Using convergence tests to understand the performance of a parallel parameter estimation sampler for gravitational wave applications.

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Abstract: Bayesian inference has become an essential tool of astronomy and astrophysics. This talk discusses its application to gravitational wave observations, where one obtains the probability distribution for the physical parameters of the source, such as the masses and spins or extrinsic parameters such as the distance. The project focuses on a new parallel nested sampling method, Dynesty. We study its convergence and computational performance depending on the settings used in open data signals parameter estimation utilizing the non-precessing version of very accurate and fast waveforms, IMRPhenomXHM, which includes higher order modes.

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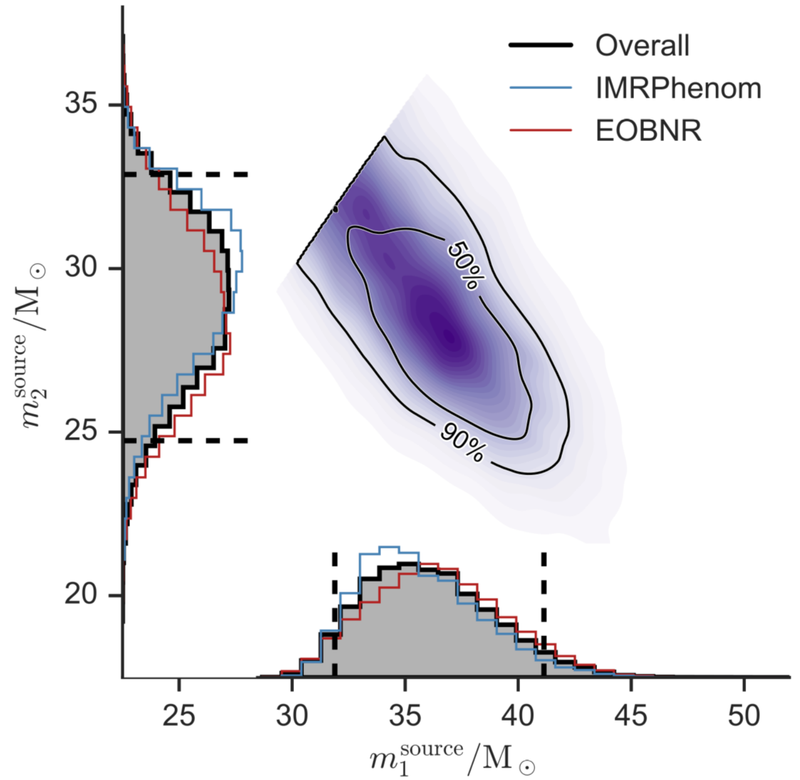
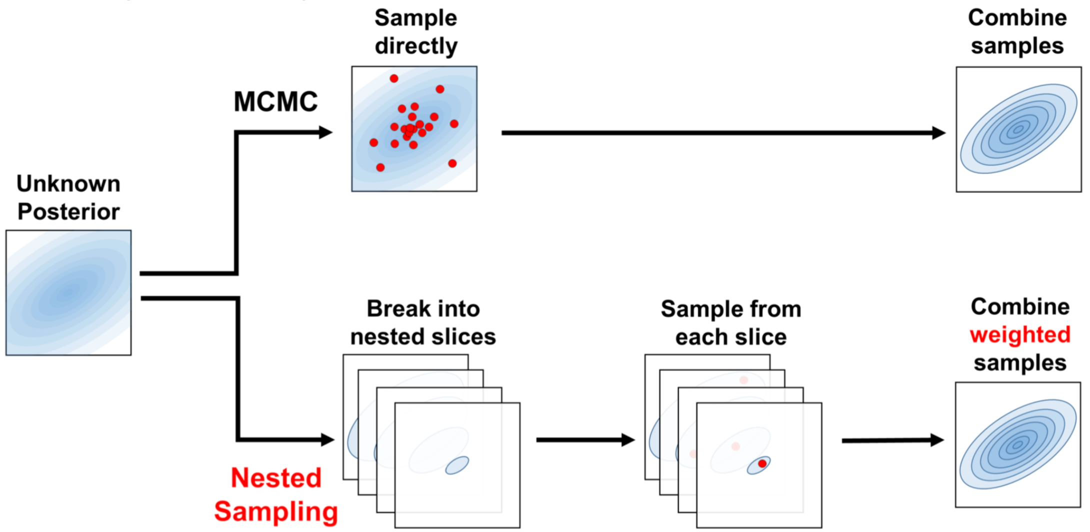
Context of the research

- Gravitational waves encode information from the sources.
- For their analysis, physical parameter must be recovered.
- Their probability distribution are infered by Bayesian parameter estimation.



