Recurrence Plots in Gravitational Waves Emitted by Binary Neutron Star Mergers

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Abstract

Recurrence analysis is a method for visualizing the dynamics of a system given its time-series. In the case of Binary Neutron Star mergers, we use the simulations of the CoRe Database to identify possible patterns in their recurrence plots so it can be possible to characterize them. If particular patterns are effectively found, then the recurrence analysis can be a complementary tool to analyze the gravitational wave signals for this kind of mergers. In this work, we visualize some examples of the patterns that would characterize the inspiral and the post-merger stage in a binary neutron star coalescence.

Introduction

The fate of a Binary Neutron Star (BNS) merger depends on the characteristics of the initial neutron stars, especially on their masses and spins. These pre-merger parameters can be inferred from current gravitational waves (GW) observations. There are specific techniques available to analyze the inspiral signals, but an equivalent roadmap has to be developed for the Post-Merger (PM) inferences which third generation (3G) detector observations will allow to make in the future. It is in this matter that we think a Recurrence Plot (RP) might be a complementary tool for such analysis.

Therefore, we choose some representative BNS simulations given by the Computational Relativity (CoRe) Database [Gonzalez et al. (2023)] and based on previous studies of time-series from systems that generate gravitational waves [Zelenka et al. (2019), Fan et al. (2018)], we investigate possible patterns in the RPs of the strain signals of the simulations.

The transition from the inspiral to the post-merger stage can be observed in the RPs. Also, particular partterns arise when the signal represents, for example, a high eccentricity.

Clearly, we need to use the Recurrence Quantification Analysis (RQA), which allows us to obtain several metrics or parameters that will characterize the dynamics in the system.

Results

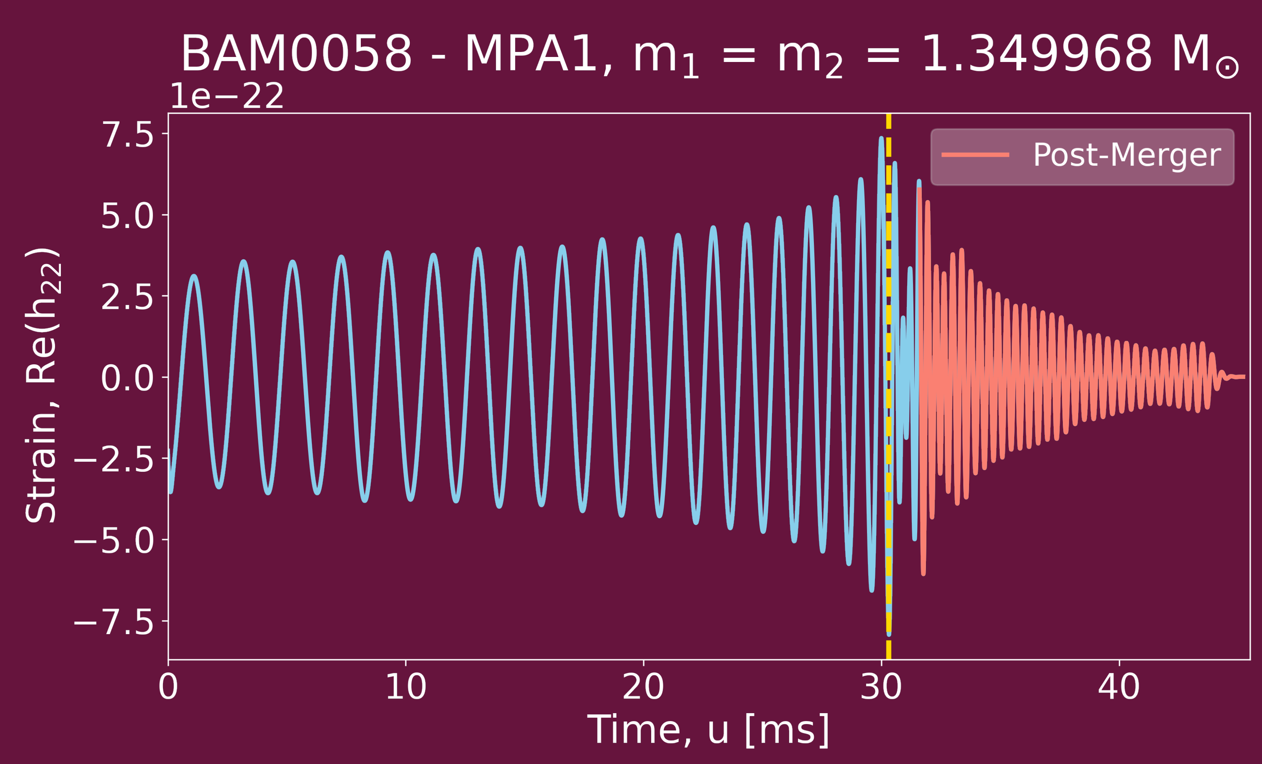
We show the gravitational wave strain for two simulations. We choose the starting time of the PM stage to be at 1.3 ms after the maximum amplitude (yellow vertical dashed line).

