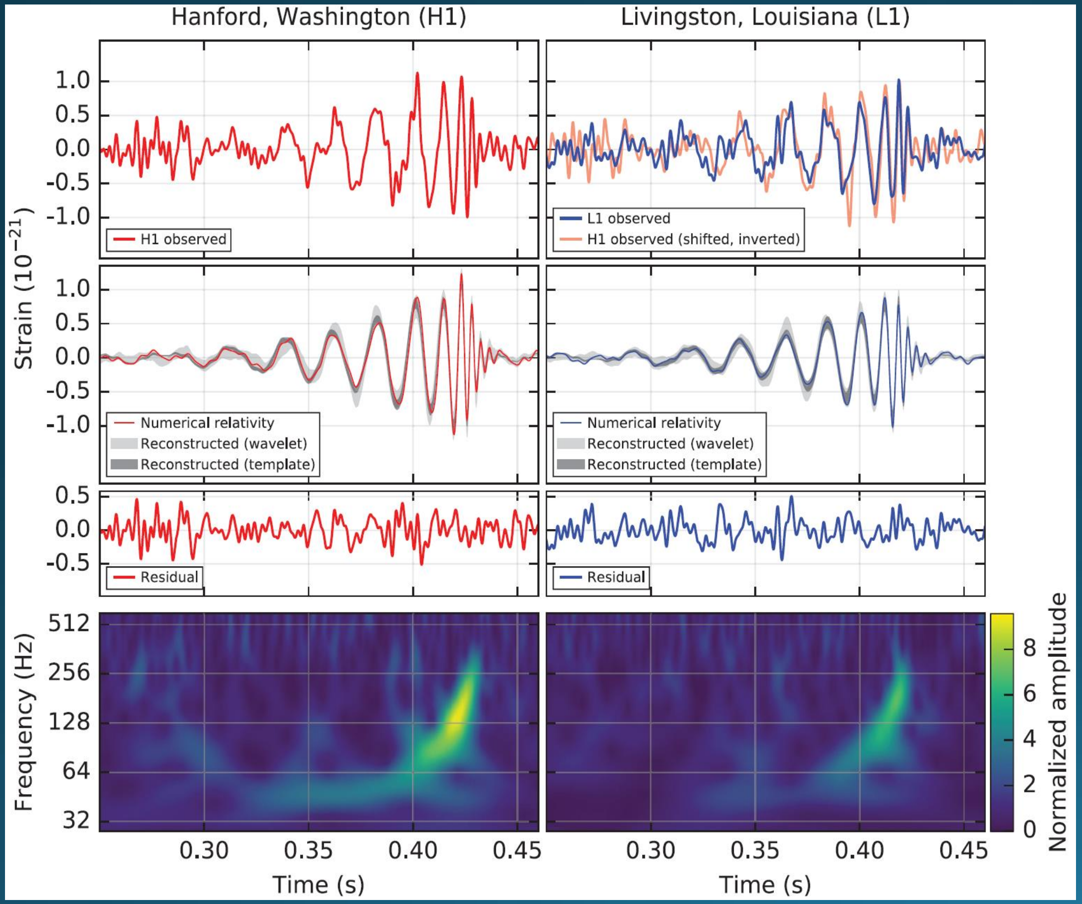
The Merger Rates of Binary Black Holes in Star Clusters

Michiko Fujii (UTokyo)

With Ataru Tanikawa (UTokyo) and Jun Makino (Kobe Univ.)

