LIGO

Marginalizing over Noise Properties in Parameter Estimation

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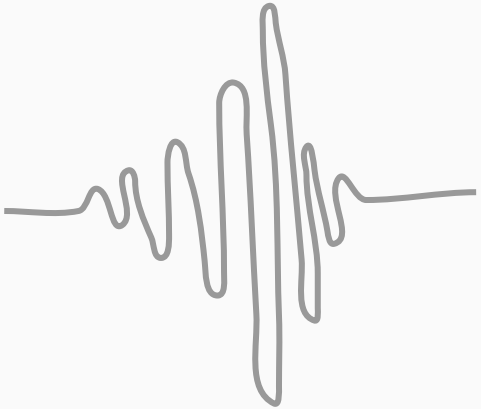
Background:
•PSDs
•BayesWave

Signal and PE Results

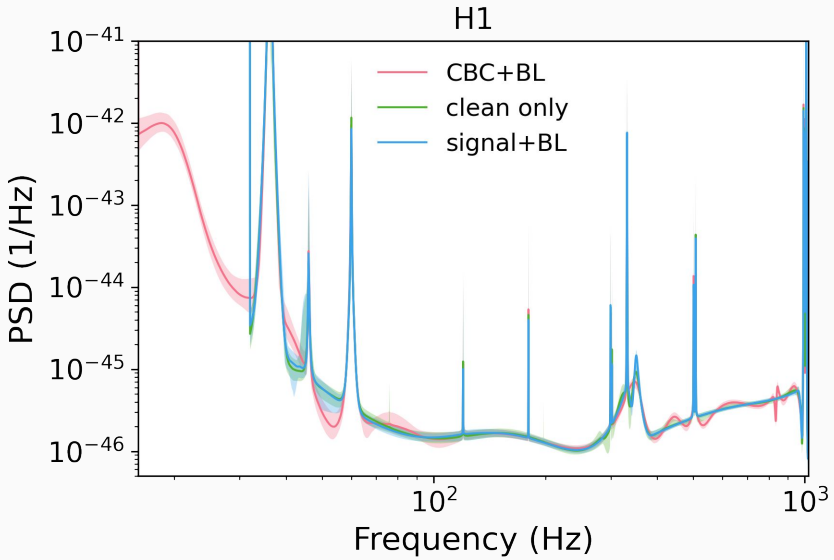
Discussion & Future work



Power Spectral Density (PSD)

What is it and what does it tell you?

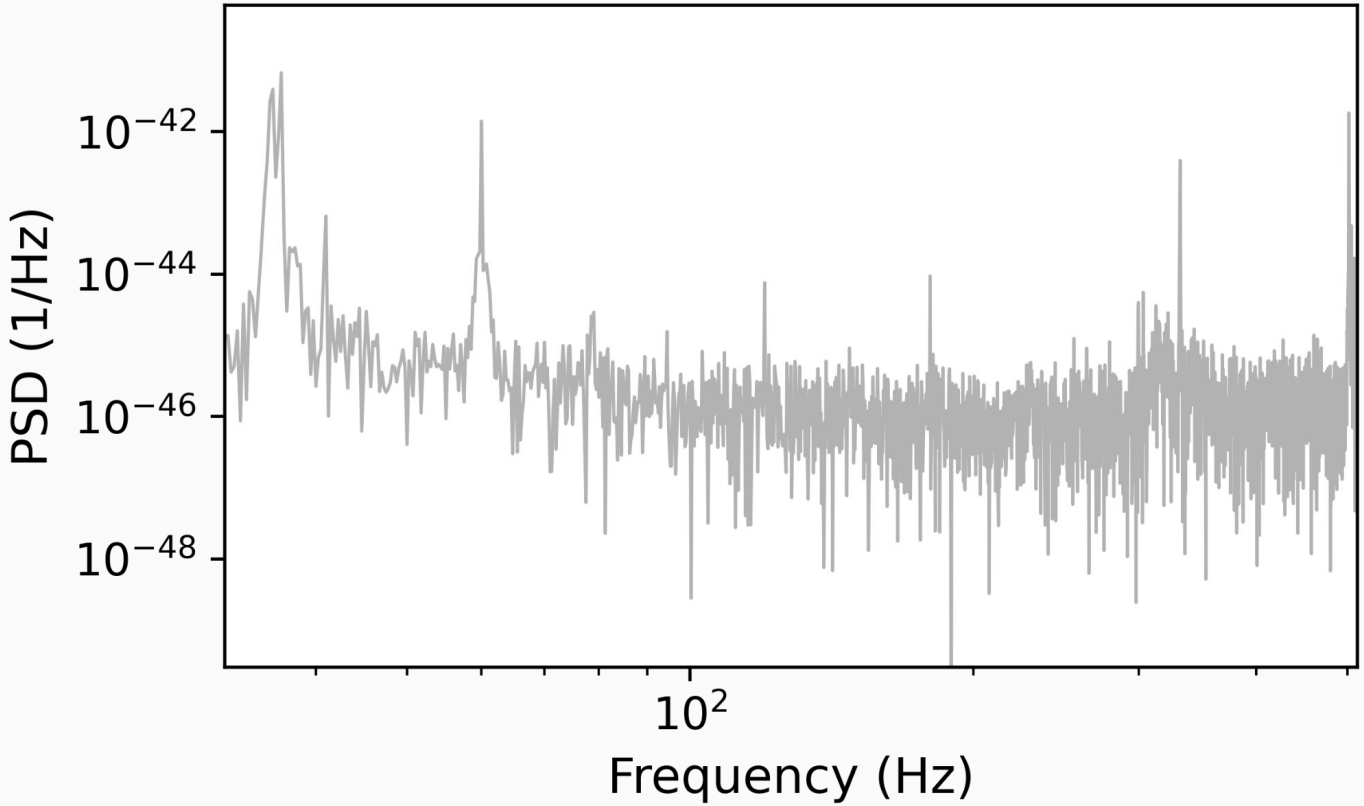
- ★ Characterizes stationary random noise in the frequency domain
- ★ Variance of the noise at each frequency
- ★ Squared, normalized FFT



