Simultaneous inference of CBC and noise parameters via on-source PSD modeling

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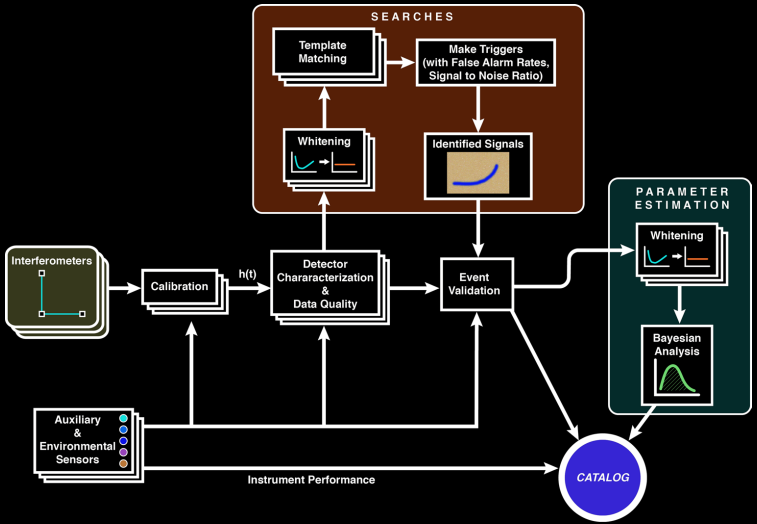
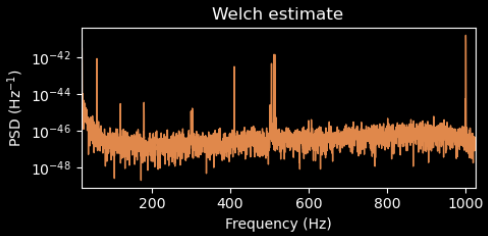
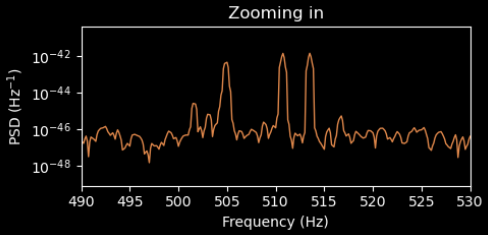
Data Processing



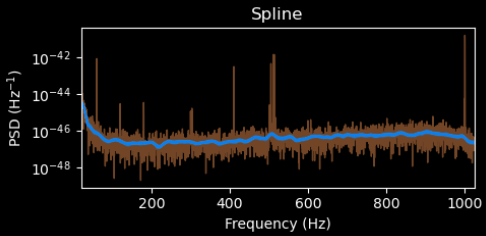
Power Spectral Density

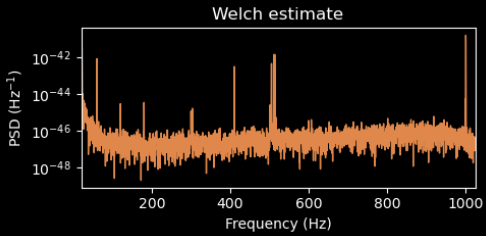
- Noise = Broadband + Narrowband.
- Broadband:
  Seismic, Thermal, Quantum Photon Shot, etc.
- Narrowband:
  AC power supply, Calibration lines, Vibrational modes of suspension system, etc.