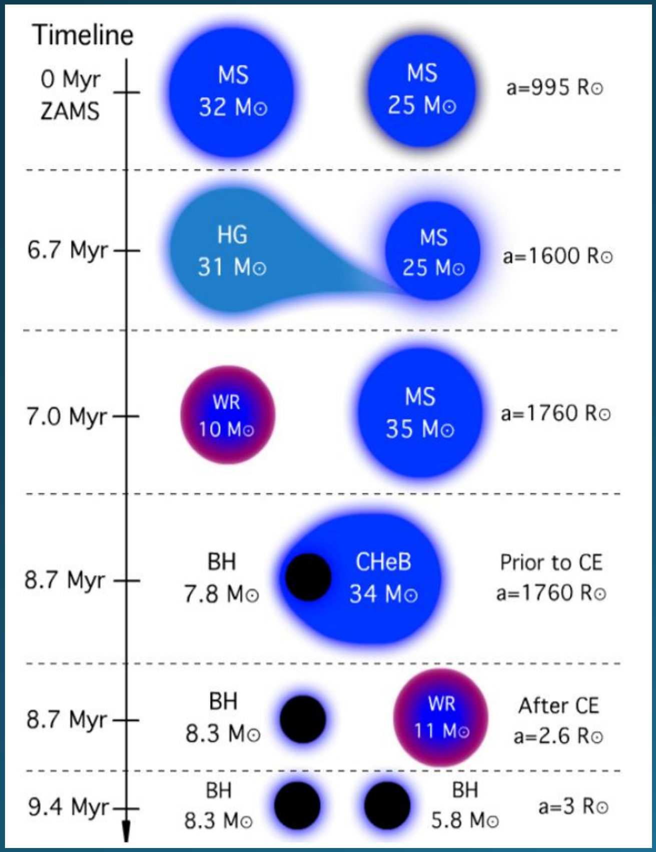
Gravitational Wave from Binary Black Hole



- The first GW (GW150914) has been detected!
- It was from a binary black hole (BBH); 29 + 36 Msun!
  - More massive than any known stellar-mass BHs
- BBH may be more common than expected before

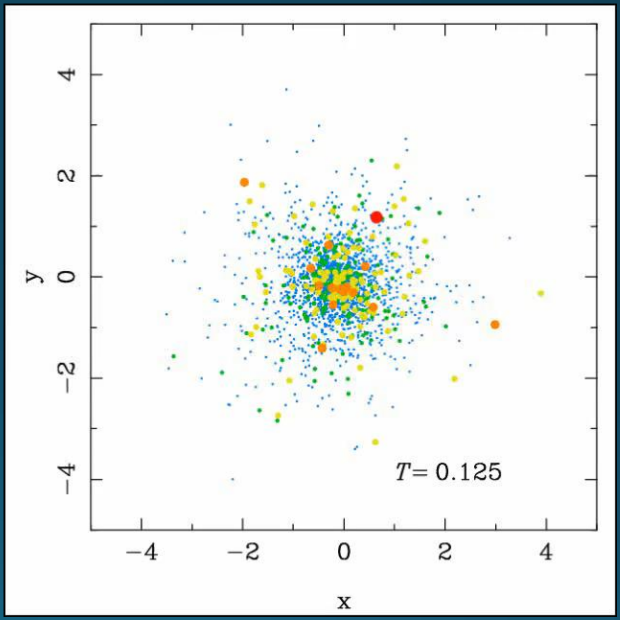
Two Possible Formation Paths

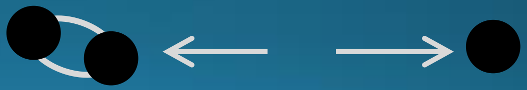
- Primordial binaries + Common envelope evolution
  Belczynski et al. (2007)



Dominik et al. (2013)