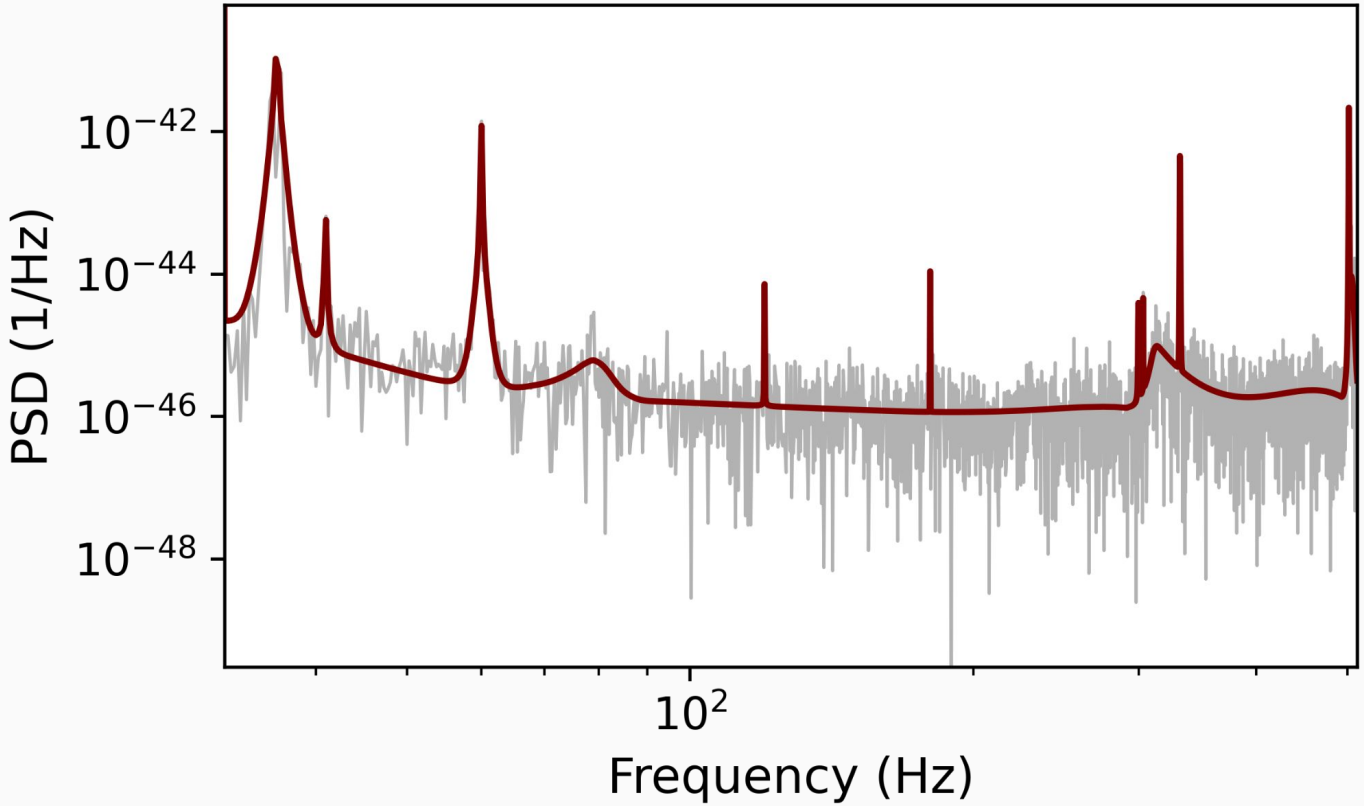
LIGO Data

$$d = h + n$$

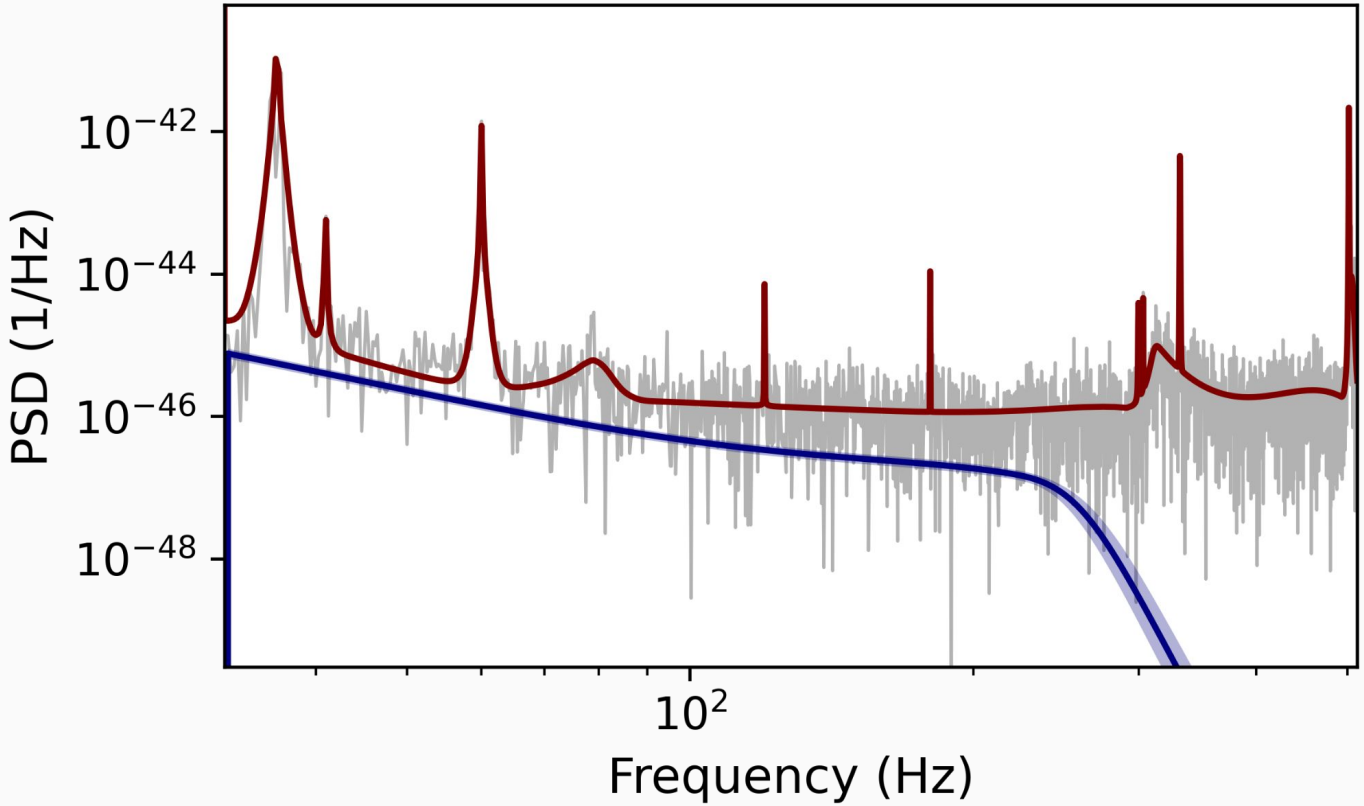
Finding signals:



Finding signals:



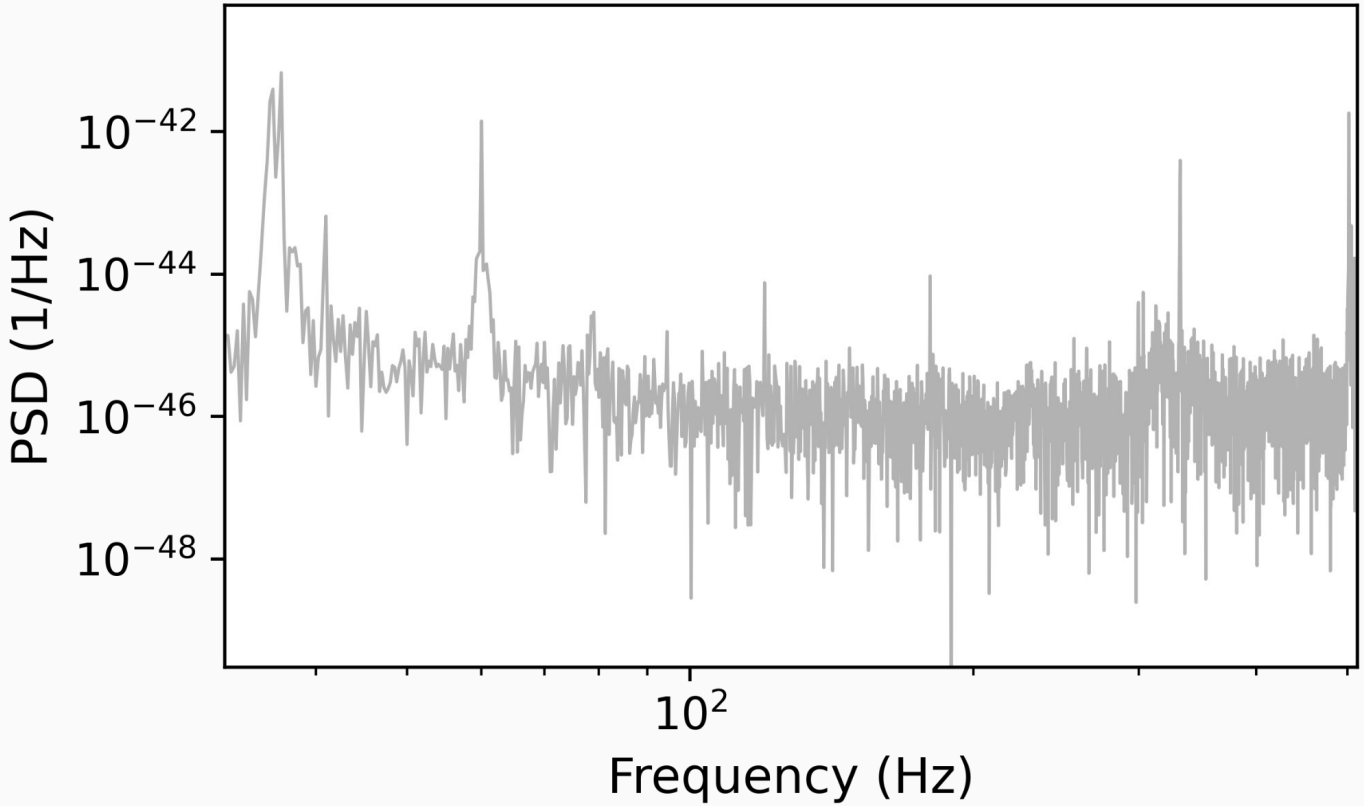
Finding signals:



