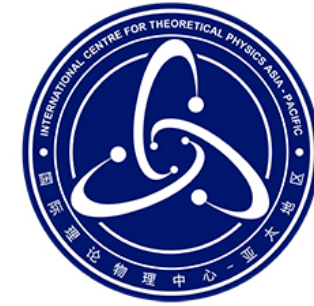




中国科学院大学
University of Chinese Academy of Sciences



ICTP-AP
International Centre
for Theoretical Physics Asia-Pacific
国际理论物理中心-亚太地区

Searches and Latest Results for the Isotropic Gravitational-Wave Backgrounds with LIGO-Virgo-KAGRA detectors

LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration. Updated Upper Limits on the Isotropic Gravitational-Wave Background from LIGO, Virgo, and KAGRA Data through April 2025. [arXiv:2608.23477](https://arxiv.org/abs/2608.23477)

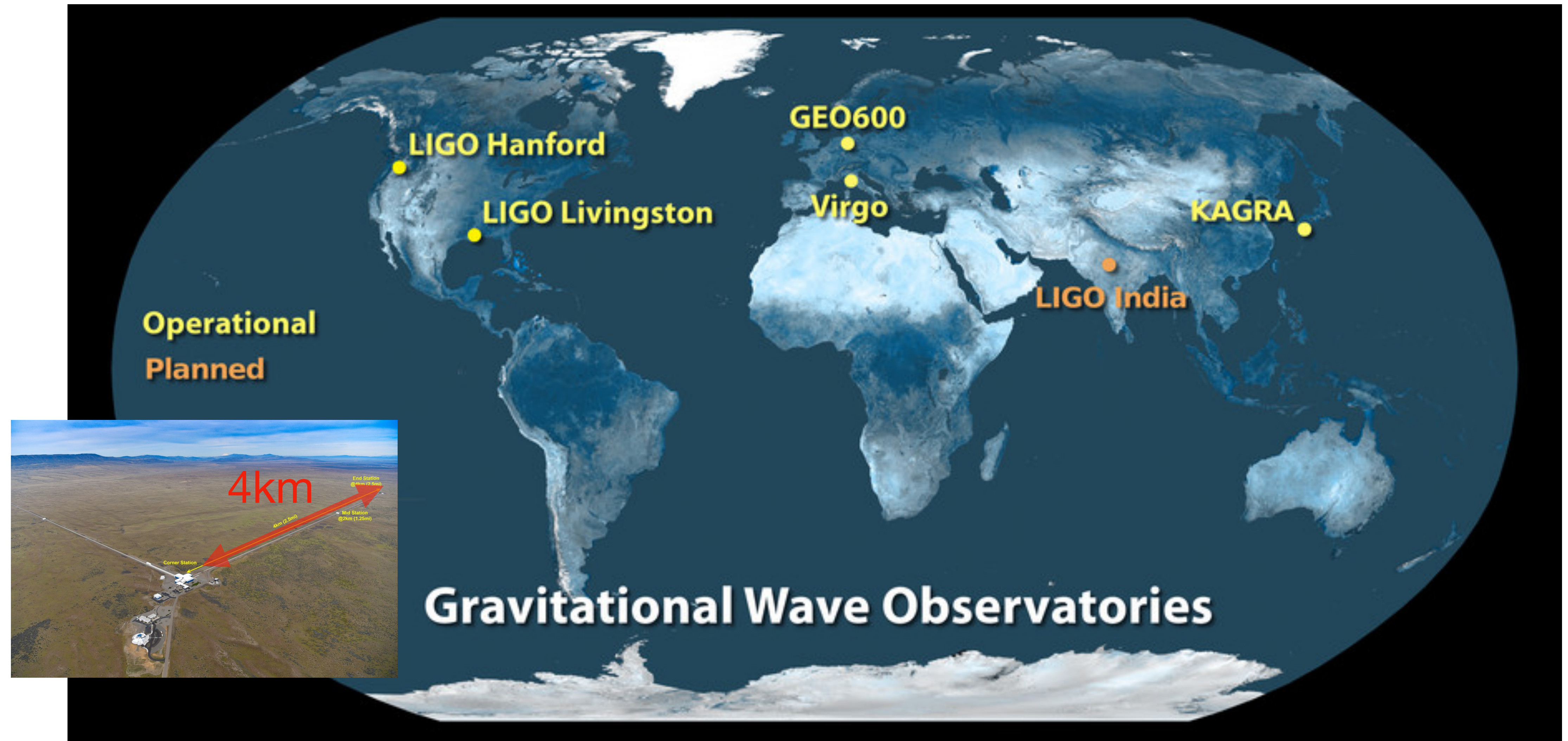
ICFP 2026, Beijing, 24 October 2026

Ruhan Rao(饶茹涵)

ruhanrao790@gmail.com



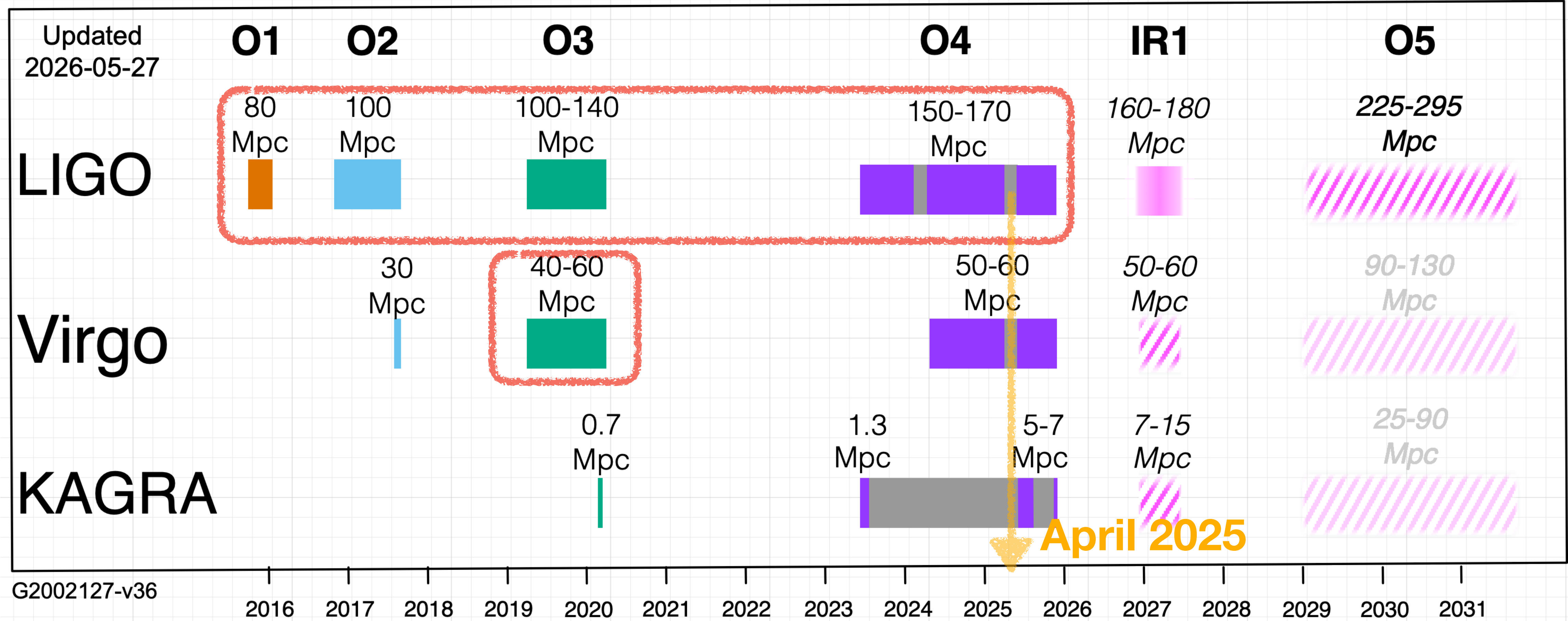
The LIGO-Virgo-Kagra detectors



Gravitational-Wave Observatories Across the Globe
<https://www.ligo.caltech.edu/image/ligo20160211c>