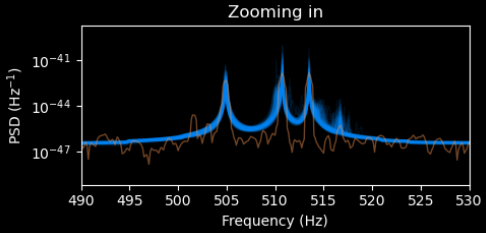


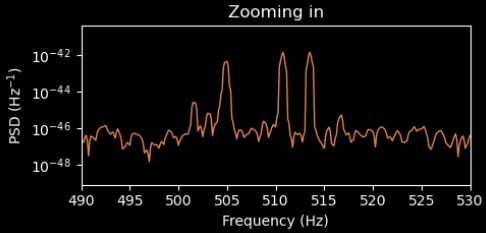


PSD


Spline
PSD (Hz^{-1})
10^{-42}
10^{-44}
10^{-46}
10^{-48}
200
400
600
800
1000
Frequency (Hz)


Welch estimate
PSD (Hz^{-1})
10^{-42}
10^{-44}
10^{-46}
10^{-48}
200
400
600
800
1000
Frequency (Hz)


Zooming in
PSD (Hz^{-1})
10^{-41}
10^{-44}
10^{-47}
490
495
500
505
510
515
520
525
530
Frequency (Hz)


Zooming in
PSD (Hz^{-1})
10^{-42}
10^{-44}
10^{-46}
10^{-48}
490
495
500
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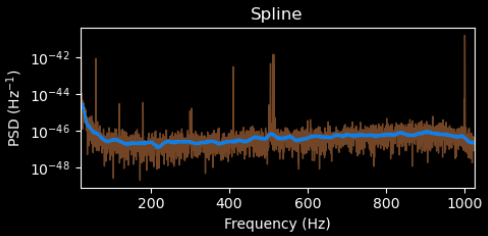
510
515
520
525
530
Frequency (Hz)

PSD Model


Spline
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200
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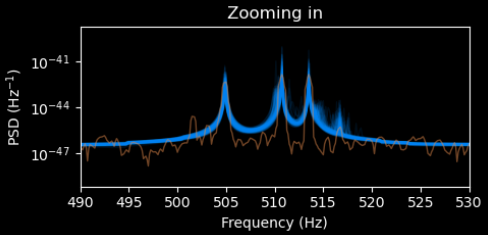
Frequency (Hz)


Zooming in
PSD (Hz^{-1})
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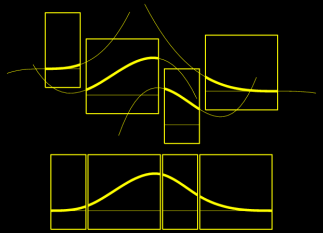
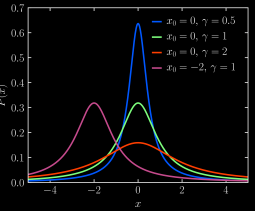



$x_0 = 0, \gamma = 0.5$
$x_0 = 0, \gamma = 1$
$x_0 = 0, \gamma = 2$
$x_0 = -2, \gamma = 1$
$P(x)$
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−4
−2
0
2
4
x

Parametric PSD Model

- Noise per detector:

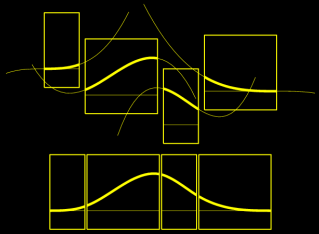
$$S_n(f;\vec{\theta}_n) = S_S(f;\vec{\theta}_S) + S_L(f;\vec{\theta}_L)$$

- Broadband: cubic B-splines

$$S_S(f) = a(f) + m(f)\sum_i^{n_{\text{knots}}} c_i B_{i,k}(f;\vec{t})$$

- Narrowband: Lorentzians (approx.)

$$S_L(f) = \sum_\ell^{n_{\text{Lor}}} w_\ell(f)\frac{a_\ell f_\ell^4}{(f_\ell f)^2 + q_\ell^2(f_\ell^2 - f^2)^2}$$