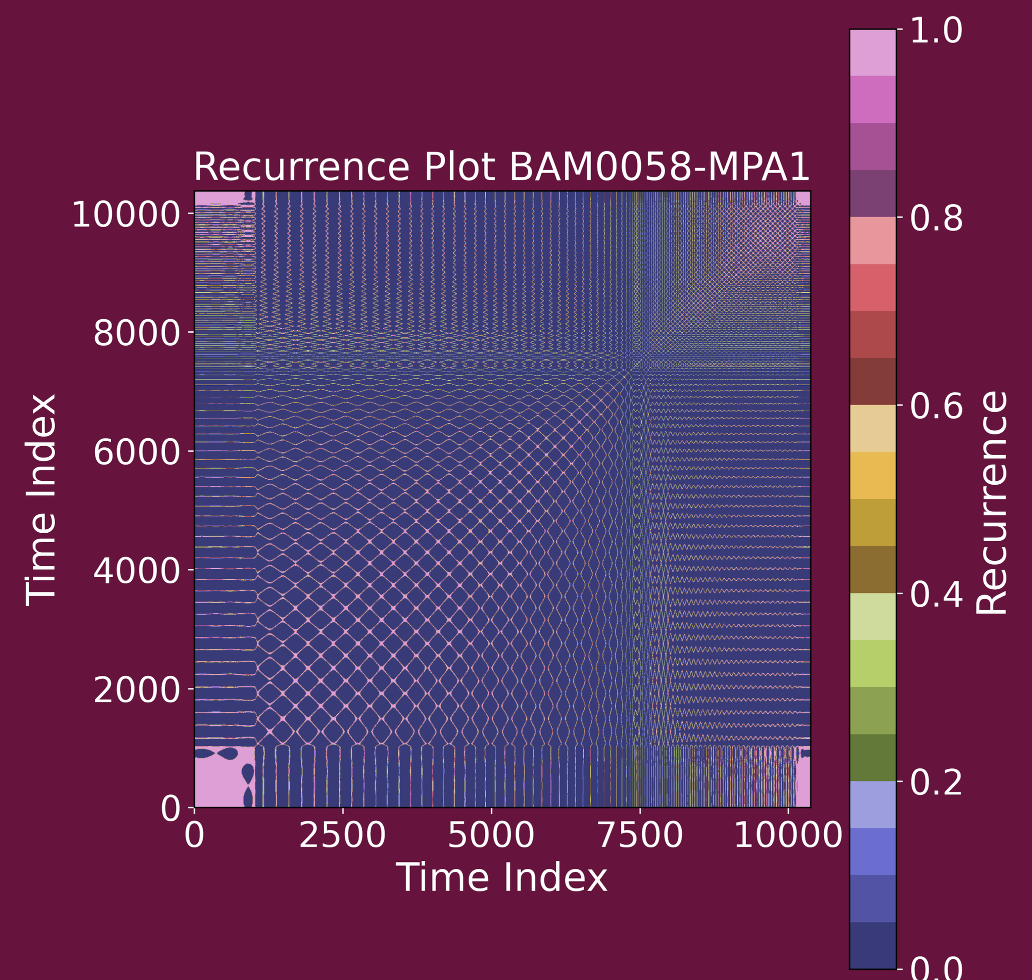
The RPs of each simulation show different patterns along the evolution of the signal. The more regular the pattern is, the system is passing through a periodic oscillation, as can be seen during the inspiral of BAM0058. The increasing amplitude and then the damped-like behavior of the post-merger is represented by a structure that seems to be drifting towards the upper right corner.

