Observational implications of lowering the LIGO-Virgo alert threshold

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LVEM Town Hall, 03/16/18

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ABSTRACT

The recent detection of the binary-neutron-star merger associated with GW170817 by both LIGO-Virgo and the network of electromagnetic-spectrum observing facilities around the world has made the multi-messenger detection of gravitational-wave events a reality. These joint detections allow us to probe gravitational-wave sources in greater detail and provide us with the possibility of confidently establishing events that would not have been detected in gravitational-wave data alone. In this paper, we explore the prospects of using the electromagnetic follow-up of low-significance gravitational-wave transient event candidates to increase the sample of confident detections with electromagnetic counterparts. We find that the gravitational-wave alert threshold change that would roughly double the number of detectable astrophysical events would increase the false-alarm rate by 5 orders of magnitude from 1 per 100 years to 1000 per year. We quantify the expected purity of low-significance candidate alerts issued by LIGO-Virgo as a function of the alert threshold. Our analysis suggests that increasing the number of gravitational-wave detections via the electromagnetic follow-up observations of low-significance LIGO-Virgo events will incur significant human and opportunity costs in all-sky surveys, galaxy-targeted imaging, and large-aperture spectroscopy in the near future. Nevertheless, increases in the rate of detected gravitational-wave events may partially mitigate these costs as the Advanced LIGO-Virgo network reaches its design sensitivity.

See recent paper: arXiv:1803.02880

What can we expect to gain by lowering the EM follow-up threshold?

- Raising the false-alarm rate (FAR) threshold = greater number of detectable GW events...
  - Use FAR of 1/100 years as baseline threshold
    - Proposed LVEM alert threshold for O3
  - Ensemble measurements, like H_0, can improve by up to $(N_{detections})^{-1/2}$
    - Actual improvement may be much lower if only add low-significance events, see Chen, et. al. 2017
- ...but also means more alert contamination
  - What contamination rate EM observers handle? And what is the expected reward?

LIGO-Virgo search backgrounds are very “steep”!

