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Locating Gravitational Waves with BayesWave

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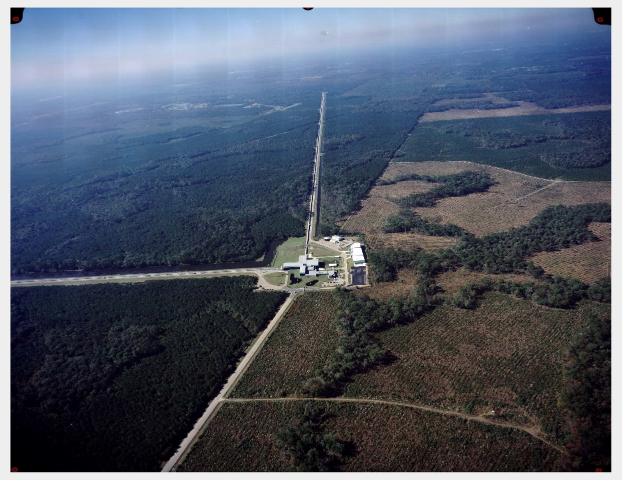
Abstract

LIGO is the Laser Interferometer Gravitational Wave Observatory. Its mission is to detect gravitational waves that could be caused by the interaction of massive gravitating bodies such as coalescing black holes, in-spiraling neutron stars, etc. BayesWave is an algorithm that can analyze possible gravitational wave event data and determine the properties of candidate events such as sky location. This algorithm uses a combination of Bayesian probability theory and the Reverse Jump Markov chain Monte Carlo (RJMcMC) method to accomplish this goal. BayesWave is able to simultaneously model the gravitational wave signal the noise by using multi-component models. It uses the RJMcMC to simultaneously perform model selection and fully sample the posterior, to stimate model parameters. This study applies BayesWave to mock events in order to measure its efficacy and compare it with other parameter estimation methods.

What is LIGO?

LIGO or the Laser Interferometer Gravitational Wave Observatory is an observatory that is dedicated to the detection of gravitational waves There are two detectors; one in Hanford Washington and the other in Livingston, Louisiana. LIGO is currently undergoing a transition phase to Advanced LIGO or aLIGO which will be doing its first observing run this year.



BayesWave

BayesWave is an algorithm that utilizes Bayesian probability theory, Markov chain Monte Carlo (McMC), and Reverse Jump Markov chain Monte Carlo (RJMcMC) methods to analyze and the characteristics of a gravitational wave. These characteristics include sky location, and signal and noise features such as frequency content and duration. BayesWave uses the McMC to search over all possible sky locations by sampling the posterior distribution function. To model the noise and signal of a gravitational wave, the algorithm uses a three layer model that includes a gravitational wave signal, short duration noise "glitches", and Gaussian noise.

$$[1]\quad s_i(t) = \begin{cases} n_i(t) \\ n_i(t) + A_i(t,\theta,\phi)h(t) \\ n_i(t) + g_i(t) \end{cases}$$

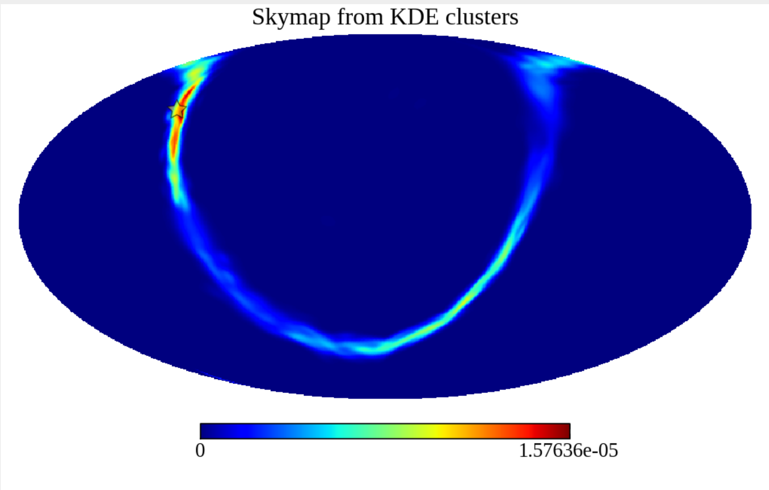
The s_i are data samples from the ith detector, h is gravitational wave strain. A_i is an operator that maps the strain at the geocenter onto the ith detector. The g_i represents a glitch from the ith detector and n_i is the Gaussian noise.

$$[2]\,\Psi(t;A,f_0,Q,t_0,\phi_0) = Ae^{-(t-t_0)^2/\tau^2}\cos(2\pi f_0(t-t_0)+\phi_0)$$

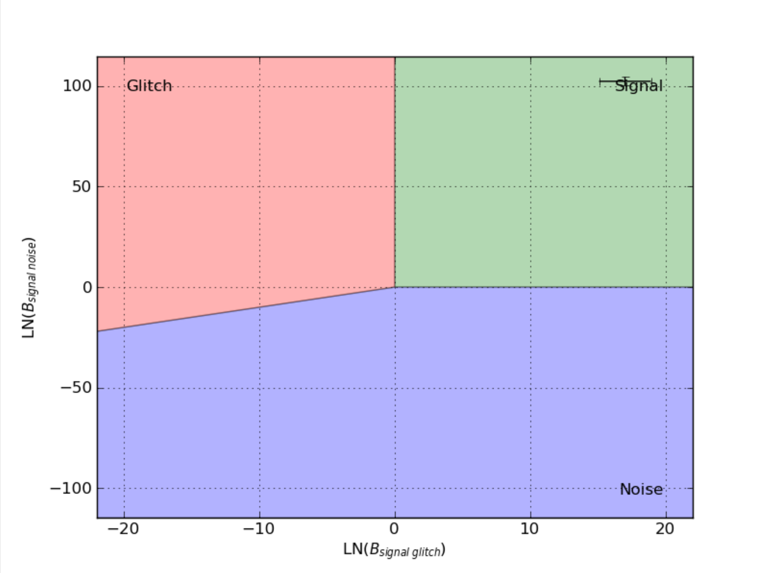
Equation [2] represents the "wave" in BayesWave. This equation is the Morlet-Gabor wavlet function. This function is the master wavelet and therefore all wavelets are derived from this function. BayesWave uses wavelets to estimate the noise and the signal of the gravitational wave.

The RJMcMC is used to calculate Bayes Factors. The Bayes Factors are relative probabilities that determine whether the data is all noise, glitch and noise, or gravitational wave signal and noise.

Results



This sky map shows the probability per square degree of the signal sky location. The star represents the actual location of the injection.



This plot shows the natural log of the Bayes Factor for signal-to-noise vs. the natural log of the Bayes Factor for signal-to-glitch.

Acknowledgements

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References

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