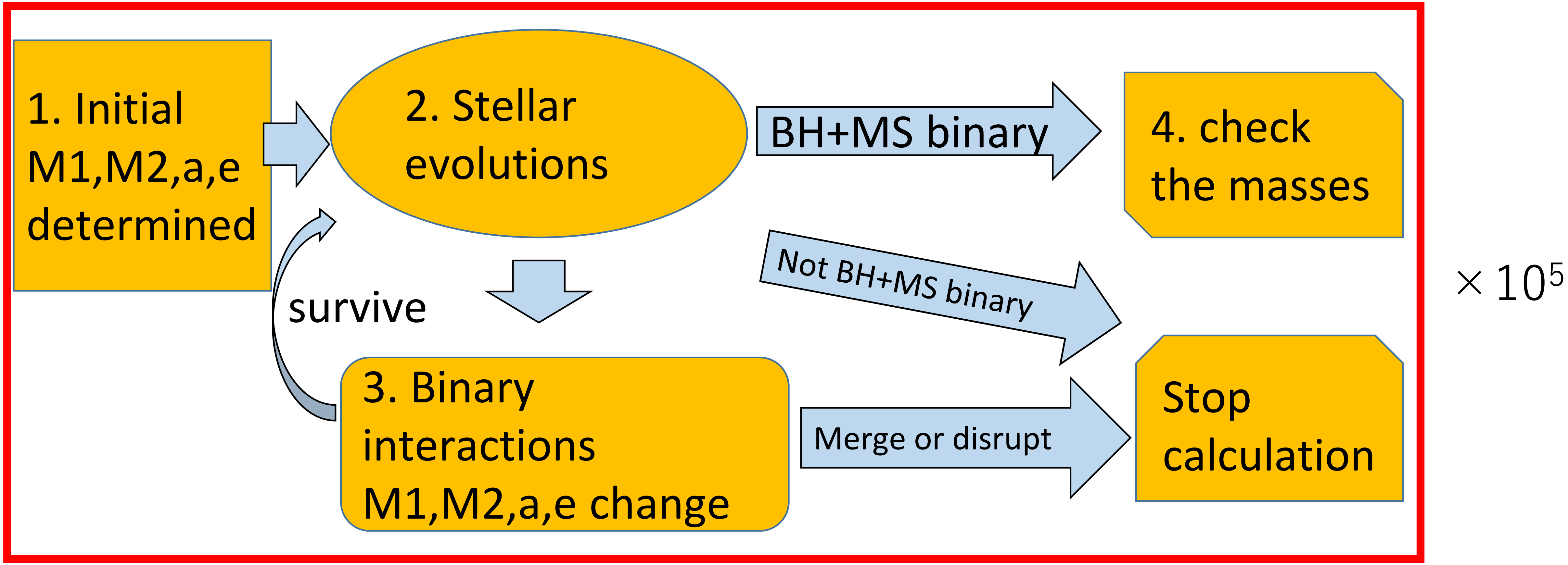
The BH mass of Pop I+II star

- The stellar wind mass loss depends on the metallicity.
- Low metallicity star possibly become a massive compact remnant.
- The BH mass distribution possibly depends on the metallicity.