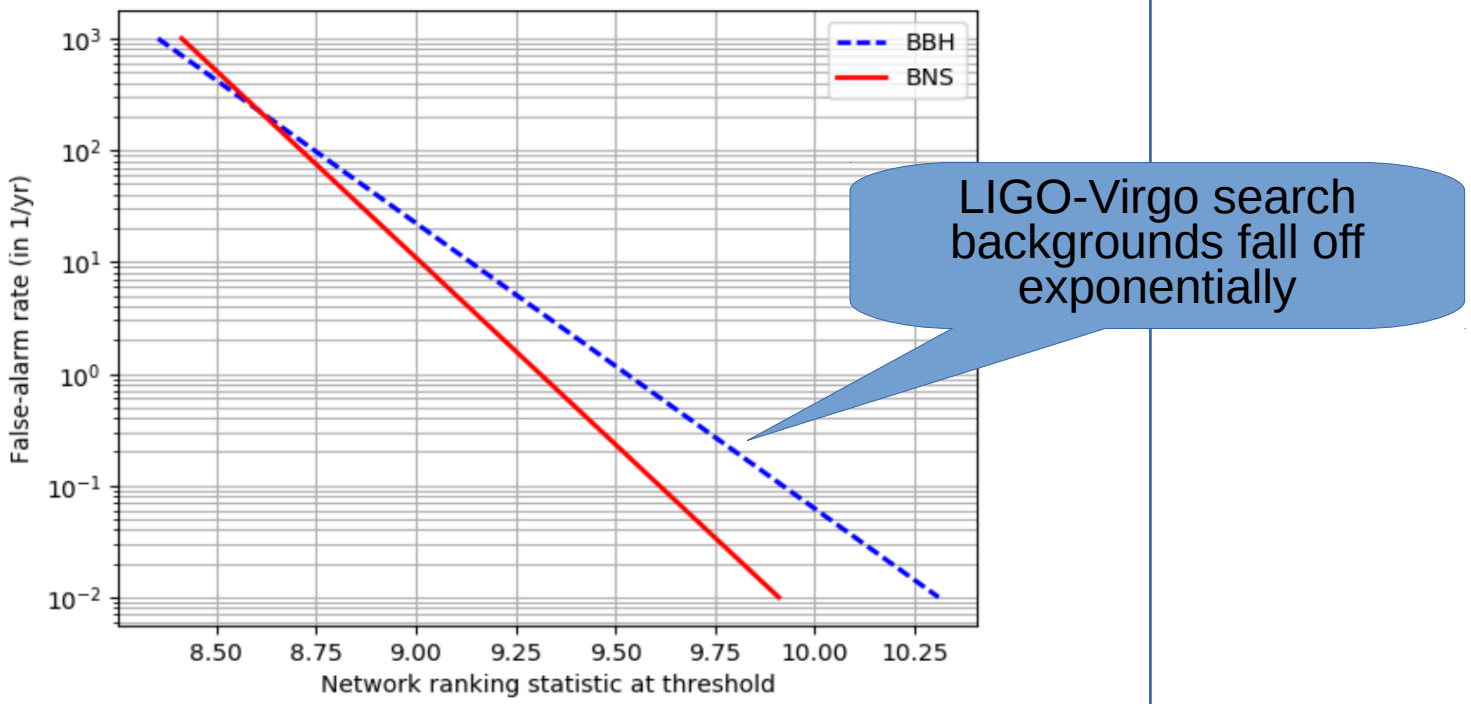
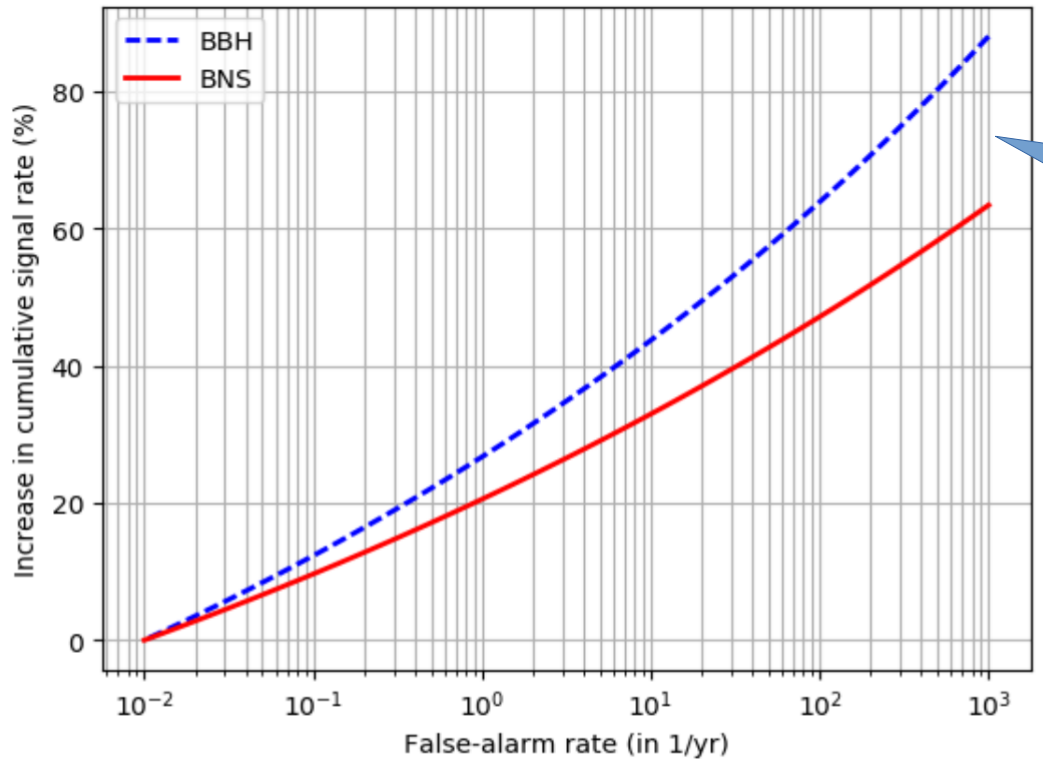


Figure 1. This log-linear plot shows the steep dependence of false-alarm rate versus the network ranking statistic (ρ) detection threshold for binary-black-hole (BBH) and binary-neutron-star (BNS) template fitting (Nitz et al. 2017). A modest $\Delta\rho = 1$ in the network ranking statistic increases the false-alarm rate by 2-3 orders of magnitude.

Changes to FAR threshold add very little to the search volume



Less than factor of 2 increase in detectable event rate

Figure 2. The relative increase in the number of GW events (in %) expected above each FAR threshold. Changing the false-alarm-rate threshold by 5 orders of magnitude increases the number of GW events by less than a factor of 2.

LVEM alert purity improves along with LIGO-Virgo sensitivity

Table 1. The probability (in %) of GW candidates being GW events (P_{GW}), as depicted in Fig. 3, at several ad hoc FAR thresholds for various LIGO-Virgo observing epochs. We also give the corresponding fractional increase of GW events (FI_{GW}) for these same thresholds. These values correspond to the median published rates for the average BBH and BNS systems (Abbott et al. 2016a, 2017e). Note that the errors on the probabilities corresponding to rate uncertainties can be large (see Fig. 3). For O2, the probability of a candidate being a GW could degrade by more than an order of magnitude for lower alert thresholds while still not doubling the number of GW events. This degradation is less severe as LIGO-Virgo improves and reaches O3 and design levels of sensitivity.

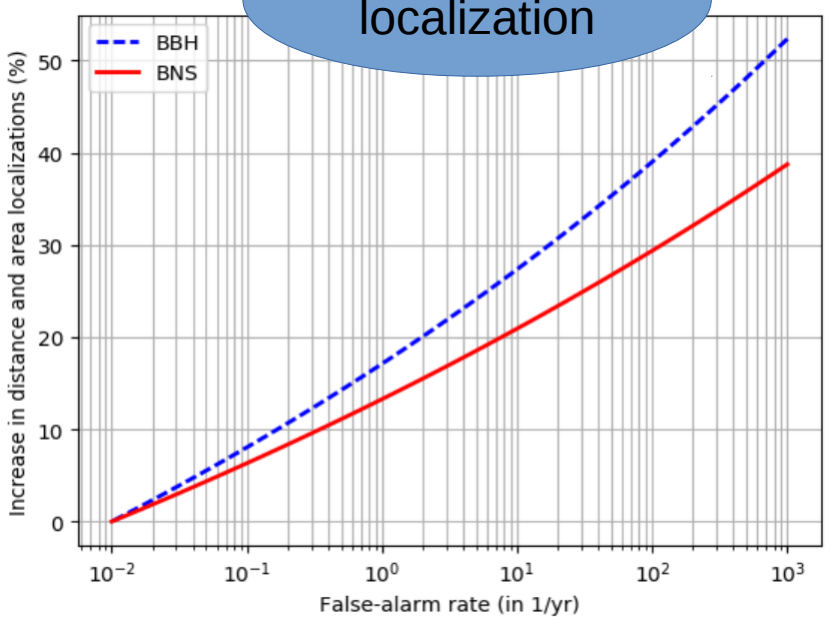
Epoch	1 per 100 years	1 per year	1 per month	1 per week	1 per day
P_{GW} O2 BBH	99.9	92.6	54.3	22.9	4.5
P_{GW} O2 BNS	99.4	66.6	15.6	4.4	0.7
P_{GW} O3 BBH	99.9	97.6	79.6	49.4	13.5
P_{GW} O3 BNS	99.8	86.9	38.2	13.2	2.3
P_{GW} Design BBH	99.9	99.4	93.8	79.3	37.9
P_{GW} Design BNS	99.9	96.6	72.6	39.4	9.2
FI_{GW} BBH	1.0	1.27	1.45	1.58	1.77
FI_{GW} BNS	1.0	1.21	1.34	1.43	1.56