Bayesian Inference

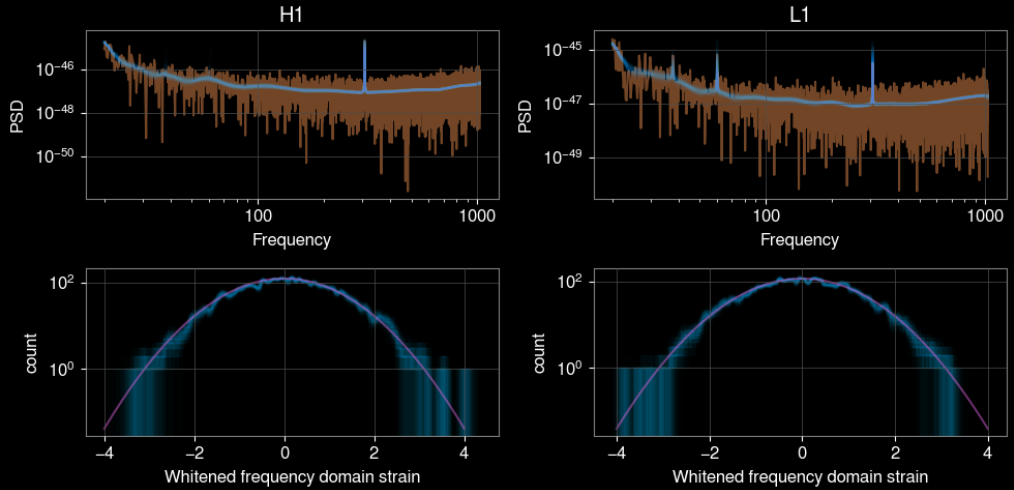
- Single-detector likelihood:

$$p(d|\theta_h, \theta_n) = \prod_i^{N_f} \frac{2}{\pi T S_n(f_i;\theta_n)} \exp\left[-\frac{2|\tilde{d}(f_i) - \tilde{h}(f_i;\theta_h)|^2}{T S_n(f_i;\theta_n)}\right]$$

$$\log p(d|\theta_h, \theta_n) = -\frac{2}{T}\sum_i^{N_f} \frac{\left\langle \tilde{d}\middle|\tilde{d}\right\rangle - 2\left\langle \tilde{d}\middle|\tilde{h}\right\rangle + \left\langle \tilde{h}\middle|\tilde{h}\right\rangle}{S_n} - \sum_i^{N_f} \log S_n + N_f \log \frac{2}{\pi T}$$

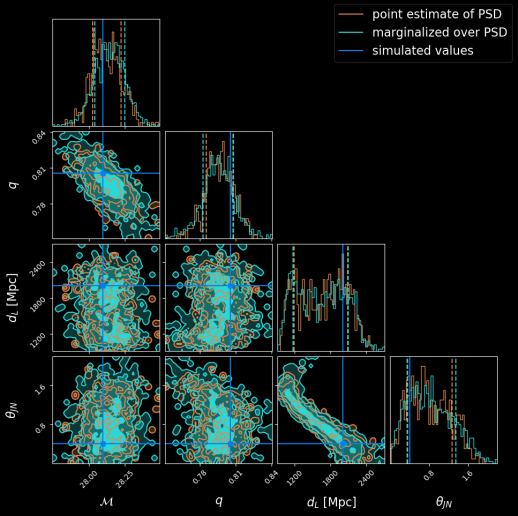
- extended `bilby`
- Number of dimensions: $15 + n_{\text{IFO}} \times (2n_{\text{knots}} + 2 + 3n_{\text{Lorentzians}})$

PSD posteriors



CBC posteriors

- Chirp mass:
  $\Delta\mu = 0.08\%$
  $\Delta\sigma = 4.76\%$
- Mass ratio:
  $\Delta\mu = -0.10\%$
  $\Delta\sigma = 14.66\%$
- Luminosity distance:
  $\Delta\mu = -1.42\%$
  $\Delta\sigma = 2.02\%$
- Inclination:
  $\Delta\mu = 4.63\%$
  $\Delta\sigma = 8.96\%$



Future

- Seamless integration into `bilby`
- Revisiting past catalogs
- Testing on O4 detection candidates
- Time-dependent 2d PSD $S_n(f, t)$

Thank You