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

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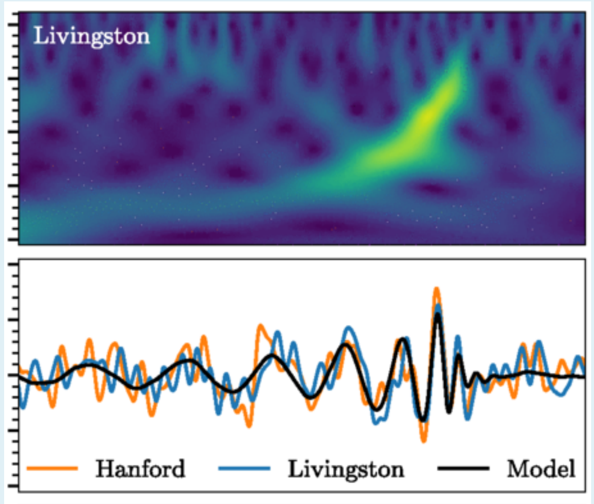
LIGO document G1700911-v2

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

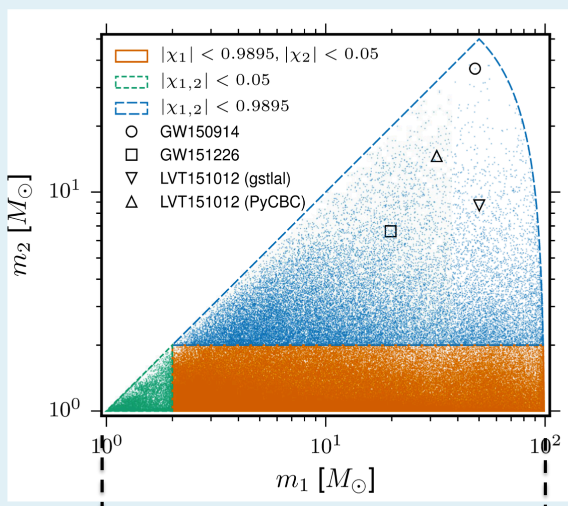


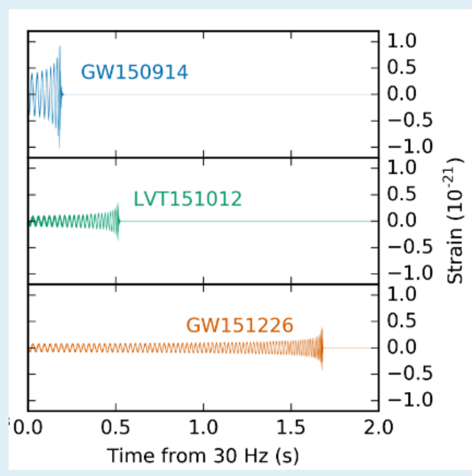
LSC&Virgo, Phys. Rev. Lett. 118, 221101

- Search space extended for O2 run up to maximum binary mass ~500 $M_\odot$, component spin ~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

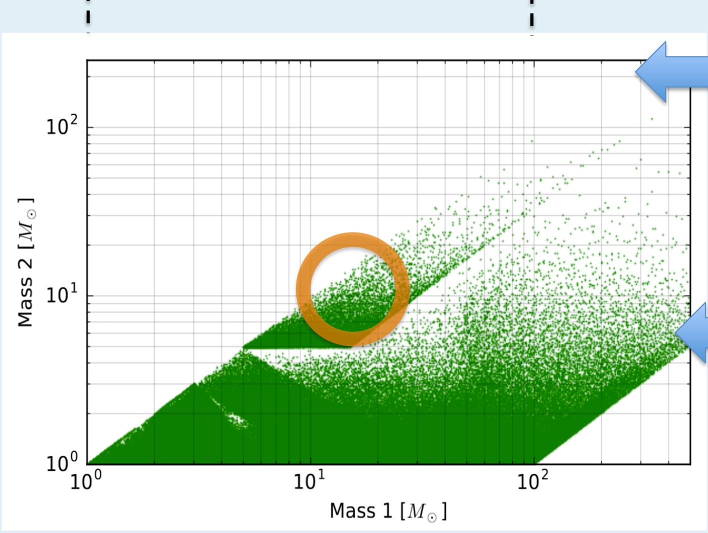
- O1 bank : binary mass M 2 - 100 $M_\odot$ max component spin ~0.9895 (non-precessing)