Properties of the Binary Black Hole Merger GW150914, Abbott et al. (LVC) Phys. Rev. Lett. 116, 241102 (2016)



dynesty: A Dynamic Nested Sampling Package for Estimating Bayesian Posteriors and Evidences, J. S. Speagle, arXiv:1904.02180 [astro-ph.IM], 2019.

Bayes theorem

$$P(\theta|D,M) = \frac{P(D|\theta,M)\cdot P(\theta,M)}{P(D,M)}$$

Parameter estimation

$$\mathscr{P}(\theta_1) = \int d\theta_2 \cdots d\theta_N \mathscr{P}(\theta)$$

Description of the project: Convergence tests for PE

PROJECT:
1. Convergence test for several setting configurations.
2. Public data from O3a – GW190412.
3. Fast new model family - IMRPhenomX.
4. New LIGO's PE infrasctructure – Parallel Bilby – **Dynesty (sampler parallelized).*

Diagnostic test based on nestcheck analysis

Nestcheck: diagnostic tests for nested sampling calculations. E. Higson et al. , arXiv:1804.06406 [stat.CO], 2018.

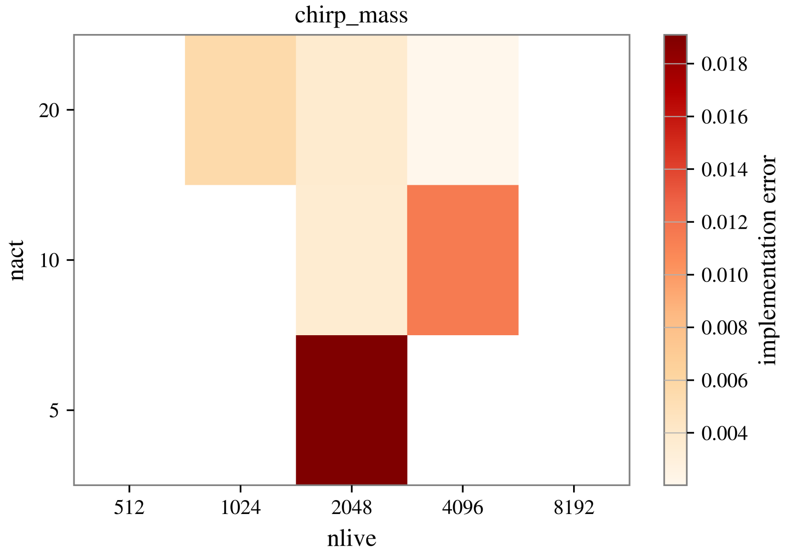
__Assumption__: Nested sampling errors come from implementation-specific and stochastic errors.

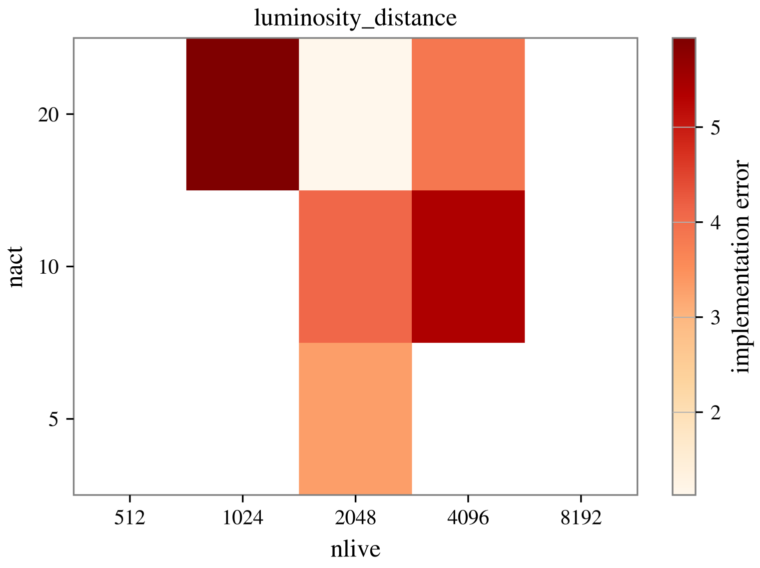
$$\sigma^2_{values} = \sigma^2_{bs} + \sigma^2_{imp}$$

