Estimation of binary black hole coalescence event rate exclusion plots with mass and spin parameters from burst search results.

The sensitivity of burst searches have been generally expressed in terms of the root-sum-squared strain amplitudes $h_{rss}$ on a variety of waveforms such as sine-Gaussians, Gaussians and harmonic ringdowns [1]. Upper limits have been expressed as event rate versus $h_{rss}$ exclusion plots for several of these waveforms. Binary black hole coalescence Gravitational Wave (GW) signal properties depend on the mass and spin parameters of the binary system. The resulting signal in a ground-based detector’s sensitive band could be a long duration chirp (few seconds), for small mass binary system, e.g. total mass = 6 M$_\odot$ or could resemble a short duration (10 ms to < 1 s) GW burst for high mass binary system, e.g. total mass = 100 M$_\odot$. The $h_{rss}$ of these signals in a ground-based detector’s sensitive band also depends on the source parameters mass, spins and distance. This poster focuses on the high mass binary systems (> 100 M$_\odot$) and the corresponding ‘bursty’ GWs. In this poster exclusion surfaces of event rate versus mass and spin parameters of the binary black hole are estimated using published burst search results. For the binary black hole coalescence model spin-aligned phenomenological waveform [2] is used.

1. Gravitational Wave Burst Sensitivity

The $h_{rss}$-efficiency sigmoid is determined by the following equation:

$$h_{rss} = \int_{f_{min}}^{f_{max}} [h(f)]^2 df$$

In absence of detection, the 90% CL upper limit on event rate ($R_{90%}$) is estimated assuming a Poisson distribution for astrophysical events.

2. Non-precessing spinning Inspiral-Merger-Ringdown (IMR) Gravitational Wave

- Spin plays an important role. Orbital hang-up effect shows up in $h_{rss}$, efficiency and event rate upper limit plots.
- Event rate per volume is determined by the following equation:

$$R_{90%} = \frac{4\pi \chi_1 \chi_2}{\Omega_\alpha M} \frac{1}{c^2 \Omega} h^2$$

- Both $h_{rss}$ and peak-frequency determine the rate at a particular mass and spins.
- We assume a uniform mass, spin and distance distribution for the binary black hole population to estimate these upper limits.
- Integrating the event rate limit per volume over a spherical volume gives the rate per year; e.g. for a 100 M$_\odot$ binary black hole the rate estimate is 3.8 yr$^{-1}$.

3. IMR signal: efficiency with effective distance

- Detection efficiency for IMR signals injected in simulated initial LIGO noise and SNR > 5.5.
- This efficiency plot is for a uniform mass distribution from 100 to 300 M$_\odot$ and zero spin.
- $h_{rss}$ is inversely proportional to distance.
- $h_{rss}$ also depends on mass and spins of the binary black hole.
- We show $h_{rss}$-efficiency for different source parameters at 50% and 90% distance efficiency (167 Mpc and 531 Mpc respectively) in section 7 and 8.

4. IMR signal: coalescence time in LIGO band

- Coalescence time of a binary black hole system observed in LIGO sensitive frequency band.
- GWs for high mass binary system resemble short duration GW bursts.
- We focus on binary system with total mass > 100 M$_\odot$; the region of interest is shown with a black line in the figure.

5. IMR signal: expected frequency to be measured by a burst search

- Peak frequency of IMR waveform injected to simulated LIGO noise expected to be measured by a burst algorithm in m1 vs m2 space.
- This peak frequency is modeled as the frequency at which the ratio of the signal amplitude, h(f), to the noise spectra is maximum [3].

6. $h_{rss}$ in the parameter space at 50% and 90% efficiency distances

- Total mass $M = m_1 + m_2$.
- Symmetric mass ratio $\eta = m_2/M$.
- Mass weighted spin $\chi = (1+\delta)\chi_2/2$ (1-$\delta$)\chi_2$ where $\delta = (m_1-m_2)/m_1$.
- $S$ is the spin of the $i^{th}$ black hole.

7. efficiency and event rate ($R_{90%}$) upper limit in ‘m1 vs m2’ space (zero spin)

- Detection efficiency is estimated using $h_{rss}$-efficiency sigmoids from the burst search sensitivity results and from the peak-frequency profile.
- Event rate upper limit is estimated from the efficiency plot in the left.

8. efficiency and event rate ($R_{90%}$) upper limit in ‘m vs \chi’ space (equal mass)

- “Complete” gravitational waveforms for black-hole binaries with non-precessing, spinning orbiting, symmetric mass ratio $1:10$. The waveform family is parametrized with spin parameter 0.65, 0.85 and mass ratio 1:10.
- The waveform family is parametrized by: $\chi_i$, $\eta_i$ and $\chi$.

9. event rate upper limit per volume ($R_{90%}$)

- The rate estimate by this method is consistent with the rate upper limit paper [4]. The coalescence rate for a 100 M$_\odot$ binary black hole is 3.8 yr$^{-1}$ which is an order of magnitude higher than the optimistic rate.
- The rate upper limit from this method will be compared with upper limit estimates from the studies conducted in the IMR working group in the LIGO Scientific collaboration.

Conclusion and Future Plans:

- In this preliminary study we show a method of estimating binary black hole coalescence rate from burst search results.
- The efficiency estimated from the burst search $h_{rss}$-sigmoids are consistent with the IMR injection runs.
- The rate estimate by this method is consistent with the rate upper limit paper [4]. The coalescence rate for a 100 M$_\odot$ binary black hole is 3.8 yr$^{-1}$ which is an order of magnitude higher than the optimistic rate.
- The rate upper limit from this method will be compared with upper limit estimates from the studies conducted in the IMR working group in the LIGO Scientific collaboration.

References: