ET’s Nullstream

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What are the uses of a nullstream?

1) Estimation of instrument-noise PSD
2) Detector calibration
3) GW detection in the presence of non-Gaussian noise
4) CBC parameter estimation (?)
5) Stochastic searches

ET Nullstream vs Network Nullstream

1) ET nullstream (in contrast to a network nullstream)
   a) also works in the simultaneous presence of many GW signals;
   b) is not affected by changing source directions (like in the case of BNS observations due to Earth rotation).
2) Dependence of network nullstream on source-direction estimates poses a significant limitation (e.g., see glitch vetoing slide)

Estimation of PSD of Instrument Noise

Binary neutron stars (800,000 mergers per year)

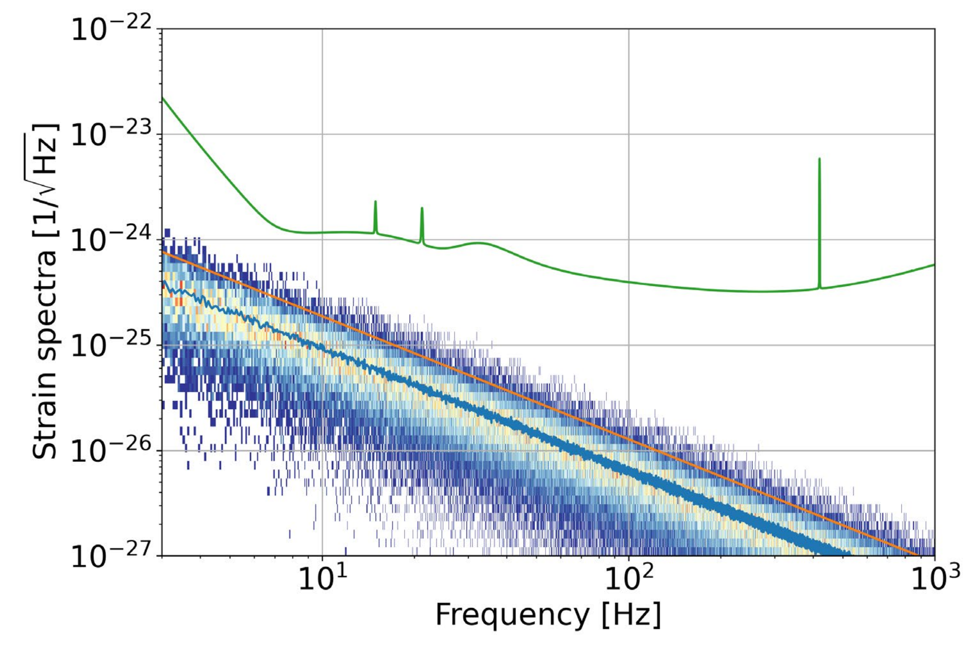
Time segment	Number of BNS contributing energy above 2Hz
1 minute	100
10 minutes	300
1 hour	500
4 hours	800
24 hours	2500

Binary black holes (100,000 mergers per year)

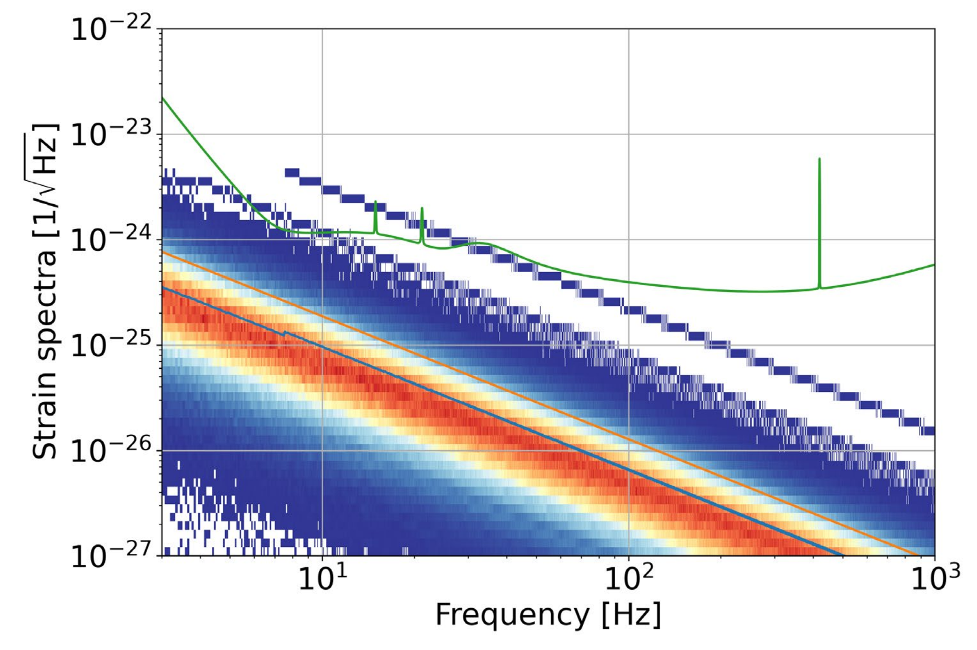
Time segment	Number of BBH contributing energy above 2Hz
1 minute	2
24 hours	300

Astrophysical Foreground: BNS

24 hours PSD/FFT time
100 PSDs forming histogram



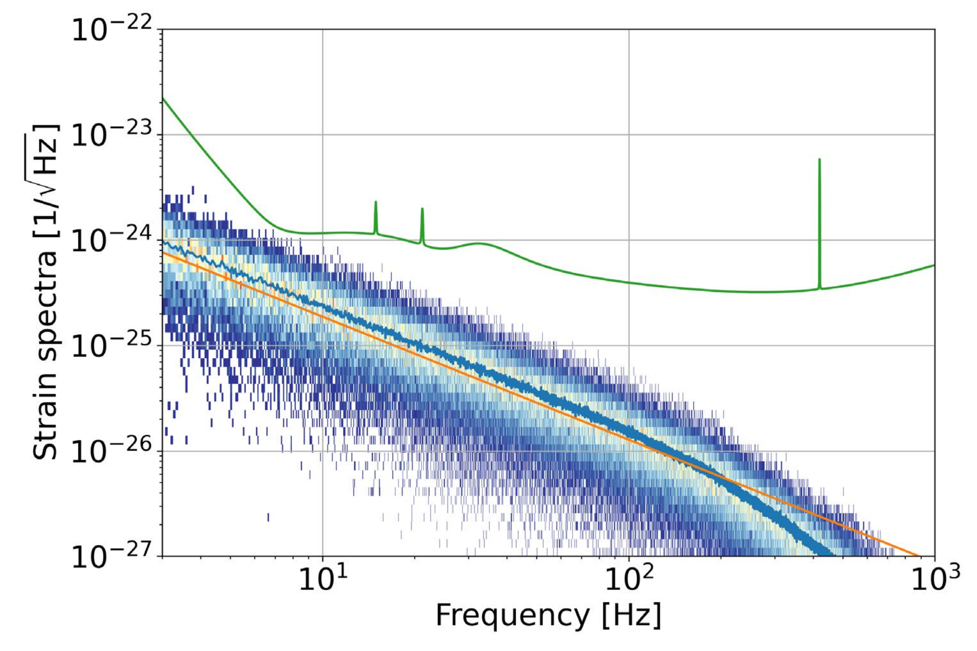
1 min PSD/FFT time
7200 PSDs forming histogram