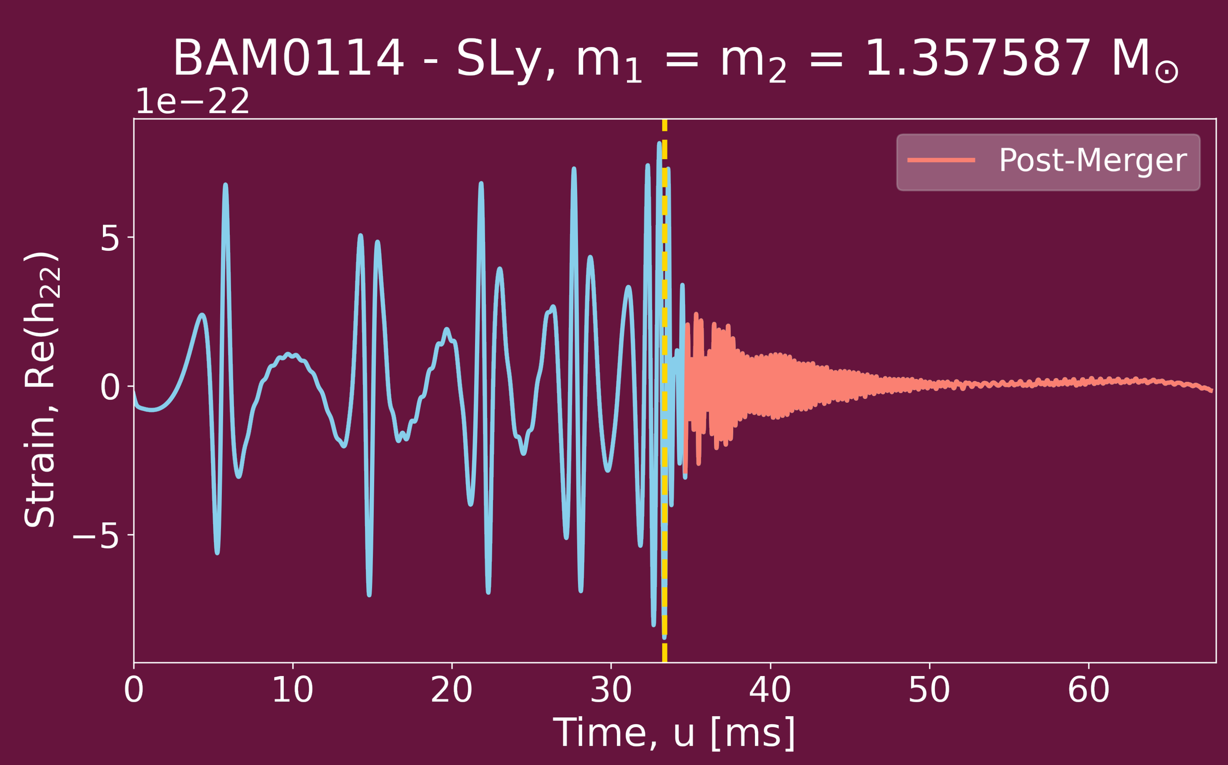
It is interesting to see that when the behavior is more complex, the structure is very particular, as seen in the RP of BAM0114.

