Evaluating the GW detectability of stellar populations with BPASS and LEGWORK

WOUTER G. J. VAN ZEIST
RADBOUD UNIVERSITY / LEIDEN UNIVERSITY

Introduction and previous work

- In my previous research paper, van Zeist et al. (2023) (arXiv: 2301.06888), I worked on gravitational wave spectral synthesis: simulating the cumulative GW spectrum of all the different binary sources in a stellar population.
- I used the population synthesis code BPASS to simulate stellar populations similar to open and globular clusters, and using these calculated the number of binaries in the LISA frequency band and computed the overall GW spectra of these stellar populations.

Introduction and previous work

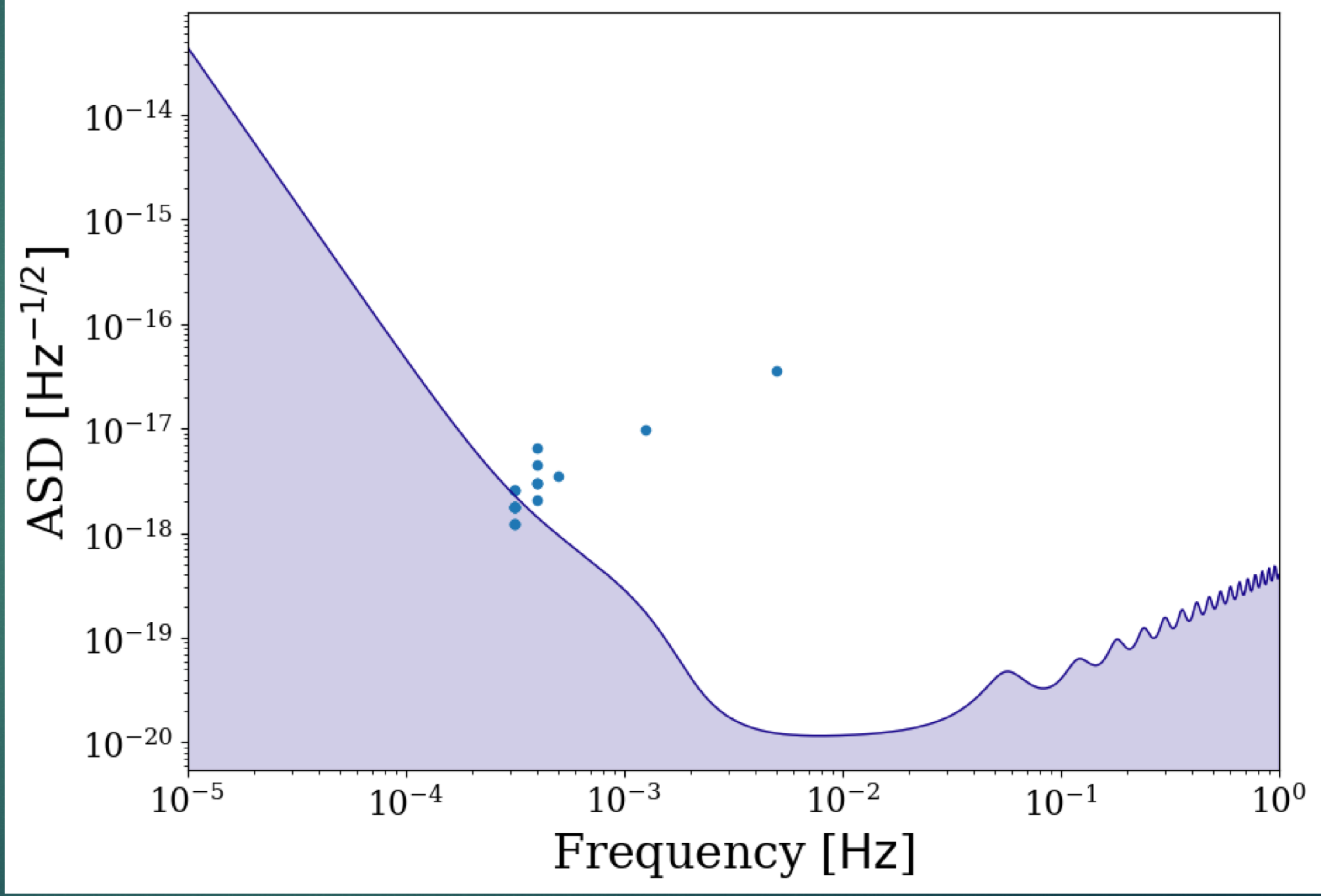
- We found the overall (averaged) spectra for generic cluster simulations exceeded the LISA strain sensitivity.
- We found that O(10) of the most massive GCs around the Milky Way would be expected to have >1 binaries in the LISA frequency range.
- But what about the detectability of individual sources in these clusters for LISA?
- To compute the SNRs of individual sources and plot them on frequency spectra, I used the software package LEGWORK.

