Enhancing the gravitational-wave burst detection confidence in expanded detector networks with the *BayesWave* pipeline

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OzGrav

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Expanded Detector Networks

The Laser Interferometer Gravitational-Wave Observatory (LIGO) has completed three observing runs (O1, O2, O3) with Virgo joining at the end of O2 and the whole of O3. The Kamioka Gravitational Wave Detector (KAGRA) also began observing at the end of O3. The global gravitational-wave detector network achieves higher detection rates, better parameter estimates, and more accurate sky localisation as number of detectors, $\mathscr{I}$, increases.

BayesWave: Unmodelled burst searches

BayesWave is a source-agnostic, Bayesian algorithm that reconstructs features in the data as a sum of sine-Gaussian wavelets. *BayesWave* can distinguish between gravitational wave (GW) signals and instrumental glitches by comparing the models where the data contains (i) GW signal + Gaussian noise and (ii) instrumental glitch + Gaussian noise.

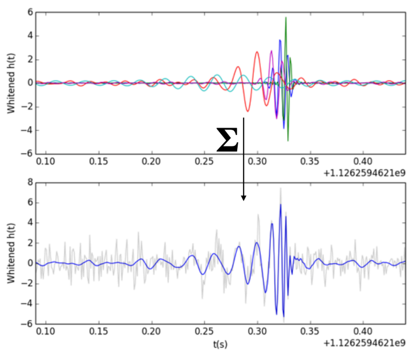

Figure 1: Top panel shows individual sine-Gaussian wavelets, each of different colour, used in the re-construction of GW150914 in the time-domain. Bottom panel shows the resulting waveform as a sum of all wavelets, overlaid on the actual data shown in grey. [Image courtesy of Meg Millhouse]

BayesWave and Expanded Detector Networks

Aim: Quantify *BayesWave*'s detection confidence as a function of number of detectors, $\mathscr{I}$, using the signal-to-glitch Bayes factor, $\mathscr{B}_{\mathcal{S},\mathcal{G}}$ (i.e. evidence ratio between signal and glitch models) as a figure of merit. The three configurations used in this study are: (i) the LIGO Hanford-Livingston (HL) network, (ii) the HL-Virgo (HLV) network and (iii) the HLV-KAGRA (HLKV) network.

Method: Inject 150 phenomenological binary black hole (BBH) waveforms into simulated Gaussian noise coloured by the projected power spectral density (PSD) of LIGO, Virgo and KAGRA for the fourth observing run (O4). The simulated BBHs in this study has equal component masses of $30M_{\odot}$ and is modelled using IMRPhenomD. [2]

Analytic Bayes factor scaling

We use Laplace approximation to the Bayesian evidence to estimate the primary scaling of the log signal-to-glitch Bayes factor, $\ln \mathscr{B}_{\mathcal{S},\mathcal{G}}$ [3]. We found that $\ln \mathscr{B}_{\mathcal{S},\mathcal{G}}$ scales mainly with $\mathscr{I}$, number of wavelets, N and signal-to-noise ratio ($\mathrm{SNR_{net}}$) of the injected waveform:

$$\ln \mathscr{B}_{\mathcal{S},\mathcal{G}} \sim \mathscr{I} N \ln \mathrm{SNR_{net}}$$

Results and Discussion

Figure 2 shows $\ln \mathscr{B}_{\mathcal{S},\mathcal{G}}$ as a function of $\mathrm{SNR_{net}}$ for the HL, HLV and HLKV networks. All three networks show a clear trend of increasing Bayes factor with increasing $\mathrm{SNR_{net}}$ as expected. We also see that injections at comparable SNRs are recovered with higher $\ln \mathscr{B}_{\mathcal{S},\mathcal{G}}$ in the HLV and HLKV network than the HL network. **Even after accounting for the increased SNR, we observe further enhancement in detection confidence for an expanded detector network.** To test the scaling of $\ln \mathscr{B}_{\mathcal{S},\mathcal{G}}$ with $\mathscr{I}$ alone, we inject a set of sine-Gaussian wavelets ($N = 1$) as coherent signals into detector noise the HL, HLV and HLKV networks and recover them using *BayesWave*. Figure 3 shows agreement between analytic and empirical results.

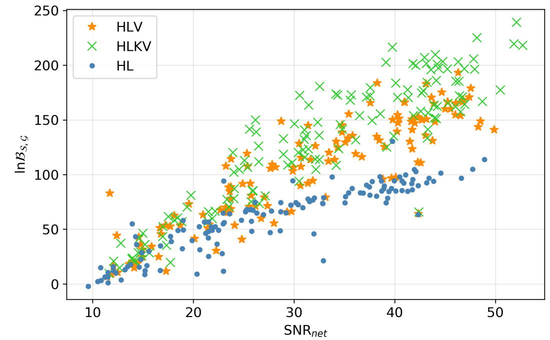

Figure 2: $\ln \mathscr{B}_{\mathcal{S},\mathcal{G}}$ of BBH injection recoveries versus $\mathrm{SNR_{net}}$. Each data point represents one BBH injection. The horizontal axis corresponds three different $\mathrm{SNR_{net}}$: (i) for the blue dots it corresponds to $\mathrm{SNR_{net}}$ of the HL network, (ii) for the orange stars it corresponds to $\mathrm{SNR_{net}}$ of the HLV network, and (iii) for the green crosses it corresponds to $\mathrm{SNR_{net}}$ of the HLKV network.

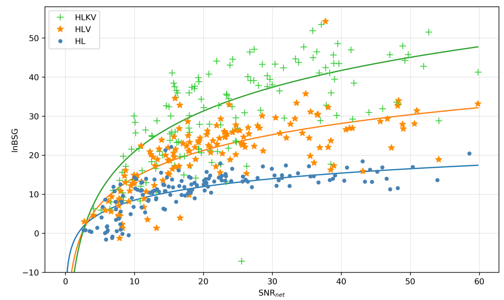

Figure 3: $\ln \mathscr{B}_{\mathcal{S},\mathcal{G}}$ of sine-Gaussian wavelet injection recoveries versus $\mathrm{SNR_{net}}$. The solid lines with colors corresponding to the data symbols are analytic predictions of $\ln \mathscr{B}_{\mathcal{S},\mathcal{G}}$.

Acknowledgement & References

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