Belczynski et al. 2010

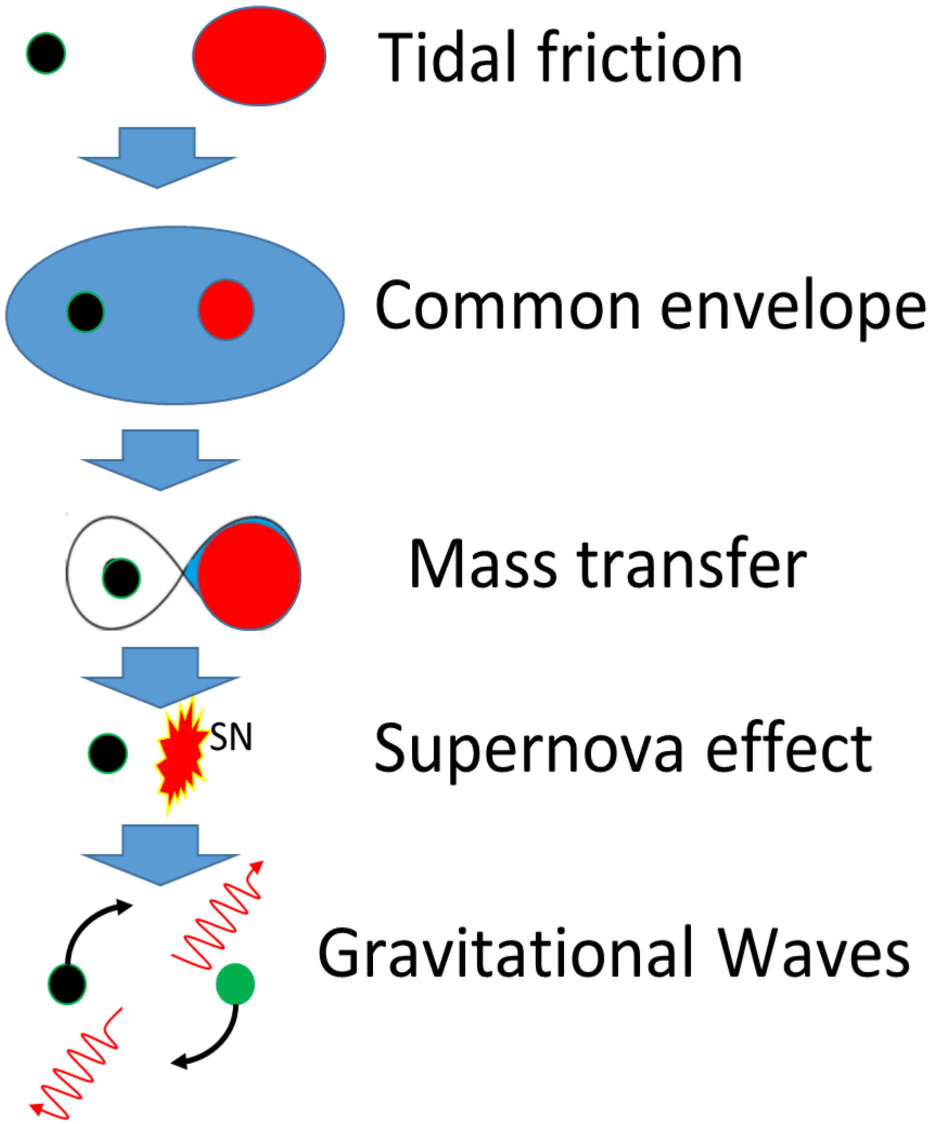
The binary population synthesis



Binary interactions

- Tidal friction
- Common envelope (CE)
- Mass transfer (MT)
- Supernova (SN) effect
- Gravitational radiation

Change
M1,M2,a, e



We need to specify some parameters to calculate these effects.

e.g. CE parameter αλ=1
Conservative MT
SN kick 0 km/s

Pop I+II binary population synthesis

- We simulate 10^5 binary evolutions for each metallicity and estimate how many binaries become a BH+MS binary whose period is 50 days<P< 5 yrs.
- We use Hurley code which is modified on the wind and some binary interaction parts.
- Initial parameter (M1,M2,a,e) distribution function P(x)

    M1 : Salpeter (5 Msun<M<100 Msun)

    q=M2/M1 : P(q)=const. (0<q<1)

    a : P(a) $\propto$ 1/a (amin<a<106Rsun)

    e : P(e) $\propto$ e (0<e<1)

- $\alpha\ \lambda$ =1
- SFR=2.5 Msun/yr
- Zsun:0.1Zsun=1:1

The number of BH-MSs in the entire galaxy $N_{\rm G}$ for each metallicity is

$$N_{\rm G} = \frac{1}{N_{\rm total}} \sum_{i=1}^{N_{\rm BHMS}} \frac{f_{\rm B}}{1+f_{\rm B}} \cdot \frac{SFR}{2} \cdot t_{{\rm life},i} \cdot f_{\rm IMF}, \qquad (4)$$

$$\rho_{\rm BHMS} = \rho_0 \exp\left(-\frac{z}{h_z} - \frac{r-r_0}{h_r}\right)$$

$$\rho_0^{-1} = \int_0^\infty dr \int_0^\infty \exp\left(-\frac{z}{h_z} - \frac{r-r_0}{h_r}\right).$$

where ρ_0, z, r, r_0 (= 8.5 kpc), h_z (= 250 pc), and h_r(= 3.5 kpc)

