BBH formation in globular clusters

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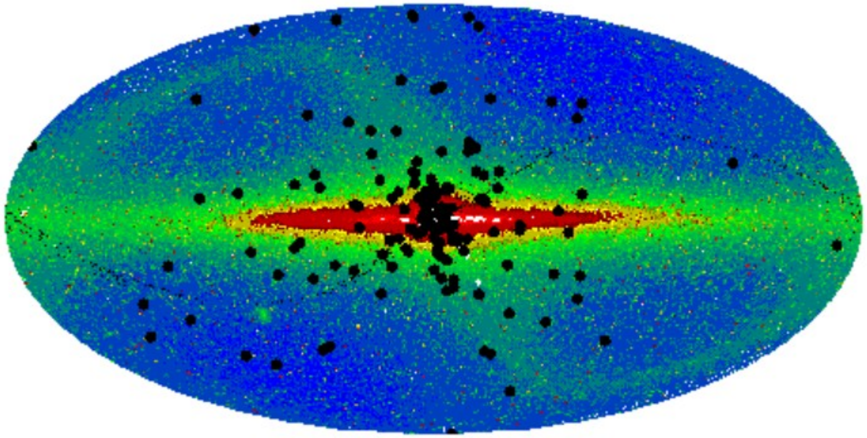
Globular Clusters

- Spherical collections of stars that orbit a galactic core as satellites. More than 60 000 extragalactic Globular Cluster (GC) observed ~157 GC in Milky Way (Harris catalog)
- GC contain 10000 to several milions stars
- Most of stars are old Population II (metal-poor) stars
- Stars are clumped closely together, especially near the centre of the cluster --> close dynamical interactions → tight binary systems containing compact objects
- Globular Clusters in the Milky Way are estimated to be at least 10 billion years old. 50% GC within 5kpc, the most distant 130 kpc