Aerial photograph (taken in 2023) of LIGO Hanford
Observatory (Caltech/MIT/LIGO Lab)
<https://www.ligo.caltech.edu/page/ligo-detectors>

LVK observing runs



<https://observing.docs.ligo.org/plan/>

Analysis pipeline

Python-based package tailored to searches for isotropic GWBs with LVK detectors [arXiv:2303.15696](https://arxiv.org/abs/2303.15696)

PyGWB isotropic workflow

Strain data → Preprocessing → Computing Spectra → Data quality → Postprocessing

Output: Stochastic intermediate data

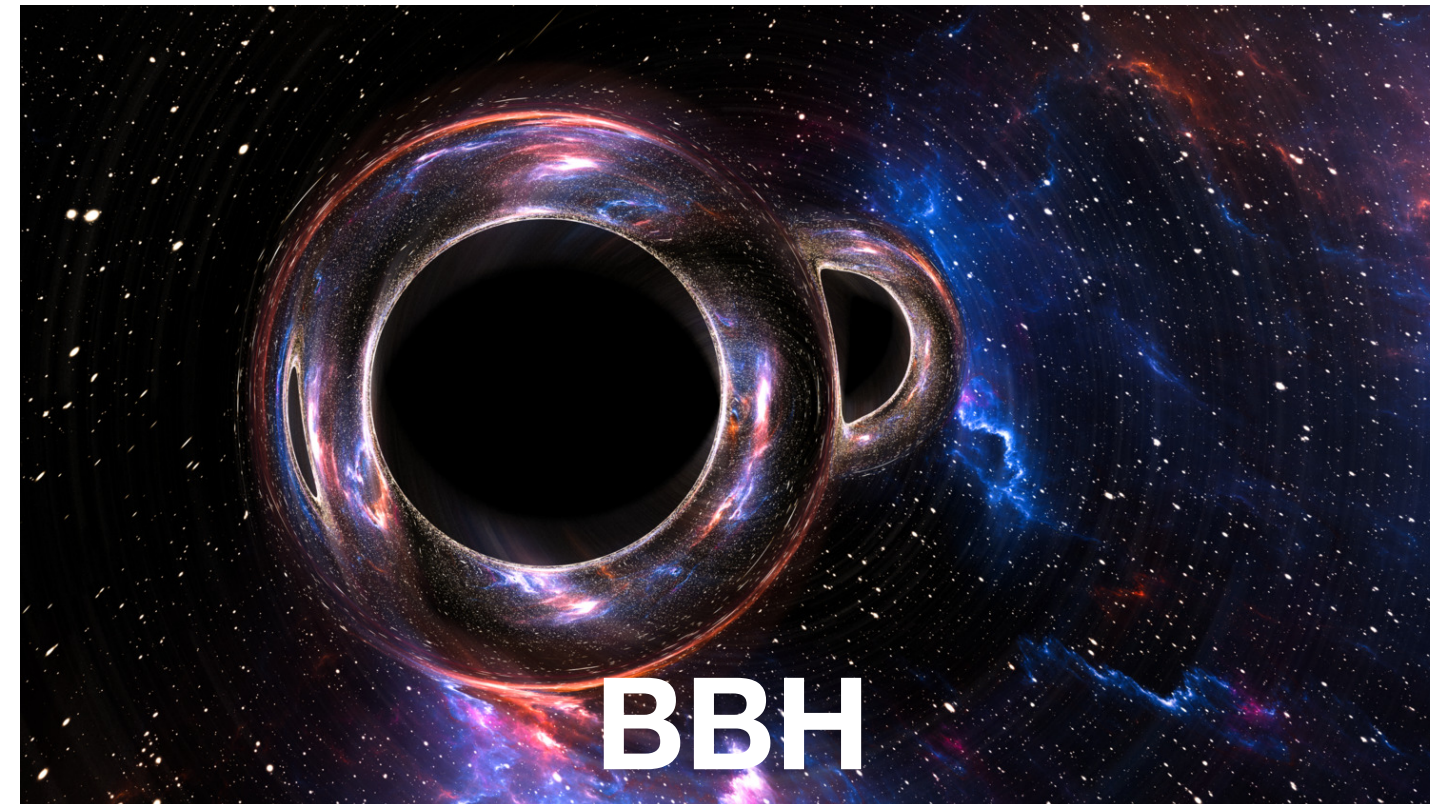
Frequentist & Bayesian Analysis

Results

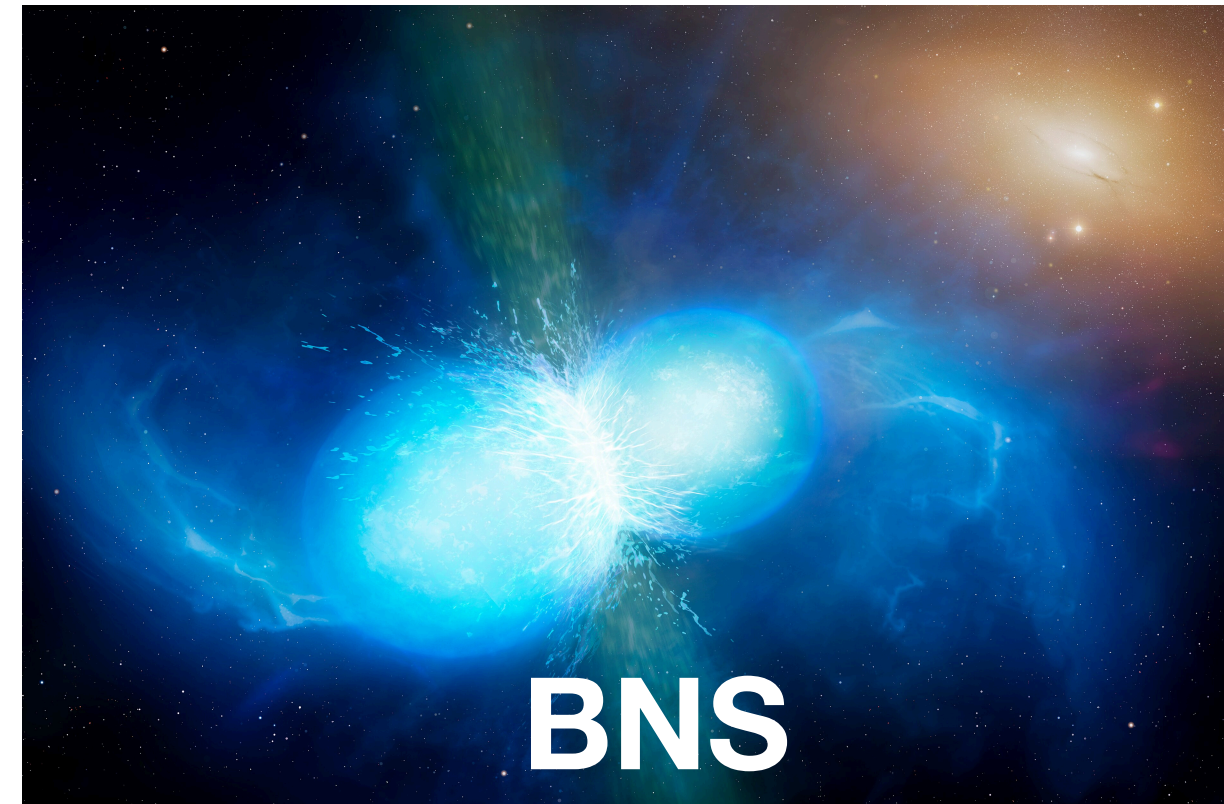
Frequentist result & Bayesian result & Astrophysical implications

