Accurate parameter inference of binary neutron stars in one second

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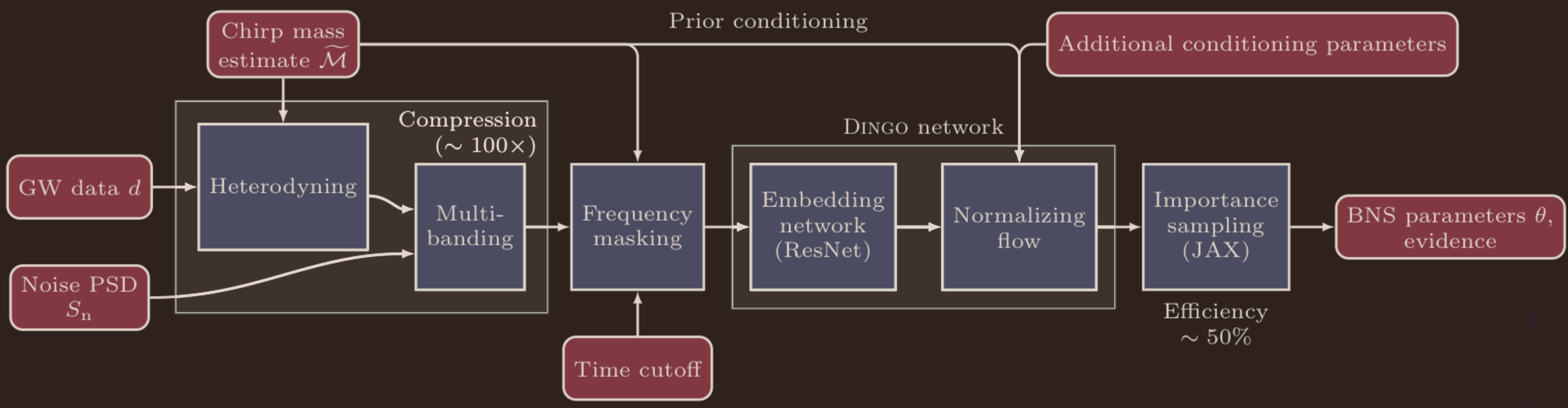
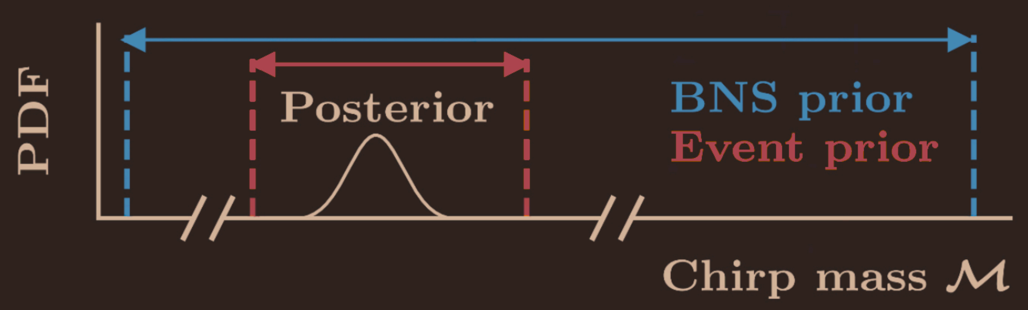