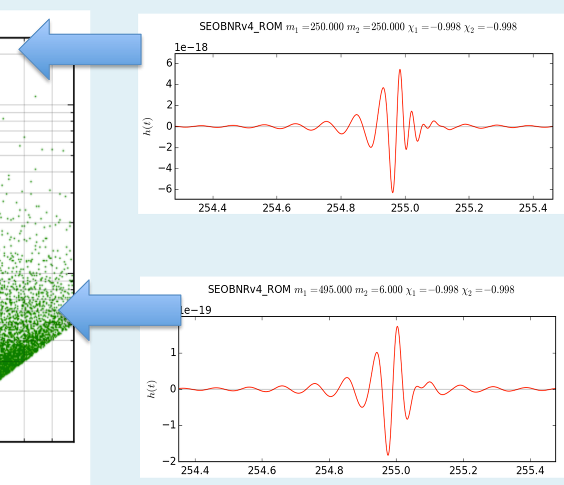




LSC&Virgo, Phys. Rev. X 6, 041015

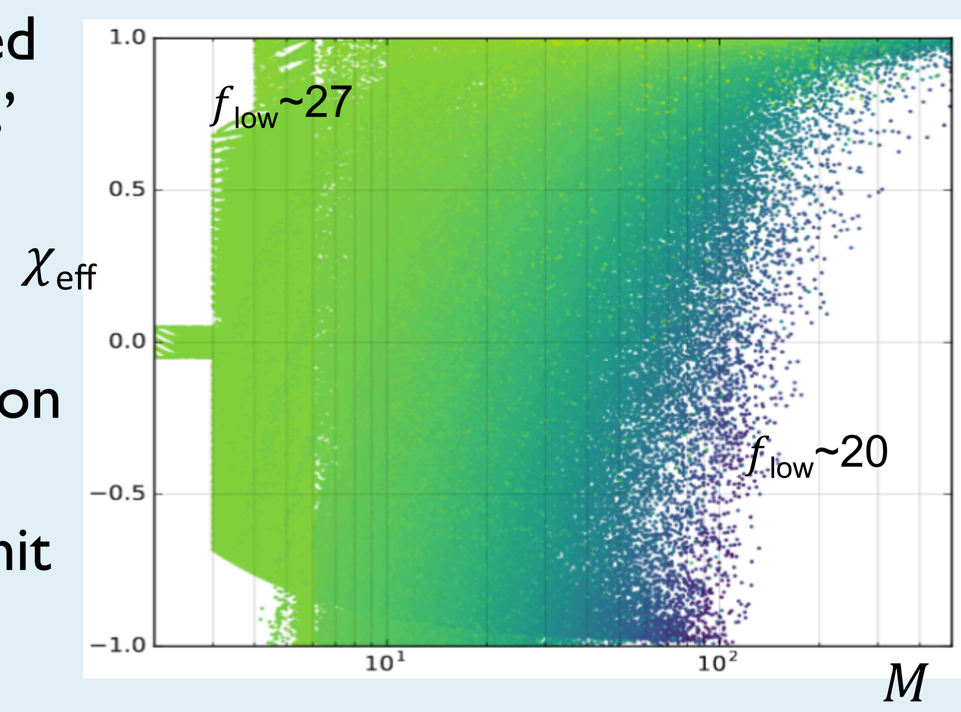
- O2 bank : binary mass M 2 - 500 $M_\odot$ max component spin 0.998 (non-precessing)