The Gravitational-Wave Background(GWB)

The GWB is a random superposition of a large number of **weak**, **independent**, and **unresolved** gravitational-wave (GW) signals

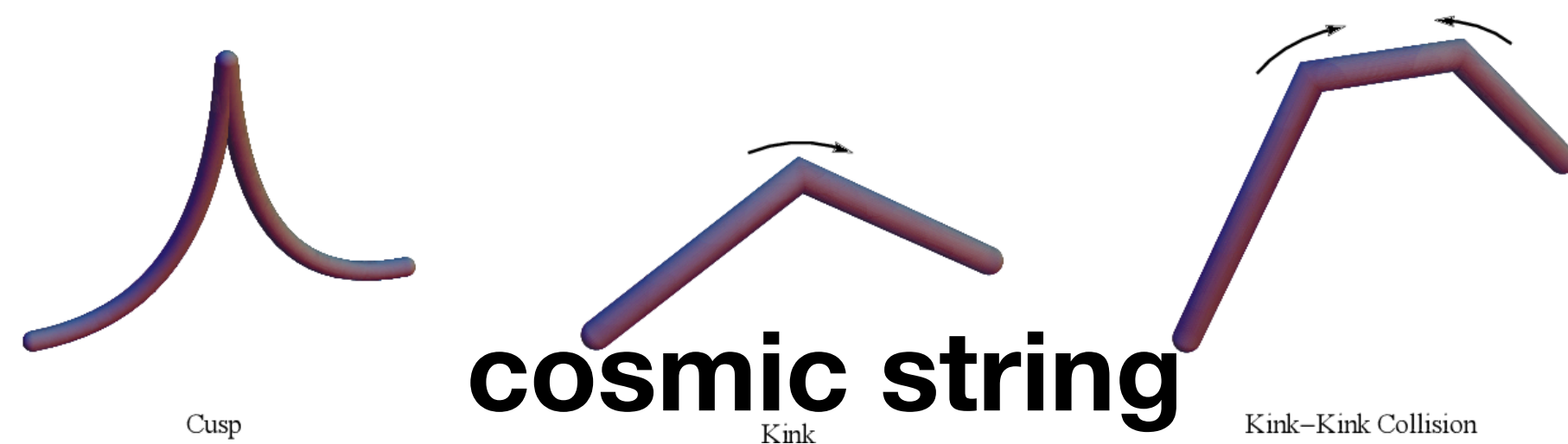


Carl Knox, OzGrav, Swinburne University of Technology



Mark Garlick, University of Warwick

Astrophysical



Long, Hyde and Vachaspati



Weir, David arXiv:1705.01783

Cosmological

LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration. Phys. Rev. X 16, 041023
Published 22 October, 2026 DOI: <https://doi.org/10.1103/dlfb-z6m2>

Statistical properties & Fractional GW energy density

B. Allen and J. D. Romano, Phys. Rev. D 59, 102001 (1999)

- Characterize the background statistically:

Gaussian, **zero-mean**, **stationary**, **isotropic**, and **unpolarized**

$$\langle h_A^*(f, \hat{\mathbf{n}}) h_{A'}(f', \hat{\mathbf{n}}') \rangle = \delta^2(\hat{\mathbf{n}}, \hat{\mathbf{n}}') \delta_{AA'} \delta(f - f') H(f), \quad \langle h_A(f, \hat{\mathbf{n}}) \rangle = 0$$

- Fractional GW energy density:

$$\Omega_{\text{GW}}(f) = \frac{1}{\rho_c} \frac{d \rho_{\text{GW}}(f)}{d \ln f}$$

- Relation:

$$H(f) = \frac{3H_0^2}{32\pi^3} \frac{\Omega_{\text{GW}}(f)}{f^3}$$

Analysis methods

B. Allen and J. D. Romano, Phys. Rev. D 59, 102001 (1999)

Cross-correlation spectra (for each time segment)

- Detector strain data (time domain):

$$s_I(t) = h_I(t) + n_I(t) \quad \langle \tilde{s}_I^* \tilde{s}_J \rangle = \langle \tilde{h}_I^* \tilde{h}_J \rangle + \underbrace{\langle \tilde{h}_I^* \tilde{n}_J \rangle + \langle \tilde{n}_I^* \tilde{h}_J \rangle + \langle \tilde{n}_I^* \tilde{n}_J \rangle}_{=0}$$

- Unbiased Estimator for $\Omega_{\text{GW}}(f)$:

data from t_i to $t_i + \Delta t_i$

$$\hat{\Omega}_0(f; t_i) = \frac{\text{Re}[C_{\text{IJ}}(f; t_i)]}{\gamma_{\text{IJ}}(f) S_0(f)} \rightarrow C_{\text{IJ}}(f; t_i) = \frac{2}{T} \tilde{s}_I^*(f; t_i) \tilde{s}_J(f; t_i)$$

cross-spectral density

overlap reduction function

$$\langle \hat{\Omega}_0(f; t_i) \rangle = \Omega_{\text{GW}}(f) \quad S_0(f) = \frac{3H_0^2 F_0^2(f)}{10\pi^2} \frac{1}{f^3}$$

- Variance estimates:

