Detecting Eccentric White-Dwarf Binaries with the Laser Interferometer Space Antenna

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Abstract

Gravitational wave (GW) astronomy has witnessed several milestones in recent years and will continue to do so with the launch of the Laser Interferometer Space Antenna (LISA). Detecting GWs with frequencies ranging from 0.1 mHz to 1 Hz, LISA's primary signal source is expected to be binary white-dwarf (WD) systems. This study delves into the relatively untouched territory of detecting eccentricity within these systems; in both the individually resolvable signal from single systems and the unresolvable GW foreground created by a population of such systems. Such work builds on previous studies only considering binary WD systems with exclusively circular orbits. We present our results from exploring the orbital frequency vs. eccentricity parameter space of these systems and discuss the implications of the findings. The research aimed to determine the signal-to-noise ratio (SNR) of detections across this parameter space, shedding light on the detectability of systems with varying eccentricities. Additionally, this work is poised to evaluate the extent of any GW foreground emanating from a galactic population of binary WD systems.

Methods

- All programs written from scratch in Python
- Simultaneously evolve differential equations describing orbital changes due to gravitational wave radiation
- Calculate strain on gravitational wave detector
- Calculate signal-to-noise ratio across the parameter space
- Write a Monte Carlo simulation to evolve a population of 100,000 binary systems that we can compare to modern observation

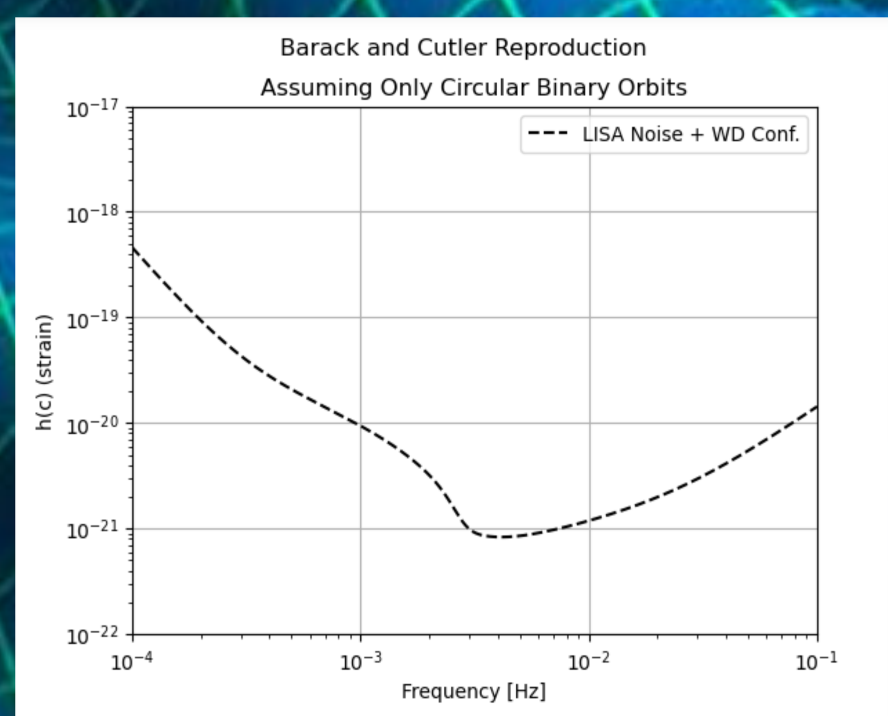

Figure 1: LISA's noise profile, composed of electronics noise and the gravitational wave foreground, calculated by Barack and Cutler assuming only perfectly circular orbits.

Motivations

- Eccentricity occurs naturally due to perturbations of astrophysical systems. Therefore, it is an expected result that could play a role in our detections of gravitational waves.
- There is currently very little literature that exists considering the possibility of populations of binary white-dwarf stars that contain any range of eccentricity. Considering only perfectly circular orbits greatly simplifies the computations.
- More physical models of these systems can help us better prepare for when LISA is in orbit and allow us realistic expectations for the performance of the detector.