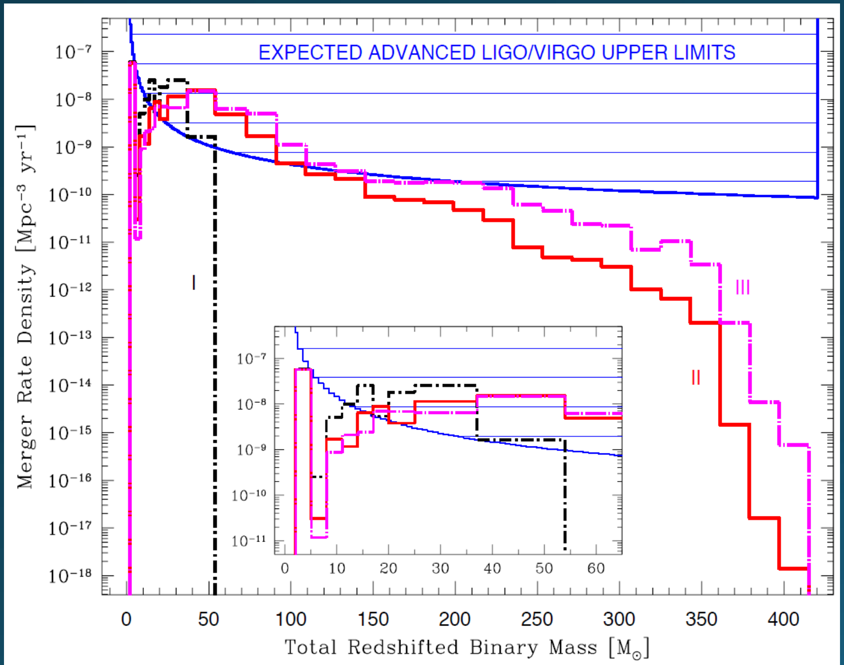
- Dynamical evolution in dense star clusters
  Portegies Zwart & McMillan (2000)



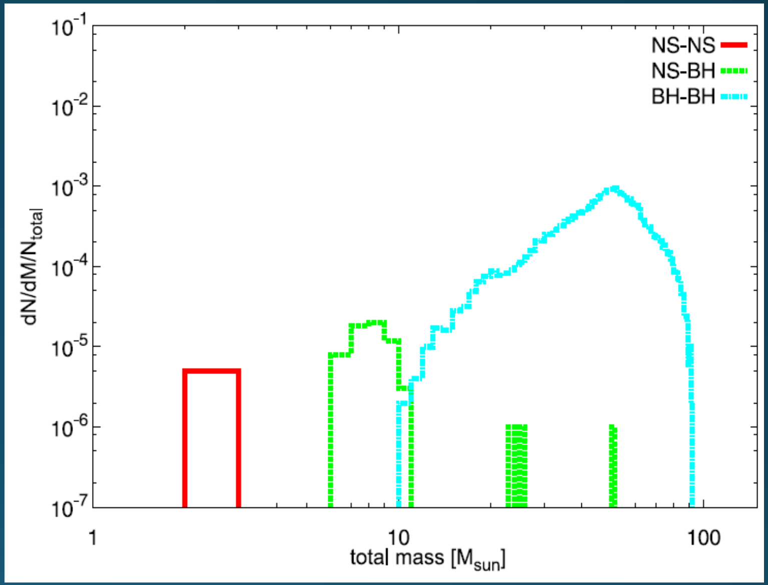


Previous works: Primordial binaries

Belczynski et al. (2016)



Kinugawa et al. (2014)

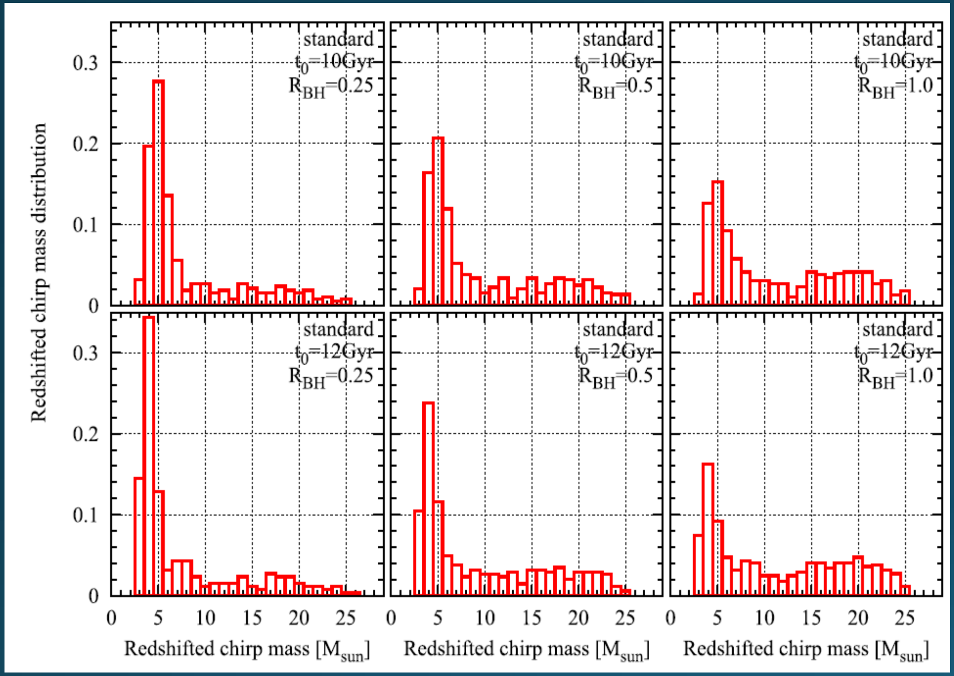


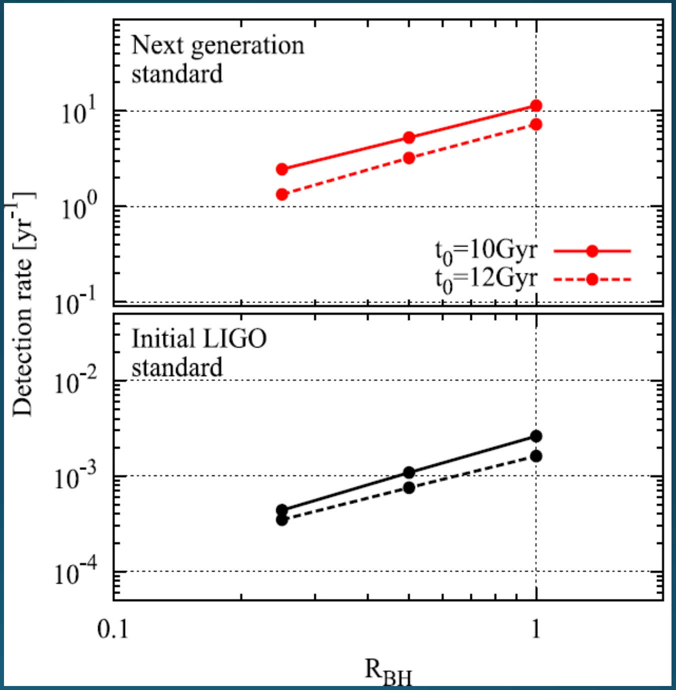
Pop III stars

- The result strongly depends on the initial mass function, binary population, and stellar evolution (binary evolution) model
- These are still unclear

Previous works: Star clusters

Tanikawa (2013)





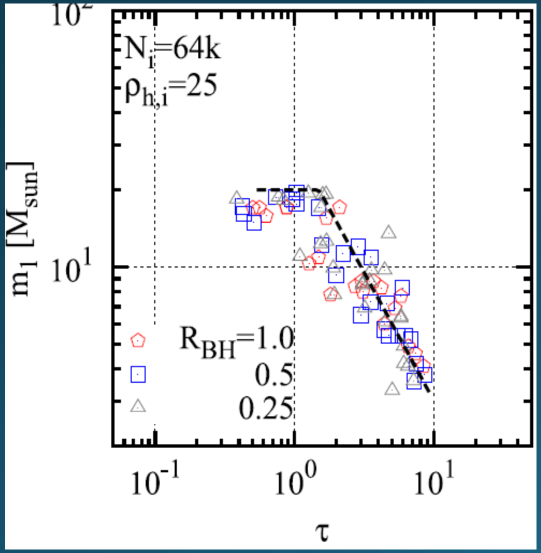
Similar works: O'Leary (2006), Banerjee+ (2010), Rodriguez (2016)

- Perform several N-body simulations of star clusters
  - The number of samples is not so large (10-a few hundreds per cluster)
  - The simulations consume a lot of computer resources