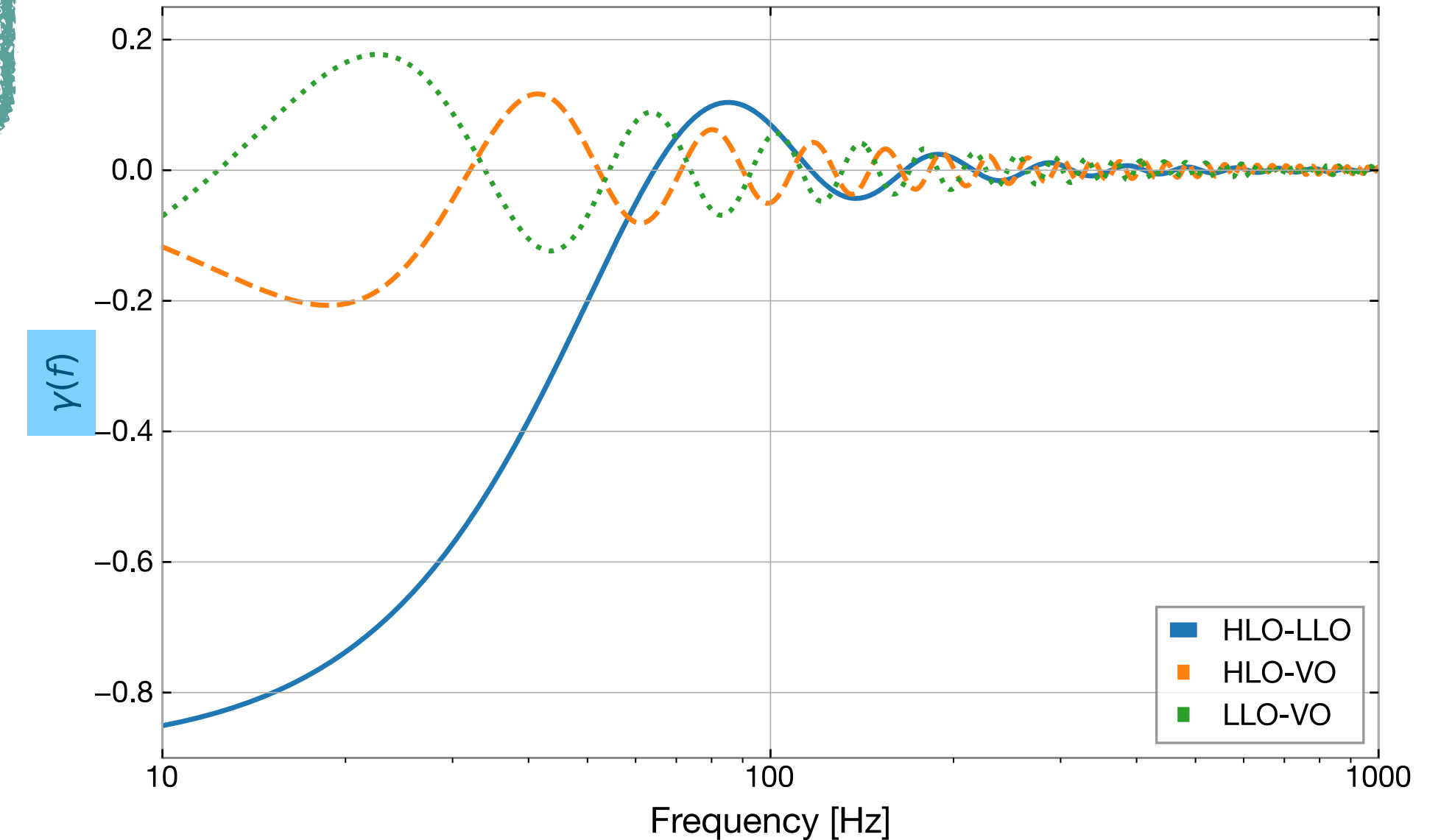
$$\sigma_0^2(f) = \frac{1}{2T\Delta f} \frac{P_I(f)P_J(f)}{\gamma_{\text{IJ}}^2(f)S_0^2(f)}$$

- Power-law spectral model:

$$\Omega_{\text{GW}}(f) = \Omega_\alpha F_\alpha(f)$$

$$F_\alpha(f) = \left(\frac{f}{25\text{Hz}}\right)^\alpha$$

$$\alpha = 0, 2/3, 3$$



overlap reduction function

$$\gamma_{IJ}(f) = \frac{5}{8\pi} \sum_{A=+, \times} \int_{S^2} d^2\hat{\mathbf{n}} F_I^A(\hat{\mathbf{n}}) F_J^A(\hat{\mathbf{n}}) e^{2\pi i f \hat{\mathbf{n}} \cdot \Delta \mathbf{x} / c}$$

Analysis methods

Frequency estimator

- Narrowband estimator and variance:

$$\hat{\Omega}_0(f) = \frac{\sum_i \left[\hat{\Omega}_0(f; t_i) \sigma_0^{-2}(f; t_i) \right]}{\sum_i \sigma_0^{-2}(f; t_i)}$$

$$\sigma_0(f) = \left[\sum_i \sigma_0^{-2}(f; t_i) \right]^{-1/2}$$

data from t_i to $t_i + \Delta t_i$

- Power-law spectral model:

$$\Omega_{\text{GW}}(f) = \Omega_\alpha F_\alpha(f)$$

$$F_\alpha(f) = \left(\frac{f}{25\text{Hz}} \right)^\alpha$$

$$\alpha = 0, 2/3, 3$$

- Broadband estimator and variance:

$$\hat{\Omega}_{\alpha|25\text{Hz}} = \frac{\sum_f \hat{\Omega}_0(f) F_\alpha(f) \sigma_0^{-2}(f)}{\sum_f F_\alpha^2(f) \sigma_0^{-2}(f)}$$

$$\sigma_{\alpha|25\text{Hz}} = \left[\sum_f F_\alpha^2(f) \sigma_0^{-2}(f) \right]^{-1/2}$$

optimally weighting the narrowband estimator

Analysis methods

Parameter estimation

- Noise only: $\Omega_{\text{GW}}(f; \Theta) = 0$

- Power Law

GWB signal models

$$p(\hat{\Omega}_0 | \Theta) \propto \exp \left[-\frac{1}{2} \sum_f \frac{(\hat{\Omega}_0(f) - \Omega_{\text{GW}}(f; \Theta))^2}{\sigma_0^2(f)} \right],$$

model parameters

Gaussian likelihood

$$p(\Theta | \hat{\Omega}_0, M) = \frac{p(\hat{\Omega}_0 | \Theta, M) \pi(\Theta | M)}{Z_M}$$

Bayes evidence

$$\text{Log Bayes factor } \log_{10} \mathcal{B}_N^S = \log_{10} \left(\frac{\mathcal{B}_S}{\mathcal{B}_N} \right)$$