We use the spherical coordinate centered at the earth, (D, b, l), as

$$r = [r_0^2 + D^2 \cos^2 b - 2Dr_0 \cos b \cos l]^{1/2}, \tag{7}$$

$$z = D \sin b, \tag{8}$$

where D, b, and l is the distance from, respectively, the earth, the galactic latitude, and the galactic longitude. The number of BH-MSs detected by *Gaia* $N_{\rm D}$ is calculated by

$$N_{\rm D} = N_{\rm G} \times \int_0^{2\pi} dl \int_0^{\pi/2} \cos b db \int_0^{D_{\rm max}(M)} D^2 dD \rho_0, \tag{9}$$

where $D_{\rm max}(M)$ is the maximum detectable distance of the BH-MS whose main sequence mass is M.

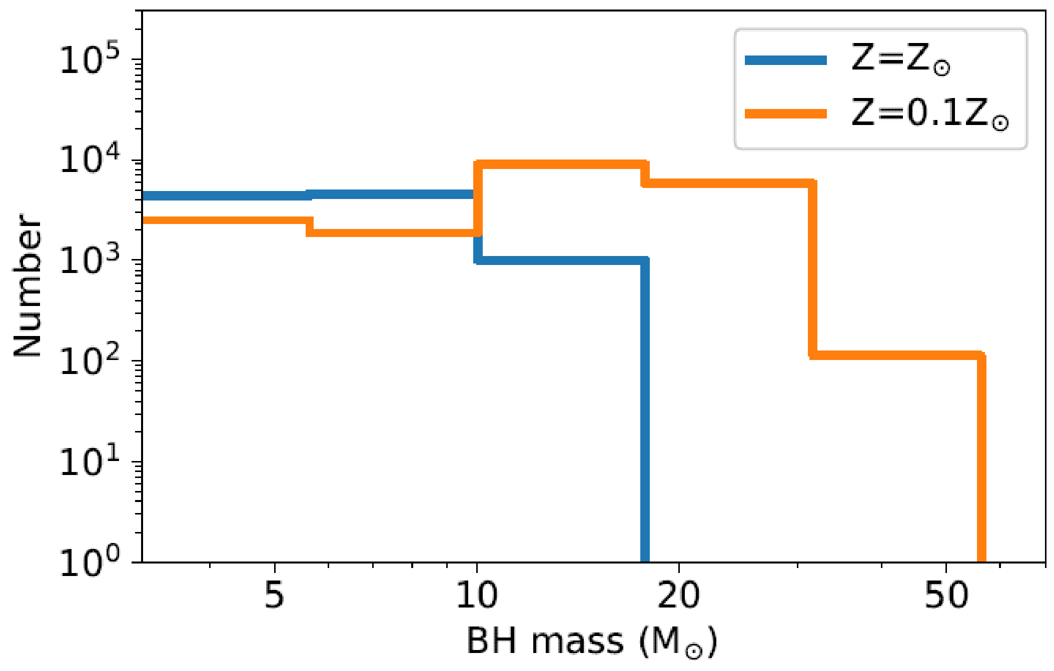
Result

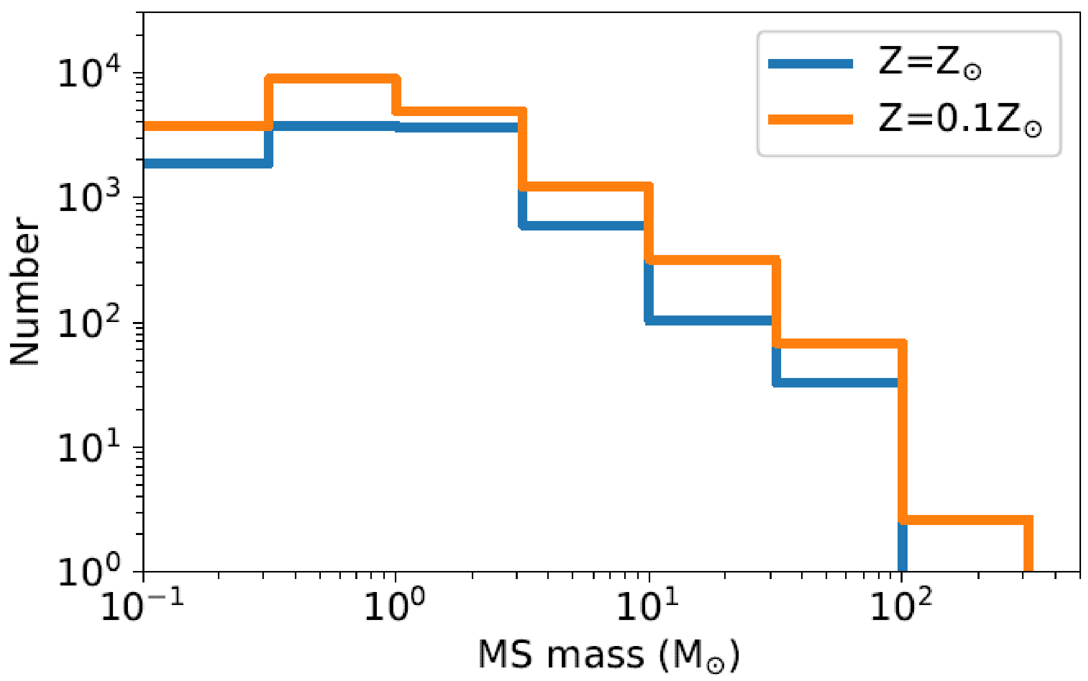
- The numbers of BH-MSs N_{BHMS} whose periods are 50 days < P < 5 yrs for 10^5 binaries, the numbers of such BH-MSs in the entire galaxy N_G, and the number of BH-MSs detected by Gaia N_D for each metallicity case.

metallicity	$Z_\odot$	$10\% Z_\odot$
$N_{\rm BHMS}$	1322	2841
$N_{\rm G}$	4985	9586
$N_{\rm D}$	234	412