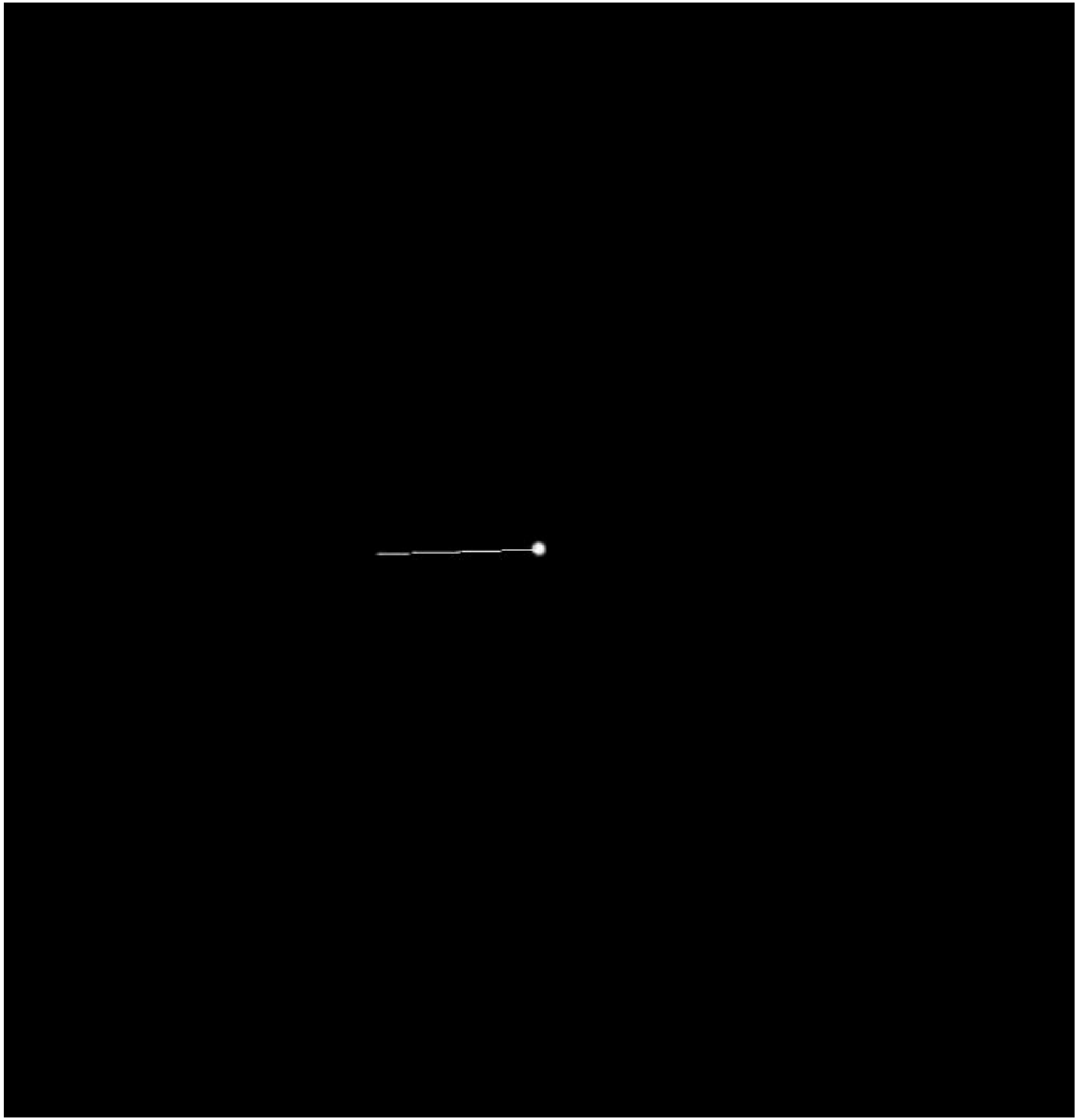
NGC 104 aka 47 Tucanae



Credit: M. Benacquista & Downing, 2011, the distribution of 157 GC in the Milky Way from Hariss catalog

What makes them special

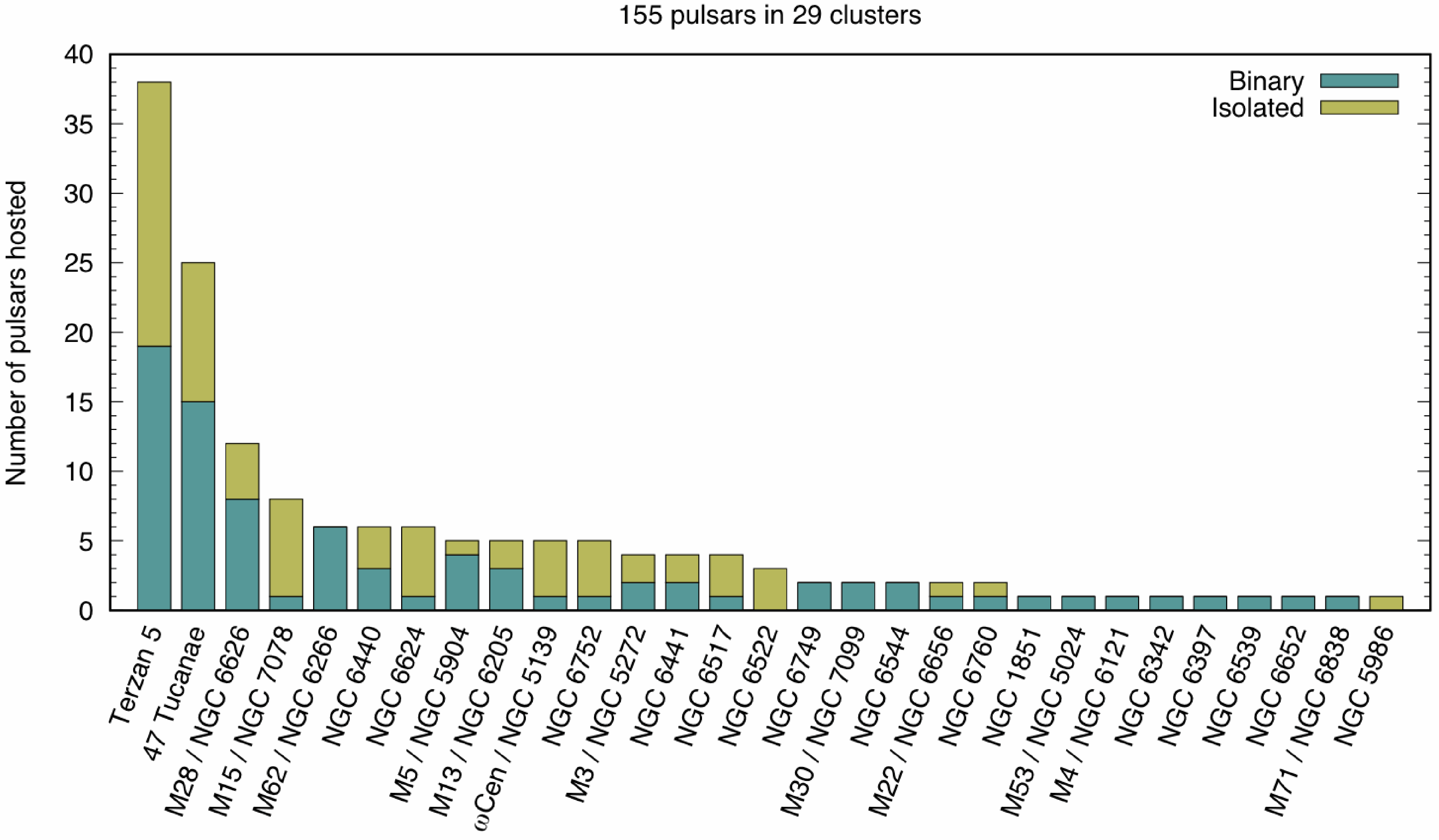
- Many body interactions
- Many NS binaries
- Possible sites of IMBH