Hybrid method

Frequentist analysis

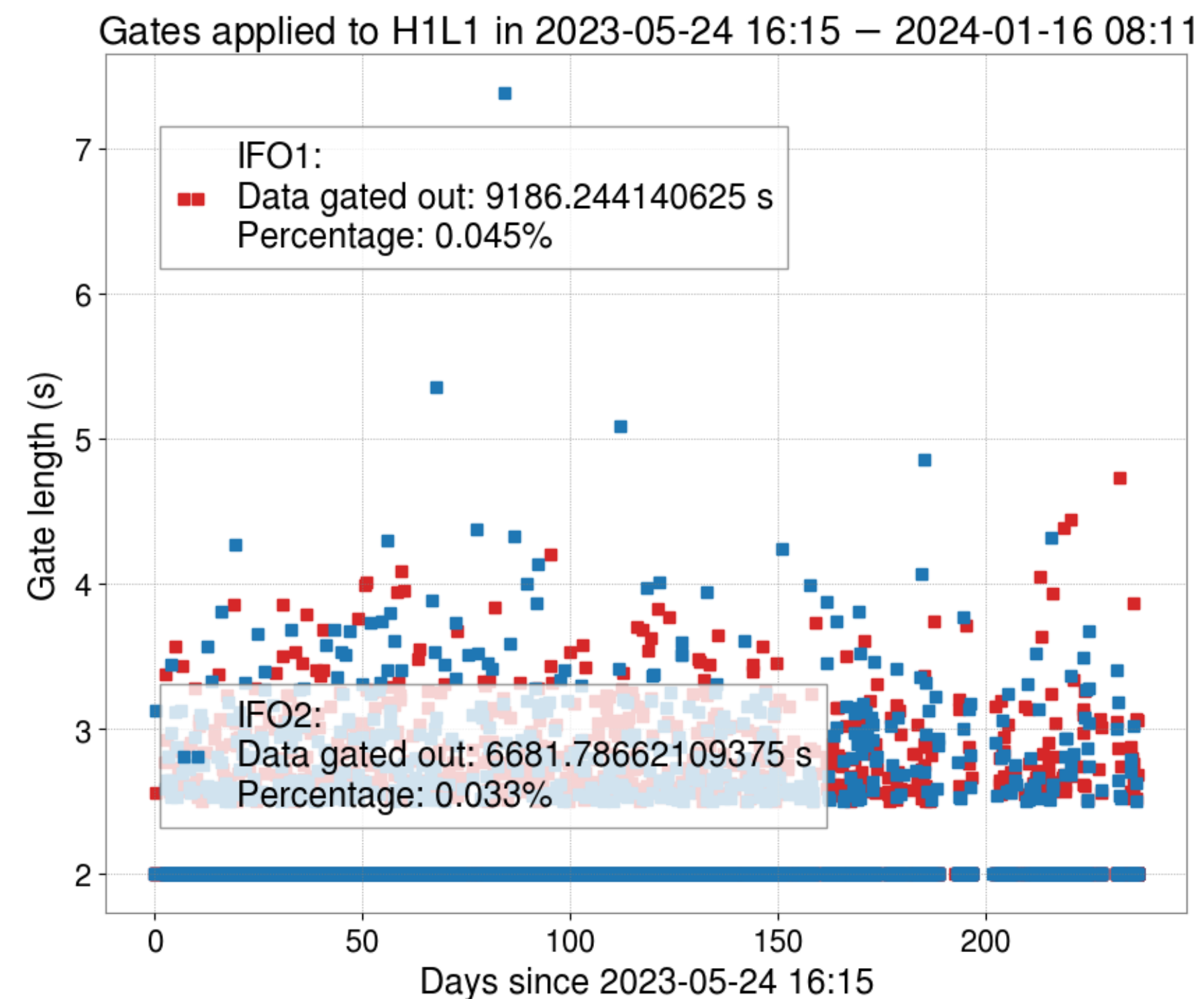
Bayesian analysis

- Obtain posteriors of Θ
 - set up UL at 95% C.L.
- Bayes factors
 - test different models

Data Quality

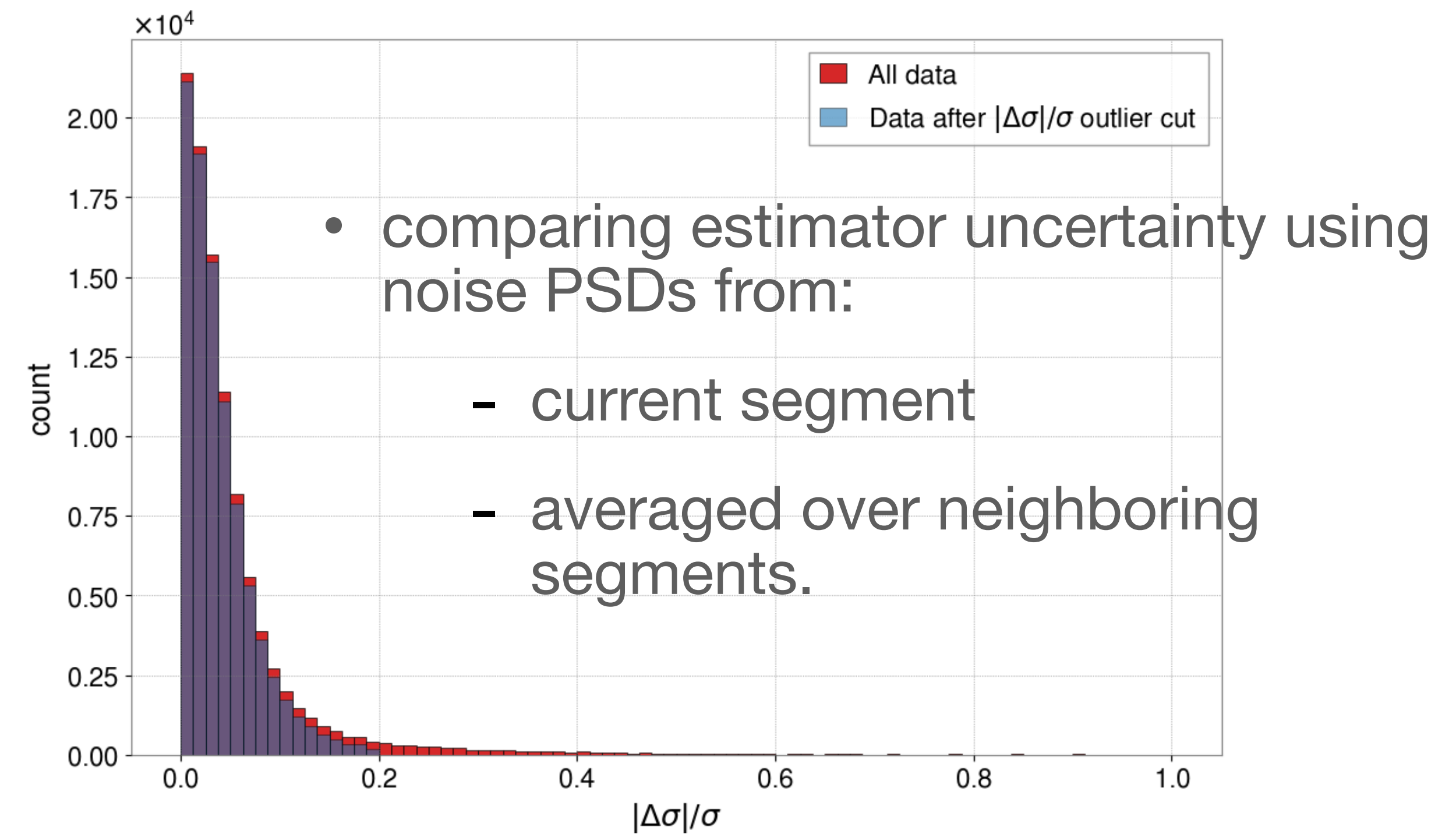
Time-domain cut

gating



delta-sigma cut

$\Delta\sigma$ and σ distributions in 2023-05-24 16:15 – 2024-01-16 08:11 with/out $\Delta\sigma$ cut



output of pygwb using publicly available O4a data

Data Quality

Frequency-domain cut (Notching)

