Constraint on the progenitor of Binary Black Hole merger using extremely metal-poor population

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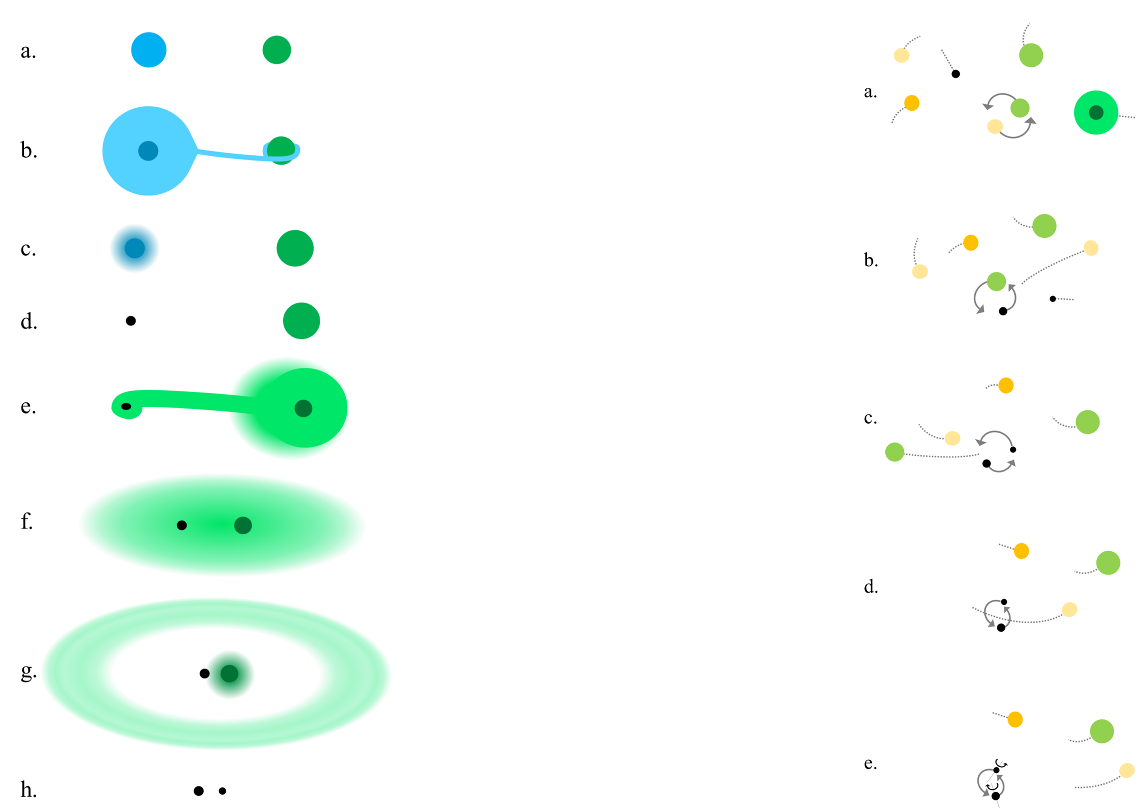
1. Abstract

The latest Gravitational Wave Transient Catalog (GWTC-3) contains 90 compact binary merger candidates observed as gravitational waves (GWs). Most of them are considered to be the coalescence of binary black holes (BBH), while the formation process of BBH is still under discussion. In this poster, we report the constraints on the BBH formation scenario when we take extremely metal-poor stars into account. We perform hierarchical Bayesian analysis on GWTC catalog with astrophysical formation models, including extremely metal-poor stars. We find that the contributions of each model to the observed distribution are of comparable magnitude, and adding the metal-poor star model results in a 5.5 improvement in log likelihood value.

2. Background

- Population properties of observed BBHs has posed various challenges.
- Many researchers have attempted to clarify the physics behind the formation of BBHs.
- Theorists presents two major pathway to form BBH.
  - The field binary channel and the dynamical channel



Schematic picture of BBH formation channels[1].

