Measuring Impacts of Glitch Removal on Gravitational Wave Parameter Estimation

No scientific endeavor ever runs flawlessly. There are always malfunctions and interference that cause the data to be less than perfect. In the case of gravitational wave data, one of the defects often found in the signals are noise transients, called glitches. These glitches are often difficult to model due to their non-Gaussian nature. It is not currently routine practice to remove them, although sometimes glitch subtraction must be done when the glitch strongly interferes with the signal. Each glitch is unique, and there are certain glitch parameters that cannot be found using an algorithm, because the algorithm has not yet been constructed. If we were able to calculate these parameters in an automated way, it would greatly improve the process of glitch removal. Additionally, the process of glitch subtraction has not yet been tested and documented in a systematic way. We hope to add to the documentation on the effects of glitch removal on parameter estimation by running parameter estimation on a data set of simulated signals with glitches injected at varying distances from the signal. We will then remove the glitch from the data and run parameter estimation on the clean waveform. This will allow us to study how the distance between the glitch and the signal plays a role in the accuracy of the parameter estimation. We have yet to draw any conclusions, but we anticipate that there may be a distance at which the glitch subtraction has negligible effect on estimating parameters.

Constraining the Properties of Kilonovae Based on Zwicky Transient Facility Searches for 13 Neutron Star Mergers

In their third observing run (O3), LIGO and Virgo detected gravitational-wave (GW) candidates from several neutron star-black hole (NSBH) and binary neutron star (BNS) mergers. The Zwicky Transient Facility (ZTF), an optical time-domain survey telescope, followed-up thirteen of these GW events in search of Kilonovae (KNe; electromagnetic counterparts to GW events). However, no KNe were found. To assess the implications on potential KN emission based on the upper limits, empirical limits on the KN peak magnitude and evolution rate were determined. One shortcoming of these analyses was the assumption that all peak magnitudes and evolution rates are equally likely. In this work, we present a method to improve upon this assumption by comparing to light curves generated using radiative-transport based KN models, parameterized by ejecta mass and inclination angle. Specifically, we construct priors informed by these KN models to identify regions of parameter space where particular luminosities and evolution rates are improbable. We factor color evolution into the decay rates, important as observations of GW170817 have shown that photometric behavior of a KN differs in different bands. Using our band-specific priors, more realistic constraints are placed on KN source properties. Finally, we close with an application of this methodology to derive constraints on KN ejecta masses.

Using adaptive filtering to track long-transient gravitational waves with varying frequency and amplitude

Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo have observed transient gravitational wave (GW) signals from compact binary coalescences. Yet undetected GWs from other types of sources, including quasimonochromatic continuous waves (CW) from individual spinning neutron stars and long-transient signals from newly born neutron stars, are of interest. We explore the capability of an adaptive filter, named “iWave”, to track and detect weak CW or long-transient GW signals and quantify the sensitivity. This new tracking method, operating on time-series data, provides an efficient alternative to existing frequency-domain matched filter search methods. We demonstrate that it can be used in follow-ups of binary neutron star postmerger remnants. Further, we discuss the application of iWave to tracking and removing narrow-band instrumental spectral lines from the interferometric data, which could obscure astrophysical signals at the frequencies where they occur.

Do Binary Black Hole Merger Events Observed by LIGO and Virgo in their Third Observing Run Agree with Waveforms from General Relativity? A Study of Residuals

We present the study of fitness of General Relativity-predicted waveform models to binary black hole signal data from LIGO and Virgo's third observing run (O3). The data series observed by LIGO and V irgo are composed of both a merger signal and instrumental noise. Our hypothesis is that, should a waveform template predicted by General Relativity be fitted to approximate the merger signal then subtracted from the data series, what should be left over is a residual made up of pure instrumental noise. Thus, our objective is to determine if GR waveform templates accurately model O3 binary black hole signal data by creating a digital signal processing script that will derive a best fit waveform template from event parameters, subtract the template from the event data series, and then run a variety of statistical tests on the resulting residual to determine no residual signal remains.

