Form 8

Research Result Report
ICRR Inter-University Research Program 2023

Research Subject:

Developing a template-free method of searching gravitational wave signals with autoregressive modeling

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Summary of Research Result :

We have finalized a novel de-noising technique — sequential Autoregressive integrated moving-average model (seqARIMA). With a series of experiments, we have demonstrated that seqARIMA can achieve desirable performance in both simulated data and the real gravitational wave time series obtained by LIGO. It is efficient in removing the spectral lines and the non-stationarity which are commonly found in the raw data.

Using the simulated data with well-defined waveforms injected in noises of different levels, we have compared the performance of extracting the waveform by ARIMA and the conventional frequency-domain whitening. For quantifying the comparison, we have adopted two performance metrics: (i) cross-correlation function (CCF) between the original waveform and the extracted waveform, and (ii) root-mean-square error (RMSE). We have shown that seqARIMA has better performance in comparison with whitening in terms of preserving the fidelity of the injected signal and reducing the noise level. At the distance d > 1 Gpc, seqARIMA is generally superior to whitening inn extracting the signals.

We have also applied our method in extracting a number of real gravitational wave events from the LIGO data. All 11 events enlisted in GWTC-1 catalog can be well recovered by seqARIMA. We have further tested the method in two additional sources GW190814 (mass-gap object) and GW200105 (neutron star-black hole merger), which

have the timescale of their GW signals different from those in GWTC-1. We showed their signals can also be successfully extracted. We have further compared the CCF and RMSE resulted from both seqARIMA and whitening by comparing the noise-subtracted time series of these events with the model waveforms generated in accordance with the parameters specified in the corresponding literature. We found that seqARIMA generally yields improvement over whitening in terms of these performance metrics.

For the next stage, we aim to explore the feasibility of constructing a low-latency detection pipe with the novel de-noising technique we have developed, namely seqARIMA. The major advantage of this framework is template-free, which enables us to detect a gravitational wave signal without a priori acknowledgement of their waveforms.

By coupling our de-noising technique seqARIMA with various anomaly detection algorithms (e.g. auto-encoder), we will carry out a series of experiments by streaming the data during observation runs 1 and 2 (i.e. O1-2) into our framework and see if all the confirmed events can be recovered. Also, this allows us to empirically examine the false alarm rate of our framework.

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