On the other hand,

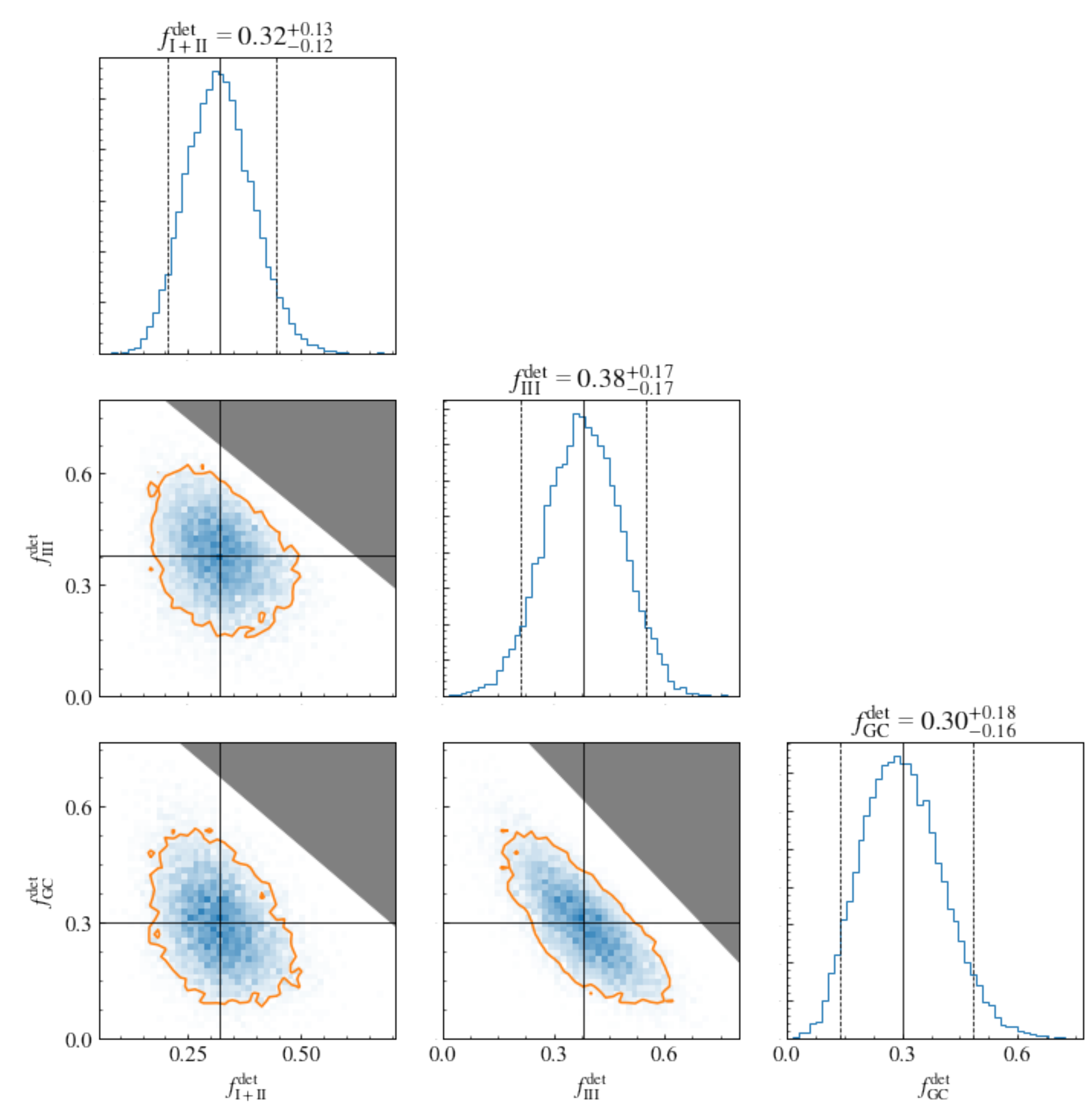
- Extremely metal-poor stars, or pop.III stars, are the first stars in the universe.
- Although they form in the early universe ($z \gtrsim 10$), some BBH from pop.III could merge within detectable range ($z \lesssim 2$)[2].
- The scenario would explain the 'substructure' of the peak in the observed mass distribution at $\sim 30\,M_\odot$.
- Question: To what extent can extremely metal-poor star scenario constrain the BBH origins?