BH+MS binaries in our galaxy

- We calculate BH+MS binaries whose period is 50 days<P< 5 yrs in our galaxy

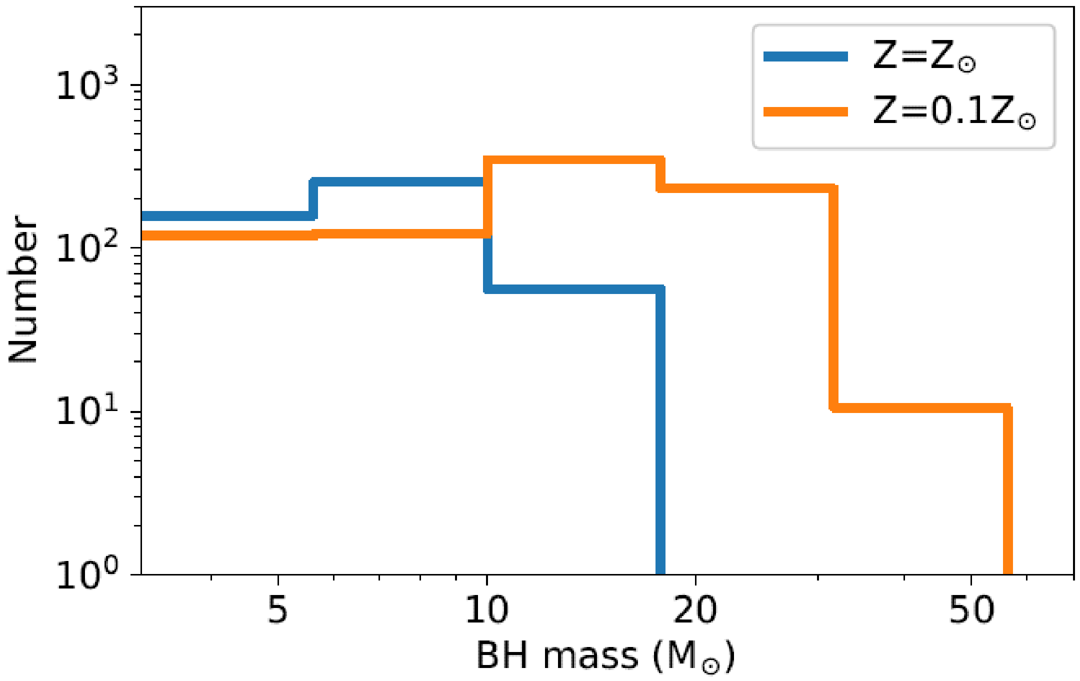


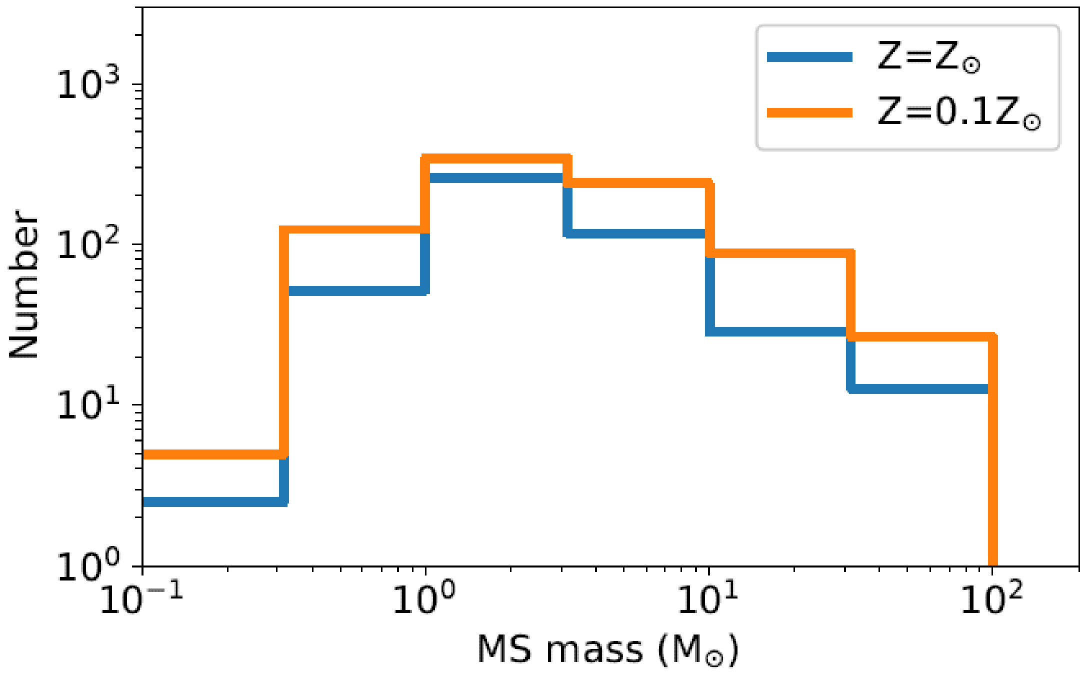


BH+MS binaries detectable with GAIA

- We consider the BH+MS which can be detected by GAIA with S/N>10.
- We use the constraint Eqs from Yamaguchi et al. 2018.

e.g. Dmax (1Msun) = 1.4 kpc





Summary

- GAIA possibly detects BH+MS binaries.
