Gravitational Wave Archival Search

Unveil Stellar-mass Binary Black Hole Formation Using Eccentricity

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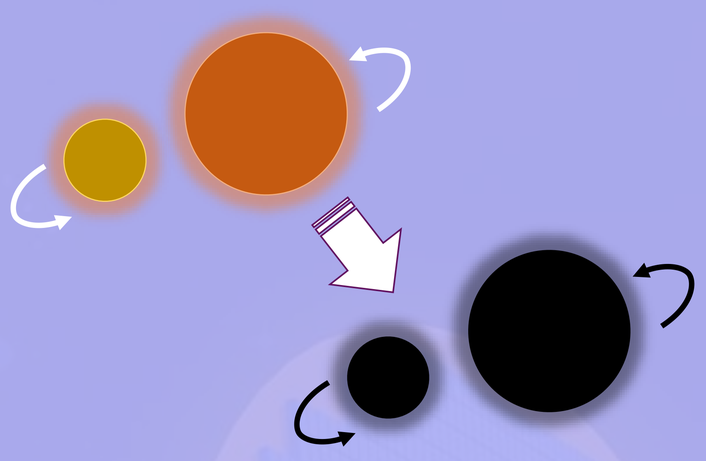
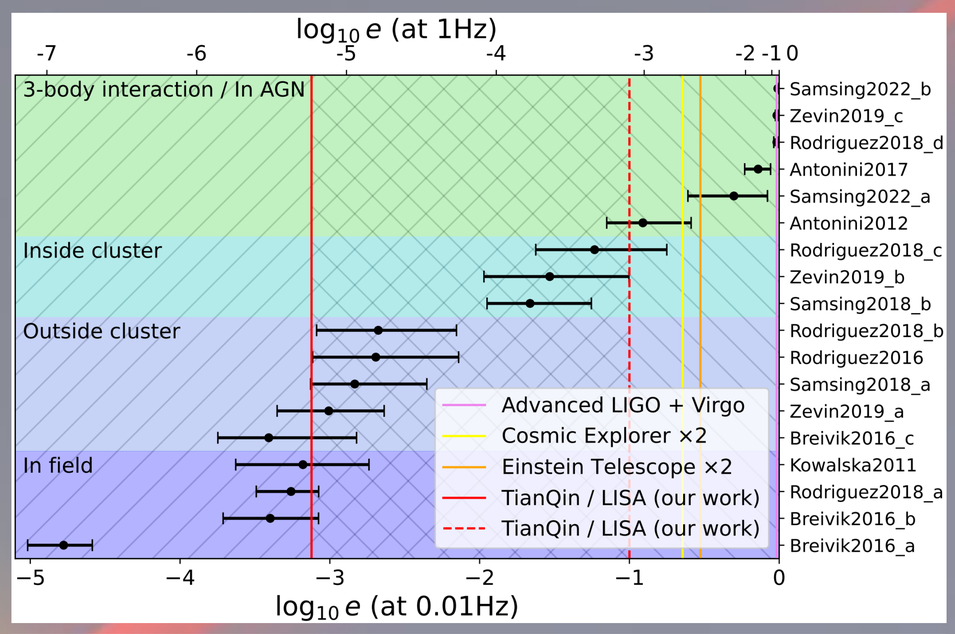
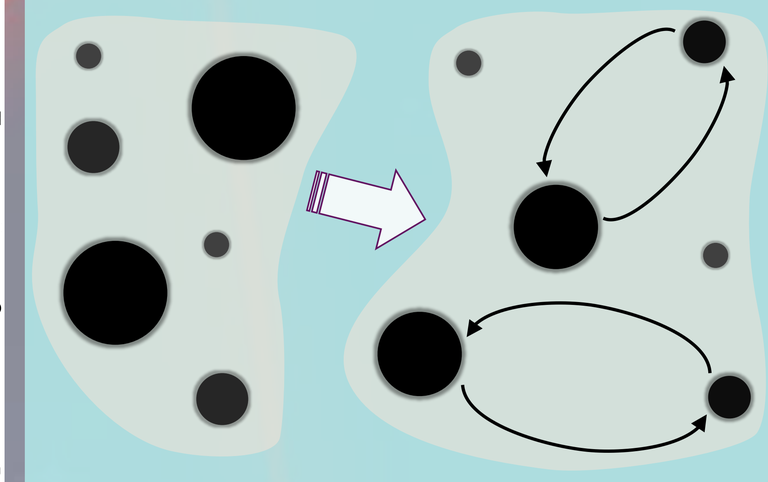


A sMBBH formed by the **co-evolution** process from an isolated pair of massive stars in (galactic) fields, whose orbit is expected to be almost **circular**



The orbital eccentricity of a stellar-mass binary black hole (sMBBH) system can be a key probe to unveil its origin



sMBBHs formed by **dynamical interaction** in a dense environment like globular clusters, which are expected to have **non-negligible eccentricities**