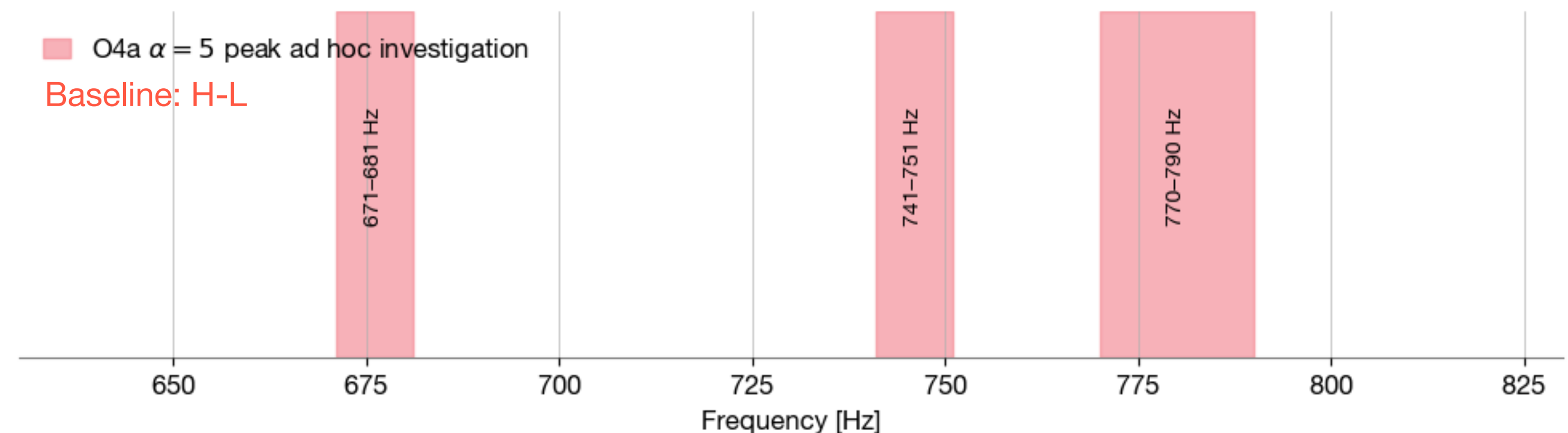
- Notching
 - narrowband deviations from Gaussianity [arXiv:2606.05959](https://arxiv.org/abs/2606.05959)
 - exclude problematic frequency bins
- **Strict notching** (newly introduced)

- $$\text{StdRatio}(f) = \text{std} \left(\frac{\text{PSD}(f)}{\text{Median}(\text{PSD}(f))} \right)$$

- Following up previous results:

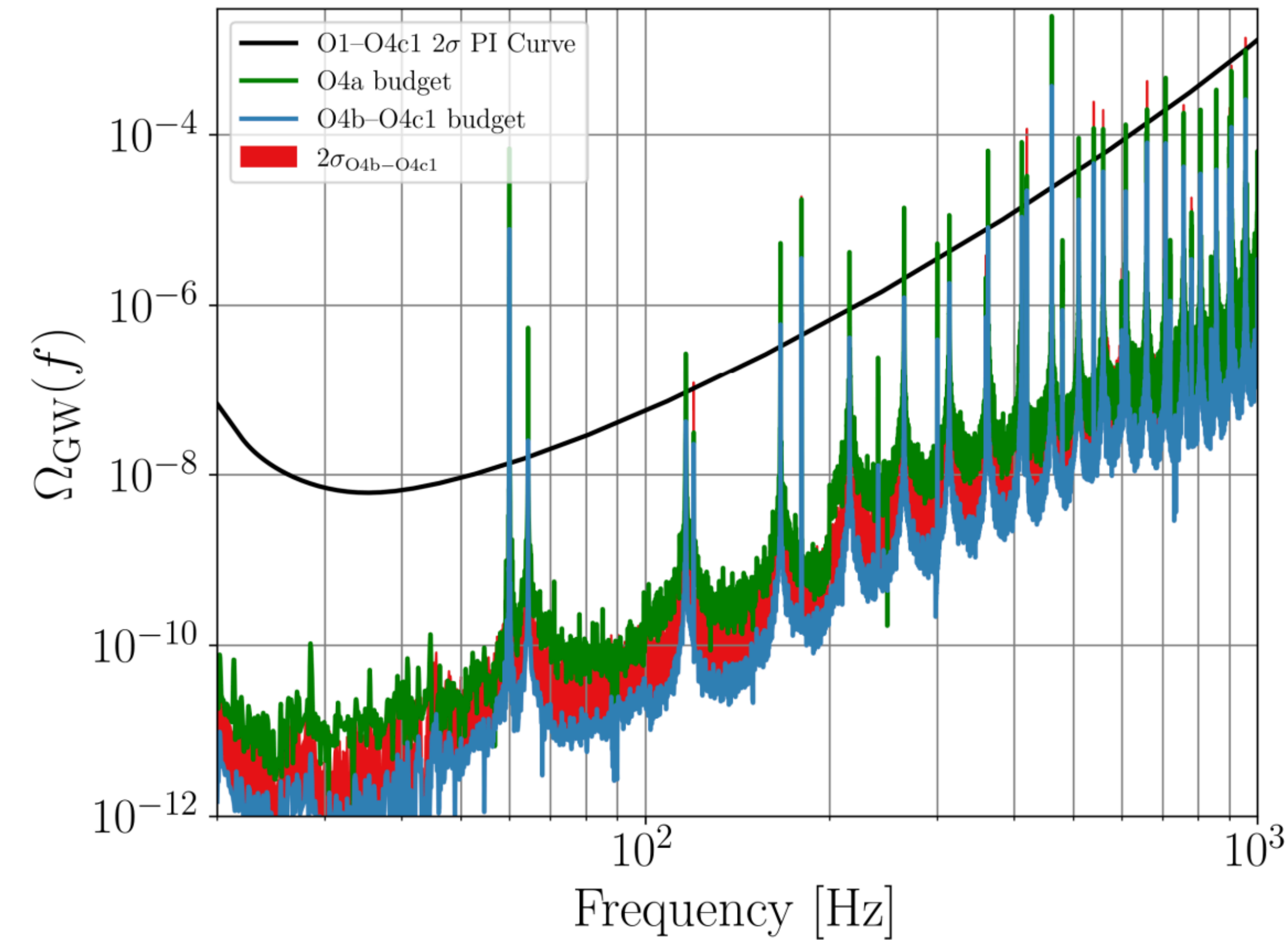
- Identify additional noise features. α posterior no longer exhibits the peak which was reported in O4a

These bins contributed to the peak in the O4a results and were identified through the new procedure



Data Quality (Correlated magnetic noise)

Magnetic noise budget



magnetic noise budget

[arXiv:2608.23477](https://arxiv.org/abs/2608.23477)

Joint magnetic and stochastic analysis

$$\Omega_{\text{GW}}(f | \Theta) = \Omega_{\text{ref}} F_{\alpha}(f) + \Omega_{\text{MAG}}(f | \Theta_{\text{MAG}})$$

$$\log_{10} \mathcal{B}_{\text{N}}^{\text{MAG}} = -0.185 \pm 0.003$$

$$\log_{10} \mathcal{B}_{\text{N}}^{\text{PL+MAG}} = -0.400 \pm 0.004$$

[arXiv:2608.23477](https://arxiv.org/abs/2608.23477)