- Using the spectroscopic observation with 4-m class telescopes, we can check the metallicity of BH+MSs
- We calculate the detection number of BH+MSs
- GAIA can detect ~200, and ~400 BH+MSs for Z=Zsun, and 0.1Zsun
- **We can check the metallicity dependence of the BH mass**

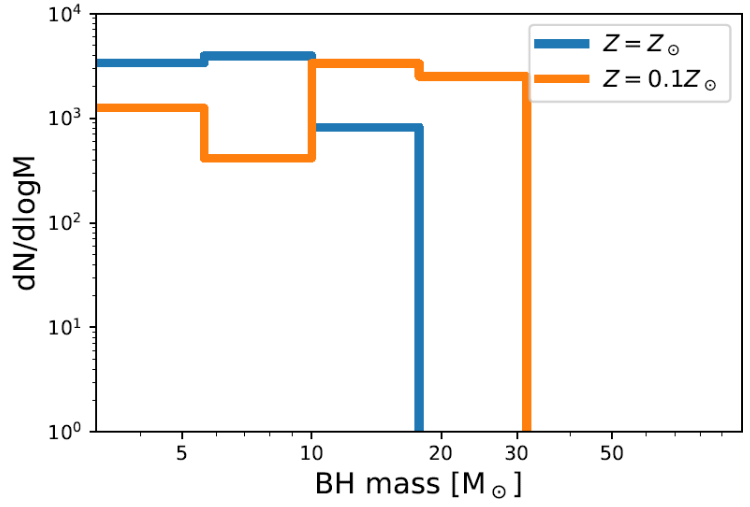


FIG. 3.— The mass distribution of black holes which are the components of BH-MSs in the entire galaxy for the ChemiEvo model.