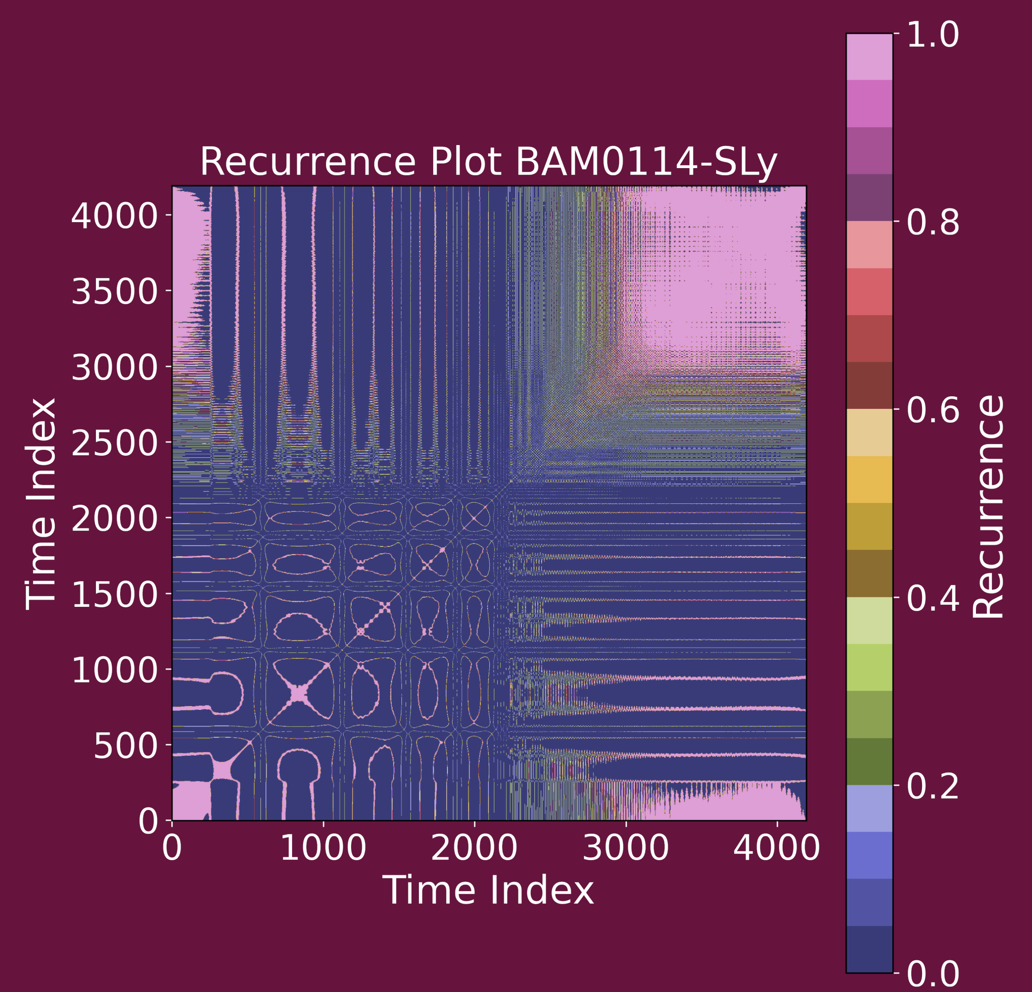
The recurrence plots can be quantified by metrics such as: Recurrence Rate (RR), Determinism (DET) and Entropy (ENT). The metrics for the simulations presented in this work are:

RQA Metrics BAM0058:	RQA Metrics BAM0114:
RR: 0.0966	RR: 0.1745
DET: 0.9971	DET: 0.9024
ENT: 2.8139	ENT: 2.3476









Perspectives

A more sensitive quantification analysis will be done in order to characterize better the dynamics of the post-merger phase for these and other BNS simulations of the CoRe Database.

References

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