Results arXiv:2608.23477

Frequentist analysis

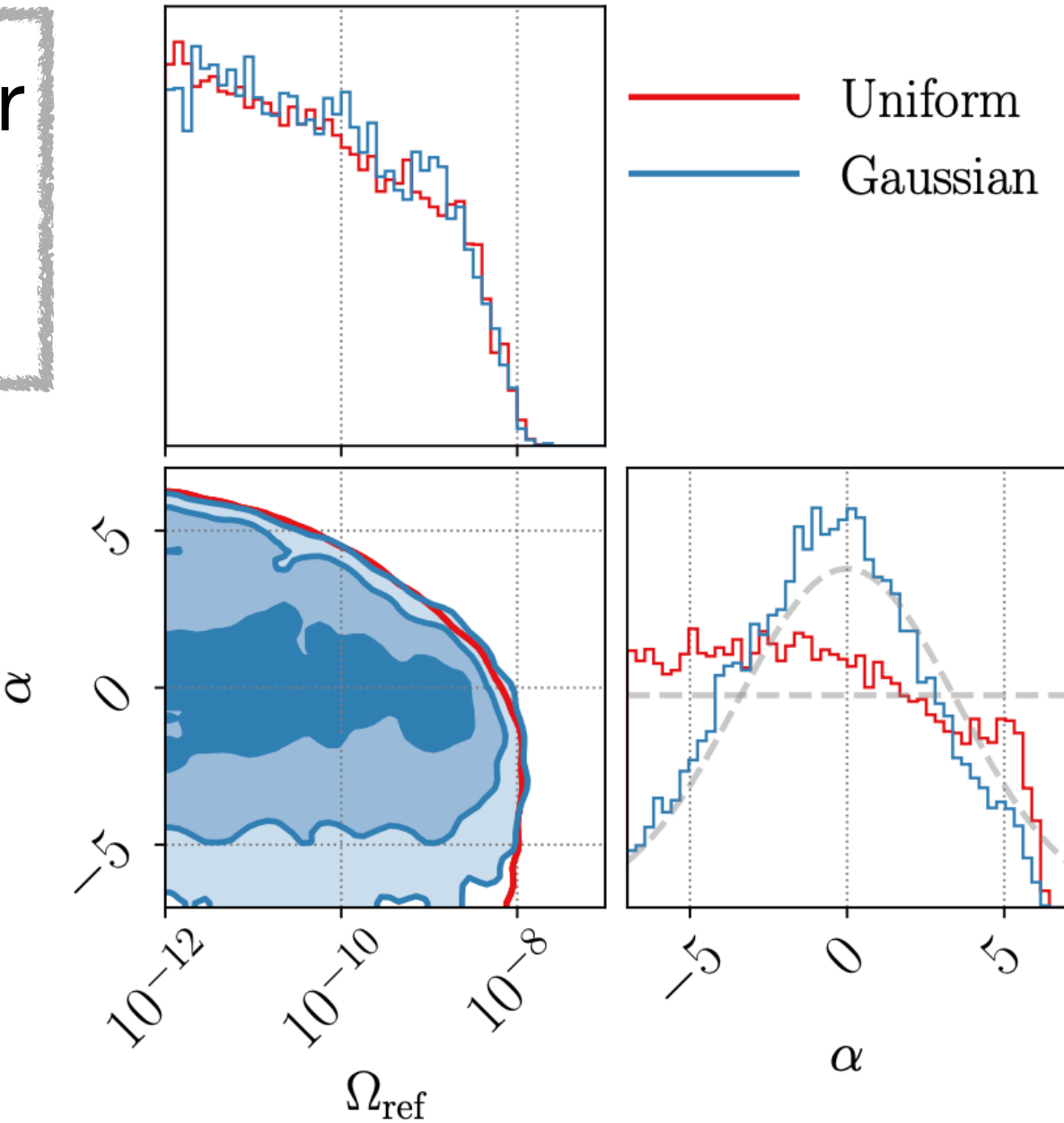
$$\Omega_{\text{GW}}(f) = \Omega_{\text{ref}} \left(\frac{f}{25\text{Hz}} \right)^\alpha$$

α	$f_{99\%}^{\text{O1-O4a}}$ [Hz]	$\hat{\Omega}^{\text{O1-O4a}}/10^{-9}$	$f_{99\%}^{\text{O4b-O4c1}}$ [Hz]	$\hat{\Omega}^{\text{O4b-O4c1}}/10^{-9}$	$f_{99\%}^{\text{O1-O4c1}}$ [Hz]	$\hat{\Omega}^{\text{O1-O4c1}}/10^{-9}$
0	64.7	1.1 ± 4.8	53.3	0.3 ± 4.9	56.2	0.7 ± 3.4
2/3	87.6	0.4 ± 3.6	84.2	-0.1 ± 3.9	86.3	0.2 ± 2.6
3	329.9	-0.3 ± 0.6	347.9	-0.3 ± 0.7	338.2	-0.3 ± 0.5

Bayesian analysis

$\log_{10} \mathcal{B} = -0.518 \pm 0.009$ for Gaussian prior
 $\log_{10} \mathcal{B} = -0.573 \pm 0.010$ for uniform prior