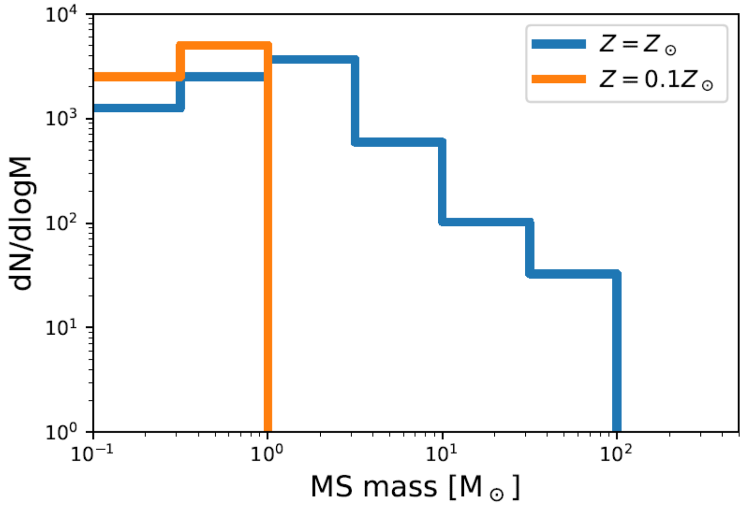


FIG. 4.— The mass distribution of main sequence stars which are the components of BH-MSs in the entire galaxy for the ChemiEvo model.

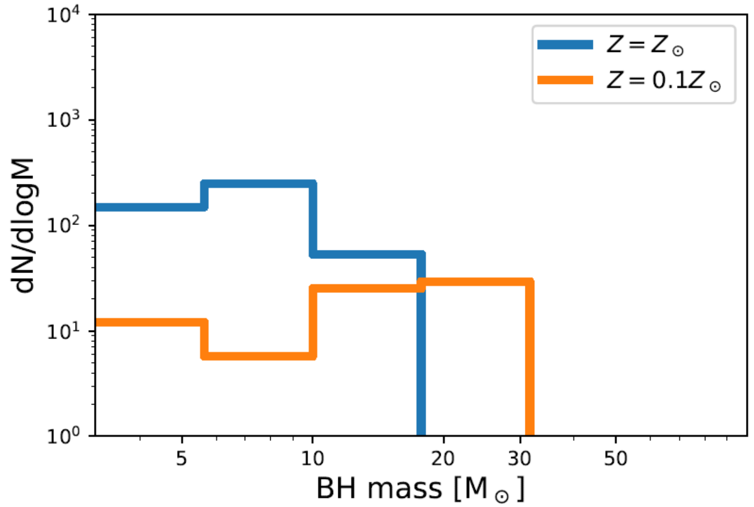


FIG. 7.— The mass distribution of black holes which are the components of BH-MSs to be detected by *Gaia*for the ChemiEvo model.

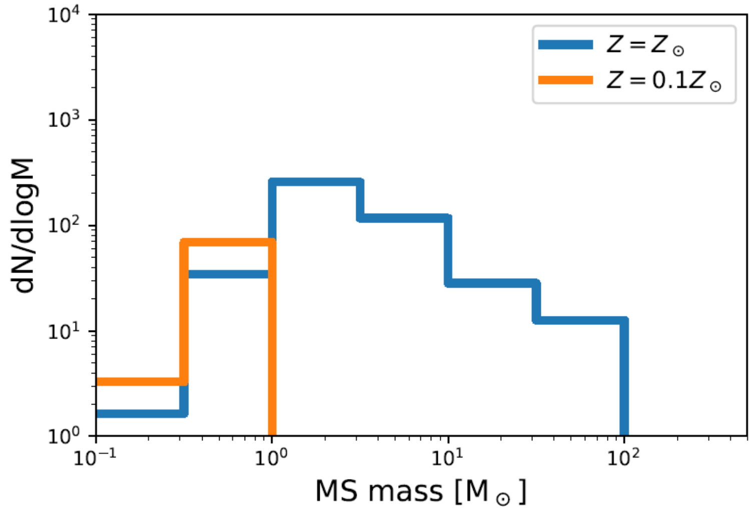


FIG. 8.— The mass distribution of main sequence stars which are the components of BH-MSs to be detected by *Gaia*for the ChemiEvo model.

- Tage-T=0-10 Gyr (Z=Zsun), 10-11Gyr (Z=0.1Zsun)