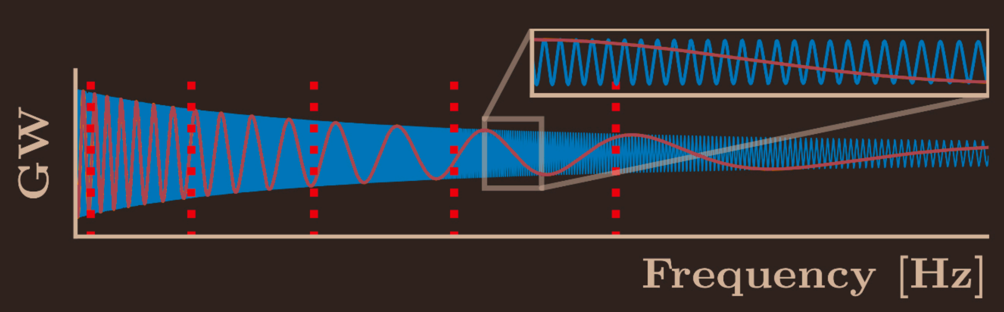
Methods

Prior conditioning



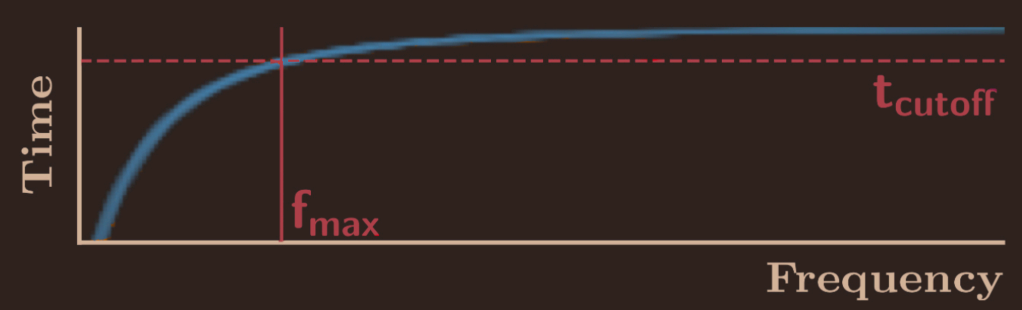
We condition the network on a chirp mass estimate. This allows us to localize the posterior with event specific priors

Heterodyning & Multibanding

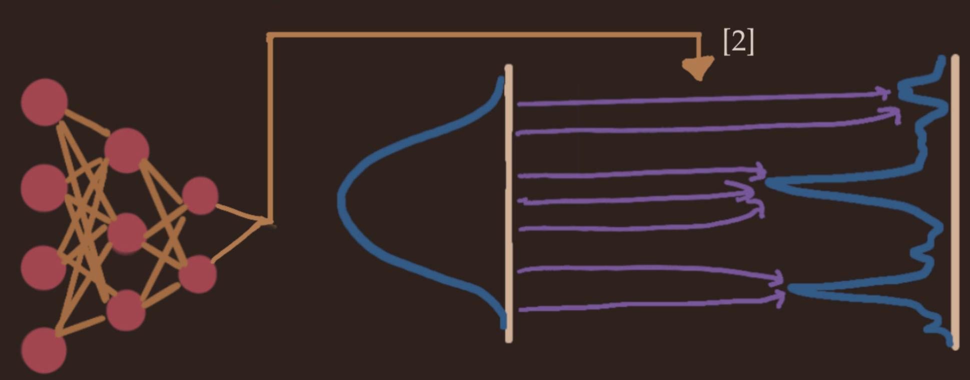


Binary neutron stars sweep the frequency range in a simple way. We can take advantage of this to compress the data by 100x. First, we use the mass estimate to heterodyne [2] the data. Second, we downsample [3] the data using coarse resolution at high frequencies.