LEGWORK example: (young) GC-like

This is a randomly sampled set of binaries for 10^6 Msun population, 10^8 years old, metallicity Z = 0.001, at 1 kpc distance.

22 binaries in total (above $10^{-3.8}$ Hz), though fewer dots appear on plot because of limited resolution of BPASS grid.

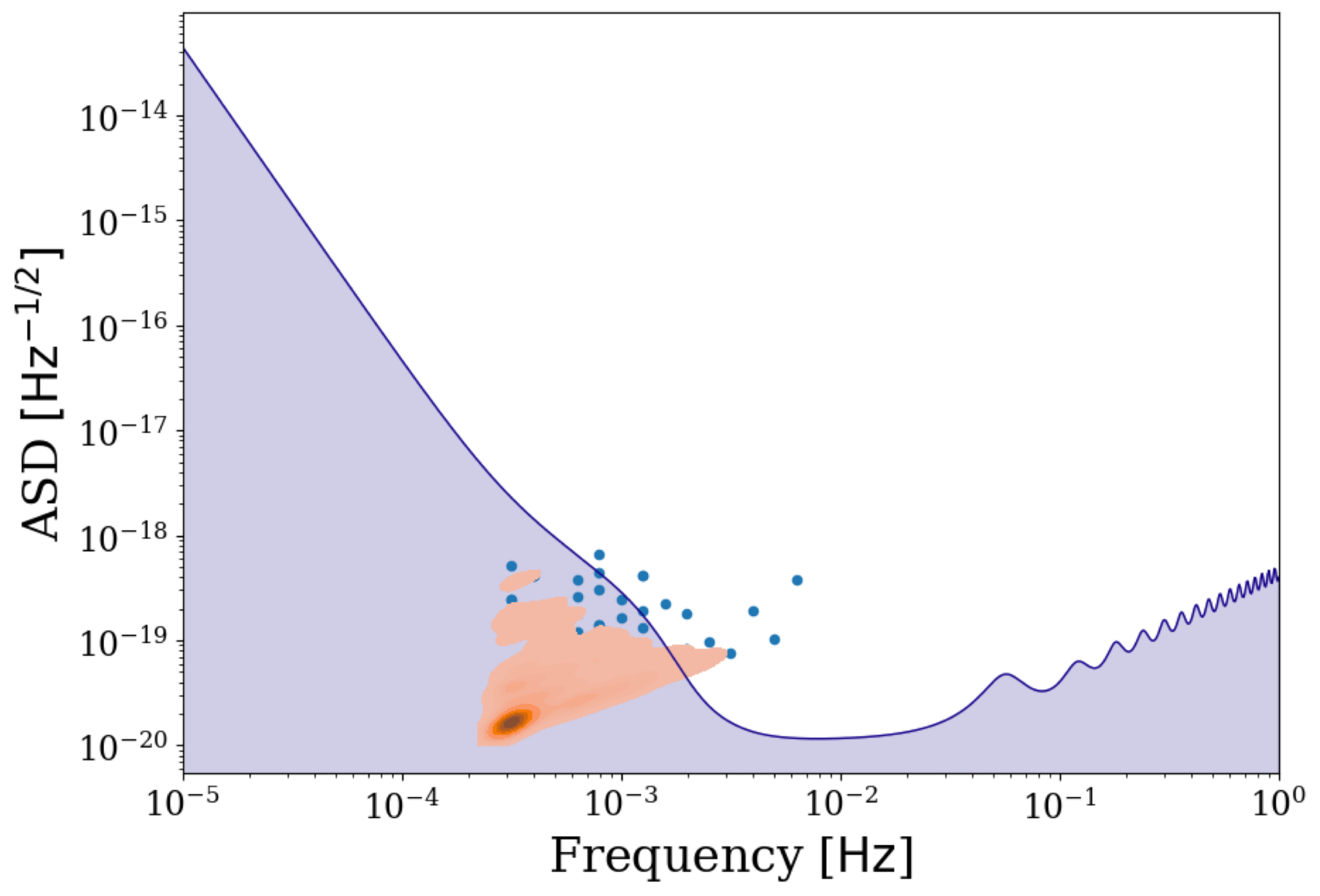
2 binaries have SNR > 7.