Globular clusters and gravitational waves

- Binary/Stellar evolution produces a number of interesting objects and exotic binary systems in globular clusters.
- Dense stellar environments of globular clusters are conducive to forming hard binaries with evolved compact objects.
- Dynamical interactions in globular clusters can eject a lot of binary systems that could be potential sources of gravitational waves.
- Numerous studies have used star cluster evolution codes to predict the number of gravitational wave events (mostly BBH mergers) originating from Globular Clusters.
  - Monte Carlo Codes: Downing et al. (2011), Rodriguez et al. (2015) and Rodriguez, Chatterjee & Rasio (2016), Askar et al. (2016).
  - Direct N-body Codes: Banerjee, Baumgardt & Kroupa (2010), Tanikawa (2013), Bae, Kim & Lee (2014) and Mapelli (2016).

Neutron stars in GC



Are there BHs?

- Unconfirmed detections of two IMBHS
- BH in a binary in NGC3201 – non accreting – from motion of a companion.
- Probably no BHs if NS binaries present

Rates general arguments

- BBH merger rate: 10-100 $Gpc^{-3} yr^{-1}$
- Galaxy density: $2x10^{7}$ Gpc^{-3}
- Supernova rate: 1/50 yr in a galaxy, so it is $4x10^{5}$ Gpc^{-3} yr^{-1}
- BH formation rate ~0.3 NS formation rate
- BH formation rate ~10^{5} Gpc^{-3} yr^{-1}
- Thus about 1 in 1000 BH must be in merging binary

Rates limits in GC

- Number of stars in GCs in Milky Way: ~10^8, i.e 10^{-3} of stars
- Thus if all BHs in GC are in merging binaries the rates can be right

Formation of BBH in GC

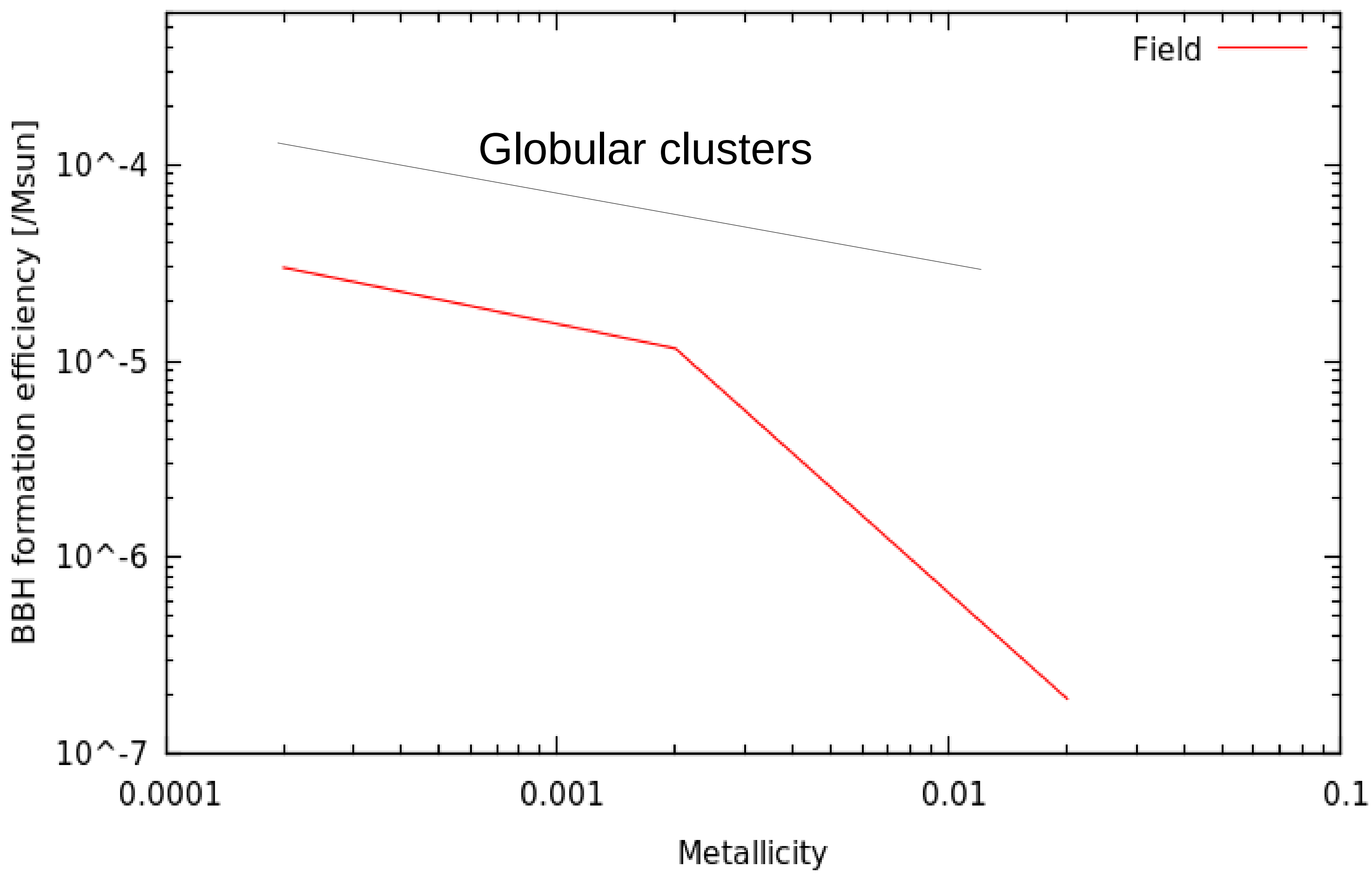
- Simulations, simulations , simulations
- Many groups working on the problem
- Results almost similar

