Thesis proposal

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1 Research project Plan

In my thesis, I will primarily focus on developing a model to assess the detectability and distinguishability of eccentric binary black hole (BBH) systems. The primary objective is to evaluate the precision with which we can estimate the parameters of eccentric waveforms. A critical aspect of detecting these eccentric mergers lies in having access to inspiral-merger-ringdown waveform models for BBH mergers. The computation of these waveforms mostly relies on Numerical Relativity (NR). While this method is highly accurate, 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 eccentric waveforms within a specific range of eccentricity.

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 generating eccentric waveforms to enhance parameter estimation for BBH mergers within dense environments.

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. To construct a surrogate model for eccentric time-domain (TD) waveforms, I will first address the issue of gauge ambiguities in eccentricity by generating gauge-invariant eccentric waveforms. Our target parameter space for these waveforms includes eccentricity values in the range of $\{0, 1\}$ and mean anomalies spanning from $\{0, 2\pi)$. If additional time permits, I also intend to explore the feasibility of developing a 3D surrogate model to account for further complexities in eccentric BBH mergers.

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 Nov	Compile a comprehensive dataset of gauge-invariant eccentric waveforms.
End Dec	Building the surrogate model for an eccentric TD Waveform.
End Feb	Train the model using the prepared dataset, optimizing its performance and accuracy.
End April	Extend the surrogate model to accommodate 2D parameter space, including mean anomaly and eccentricity.
If Extra Time	Begin exploring the possibility of building a 3D surrogate model for the 2D parameter space.