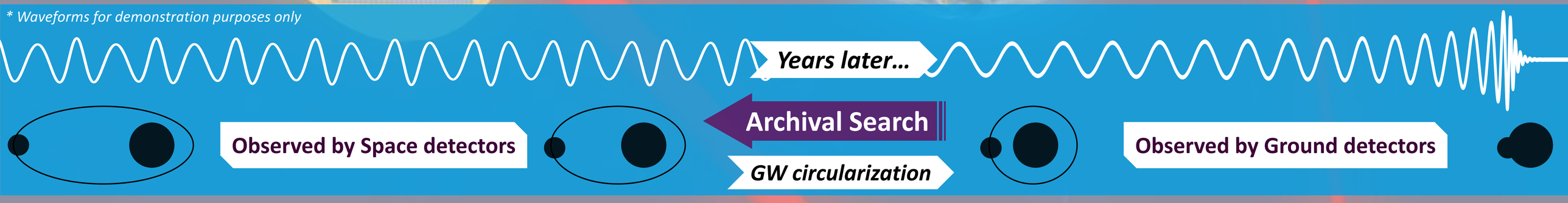
Space-based Detection

- Space-based gravitational wave (GW) detectors like TianQin and LISA will be launched in the next decade
- Longer baselines allow them observe lower-frequency GWs, preserve physical characteristics of sMBBHs like **eccentricity** from their long early inspirals
- $\mathcal{O}(10)$ sMBBHs with signal-to-noise ratio (SNR) $\rho > 8$ are expected to be detected every year
- Hard to accumulate high SNR though long observation
- Matched filtering as a detection technique require unreasonable computational cost for years of observation

Ground-based Detection

- Next-generation ground-based detectors like Cosmic Explorer and Einstein Telescope observe sMBBHs with high SNR: $\mathcal{O}(10^{2-3})$
- Measure most of the physical parameters with high precision, e.g. uncertainty of chirp mass $\Delta\mathcal{M} \sim 10^{-6}$

- However, high sensitive frequency range leads to a short observation time (around the merger)
- GW emission **circularizes** binary's orbit
- Information of how **eccentricity** evolves will be easily lost in data of ground detectors



Multiband Detection via Archival Search: "Embrace Both Sides"

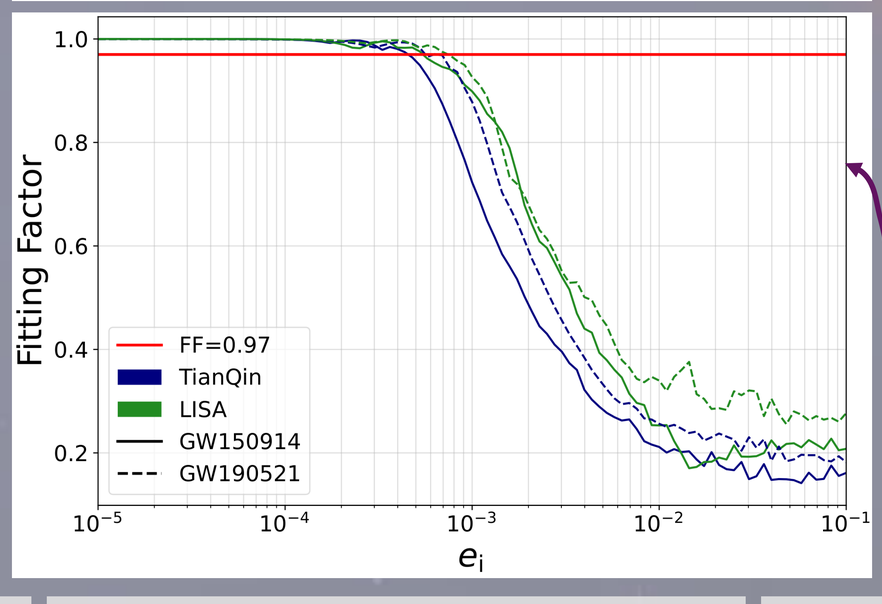
- A search of archival data from space detectors, triggered by detection with ground counterparts
- Most of the parameters are constrained by ground, so that we can focus on only *chirp mass* and ***eccentricity*** that space can improve better

`sbank`: Stochastic Template Bank Generation

- Matched filtering method requires a suitable set of waveform filters, or "template bank"
- We made it also work for space detectors, by adding their noises and responses
- And the eccentric GW waveform, by adding the impact of **eccentric harmonics** for the responses

gwastro/sbank

	Parameter space	GW150914-like	GW190521-like
TianQin	$e_i \in [0, 0.1]$	117202	49943
	$\mathcal{M} \in \mathcal{M}_0 \pm 10\sigma_\mathcal{M}$	3034	4250
LISA	$e_i \in [0, 0.1]$	100403	44867
	$\mathcal{M} \in \mathcal{M}_0 \pm 10\sigma_\mathcal{M}$	2070	3088



Conclusions

- We constructed the first template bank for an archival search that includes eccentricity
- Including eccentricity would enlarge the bank size by $\sim \mathcal{O}(10^5)$, which brings additional computational challenges
  - Efficient algorithms needed
- Non-eccentric banks will provide a significant systematic bias when $e_i \gtrsim 5 \times 10^{-4}$
- Which suggests the capability of space detectors for distinguishing sMBBHs formed by different channels

References

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