BHBH formation efficiency

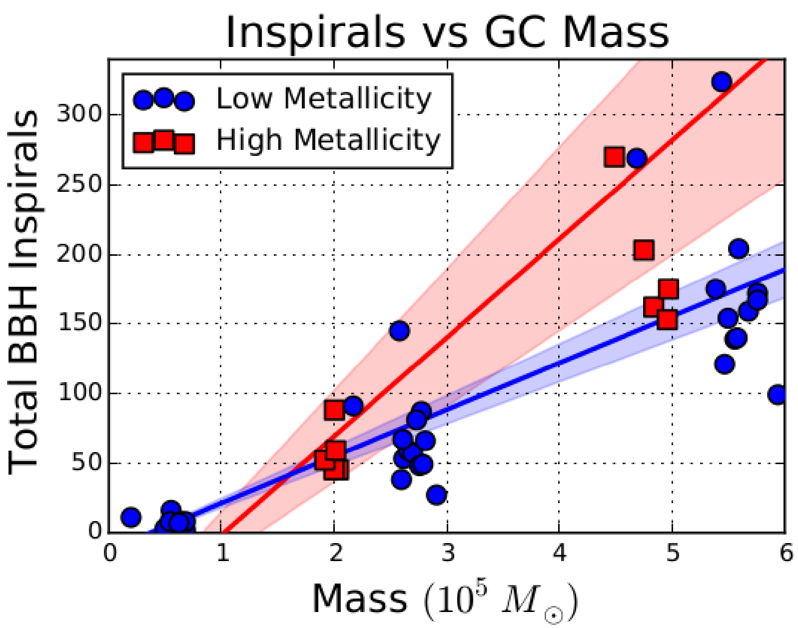
$$X_{BHBH} = \frac{N_{BHBH}}{M_*}$$

If all BHs end up in merging binaries
and with Salpeter IMF

$$X_{BHBH}^{max} = 1.8 \times 10^{-3} M_\odot^{-1}$$



Mergers as a function of GC mass



How do they scale with mass?