LEGWORK example: LMC

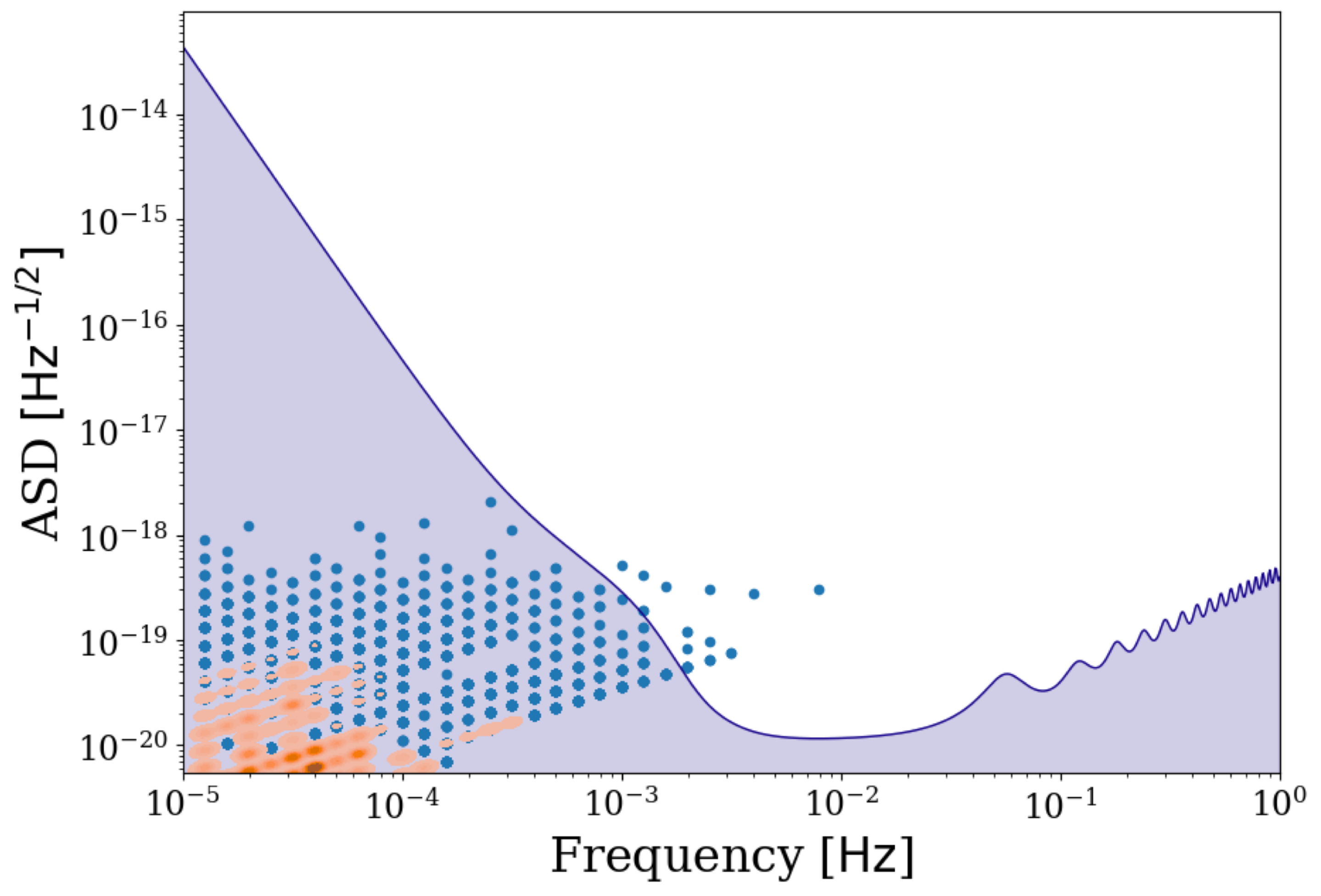
Using approximate distance, age, metallicity for the LMC (though LMC actually has multiple populations, not a single starburst).

