Compact binary merger detection for Advanced LIGO: upgrading the PyCBC search

Motivation & Summary

- 2.9 merger signals from binary black hole (BBH) systems seen in Advanced LIGO's first Observing run
- 1 BBH signal so far reported in O2 run: GW170104
- PyCBC search crucial to identifying and establishing significance of these events
- Matched filter (templated) search: optimal for signals of known form in single-ifo stationary Gaussian noise
- Optimal ranking statistic: ratio of signal event to noise event density
- Search space extended for O2 run up to maximum binary mass \( \sim 500 M_\odot \), component spin \( \sim 0.998 \)
- New methods to maintain/increase search sensitivity
- Use detectable signal distribution over the sky to reduce false alarms
- More accurate model of how noise event distributions depend on template waveform

Aligned-spin template bank in LIGO's O2 run

- O1 bank: binary mass \( M \)
  - 2 - 100 \( M_\odot \)
  - max component spin \( \sim 0.998 \)
  - Extra dense coverage in near-equal-mass BBH region
- O2 bank: binary mass \( M \)
  - 2 - 500 \( M_\odot \)
  - max component spin \( 0.998 \)
  - Very high mass/anti-aligned spin templates like 'bursts'
  - Cut off bank: impose minimum template duration 0.15s
  - Choose \( f_{\text{low}} \) to strictly limit loss of signal at low freqs

Astrophysical prior on event parameters

- LIGO detectors nearly co-aligned, strongly directional sensitivity
- Distribution of detectable signals non-uniform over
  - \( \delta t \) (LHO-LLO time difference)
  - \( \delta \phi \) (LHO-LLO phase difference)
- Modified 'signal model' ranking statistic:
  \[
  \tilde{p}^2 = p_0^2 + 2 \log \left( \frac{p^2(\theta)}{p_{\text{max}}^2} \right)
  \]

Effect on search background & sensitivity

- Signal model effectively down-ranks noise events
- Signal-noise model suppresses events in 'more noisy' templates
- O1 mass bins no longer required
- Detection efficiency increased by 10-20% compared to O1 statistic

LIGO detectors nearly co-aligned, strongly directional sensitivity

Non-Gaussian noise distributions

- LIGO detector noise contains loud non-Gaussian transient events (glitches)
- Very different distributions of search events (SNR maxima) in different templates
- Group 'similar' templates to measure variation over the bank
- Optimal ranking statistic: ratio of signal event to noise event density
  \[
  \tilde{p}^2 = 2 \log p^2(\theta) - \log p^2(\theta) + \text{const}
  \]

Effect on search background & sensitivity

- Change in detection rate using different statistics, compared to O1 search ranking
- Measured via simulated signals added to LIGO O1 data

Discussion

- More accurate models of signal and noise event distributions allow efficient search of a wider binary parameter space
- Astrophysical priors on binary mass/spin might also increase detection rate ...
- Many directions to extend framework: H1-L1-Virgo search, precessing / higher-mode signals, machine learning classifiers?

References

- A.H. Nitz et al., Detecting binary compact-object mergers with gravitational waves: Understanding and improving the sensitivity of the PyCBC search, arXiv:1705.01513