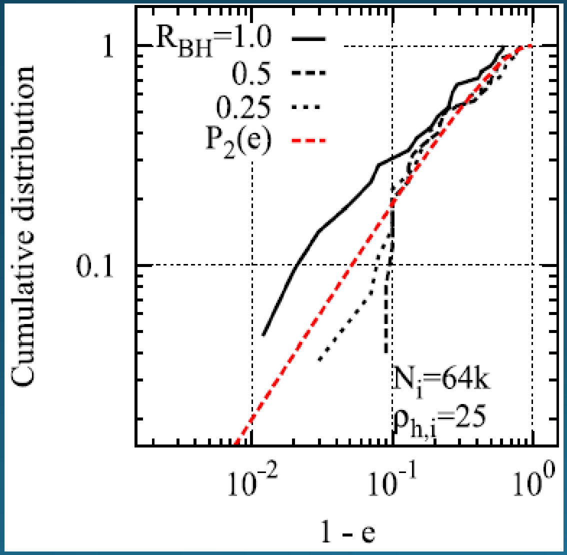
Tanikawa et al. (2013)

- Performed N-body simulations and obtained the distribution (eccentricity, mass ratio, merger time) of merging BBHs
- Following this distribution, they generated merging BBHs history per cluster and estimated the detection rate

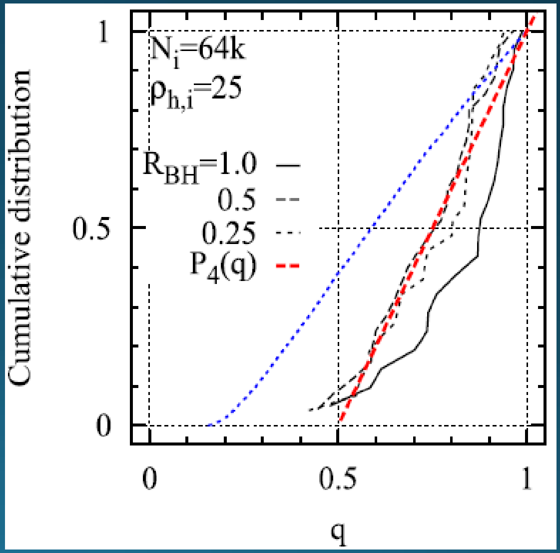
Timescale for merger



Eccentricity distribution



Mass-ratio distribution

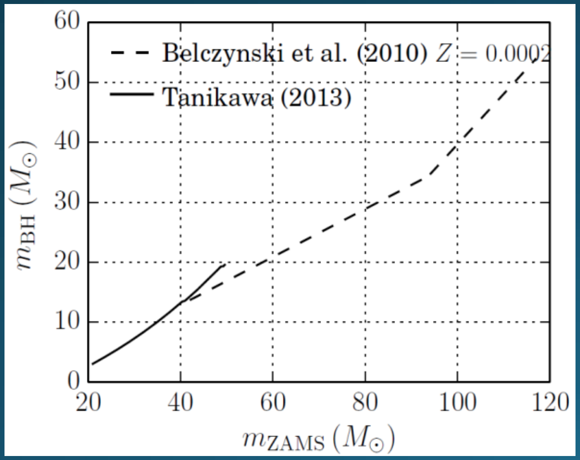


Massive BHs merge for a shorter time

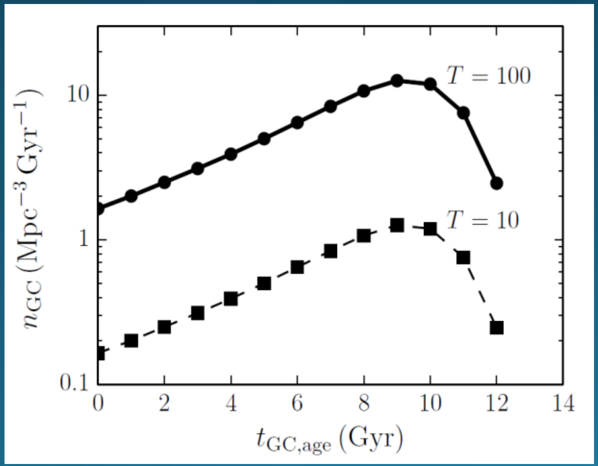
This work

- We use the results of Tanikawa et al. (2013)
- But,
  - We assume BH mass function (MF) up to 54 Msun (Belczynski+ 2014)
  - We assume a cosmic star-cluster formation history from a cosmic star formation history (Madau & Dickinson 2014)
  - We update the sensitivity spectrum of the detector