- Extra dense coverage in near-equal-mass BBH region

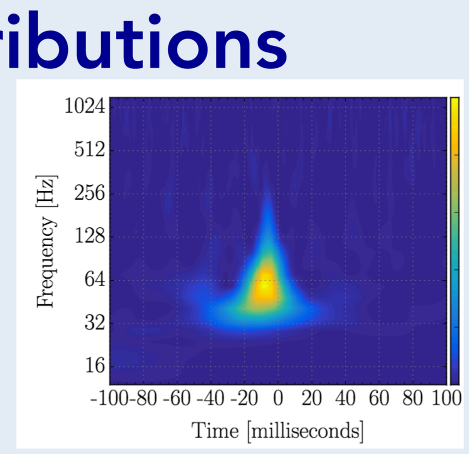
- Very high mass/anti-aligned spin templates like 'bursts'
  - templated methods less effective here
- Cut off bank : impose minimum template duration 0.15s
- Choose f_{low} to strictly limit loss of signal at low freqs



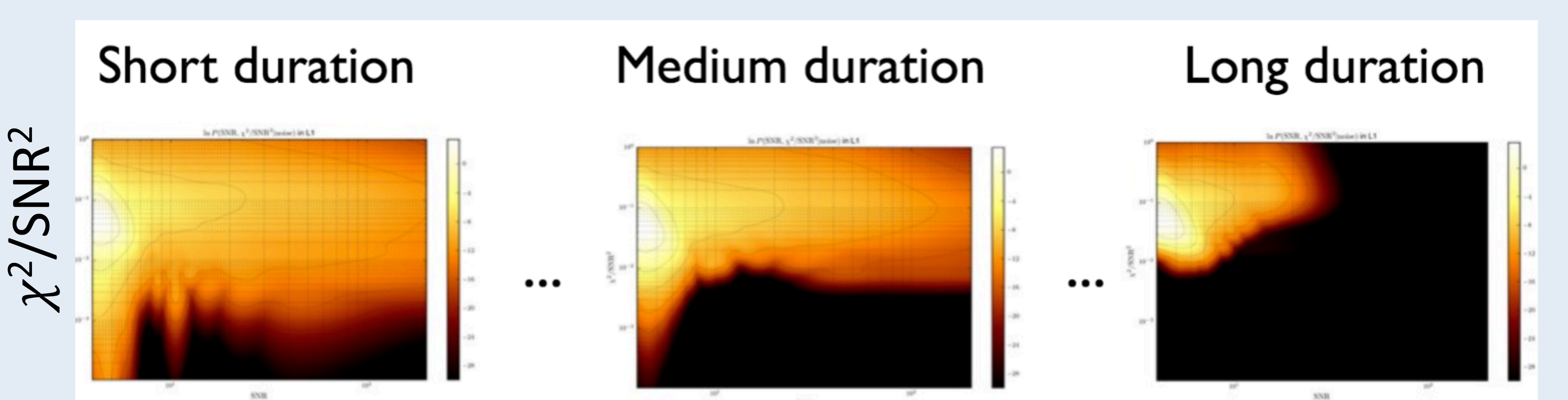
T. Dal Canton & I. Harry, arXiv:1705.01845

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



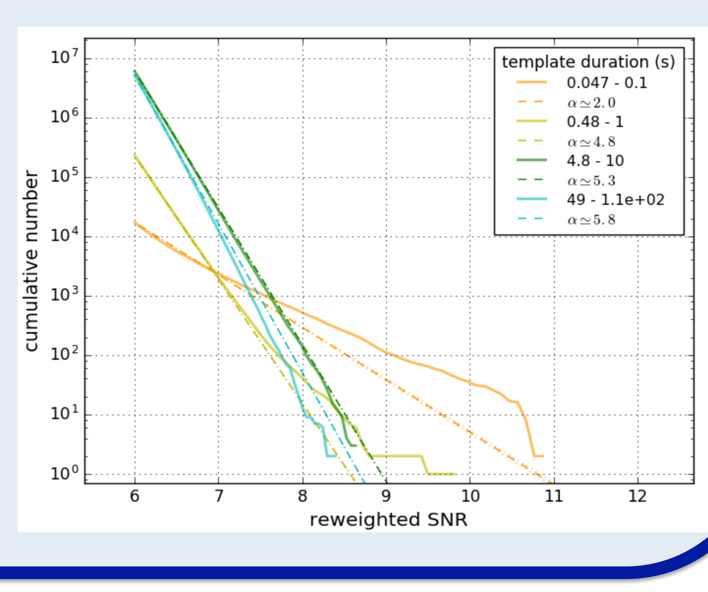
LSC&Virgo, CQG 33, 134001



PDFs of noise events from analysis of Advanced LIGO data : S. Caudill (UWM)