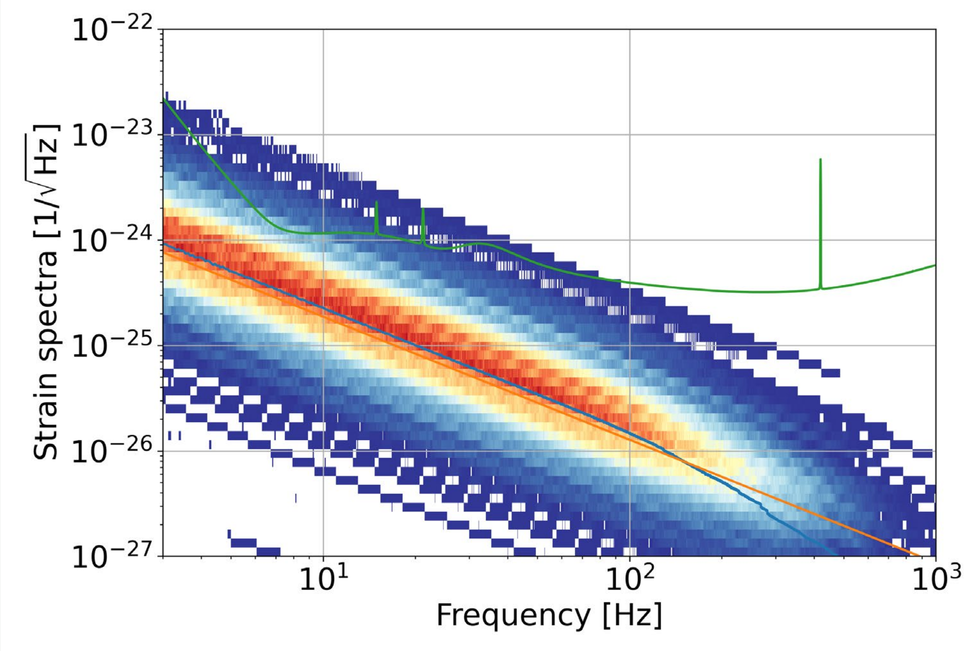
It seems that there is no significant impact of BNS foreground on estimates of instrument-noise PSDs.

Astrophysical Foreground: BBH

24 hours PSD/FFT time
100 PSDs forming histogram



1 min PSD/FFT time
7200 PSDs forming histogram



BBH signals can be expected to significantly perturb estimates of instrument-noise PSDs.

ET Nullstream for PSD Estimates

Data from k=1,2,3 ET components as sum of GW signal and noise

$$d_k(t) = s_k(t) + n_k(t)$$

Definition of nullstream

$$N(t) = d_1(t) + d_2(t) + d_3(t) = n_1(t) + n_2(t) + n_3(t)$$

Instrument noise PSD obtained as cross-correlation with nullstream

$$\langle n_k | n_k \rangle = \langle d_k | N \rangle$$

Detector Calibration

Self-calibration of Networks of Gravitational Wave Detectors

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Basic idea: construct matched filter to detect residuals of GW signals in the nullstream. The filter provides information about calibration errors.

Calibration errors — Required for network nullstreams

$$\tilde{N}^{123} = \tilde{N}^{123}_{\mathrm{n}} + \sum_a A^{(a)} c^{(a)}(f) [F_+^{(a)} \tilde{h}_+(f) + F_\times^{(a)} \tilde{h}_\times(f)] e^{2\pi i f \tau^a}$$

1) Nullstream residuals are low SNR (since calibration errors are small). So, one needs to combine analyses of many CBC signals to obtain useful information about calibration errors.
2) Absolute calibration can in principle be achieved with one detector being accurately calibrated at one frequency, or with accurate source-distance estimates, e.g., from EM counterparts.

Optimal GW Searches Using the Nullstream

1) With nullstream, it is in principle sufficient to see the GW signal in only one detector (instead of requiring coincident detections).
2) Reject transients if they appear in the nullstream. ET superior to 3-detector network: since the nullstream does not depend on GW direction, weaker glitches can be vetoed.
3) In ET, efficiency of glitch veto limited by calibration errors (calibration errors can cause glitches not to be vetoed).

Coherent network analysis technique for discriminating gravitational-wave bursts from instrumental noise