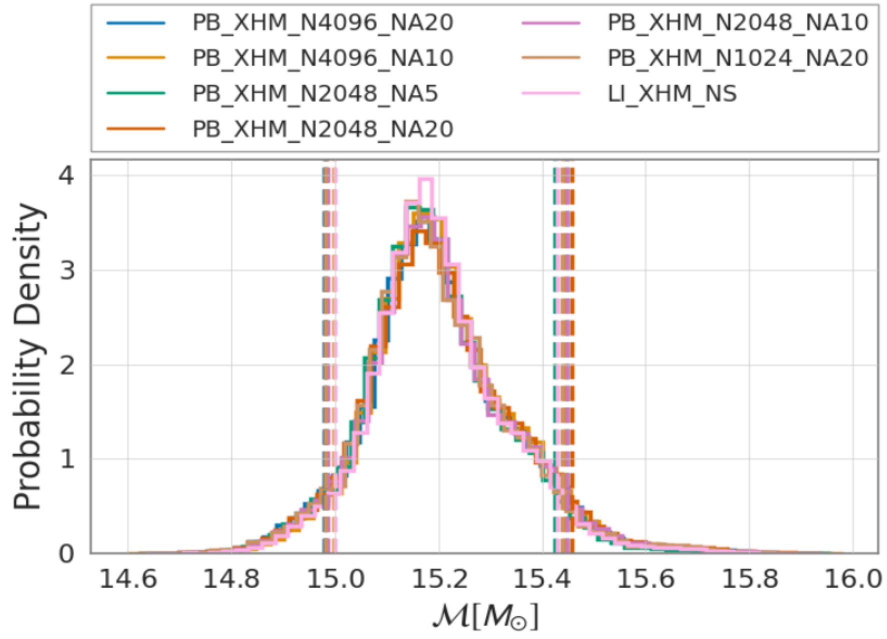
1. Implementation-specific errors (σ_{imp}): Errors due to the specific software used.
2. Stochastic errors (σ_{bs}): Errors from the stochasticity of the nested sampling algorithm.
3. Total error (σ_{values}): Observed sample standard deviation of the results.

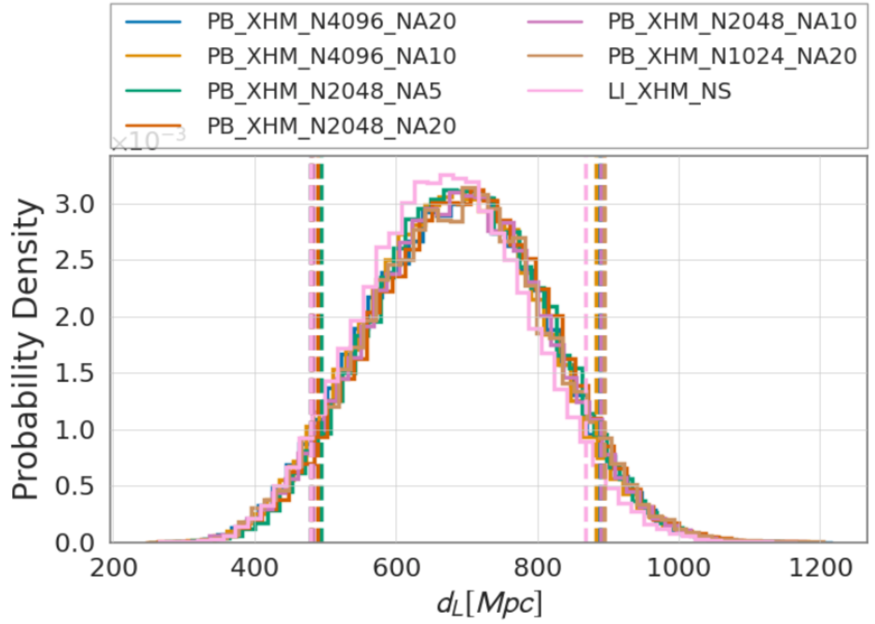
$$\sigma_{imp} = \begin{cases} \sqrt{\sigma^2_{values} - \sigma^2_{bs}} & if\ \sigma^2_{values} > \sigma^2_{bs}, \\ 0 & otherwise. \end{cases}$$