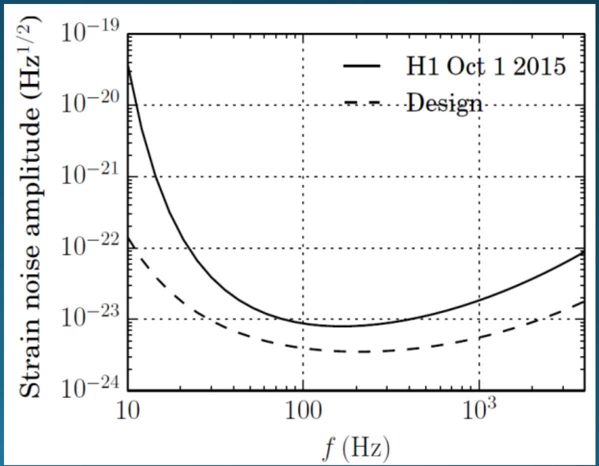
Zero-age main-sequence and BH mass



Cosmic star-cluster formation history



Sensitivity spectrum

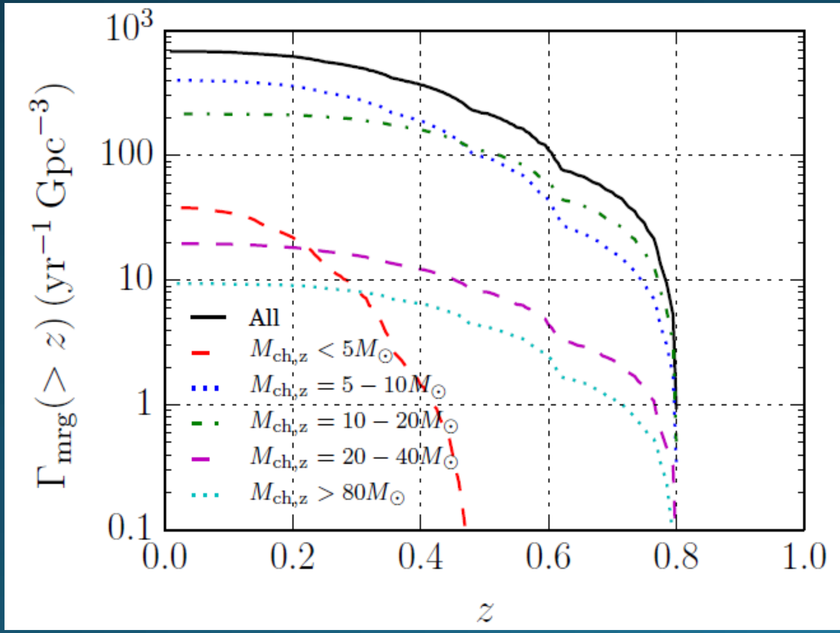


We assume 10-100 star clusters per 10^9Msun stellar mass

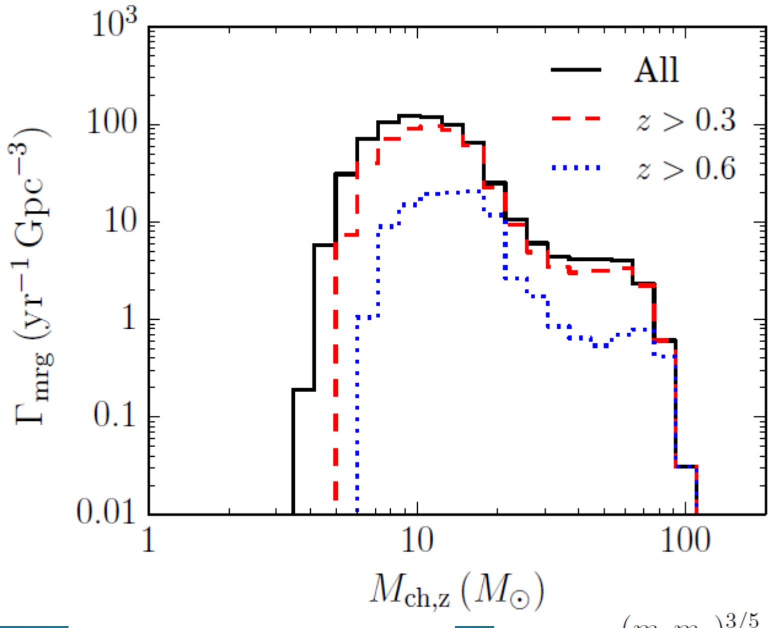
Results: BBH merger rates

- Each cluster starts to form merging BBHs after 5Gyr (core-collapse time of star cluster)
- Massive BHs merges in earlier time