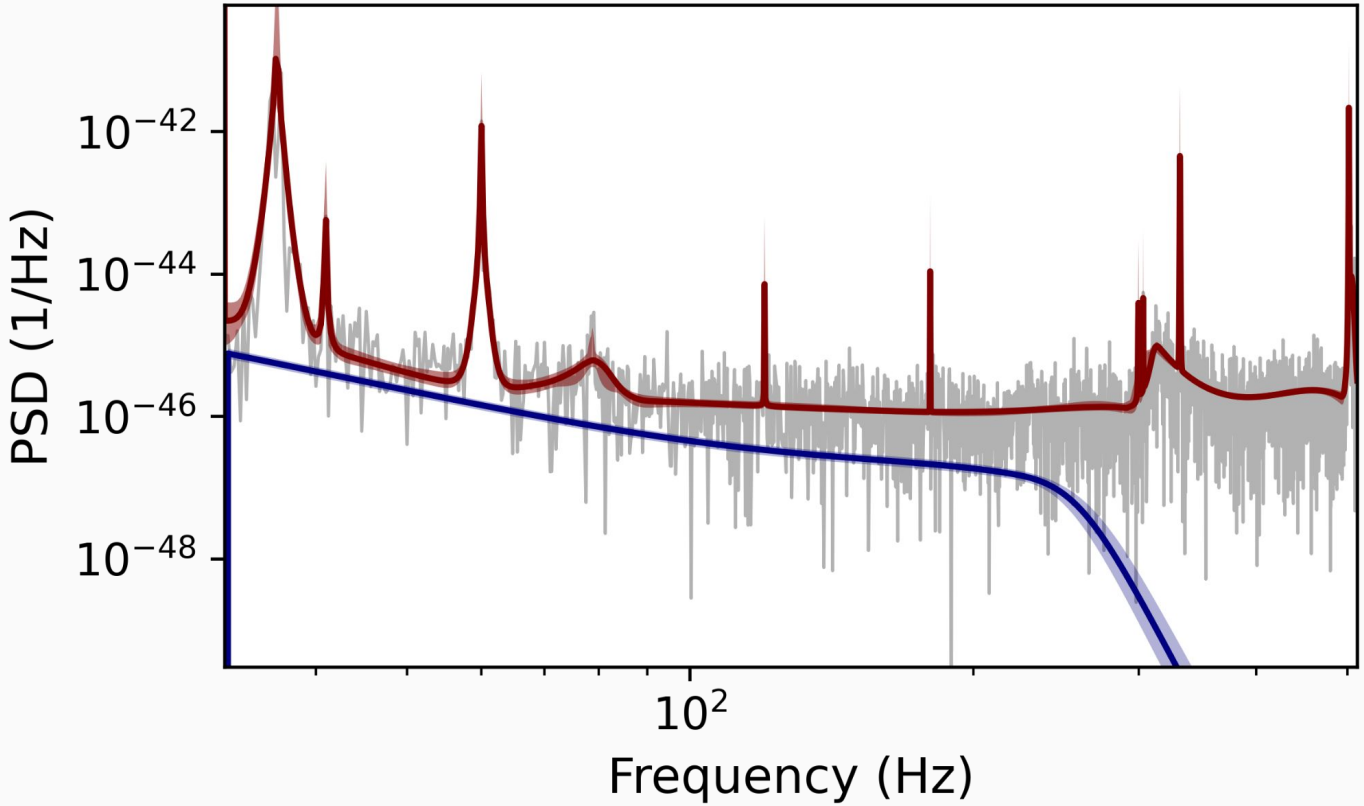
Use PSD as fixed input to PE algorithm

→ assumes PSD is perfectly known

Finding signals:



Finding signals:

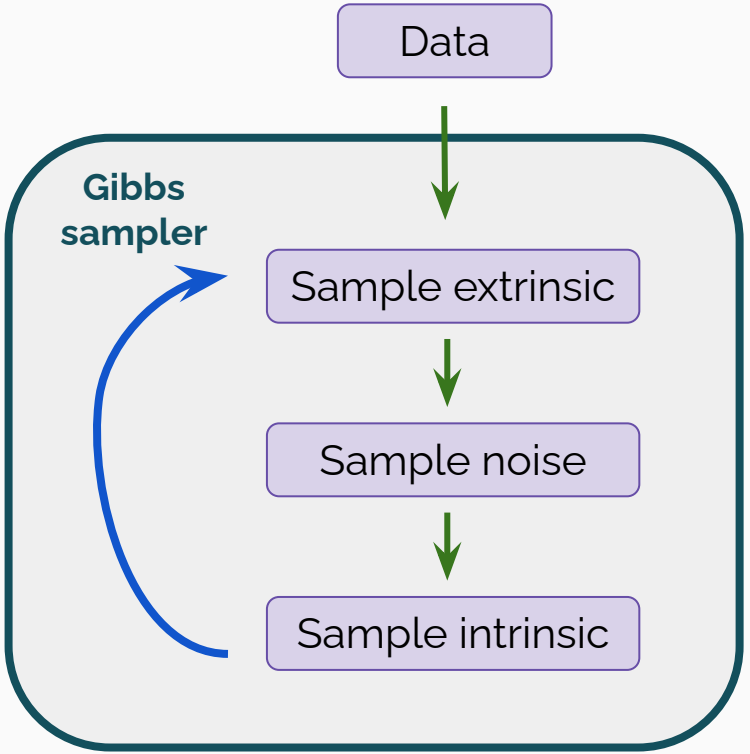


Simultaneously model PSD and GW using `bayesLine`

→ allow PSD to vary with GW

BayesWave

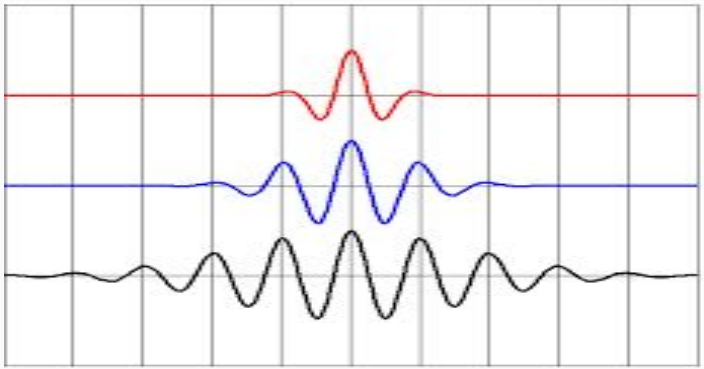
- ★ Bayesian algorithm to separate GW signals from noise and glitches
- ★ Markov Chain Monte Carlo (MCMC) algorithm: way of randomly sampling parameter space weighted by likelihood



BayesWave Models

Signal (wavelet) model

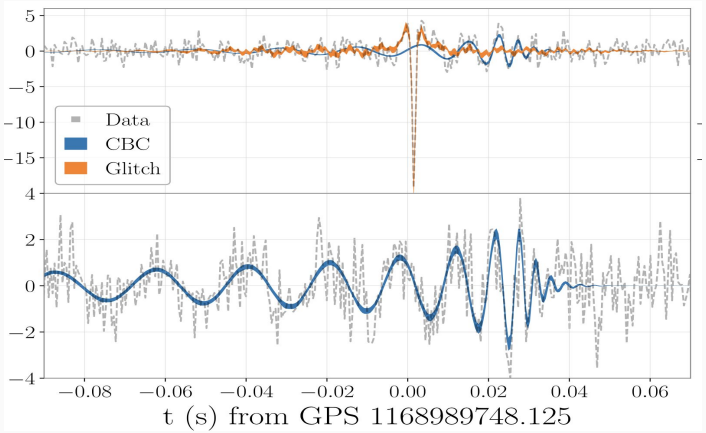
- ★ Models signal as sum of sine-Gaussian wavelets
- ★ *Weakly modeled* search



https://www.crewes.org/Documents/SlideShows/2016/CSS201630.pdf

CBC (templated) model

- ★ *Template-based* search
- ★ Returns CBC parameters



Chatziioannou et al. 2021, Fig. 2,
https://journals.aps.org/prd/abstract/10.1103/PhysRevD.103.044013

Analyses

Signal (wavelet) model

- ★ Signal +fixed PSD
- ★ Signal +BL (varying PSD)