Less than factor of 2 increase in detectable event rate

Event purity increases with LIGO-Virgo sensitivity

Lower SNR of threshold events → poorer localization

Area/distance localization



Volume localization

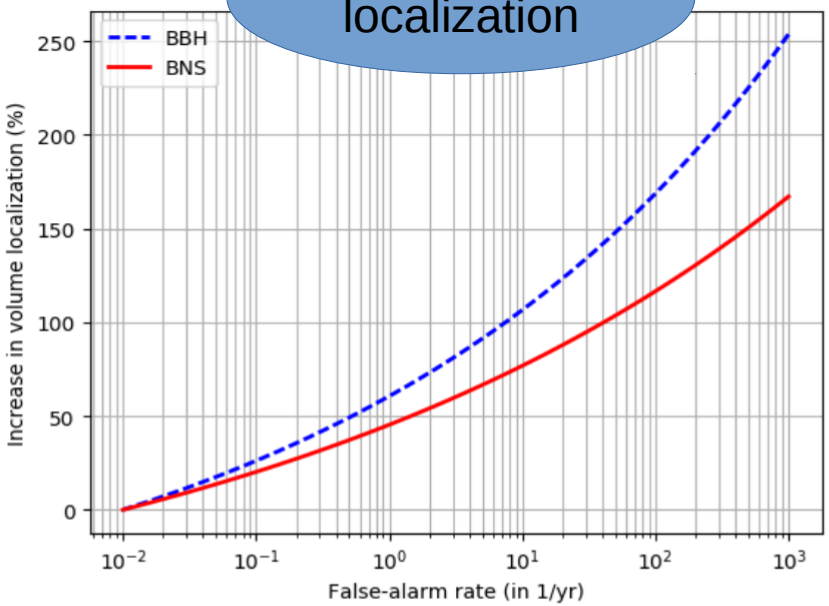
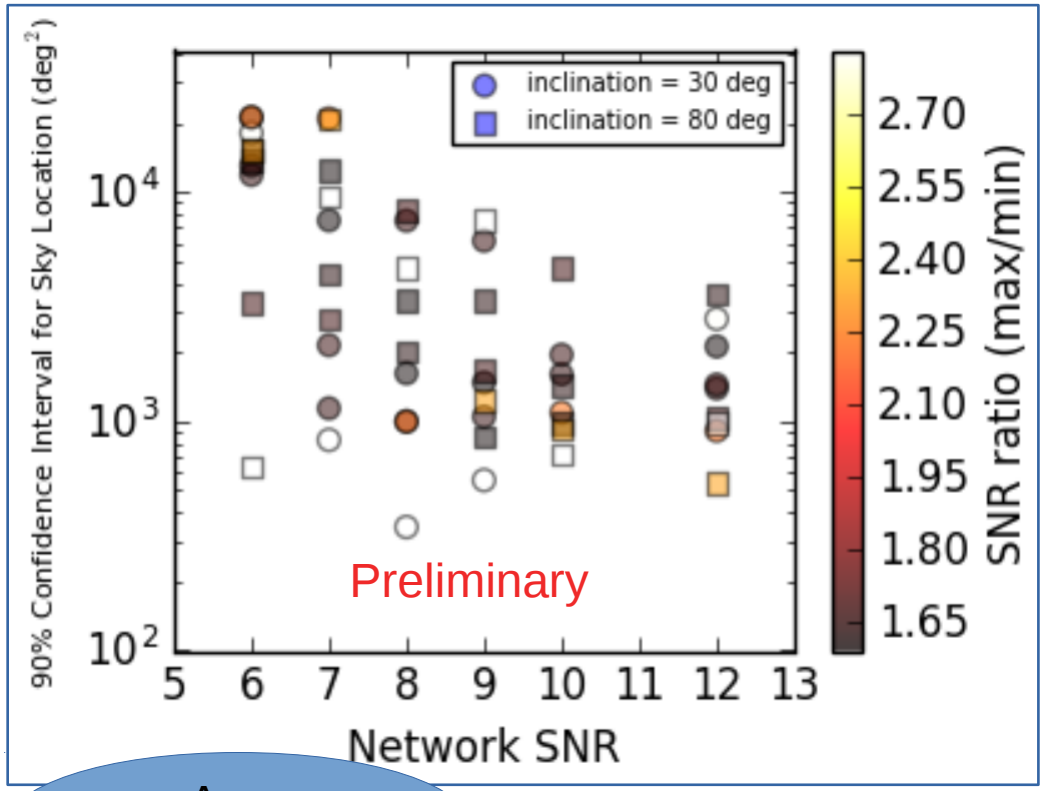
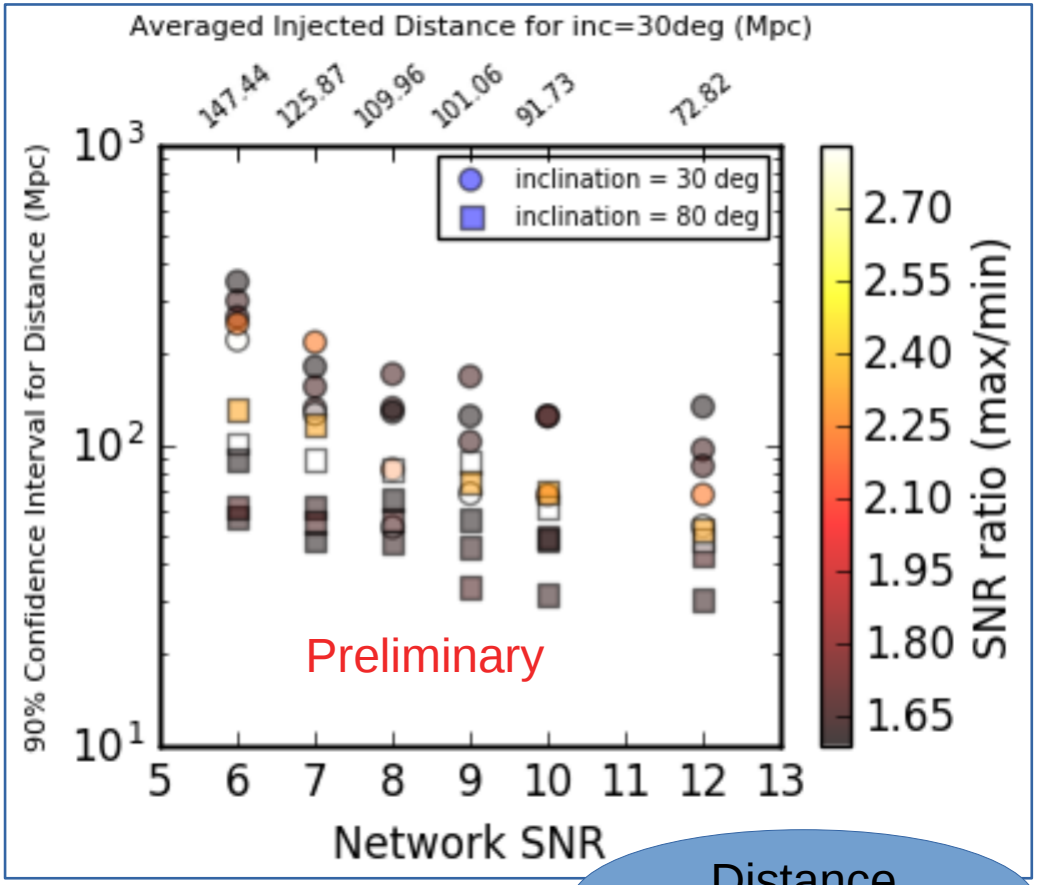


Figure 4. The relative increase (in %) in distance and angular area localizations (top) and volume localization (bottom) expected for a threshold event at each FAR. Changing the false-alarm-rate threshold by 5 orders of magnitude increases the distance and angular area localizations by less than a factor of 2 and the volume localization by less than a factor of 4.

Quantifying the poorer localization for BNS



Area localization



Distance localization

Simulations done using open-source O1 data

Takeaways

- 1.)
  - Raising the FAR threshold of LVEM alerts by 5 orders of magnitude...
  - ...will increase the number of joint GW-EM detections by less than a factor of 2
- 2.)
  - The alert purity may be low in the near future (O2 and O3)…
  - ...but increases as LIGO-Virgo approaches design sensitivity
- 3.)
  - The added detections will be low-significance events that will be more poorly localized…
  - ...i.e., they may not contribute much to measurements like H_0