Cumulative merger rate



Chirp Mass function



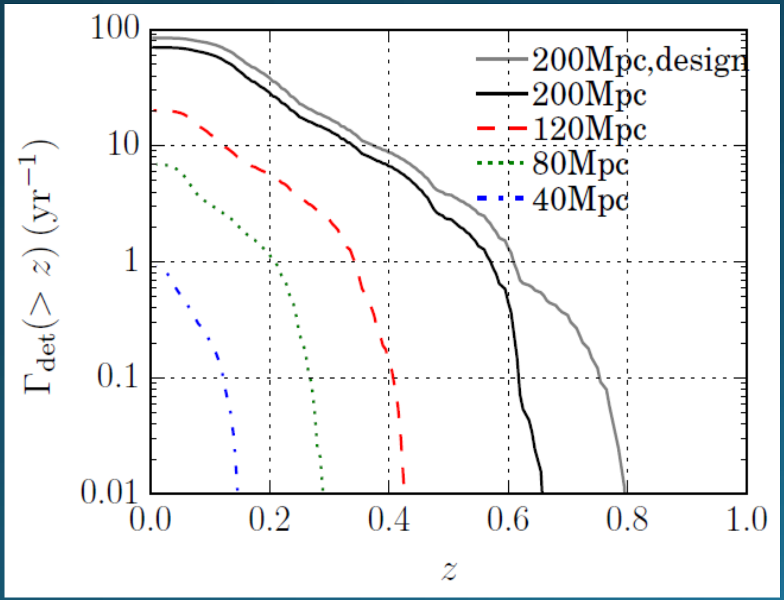
$$M_{\rm ch,z} = [1 + z(t)]M_{\rm ch}$$

$$M_{\rm ch} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

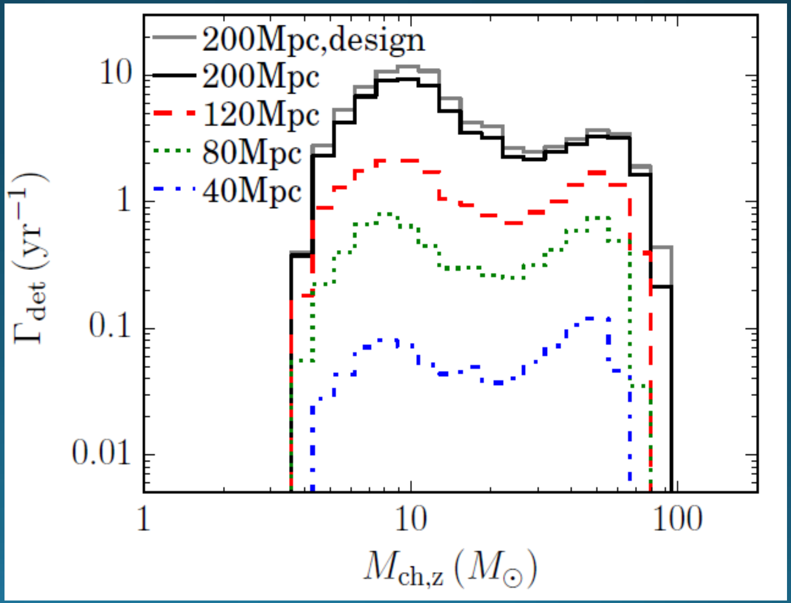
Results: Detection rates

- Weak two peaks, but almost flat mass distribution
  - Massive BHs are more effectively detected
- The detection rates is 0.69-6.9/yr for current detection limit and will be 8.5-85/yr for the designed sensitivity (depends on star-cluster formation rate)

Cumulative detection rate



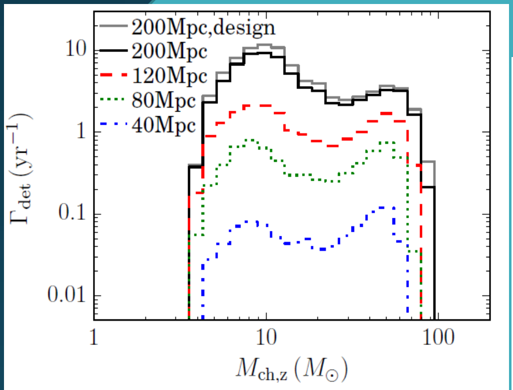
Chirp Mass function



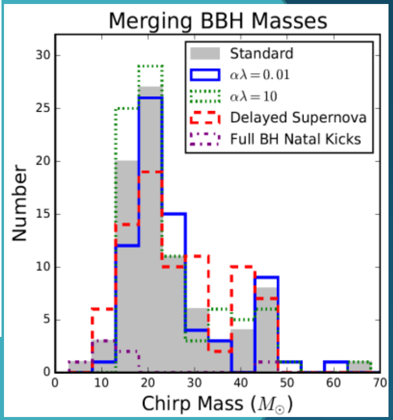
Results: MF of detected BBHs

- Observed shape of the MF will tell us the BBH formation scenario

This work