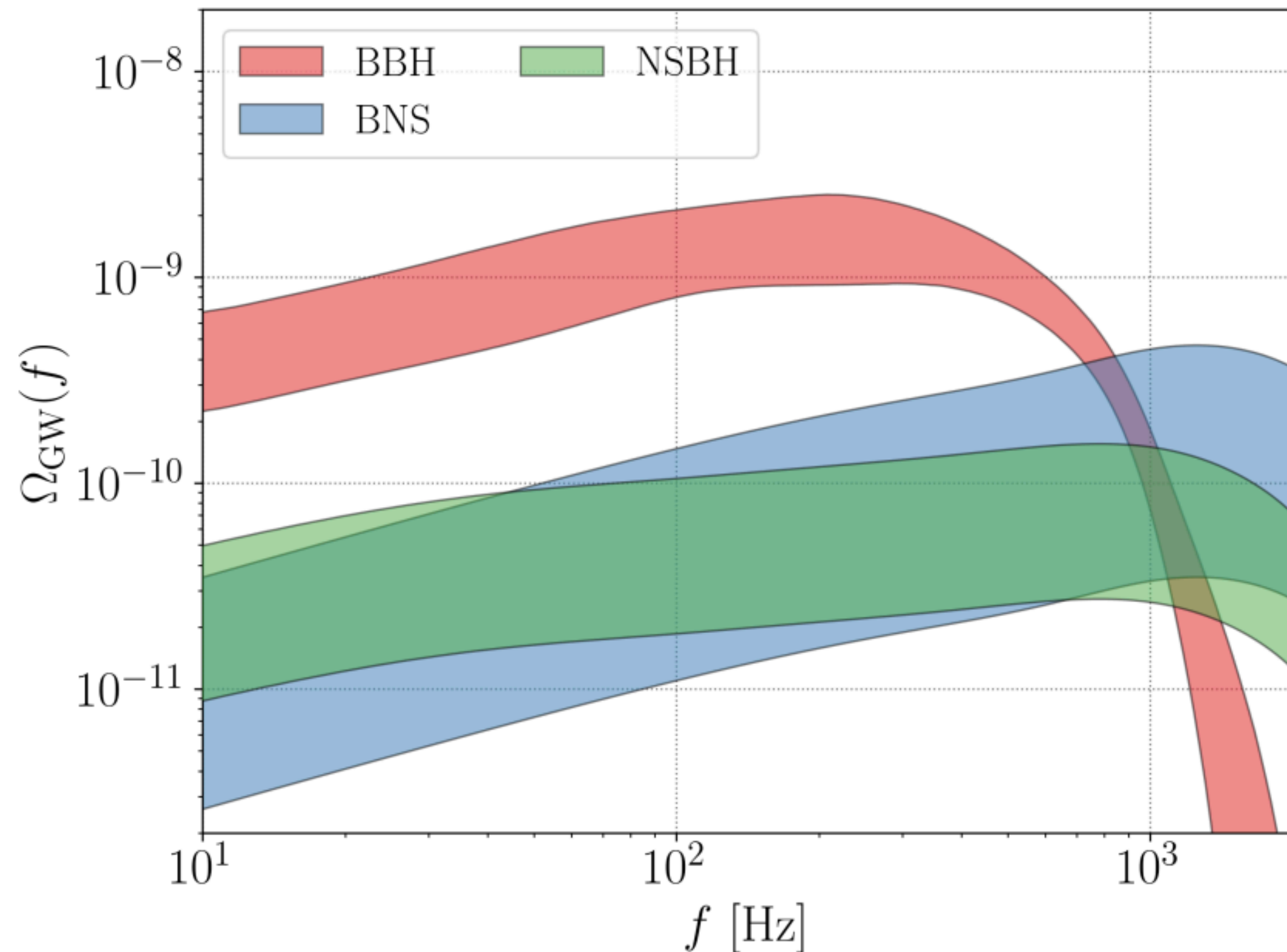
α	Uniform prior			Log-uniform prior		
	O1-O4c1	O1-O4a	Improvement	O1-O4c1	O1-O4a	Improvement
0	7.4×10^{-9}	1.1×10^{-8}	1.5	2.8×10^{-9}	3.9×10^{-9}	1.4
2/3	5.5×10^{-9}	7.9×10^{-9}	1.4	2.0×10^{-9}	2.8×10^{-9}	1.4
3	7.5×10^{-10}	1.0×10^{-9}	1.3	2.6×10^{-10}	3.6×10^{-10}	1.4
Marginalized	1.1×10^{-8}	1.7×10^{-8}	1.5	2.7×10^{-9}	4.1×10^{-9}	1.5



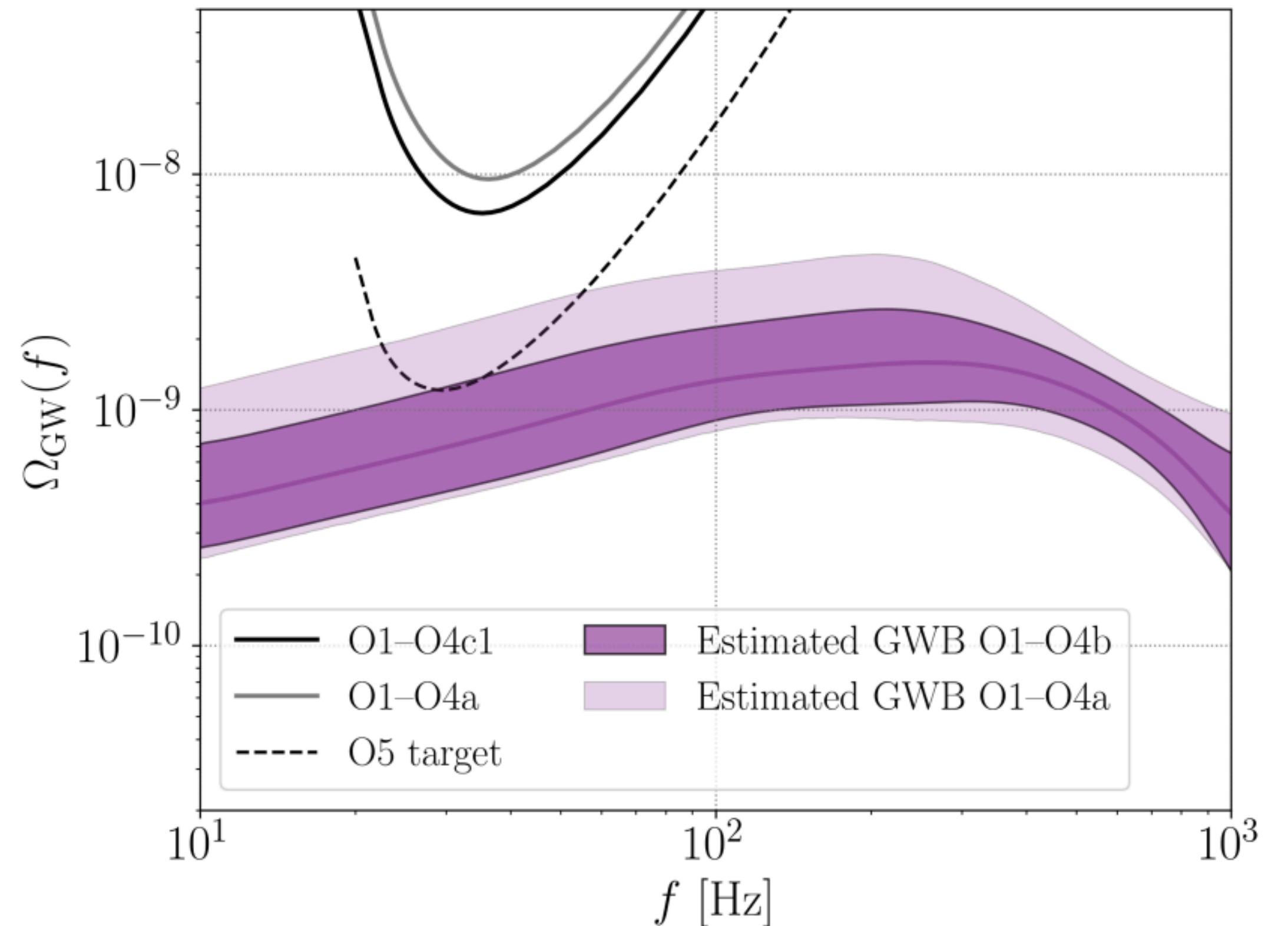
Results

[arXiv:2608.23477](#)

A detection of the CBC background remains within reach under the projected O5 sensitivity



Predicted astrophysical GWBs from BBH, BNS and NSBH at the 90% credible level



Combined estimate of CBC background and projected O5 sensitivity of the LIGO detectors

Summary

- No GWB detection: $\Omega_{\text{ref}}(25\text{Hz}) \leq 2.8 \times 10^{-9}$ for $\alpha = 0$, log-uniform prior, 95% C.L.
- Astrophysical implication: $\Omega_{\text{CBC}}(25\text{Hz}) = 6.3_{-2.2}^{+5.0} \times 10^{-10}$ (90% credible interval).
- O5 prospects: A detection of the CBC background remains within reach under the projected O5 sensitivity