- Group 'similar' templates to measure variation over the bank
- Optimal ranking statistic : ratio of signal event to noise event density

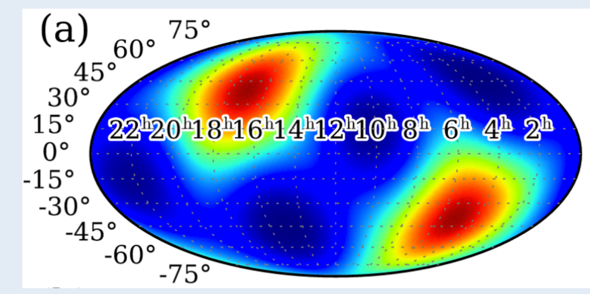
$$\rho^2 \propto 2\left[\log p^S(\vec{\theta}) - \log p^N(\vec{\theta})\right] + \text{const}$$

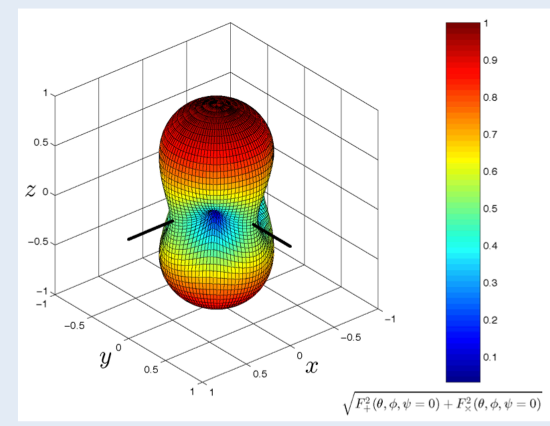


Astrophysical prior on event parameters

- LIGO detectors nearly co-aligned, strongly directional sensitivity

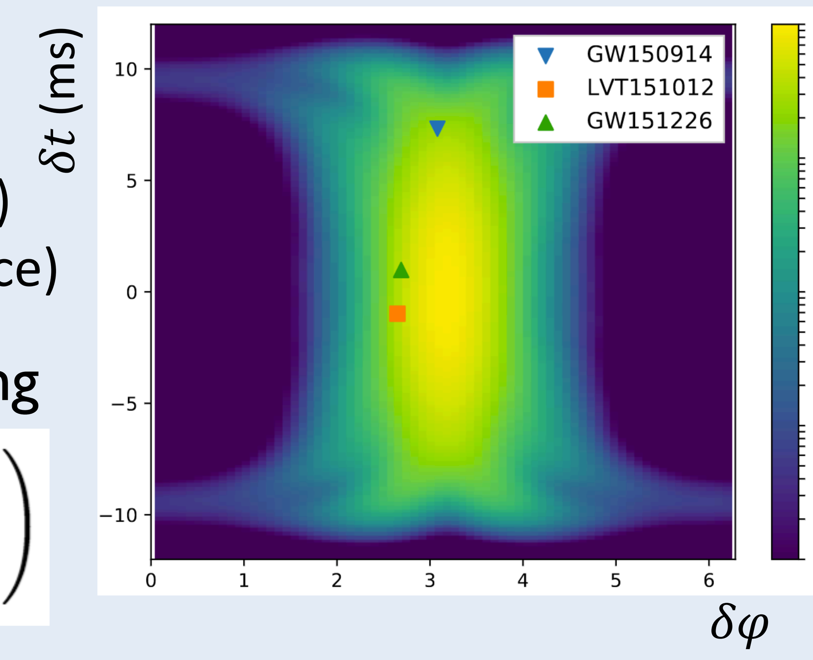
Essick et al., Astrophys.J. 83 , 31





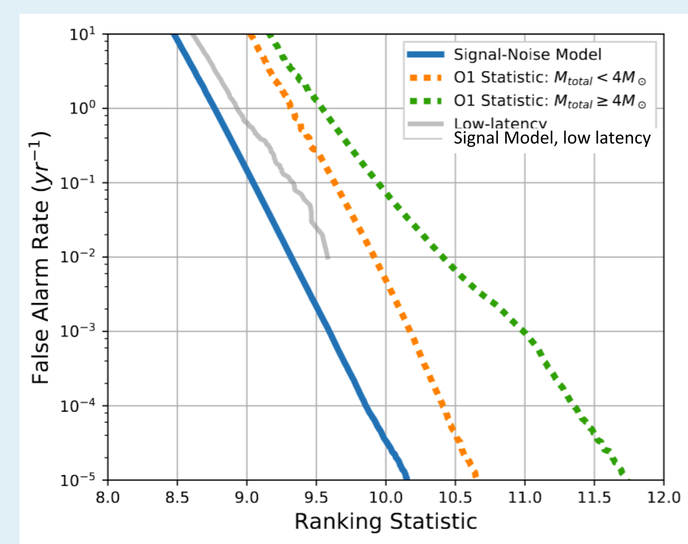
- Distribution of detectable signals non-uniform over
  - δt (LHO-LLO time difference)
  - $\delta\varphi$ (LHO-LLO phase difference)
- Modified 'signal model' ranking statistic :