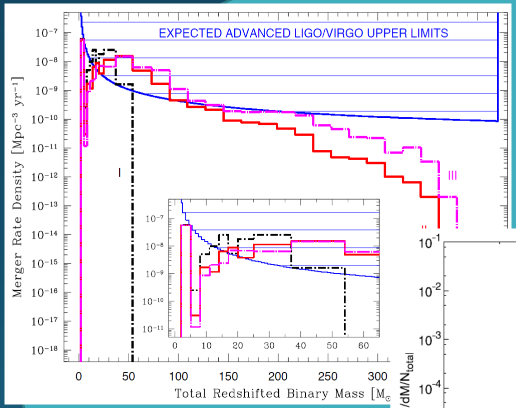


Rodriguez et al. (2016)

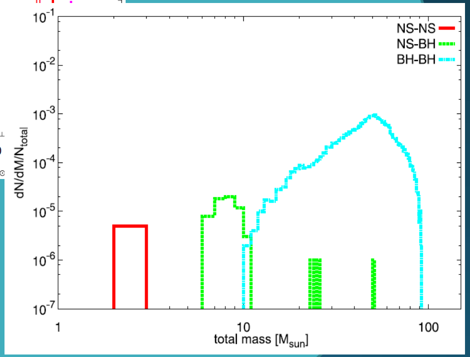


Star clusters

Belczynski et al. (2016)



Kinugawa et al. (2014)



Primordial binaries

Summary

- We estimate the detection rates and the mass function of binary black holes dynamically formed in star clusters
  - We follow the methods used in Tanikawa (2013), but update the details
- Our model predicts that the detection rates is 0.69-6.9/yr for current detection limit and will be 8.5-85/yr for the designed sensitivity
- The mass function of the detected BBHs characterize the BBH formation scenarios
  - Massive BBHs are enhanced for star cluster scenario
- Future observations will clarify the evolutionary path(s) of black hole binaries