Many more binaries in LISA frequency range (ca. 2000), but because of greater distance (50 kpc) the strain at Earth of each binary is lower. Only 3 binaries have SNR > 7 in this sample.



LEGWORK example: LMC without lower frequency threshold

If we run the simulation without the $10^{-3.8}$ Hz lower frequency threshold, there are many more binaries (more than 750 thousand), but most are far below the sensitivity curve, so our usage of the threshold is valid.



LEGWORK simulations for real GCs

For three of the largest GCs around the Milky Way, we perform 100 samplings and show the average number of binaries detectable with SNR > 7.

The number of detectable binaries is a lot less than the total number of binaries in the LISA frequency range.

Cluster name	Total binaries	SNR > 7
Omega Cen	12.09	0.26
Terzan 5	3.11	0.03
Liller 1	3.04	0.04

Comparison to other simulations

- In fact, these numbers are a lot lower than from other simulations of LISA sources for GCs. For example, Kremer+ (2018), using a Cluster Monte Carlo (CMC) simulation, found ~5 detectable WD–WD binaries across all MW GCs combined.
- Why are our numbers lower?
- Dynamical interactions: These tend to harden binaries (making them more detectable) and can form new binaries, but can also disrupt binaries. Most BH–BHs and NS–NSs in GCs are expected to be dynamically formed, but the literature is less clear for WD–WDs: some authors suggest dynamical effects could destroy as many or more WD binaries as it creates.

Comparison to other simulations

- Cluster mass loss calculations: In order to simulate a cluster, BPASS calculates what its initial mass would have been based on its current mass using rates of mass loss from stellar evolution. However, in a cluster with dynamical interactions, mass would also be lost from ejections.
- The magnitude of this effect is unclear from the literature: e.g. Shara & Hurley (2006; numerical) simulated a cluster where ~90% of stars were ejected, which would make a major difference for the initial mass calculations. However, Weatherford+ (2023; CMC) for a comparable cluster to Shara found only 10% of particles were ejected.

Plans for future work

- A more detailed simulation of the LMC than shown here, including the star formation history from Harris & Zaritsky (2009).
- Including dynamical interactions in our simulations: combining the isolated binary simulations from BPASS with cluster dynamics simulations from LonelyPlanets, a code originally designed to simulate the perturbing effects of dense clusters on planetary systems.
- Comparing this method to other simulations of GW sources in GCs, many of which are based on Monte Carlo methods.
- Investigating how well GW sources in GCs could be localized by LISA, and so to which degree they could be distinguished from background (field) binaries in the Milky Way.

Bonus slide: Simulating dynamical interactions in GCs

- The highest accuracy is achieved by a full numerical relativity simulation of the GC, but this is prohibitively computationally expensive.
- Proposed strategy based on LonelyPlanets:
  - Initial "simple" numerical relativity simulation with fewer particles (binary systems treated as one particle)
  - From these obtain an "encounter history" for each system (as in LonelyPlanets) -> O(1000) of these in total
  - Simulate an isolated binary as in BPASS, but each time there would be an encounter simulate that and then continue to simulate the isolated binary with its new orbital parameters (in the simplest case can "switch" from one pre-computed BPASS system to another, but may not always be possible depending on the parameters)