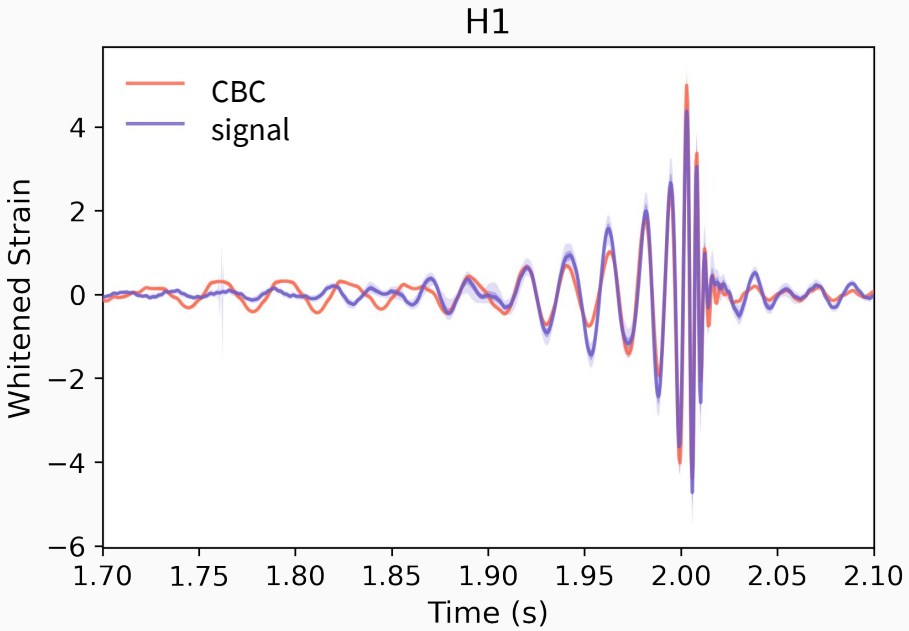
CBC (templated) model

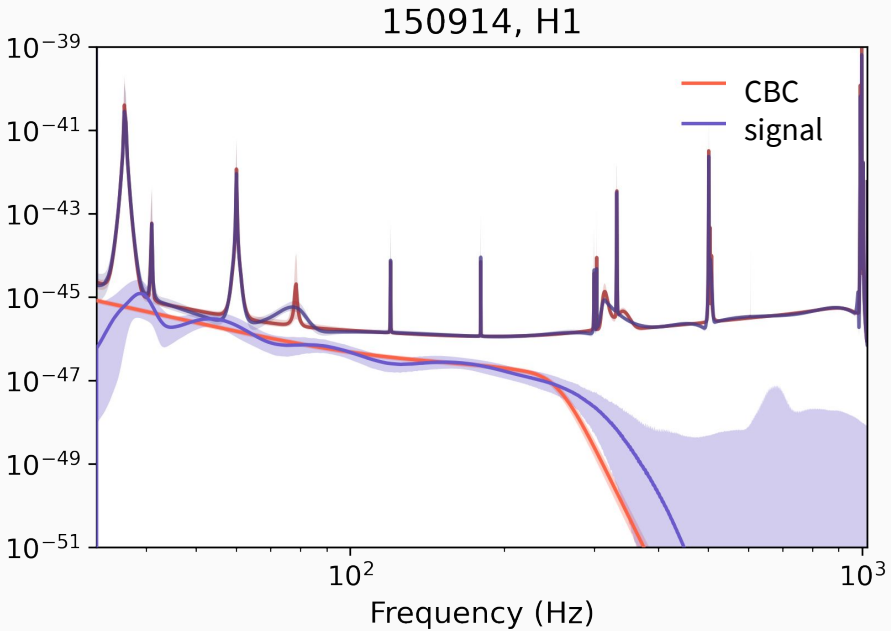
- ★ CBC+fixed PSD
- ★ CBC+BL (varying PSD)

Goal: Compare signal reconstruction and PE between fixed and BL methods

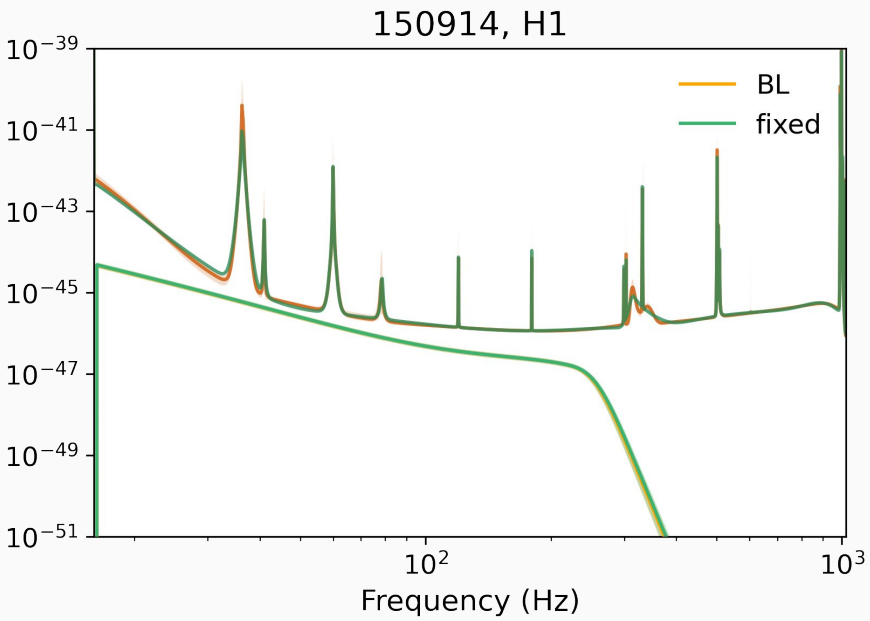
Results: signals and parameter estimation for GWTC-2 events