3.Method

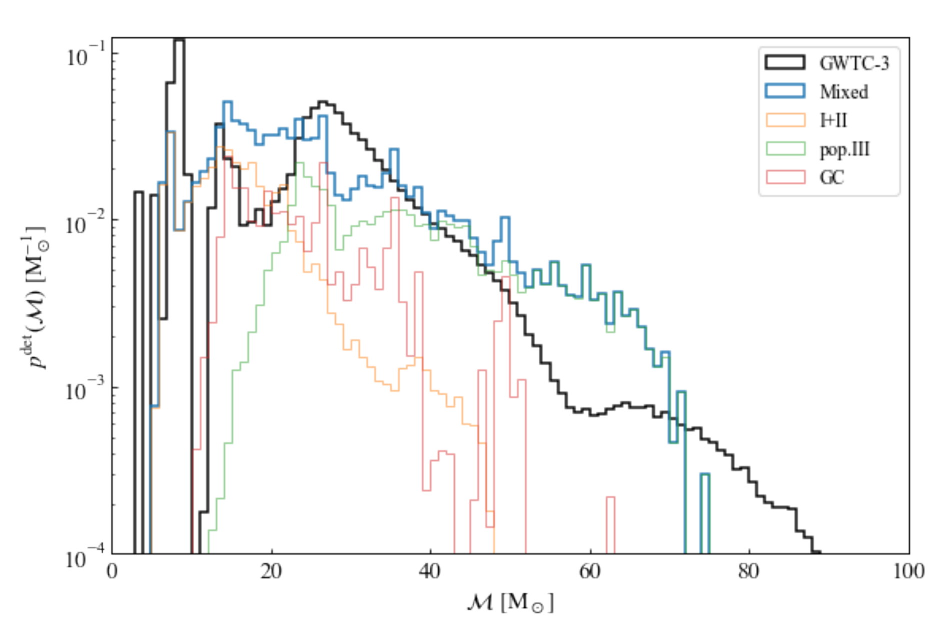
- For pop.I+II field binaries, we utilize Belczynski's calculation[3] gained by the `StarTrack`[4] population synthesis code.
- For dynamical binaries, we take the globular cluster model from Rodriguez's work[5] which is created via the cluster Monte Carlo code `CMC`[6].
- For pop.III field binaries, we adapt Kinugawa's model[2] where upgraded version of simulation code `BSE`[7] are applied.
- For each model, we construct a continuous PDF with KDE, then we employ the hierarchical Bayesian analysis on the fraction among mixture of three models.
- We extract BBHs from GWTC-3 with a false alarm rate $< 1\ \mathrm{yr}^{-1}$, giving 69 BBHs in total.

4. Results

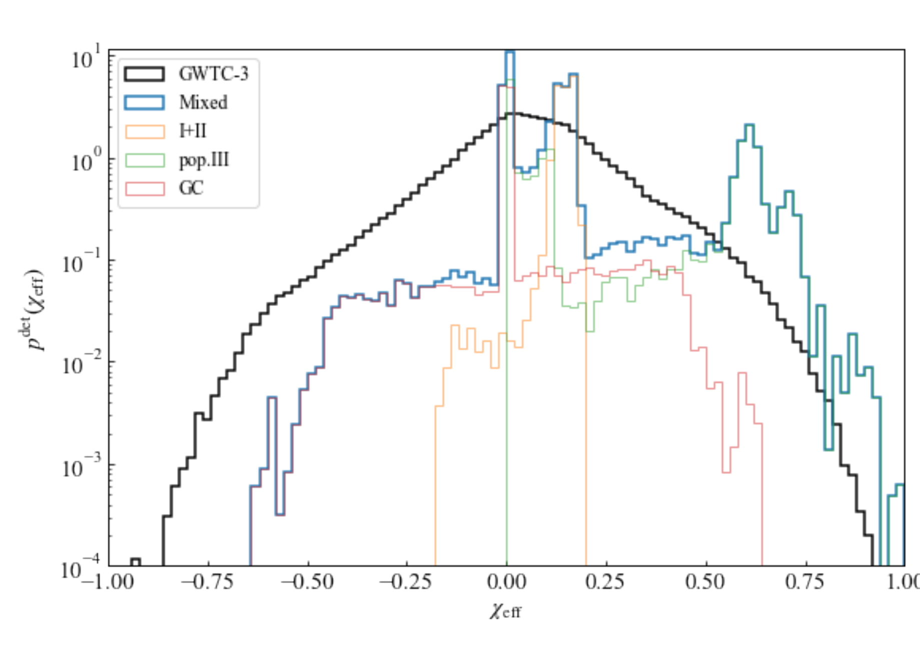
Detectable fraction of each channels



Chirp mass distributions



Spin parameter distributions



Bayes Factor for mixture models

Models	pop.I+II + GC	pop.I+II + pop.III	pop.I+II + pop.III + GC
Log Bayes factor	$\equiv 0$	-6.5	5.5

References

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[6] C.L. Rodriguez, et al. ApJS 258.2 (2022): 22.
[7] J.R. Hurley, et al. MNRAS 329.4 (2002): 897-928.