Research Report
ICRR Inter-University Research Program 2020

Research Subject:
(F08) Eccentric Binary Black Hole Waveform Template
(F09) Gravitational Wave Trigger Based on Deep Learning

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Summary of Research Result：

(F08) Eccentric Binary Black Hole Waveform Template
In this project, we publish two papers:

1) Measuring the eccentricity of binary black holes in GWTC-1 by using the inspiral-only waveform

In this article, we estimate the eccentricity of 10 binary black holes (BBHs) in `GWTC-1` by using the inspiral-only BBH waveform template `EccentricFD`. First, we test our method with simulated eccentric BBHs. Afterwards we apply the method to real BBH gravitational wave data. We find that the BBHs in `GWTC-1`, with the exception of GW151226, GW170608 and GW170729, show very small eccentricity. Their upper limits on eccentricity range from 0.033–0.084 with 90% credible interval at a reference frequency of 10 Hz. For GW151226, GW170608 and GW170729, the upper limits are higher than 0.1. The relatively large eccentricity of GW151226 and GW170729 is probably due to ignoring $\chi_{\rm eff}$ and the low signal-to-noise ratio, and GW170608 is worthy of follow-up research. We also point out the limitations of the inspiral-only non-spinning waveform template in eccentricity measurement. Measurement of BBH eccentricity helps us to understand its formation mechanism. With an increase in the number of BBH gravitational-wave events and a more complete eccentric BBH waveform template, this will become a viable method in the near future.

2) Validating the effective-one-body numerical-relativity waveform models for spin-aligned binary black holes along eccentric orbits

Effective-one-body (EOB) numerical-relativity (NR) waveform models for spin-aligned binary black holes (BBHs), known as the SEOBNR waveform models, are based on the EOB theoretical framework and NR simulations. SEOBNR models have played an important role in the LIGO Scientific Collaboration (LSC) gravitational wave (GW) data analysis for both signal search and parameter estimation. SEOBNR models for quasicircular orbits have evolved through version 1 to version 4 by extending their validity domain and including more NR results. Along another direction, we recently extended the SEOBNRv1 model to the SEOBNRE model which is valid for spin-aligned BBH coalescence along eccentric orbits. In this paper we validate this theoretical waveform model by comparing them against the NR simulation bank, simulating extreme spacetimes (SXS) catalog. In total, 278 NR waveforms are investigated which include binaries with large eccentricity; large spin and large mass ratio. Our SEOBNRE can model the NR waveforms quite well. The fitting factor for most of the 278 waveforms is larger than 99%. It indicates that the SEOBNRE model could be used as template waveforms for eccentric spin-aligned BBH coalescence. Moreover, we investigate the limitation in using circular BBH waveform templates in the Advanced LIGO and Einstein Telescope era.

(F09) Gravitational Wave Trigger Based on Deep Learning

In this project, we publish one paper:

1) Gravitational-wave signal recognition of LIGO data by deep learning

The deep learning method has developed very fast as a tool for data analysis in recent years. Moreover, as a technique, it is quite promising as a way to analyze gravitational-wave detection data. Multiple works in the literature have already used deep learning to process simulated gravitational-wave data. In this paper, we apply deep learning to LIGO data. In order to improve the weak signal recognition, we design a new structure of the convolutional neural network (CNN). The key feature of our new CNN structure is the sensing layer. This layer mimics matched filtering but is different from the usual matched-filtering technique. Usually, the matched-filtering technique uses a full template bank to match the data. However, our sensing layer only uses tens of waveforms. Our new convolutional neural network admits comparable accuracy and efficiency of signal recognition compared to other deep learning works published in the literature. Based on our new CNN, we can clearly recognize the 11 confirmed gravitational-wave events included in O1 and O2. In addition, we find about 2000 gravitational-wave triggers in O1 data.

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