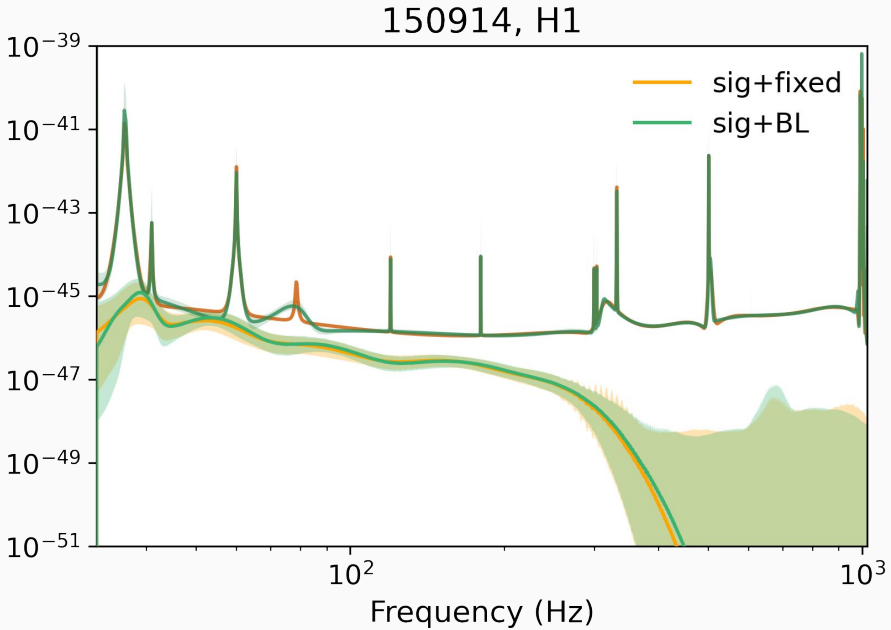
GW150914: comparing signal & CBC



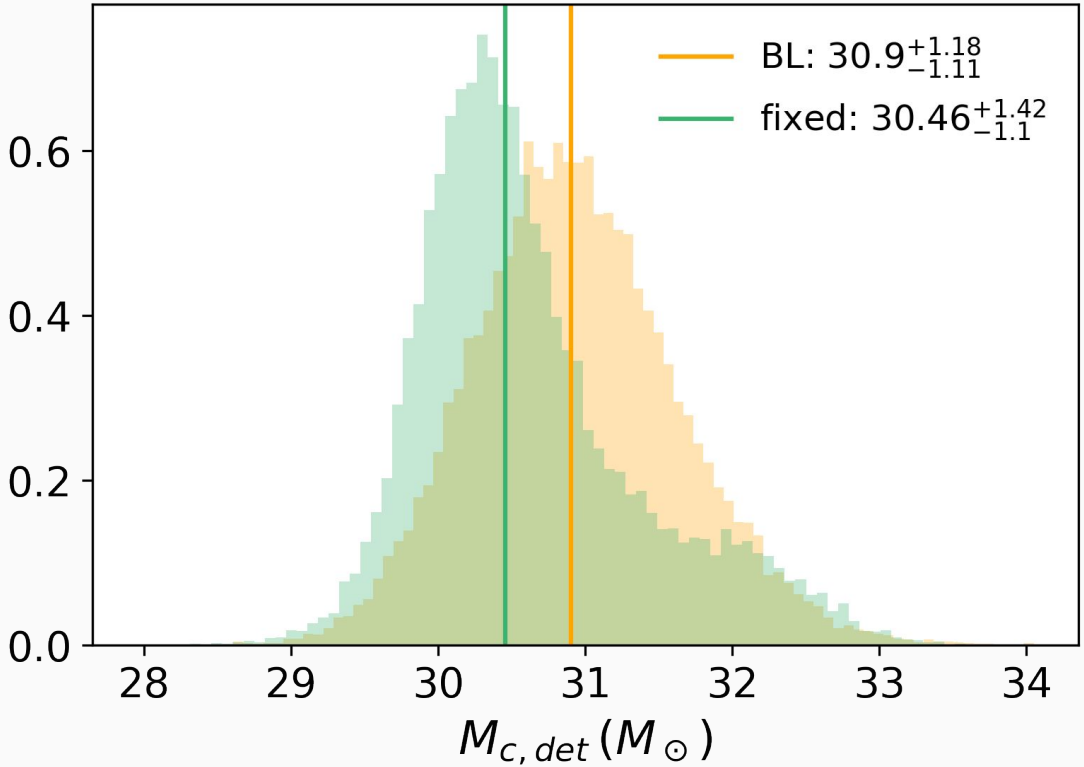


GW150914: comparing fixed & BL

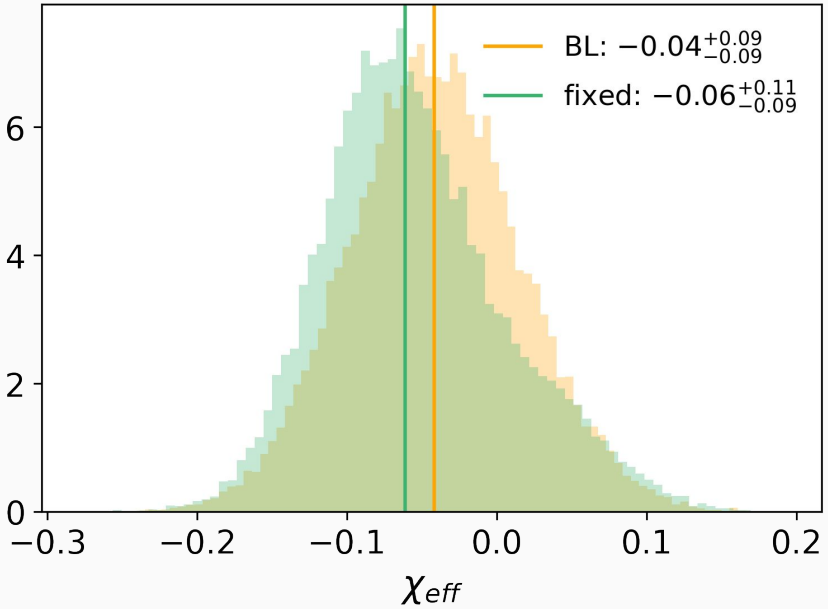


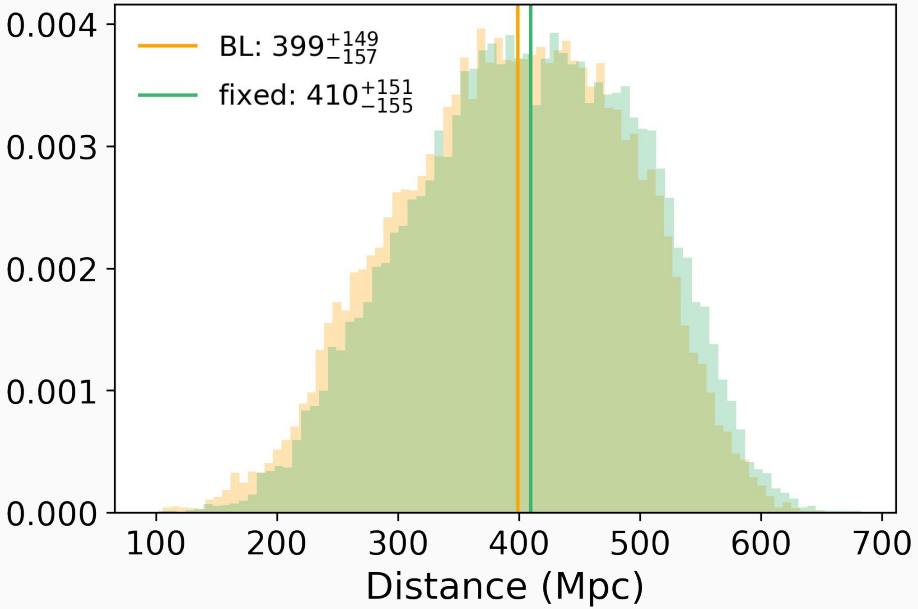


Parameter posteriors: GW150914

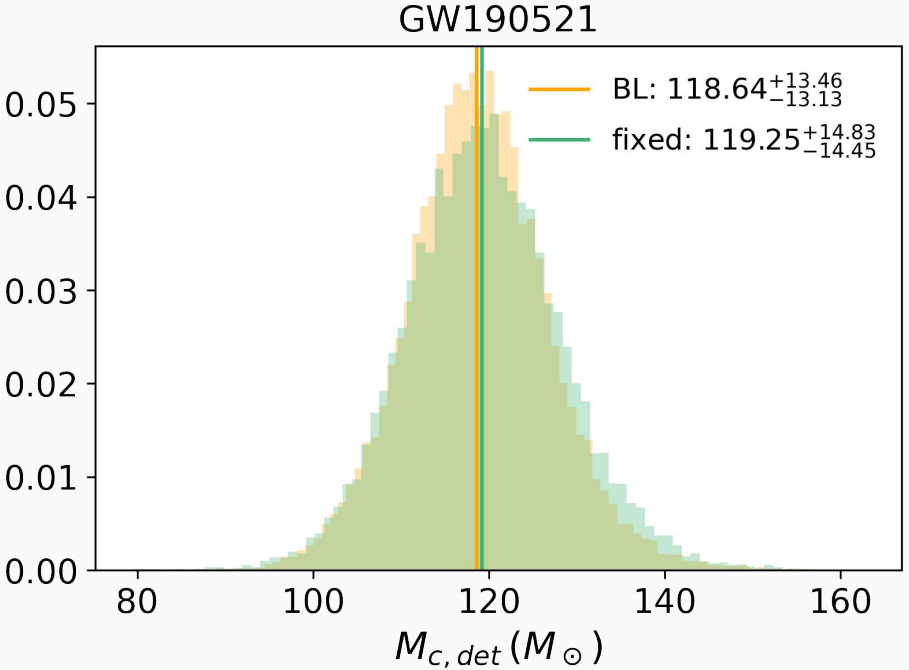


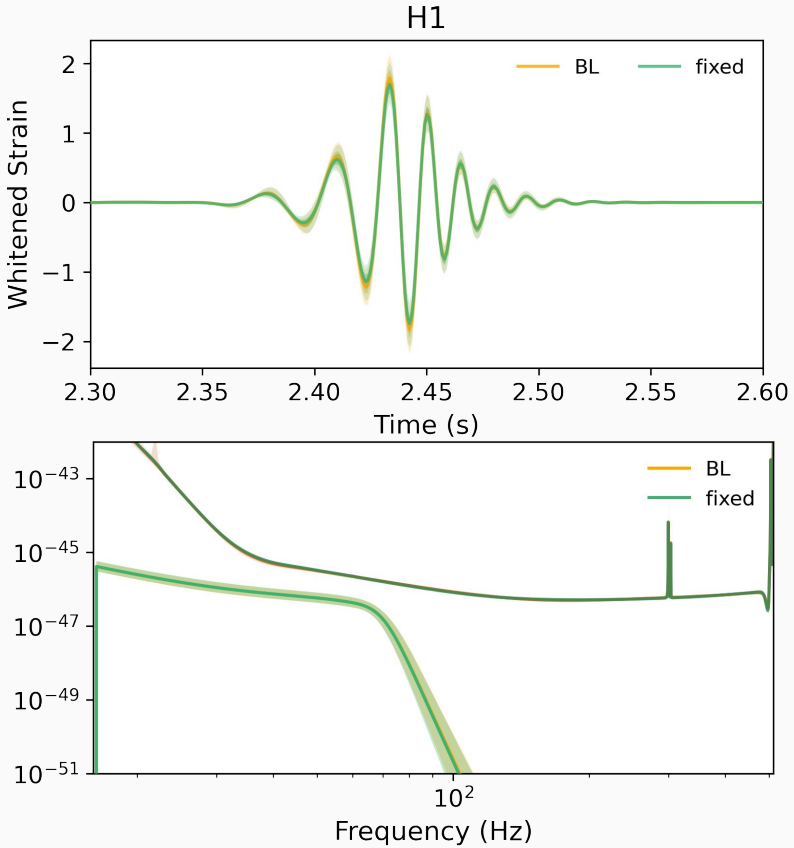
Parameter posteriors: GW150914



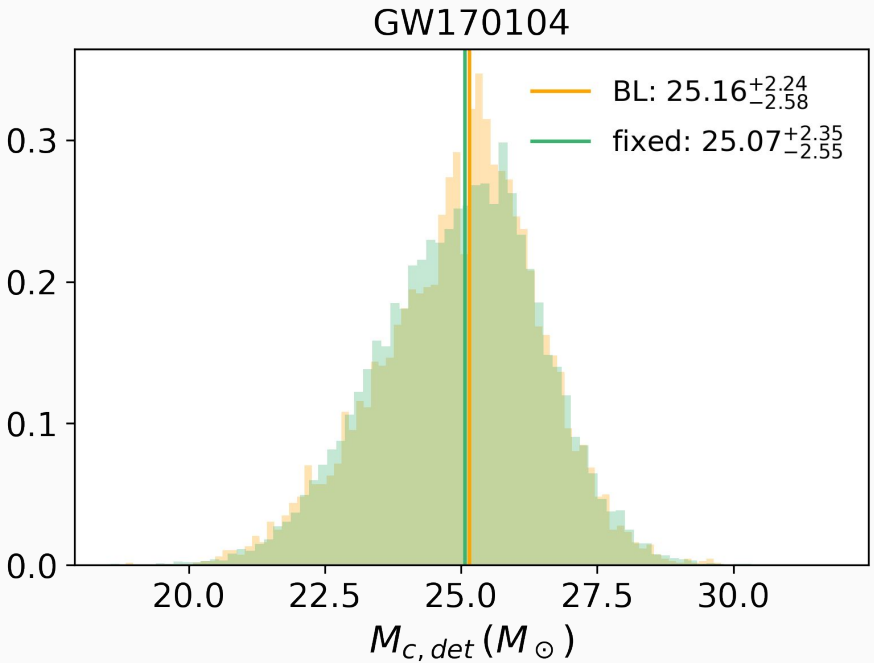


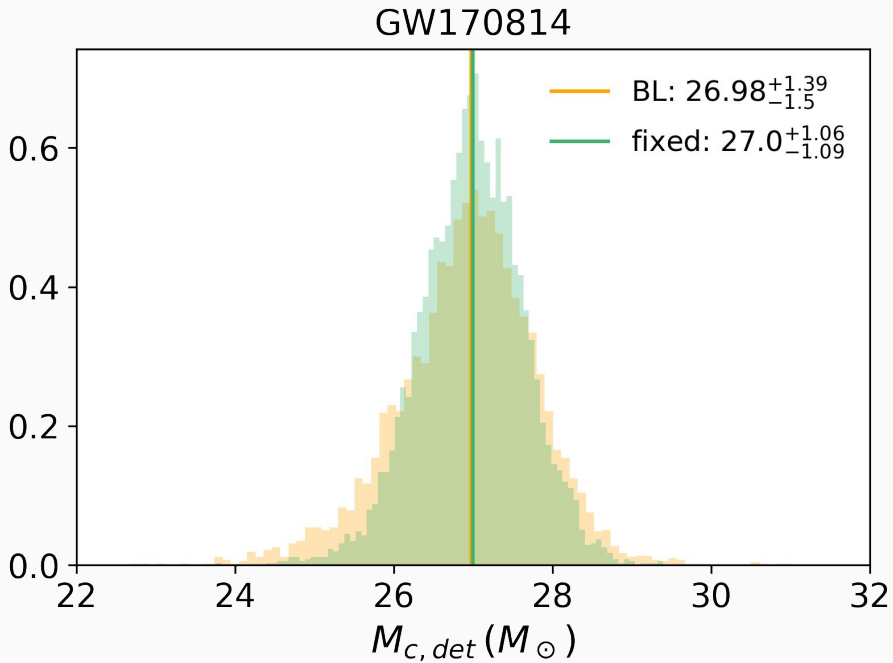
GW190521


GW190521
BL: $118.64^{+13.46}_{-13.13}$
fixed: $119.25^{+14.83}_{-14.45}$
0.05
0.04
0.03
0.02
0.01
0.00
80
100
120
140
160
$M_{c,det}\,(M_\odot)$

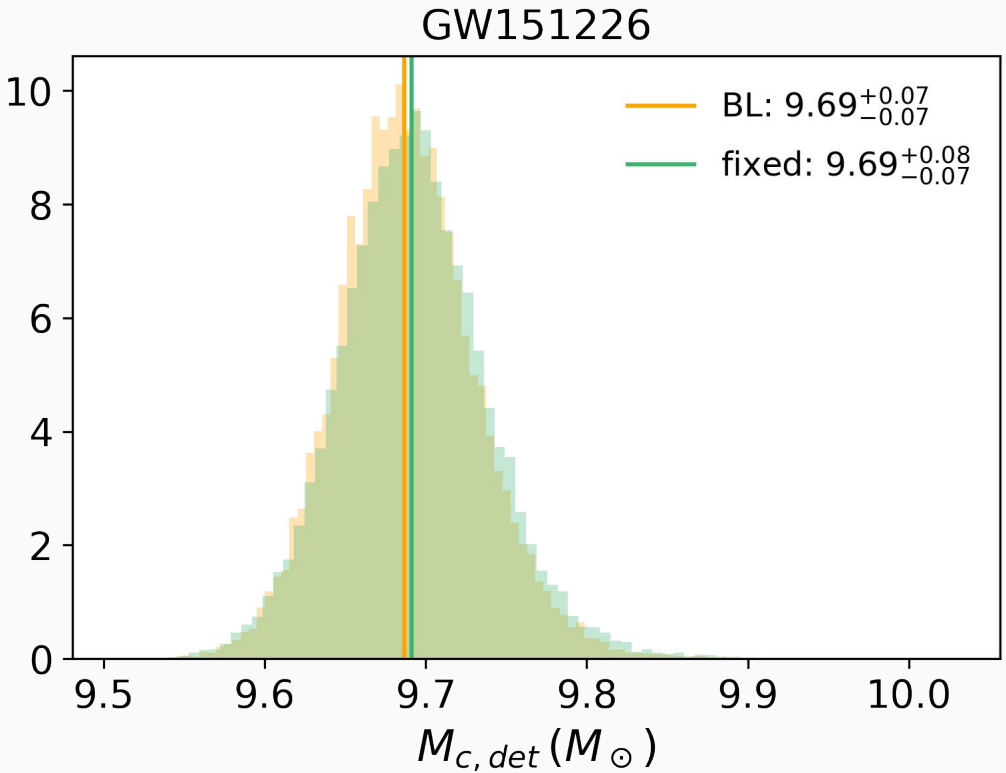

H1
BL
fixed
Whitened Strain
2