$$\tilde{\rho}^2 = \hat{\rho}_c^2 + 2\log\left(\frac{p^S(\vec{\theta})}{p^S_{\max}}\right)$$



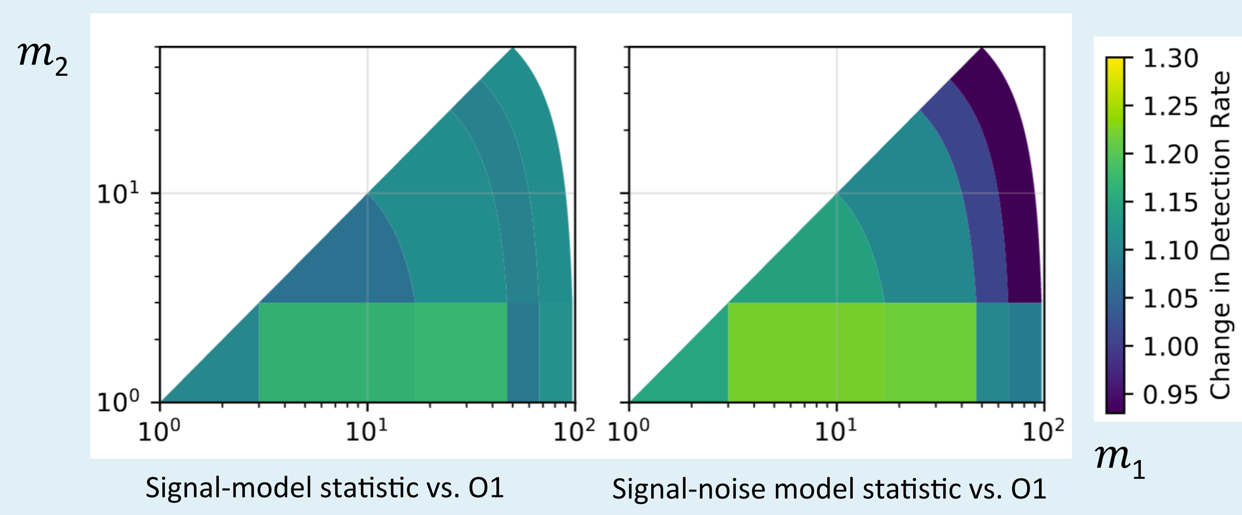
Effect on search background & sensitivity

- Signal model effectively down-ranks noise events
- Signal-noise model suppresses events in 'more noisy' templates
  - O1 mass bins no longer required



Ranking statistic vs. cumulative rate of noise events, for different choices of statistic (O1, signal-model, signal-noise-model) in LIGO O1 data

- Detection efficiency increased by 10-20% compared to O1 statistic



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
- T. Dal Canton & I.W. Harry, *Designing a template bank to observe compact binary coalescences in Advanced LIGO's second observing run*, arXiv:1705.01845