Studying the Properties of Higher Order Modes in Gravitational Wave Emission from Binary Black Hole Merger Events

Advanced LIGO and Advanced Virgo have confidently detected gravitational wave signals from ten binary black hole mergers and one merger from a binary neutron star. Each observation contains encoded information about the physical properties of the binary system. As the detectors continue to improve their sensitivity, these developments will allow us to detect rarer systems and make more confident statements regarding their source properties. In order to fully characterize the gravitational wave observations, we rely on numerical and analytical models that approximate the signal waveforms from the emitted source as specified by the source parameters (masses, spins, sky location, etc). The dominant emission frequency of gravitational waves from compact binary coalescence is at twice the orbital frequency; however, recently published events have demonstrated subdominant higher order harmonic contributions. The primary focus of this study is to explore higher order modes in gravitational wave signals with newly improved signal models.

Detectability of Nonlinear Gravitational Wave Memory

Abstract Gravitational waves passing through a region of spacetime leave behind a permanent distortion, with strain typically on the order of 1e-23, the so-called memory effect. Linear and nonlinear components exist in gravitational wave memory, the latter appearing as a non-oscillatory, cumulative signal. Current gravitational wave detectors have not yet been able to reliably detect and isolate this low-frequency, nonlinear component which skews the numerical inferences of gravitational wave source parameters. Because this effect is cumulative, it is non-negligible, and its non-oscillatory nature distinguishes it from the rest of the waveform, making it detectable, in theory. Though previous studies have quantified and suggested improvements for the detectability of nonlinear memory, more templates and new data are available than ever before. In this project, we apply Bayesian parameter estimation to simulated gravitational waves from compact binary coalescences with memory to determine nonlinear memory detectability.

Detectability of Quantum Effects in Gravitational Waves Emitted by Binary Black Hole Mergers

Gravitational wave detectors such as Advanced LIGO and Advanced Virgo provide a test of the theory of General relativity in the strong-field, highly dynamical regime, such as in compact binary coalescences. General Relativity, a purely classical theory, does not incorporate quantum mechanics. It is thought, however, that quantum mechanics must modify gravity; quantum uncertainty must manifest itself during the merger of two black hole horizons. These quantum mechanical effects could be observable in gravitational waves detected by LIGO as small perturbations in the signal waveform and higher harmonics, not explainable by current understandings of general relativity. We propose to study the detectability of such quantum mechanical effects from binary black hole mergers for future LIGO observations.

An Investigation on the Effects of Non-Gaussian Noise Transients and Their Mitigations to Tests of General Relativity

The detection of gravitational waves from compact binary coalescence by Advanced LIGO and Advanced Virgo provides an opportunity to study the strong-field, highly-relativistic regime of gravity. Gravitational-wave tests of General Relativity (GR) typically assume Gaussian and stationary detector noise, thus do not account for non-Gaussian, transient noise features (glitches). We present the false deviations from GR obtained by performing parameterized gravitational-wave tests on simulated signals from binary-black-hole coalescence overlapped with instrumental glitches. We then separately apply three glitch mitigation methods and evaluate their effect on reducing false deviations from GR.

Effects of Different Data Quality Veto Methods in the PyCBC Search for Compact Binary Coalescences

The PyCBC search pipeline has been used since the first gravitational wave detection made by Advanced LIGO and continues to be used today in the search for gravitational waves. To identify gravitational waves from compact binary coalescences, PyCBC runs a matched filtering and chi-squared consistency test to determine significant signal-to-noise ratios and compares triggers to previously modeled templates. To confidently detect gravitational waves, we need to mitigate noisy data, which in return improves the sensitivity of searches. Current veto methods use data quality flags to veto and remove triggers in LIGO data that are believed to have terrestrial origin, though these methods risk accidentally removing signals and must be finely tuned to prevent a decrease in the search sensitivity. In this investigation, we test different veto methods based on the current set of data quality flags and detector characterization tools. We analyze how simulated signals are recovered by the PyCBC pipeline and the overall change in the sensitivity of the pipeline. Our results show an improved veto method that increases the significance of signals and the overall number of detectable signals without removing data. The results of this investigation can be implemented in the PyCBC search pipeline in future observation runs held by LIGO as a data quality tool to improve the search for gravitational waves from compact binary coalescences.