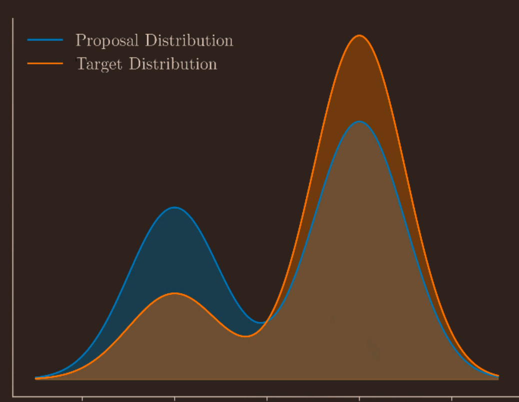
Frequency Masking



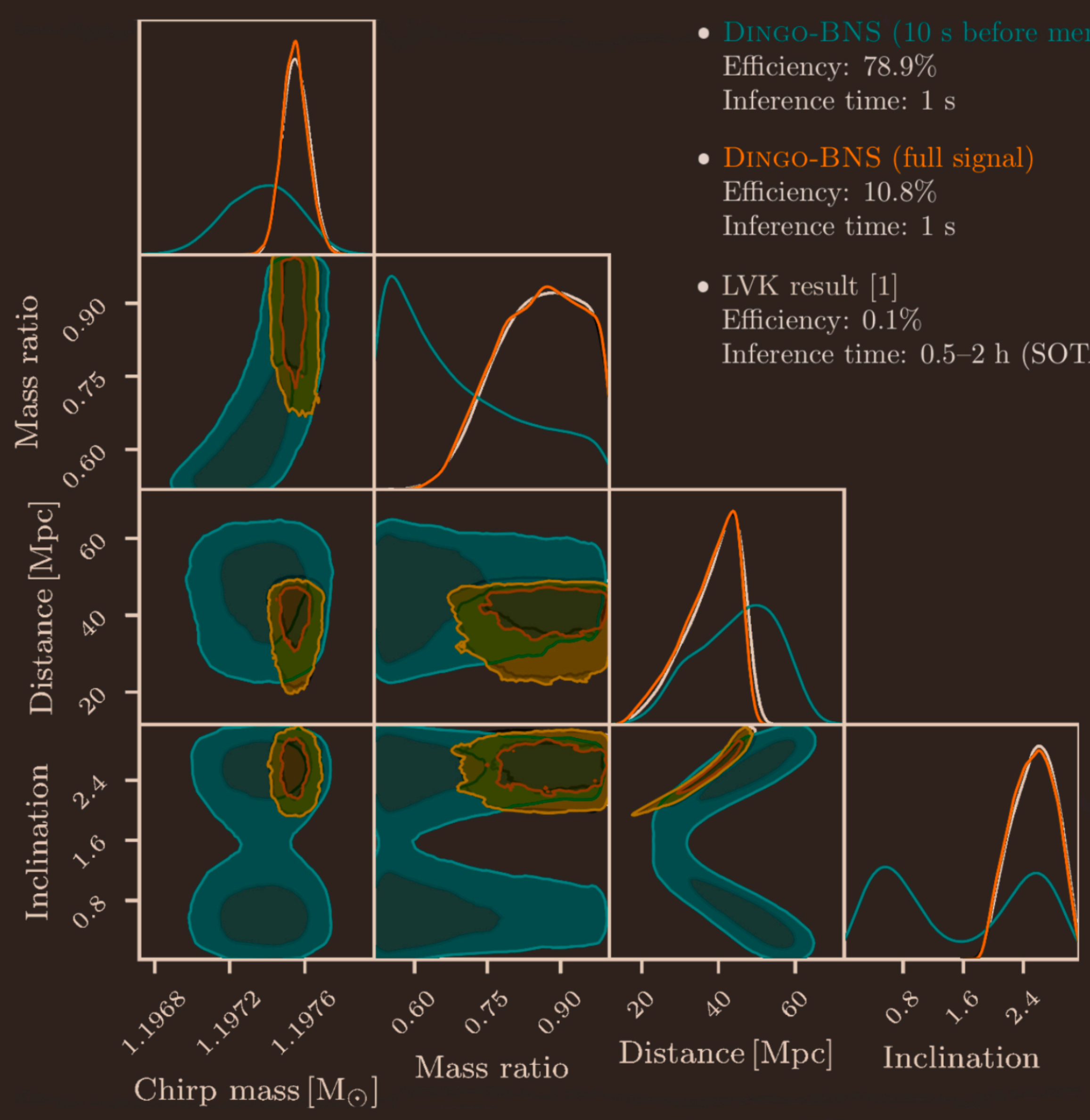
Embedding network & density estimator



JAX & Importance Sampling