1
0
−1
−2
2.30
2.35
2.40
2.45
2.50
2.55
2.60
Time (s)
BL
fixed
10^{-43}
10^{-45}
10^{-47}
10^{-49}
10^{-51}
10^{2}
Frequency (Hz)

GW170104, GW170814





GW151226


GW151226
BL: $9.69^{+0.07}_{-0.07}$
fixed: $9.69^{+0.08}_{-0.07}$
0
2
4
6
8
10
9.5
9.6
9.7
9.8
9.9
10.0
$M_{c,\,det}\,(M_\odot)$

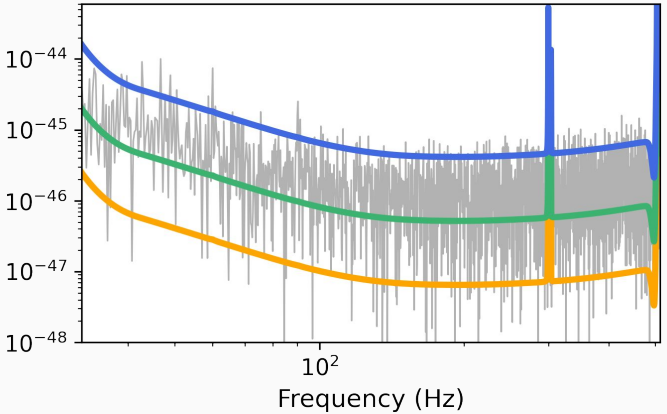
Why are the distributions so similar?

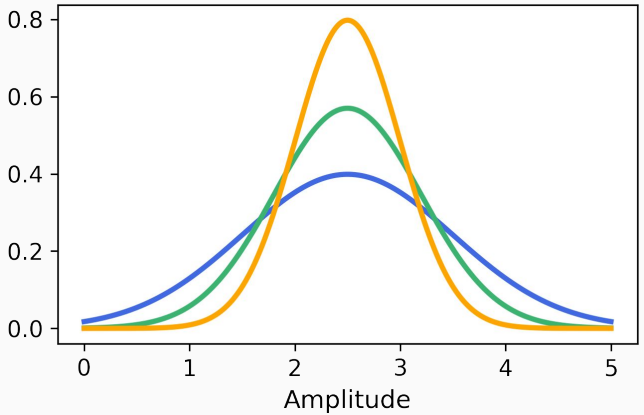
With more uncertainty, we expected a wider (but not shifted) posterior

First, what happens with a shifted PSD?

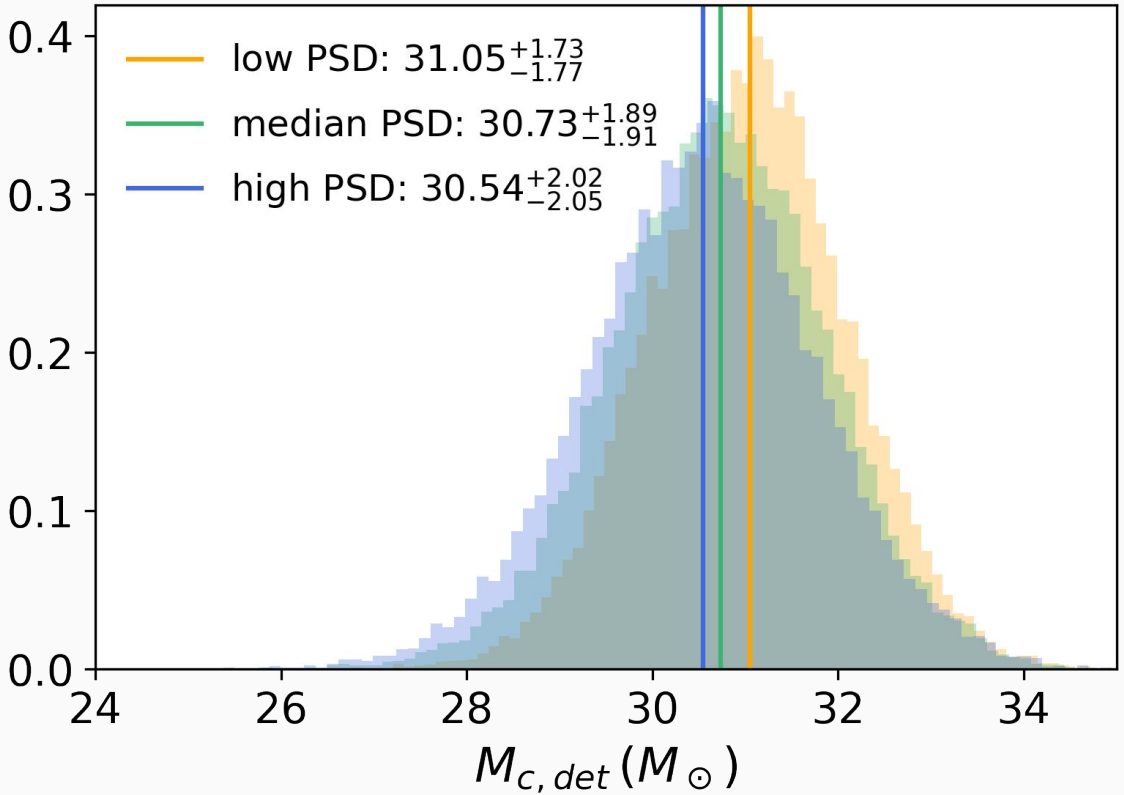
Overestimate the PSD

- ➔ Overestimate variance of noise
- ➔ Underestimate the SNR
- ➔ Overestimate uncertainty in posteriors