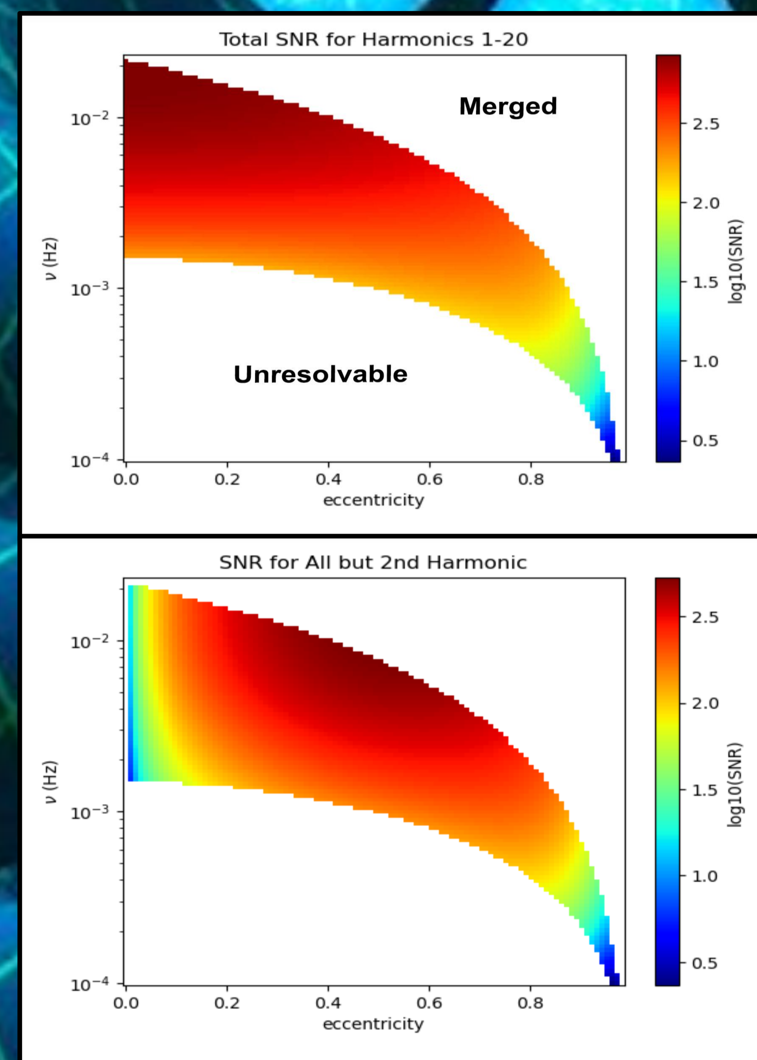

Figure 2: The signal-to-noise ratios (SNR) across the frequency and eccentricity parameter space. How much strain does the gravitational wave cause in the system vs. how much does the system fluctuate itself?

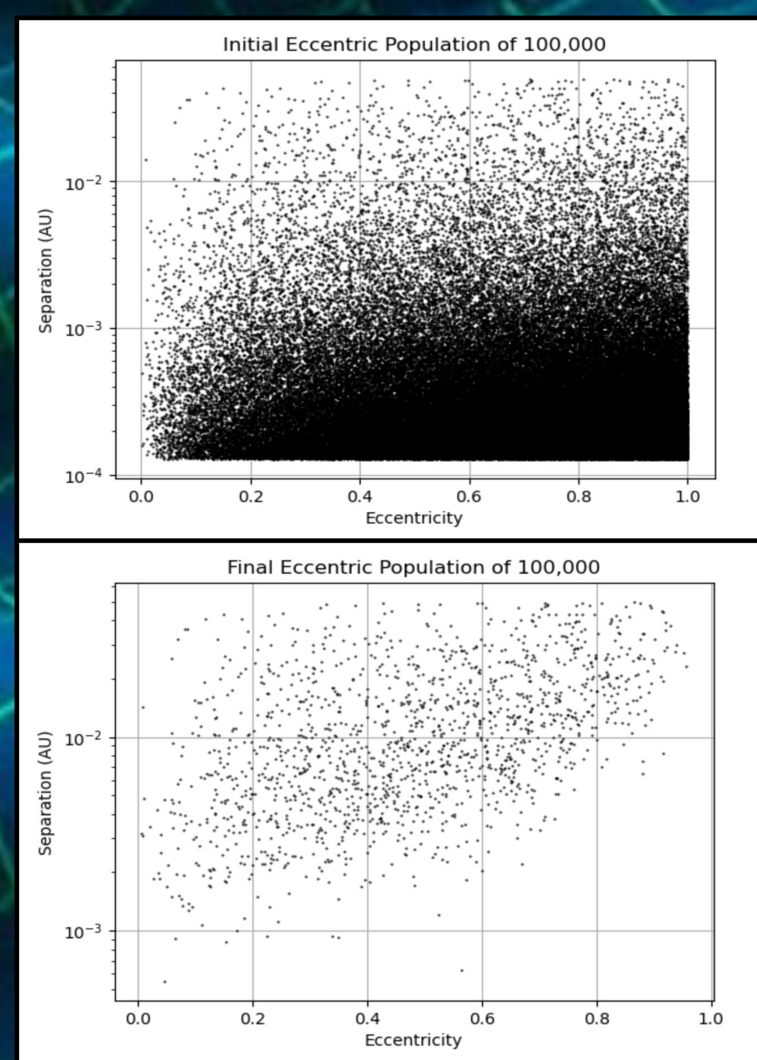

Figure 3: Initial and final populations of binary white-dwarf systems within the Monte Carlo simulation. Only about 3% of systems survive the evolution.

Summary

- LISA should be able to resolve individual systems at all eccentricities, depending on orbital frequency.
- Most systems won't be individually resolvable and will create a gravitational wave foreground noise.
- Detections other than that of the 2nd harmonic frequency are key indicators of eccentric orbits.

Future Work

- Calculate the unresolvable foreground noise
- Analyze foreground noise to determine if eccentricity is a contributing factor
- Compare results to other literature considering populations of eccentric white-dwarf binaries

References

Barack and Cutler. "LISA Capture Sources: Approximate Waveforms, Signal-to-Noise Ratios, and Parameter Estimation Accuracy." *Phys.Rev.D* 69

Bonetti and Sesana. "Gravitational Wave Background from Extreme Mass Ratio Inspirals." *Phys.Rev.D* 102

Moaz et al. "Characterizing the Galactic White Dwarf Binary Population with Sparsely Sampled Radial Velocity Data." *The Astrophysical Journal* 751

Image and Background Credit: NASA, ESA