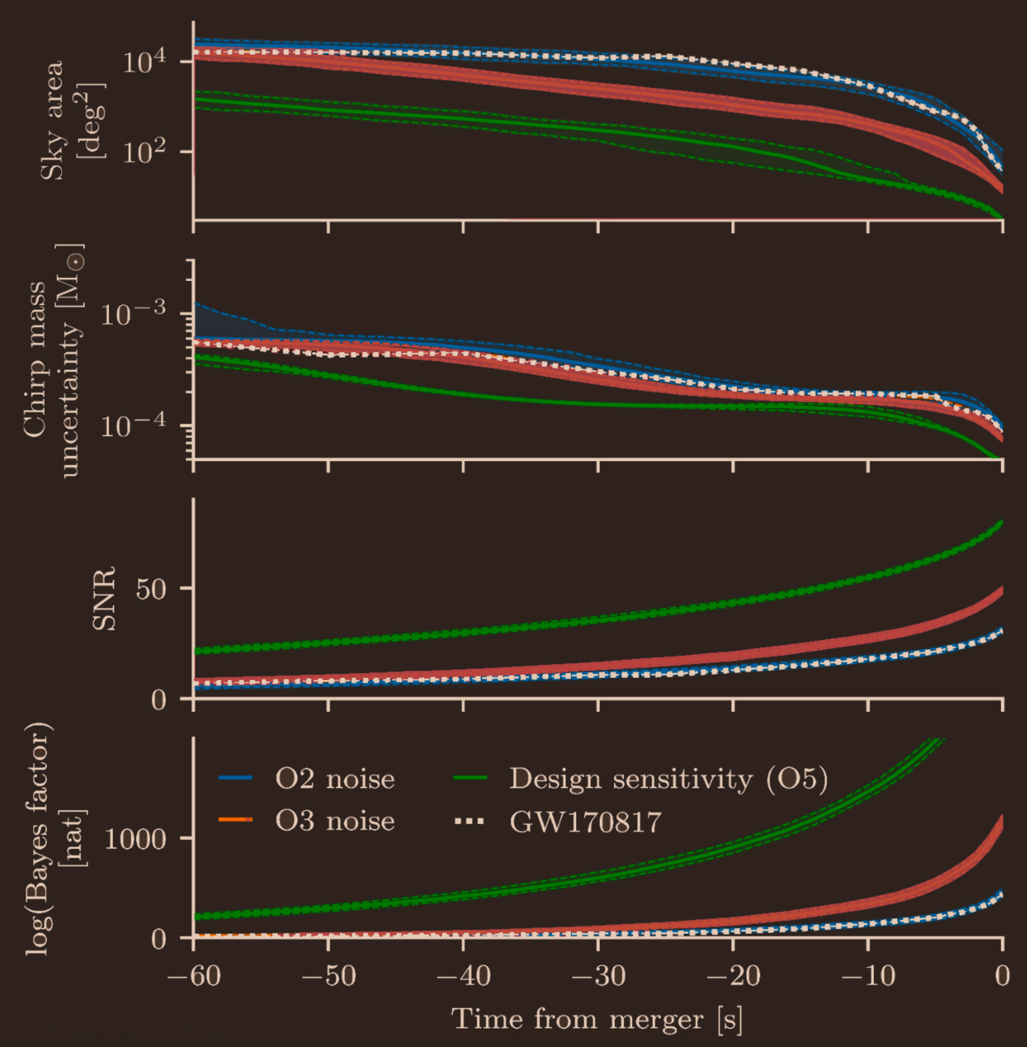


To ensure consistency with traditional Bayesian inference, we importance sample [4] the results. With JAX and a GPU this is done in 250ms [3].

