Thesis proposal

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1 Research project Plan

In my thesis, I will primarily focus on developing a waveform model that has sufficient computational speed, used to asses the detectability and distinguishability of eccentric binary black hole (BBH) systems. Even though the precision of current waveform models is very precise, the waveform evaluation time is particularly slow. The primary objective is enhancing the speed of these computationally heavy waveforms without losing parameter accuracy. A critical aspect of detecting BBH mergers is having access to inspiral-merger-ringdown (IMR) waveform models. The gold standard waveforms in terms of accuracy are NR simulations. This method is highly accurate, but it is also extremely time-consuming, sometimes taking months for waveform generation. One approach to addressing this challenge is the utilization of surrogate modeling to efficiently generate these waveforms. This modeling technique depends on a foundation of a few NR waveforms and interpolates this foundation to obtain waveforms within a specific source parameter range.

Surrogate modeling is a numerical technique used to model a waveform by employing a simpler, approximating model to predict the behavior of a more complex and computationally expensive system. Surrogate modeling has proven to be exceptionally valuable for generating gravitational wave (GW) signals. However, most research in this area has primarily focused on generating non-eccentric waveforms. This concentration stems from the belief that most eccentricity is lost during the extended inspiral phase, resulting in predominantly circular radiation within the frequency band of our detectors. Nevertheless, this assumption does not always hold. BBH mergers occurring in dense environments can produce eccentric waveforms, and the degree of eccentricity can provide significant insights into the merger environment. Various scenarios, such as the formation of BBHs through dynamical capture or hierarchical triples, can lead to eccentricity. My primary research focus will be on developing a surrogate model for eccentric waveforms to enhance generation time for the waveforms of BBH mergers in dense environments.

To construct a surrogate model for analytic TD waveforms for the eccentric inspiral, I will first address the issue of gauge ambiguities in eccentricity by preparing a training dataset using gauge-invariant definitions of eccentric orbit parameters. Targeting a suitably large range of parameter space of bound eccentric orbits ($\mathrm{e} = [0, 1]$, $\mathrm{l} = [0, 2\pi]$) for eccentricity (e) and mean anomaly (l). If additional time permits, I also intend to explore the feasibility of developing a 2D surrogate model (eccentricity and mean anomaly) to account for further complexities in eccentric BBH mergers.

2 Milestones

Deadline	**Task**
End Sept	Getting familiar with the literature and software used to generate eccentric gravitational waves.
End Oct	Develop and implement methods for measuring gauge invariance eccentricity in gravitational waveforms.
End Dec	Building a preliminary surrogate for the eccentric TD waveform model on a sparse dataset.
End Feb	Compile a comprehensive dataset of waveforms for optimized performance/ accuracy in eccentric parameter space.
End April	Train the model using the prepared dataset and develop a 1D surrogate model for eccentric waveforms of equal mass ratio.
If Extra Time	Begin exploring the possibility of building a surrogate model for 2D parameter space (eccentricity, mean anomaly) waveforms for equal mass systems.