Rodriguez et al . 2016

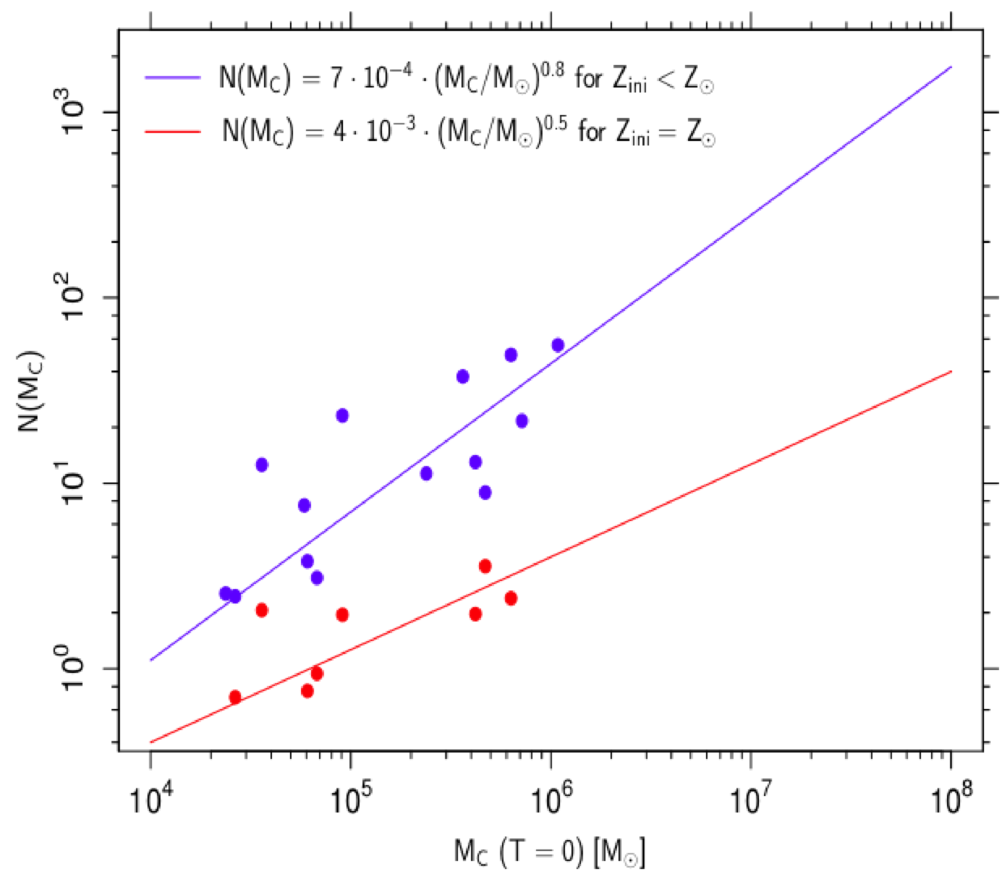
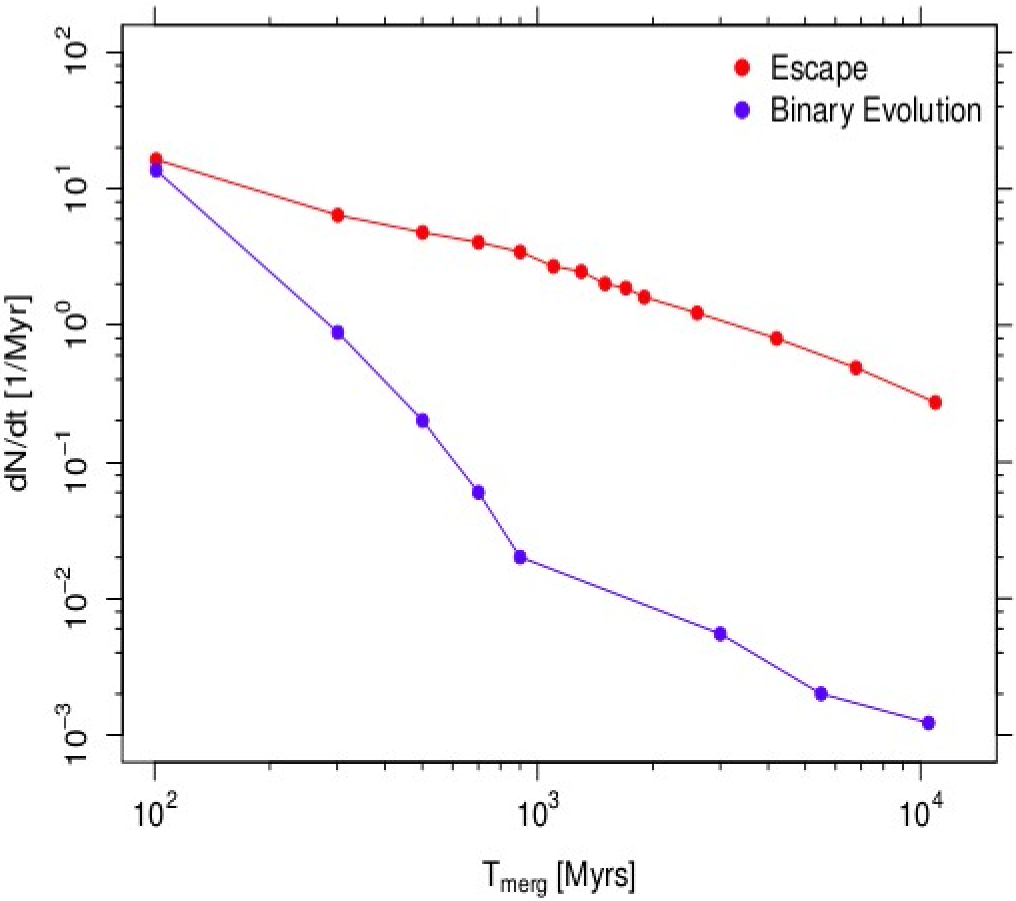


Figure 3. Normalized number of BBHs as a function of initial cluster mass M_c with fitted function $N(M_c)$. Data includes both escaped BBHs and BBHs that merge inside the cluster. Red and blue points correspond to two metallicities: solar ($Z = 0.02$) and sub-solar ($Z < 0.02$) respectively.