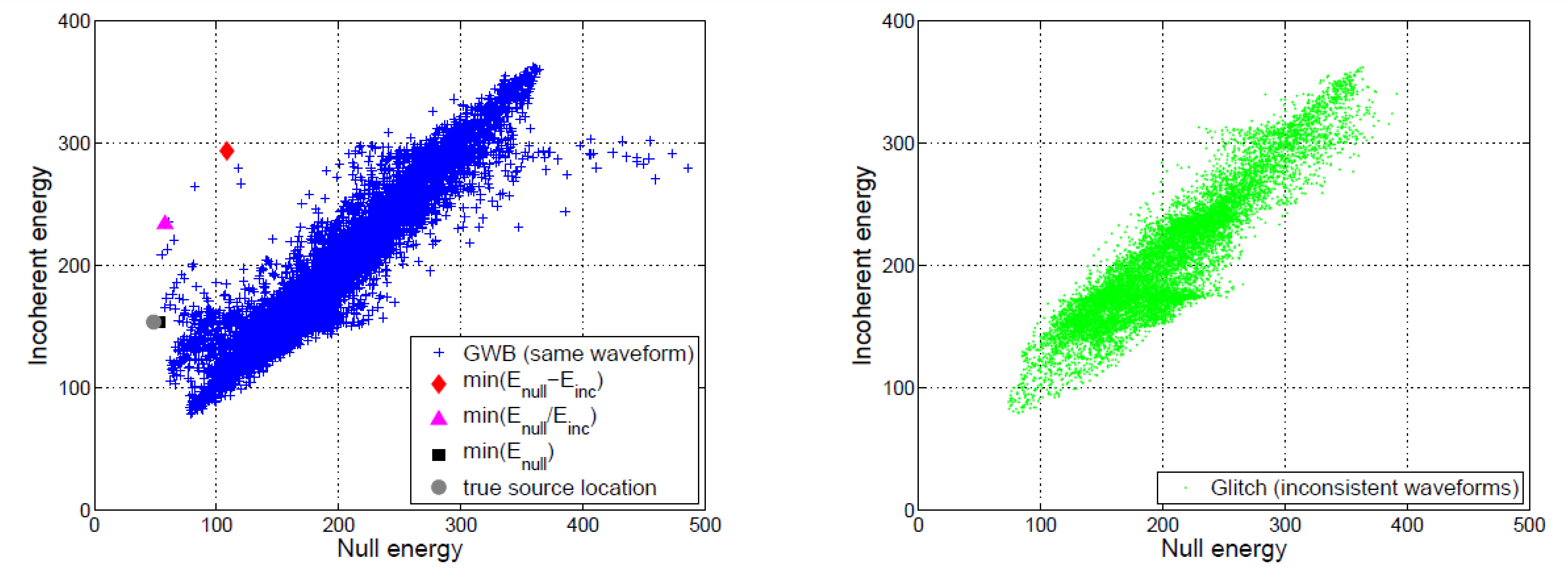
Shourov Chatterji, Albert Lazzarini, Leo Stein, and Patrick J. Sutton
LIGO - California Institute of Technology, Pasadena, CA 91125

Antony Searle
Australian National University, Canberra, ACT 0200, Australia

Massimo Tinto
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109
(Dated: October 30, 2018)

Glitch Vetoing

Each point in these plots is a trial sky location to construct a network nullstream.



Analgous study for ET under way (Goncharov, Nitz).

Nullstream and CBC Parameter Estimation

Null-stream-based Bayesian Unmodeled Framework to Probe Generic Gravitational-wave Polarizations

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What if a relatively weak glitch perturbs a GW signal? Can you faithfully subtract it without nullstream? If not, how would such a glitch PE?

Explicitly shown in Wong et al, nullstream does not help for CBC PE if noise is Gaussian.

Stochastic GW Searches

Auto-correlation

$$\rho = \sqrt{T}\left[\int_0^\infty df\, \frac{\mathcal{R}^2(f) S_h^2(f)}{P_n^2(f)}\right]^{1/2}$$

Requires estimate of instrument-noise PSD, which can be affected by calibration errors.

Cross-correlation

$$\rho = \sqrt{2T}\left[\int_{f_{\rm min}}^{f_{\rm max}} df\, \frac{\Gamma_{IJ}^2(f) S_h^2(f)}{P_{nI}(f) P_{nJ}(f)}\right]^{1/2}$$

GW cross-PSD typically significantly reduced across two different interferometers compared to the GW PSD.

Both stochastic searches are limited by instrument-noise correlations.

Sensitivity curves for searches for gravitational-wave backgrounds

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(Dated: November 26, 2013)