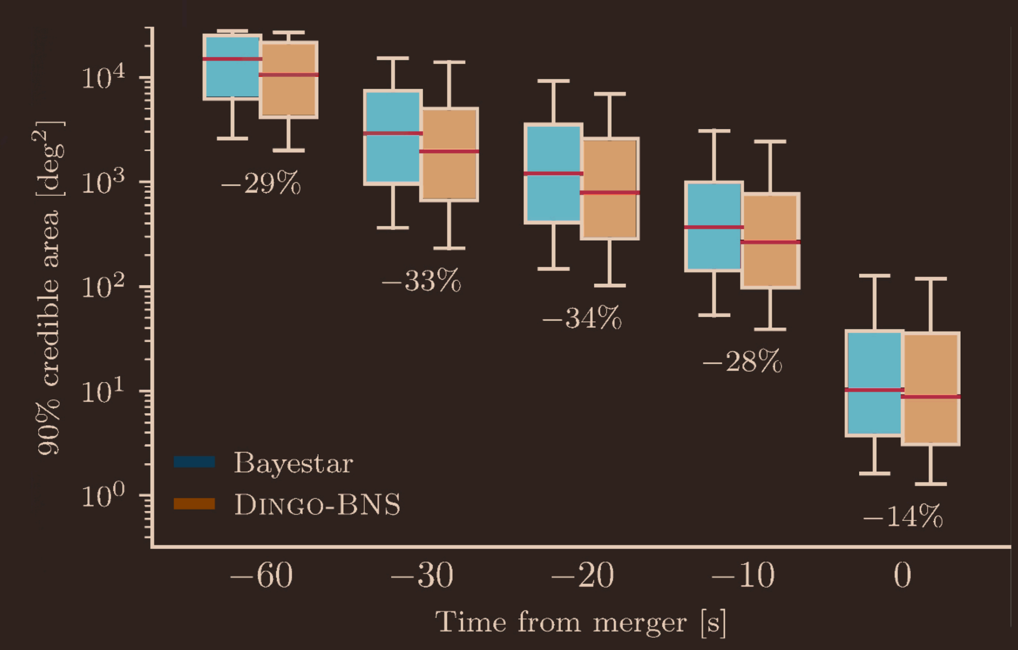


- DINGO-BNS (10 s before merger)
  Efficiency: 78.9%
  Inference time: 1 s
- DINGO-BNS (full signal)
  Efficiency: 10.8%
  Inference time: 1 s
- LVK result [1]
  Efficiency: 0.1%
  Inference time: 0.5–2 h (SOTA)

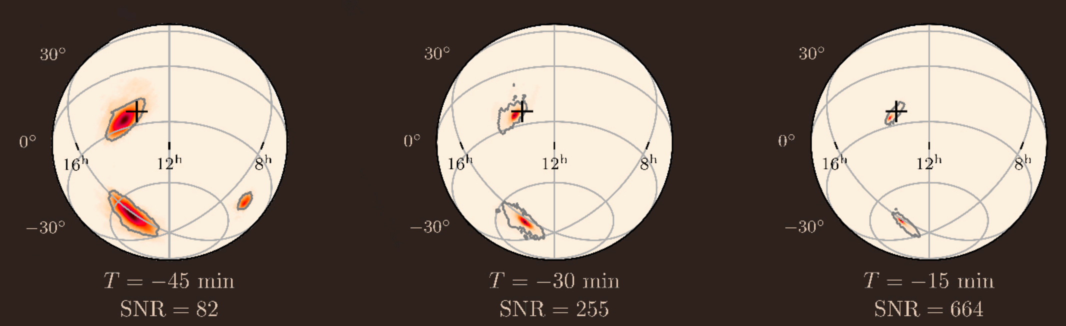
Results



We can do inference before the merger and obtain the sky map, SNR and evidence.



Comparing to Bayestar, [5] we achieve smaller sky localization before the merger. Most importantly, DINGO-BNS is fully Bayesian. Note it does not take into account non-Gaussian noise.



We demonstrate DINGO-BNS on XG setups showing one can constrain the sky map up to 45 min before merger.

Citations

[1] B. P. Abbott *et al.* (LIGO Scientific, Virgo), Properties of the binary neutron star merger GW170817, Phys. Rev. X **9**, 011001 (2019), arXiv:1805.11579 [gr-qc].

[2] M. Dax, S. R. Green, J. Gair, J. H. Macke, A. Buonanno, and B. Schölkopf, Real-Time Gravitational Wave Science with Neural Posterior Estimation, Phys. Rev. Lett. **127**, 241103 (2021), arXiv:2106.12594 [gr-qc].

[4] M. Dax, S. R. Green, J. Gair, M. Pürrer, J. Wildberger, J. H. Macke, A. Buonanno, and B. Schölkopf, Neural Importance Sampling for Rapid and Reliable Gravitational-Wave Inference, Phys. Rev. Lett. **130**, 171403 (2023), arXiv:2210.05686 [gr-qc].

[5] L. P. Singer and L. R. Price, Rapid Bayesian position reconstruction for gravitational-wave transients, Phys. Rev. D **93**, 024013 (2016), arXiv:1508.03634 [gr-qc].

[3] T. D. P. Edwards, K. W. K. Wong, K. K. H. Lam, A. Coogan, D. Foreman-Mackey, M. Isi, and A. Zimmerman, Differentiable and hardware-accelerated waveforms for gravitational wave data analysis, Phys. Rev. D **110**, 064028 (2024), arXiv:2302.05329 [astro-ph.IM].

Link to paper