Askar et al 2016

Merger delay times

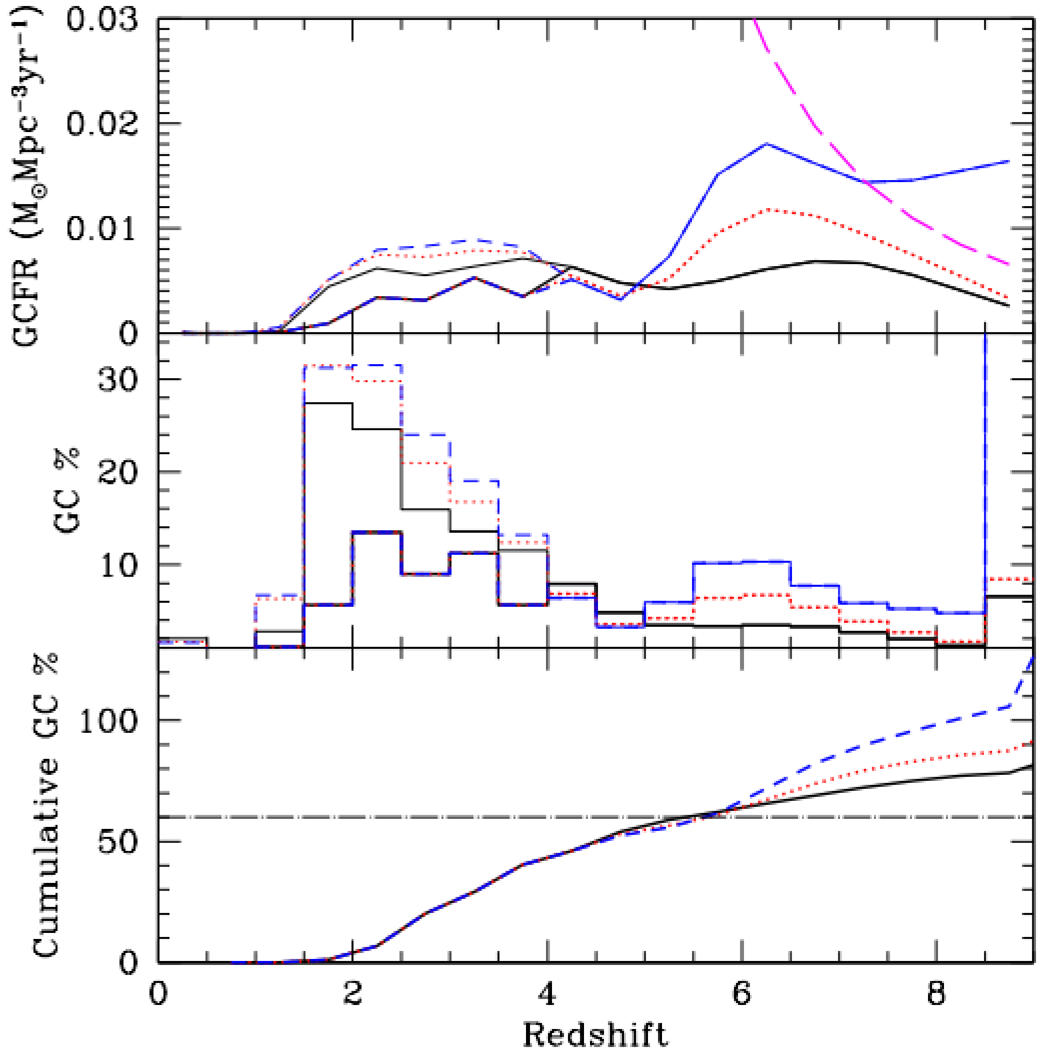


$\propto t^{-1}$

$\propto t^{-2}$

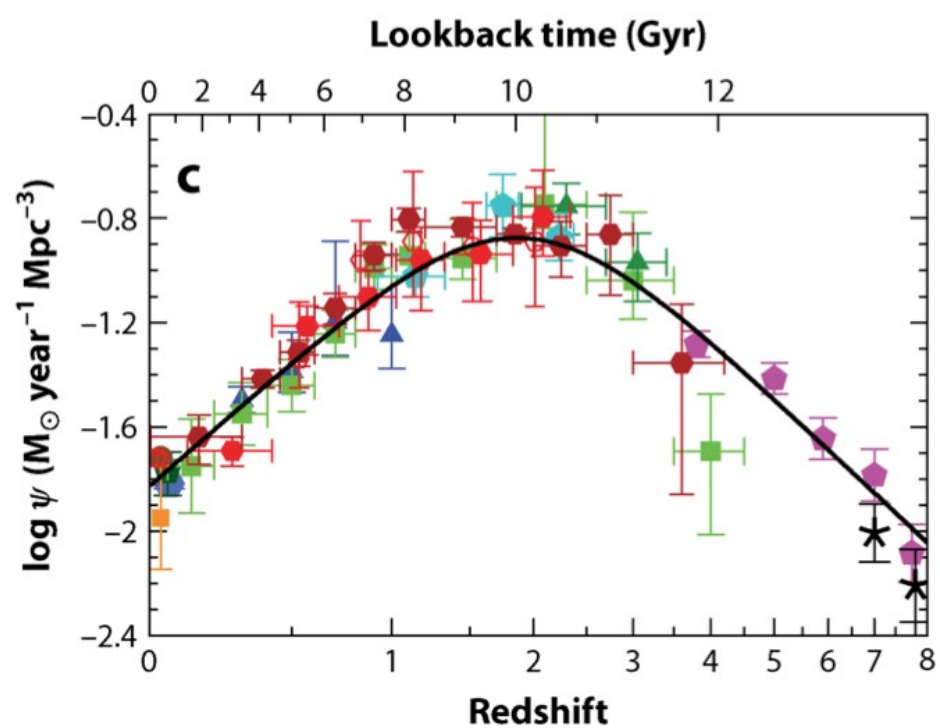