Using shifted PSDs on GW150914



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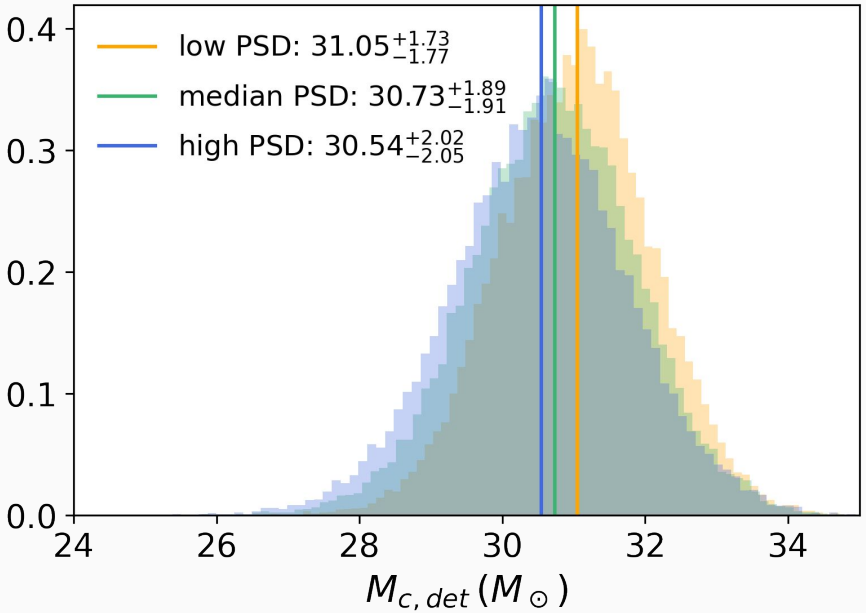
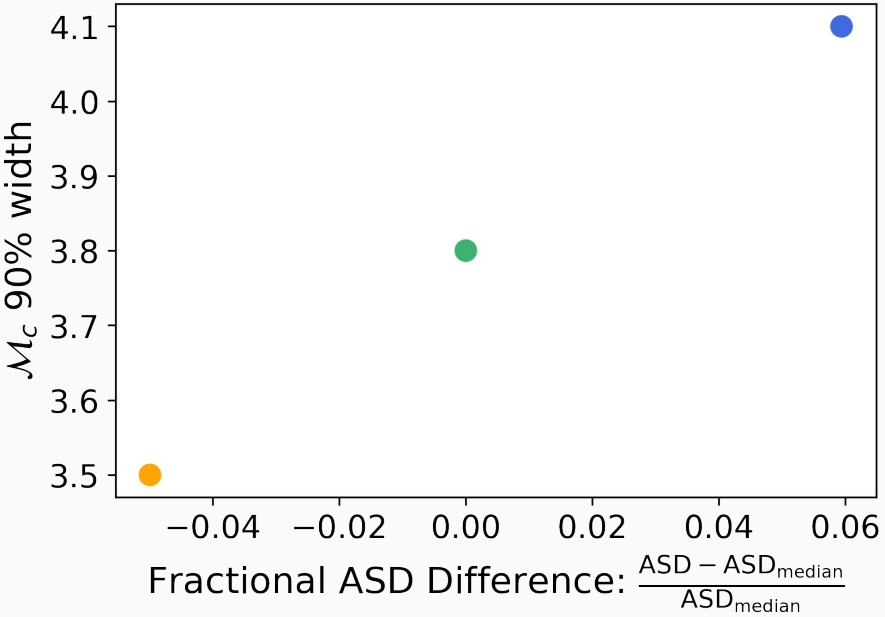




Impact of Marginalization

By marginalizing (integrating) over possible PSDs, broadening effect is limited

$$\left(\int_{-x}^{x} \mathcal{N}(\theta, (1+\varepsilon)\sigma) d\varepsilon\right) - \mathcal{N}(\theta, \sigma) \sim \varepsilon^4$$

Broadening is a higher order effect—not a leading term

Conclusions

- ★ Fixed PSD and BL recover similar waveforms for signal and CBC models
- ★ Parameter posteriors agree; we aren't currently underestimating uncertainty
- ★ At current sensitivities, PSD uncertainty is a subdominant effect compared to other uncertainties

Future Goals

- ★ Continue analyses on interesting events in O1-O3a
- ★ Thoroughly study of the impact of shifting the PSD on posterior uncertainty

Acknowledgements:

National Science Foundation REU Program

LIGO Laboratory

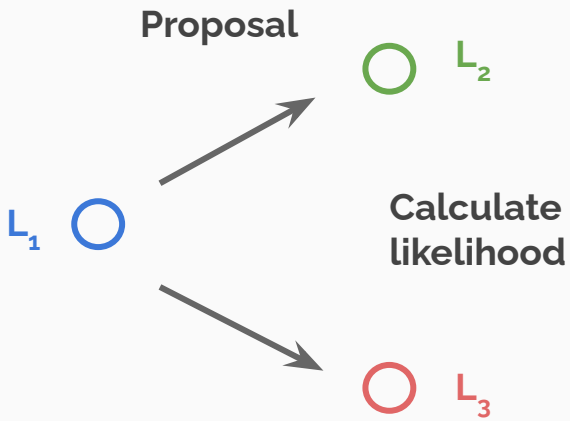
Caltech

Katerina and Sophie

All those associated with the LIGO SURF program :)

Questions?

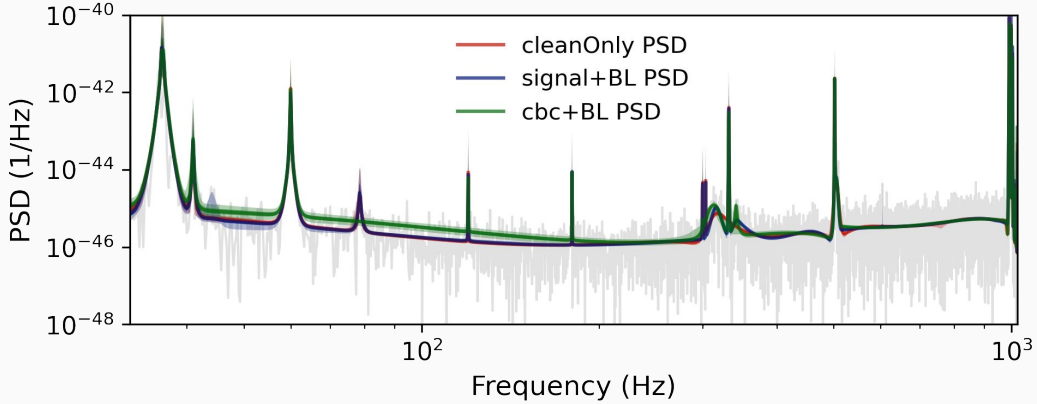
MCMC

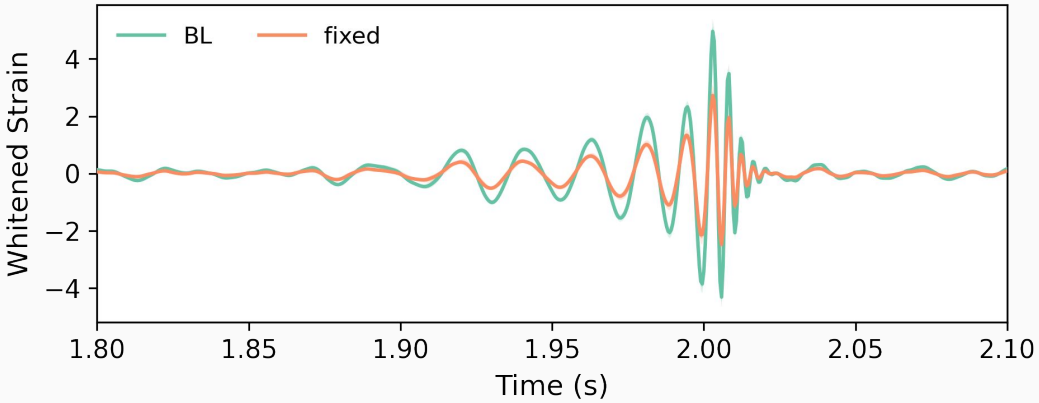


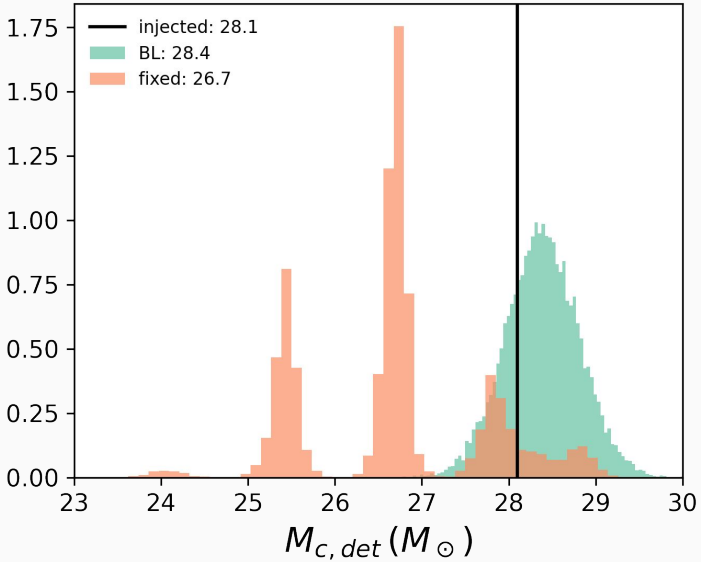
$L_2 / L_1 > 1$ → acceptance guaranteed

$L_3 / L_1 < 1$ → random draw from 0 to 1
(acceptance probability is likelihood ratio)