Askar et al 2016

GC SFR



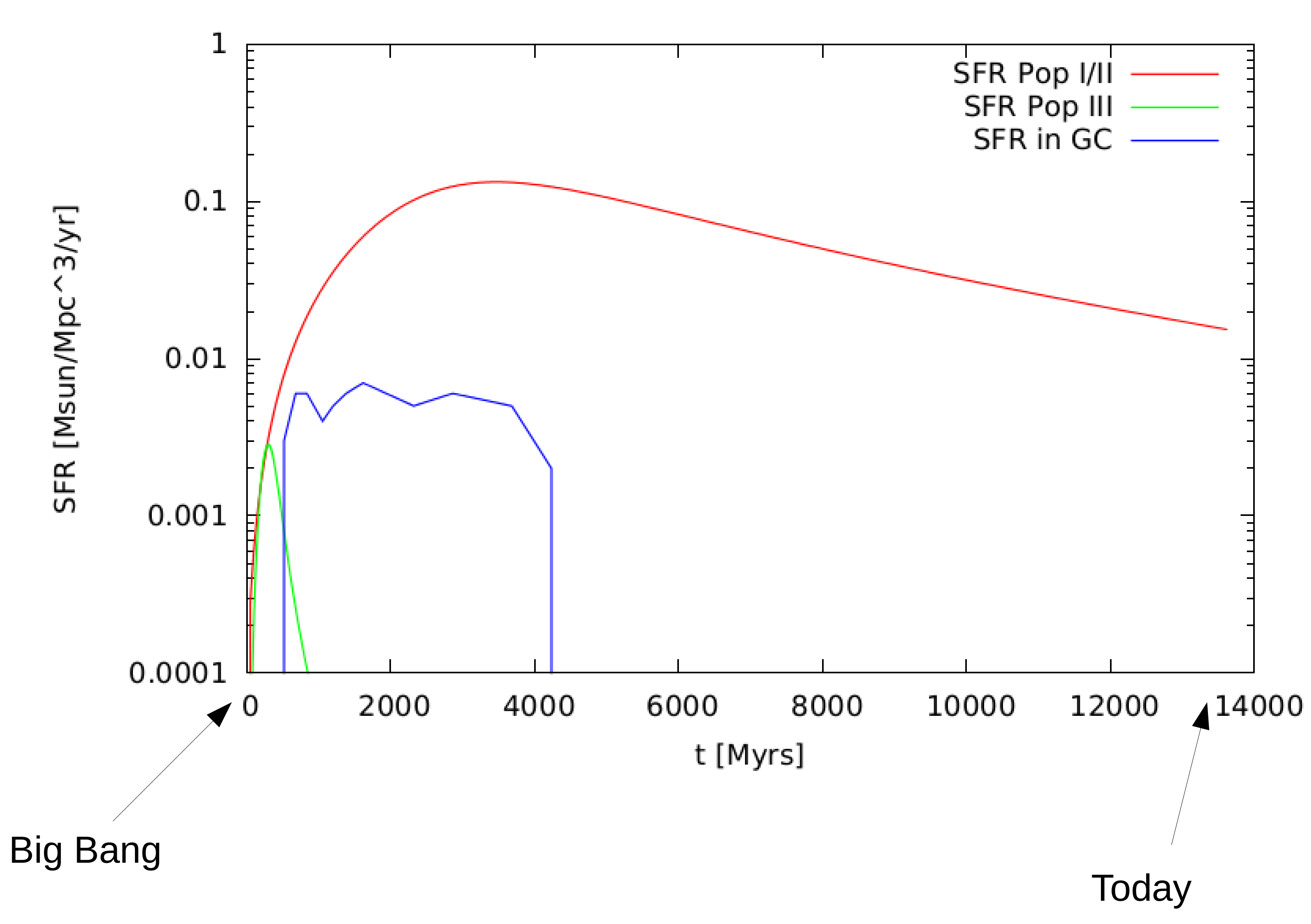
Katz and Ricotti 2012

GC SFR at z>1.5
Peaks at z=3 and 6



Madau, P ….

SFR



1
0.1
0.01
0.001
0.0001
SFR [Msun/Mpc^3/yr]
SFR Pop I/II
SFR Pop III
SFR in GC
0
2000
4000
6000
8000
10000
12000
14000
t [Myrs]
Big Bang
Today

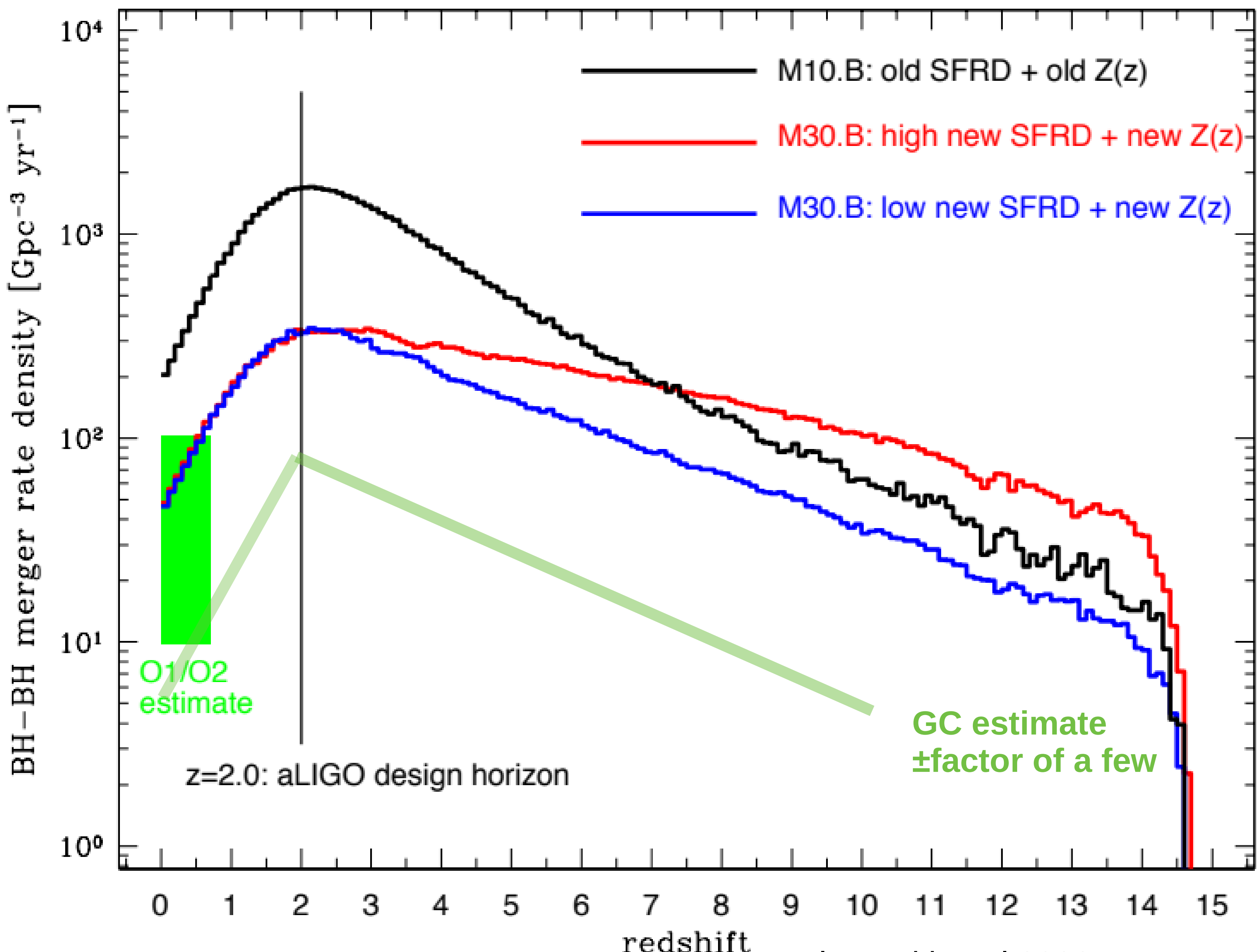
BBH rates

- Small amount of mass in GC in comparison to the field
- High efficiency of formation of BBH
- Most mergers happen a long time ago right after GC formation

Globular cluster vs Pop I/II

- SFR integral – a factor of ~ 0.01
- Formation efficiency difference < 10
- Delays a factor between 0.5 and 0.1

- Summary: GC rate is 0.05 to 0.01 of the field rate



Belczynski et al 2030

How to distinguish them

- Masses?
  - Same distribution
  - Second generation of mergers
- Spins
  - Isotropy
  - Second generation with large spins
- Ellipticity
  - A few percent of elliptical systems (detectable by LIGO/Virgo)
- Rate density at high redshift (CE and ET)
  - Maximum at z=2-3 ?