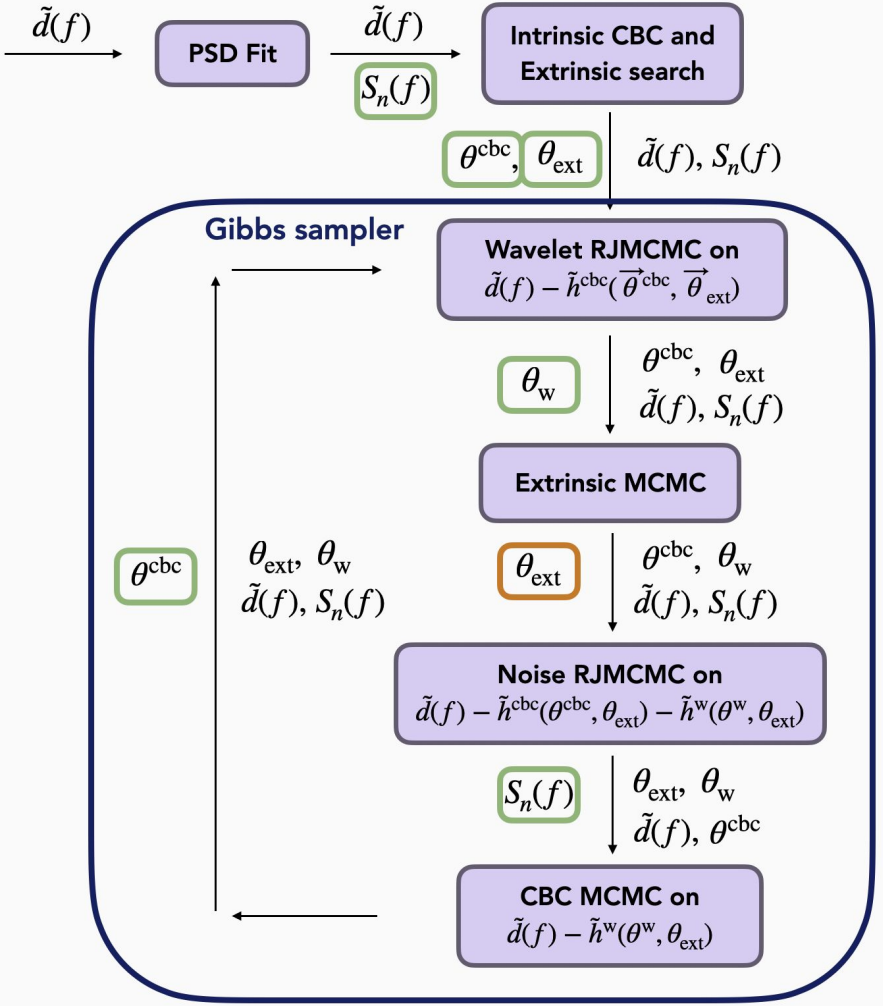
Issues & Bug Fixes





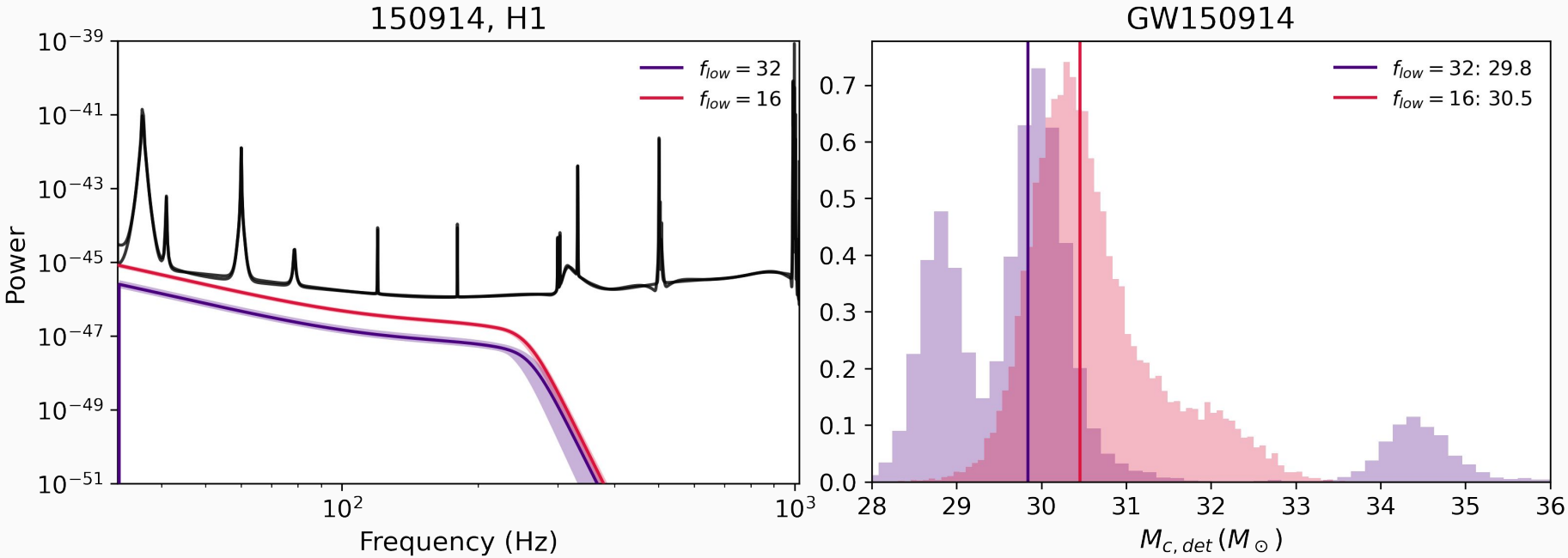


High PSD issue



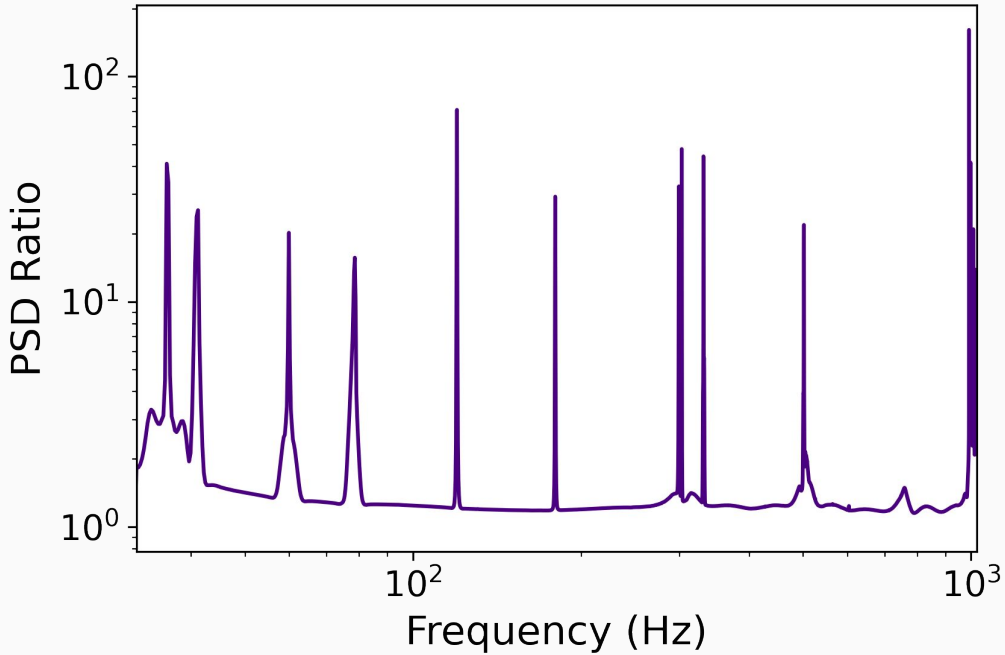
Low signal + sampling issue

Had problems when heterodyning . . . switching to f_{low}= 16 fixed things



Asterisk on shifted PSDs

The ones we used weren't shifted by a constant… especially around spectral lines



For that example, we used the upper and lower 90% CIs on the PSD that BW returned in addition to the median (the usual way)