Results I





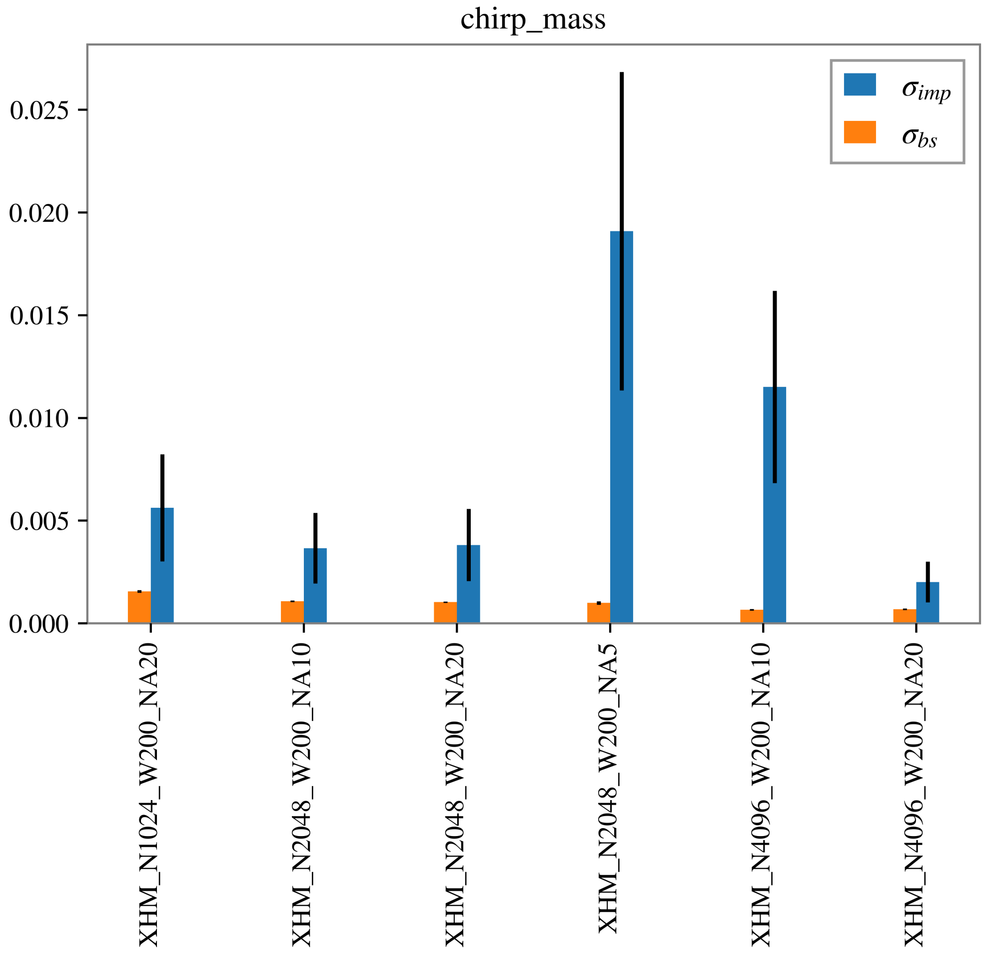


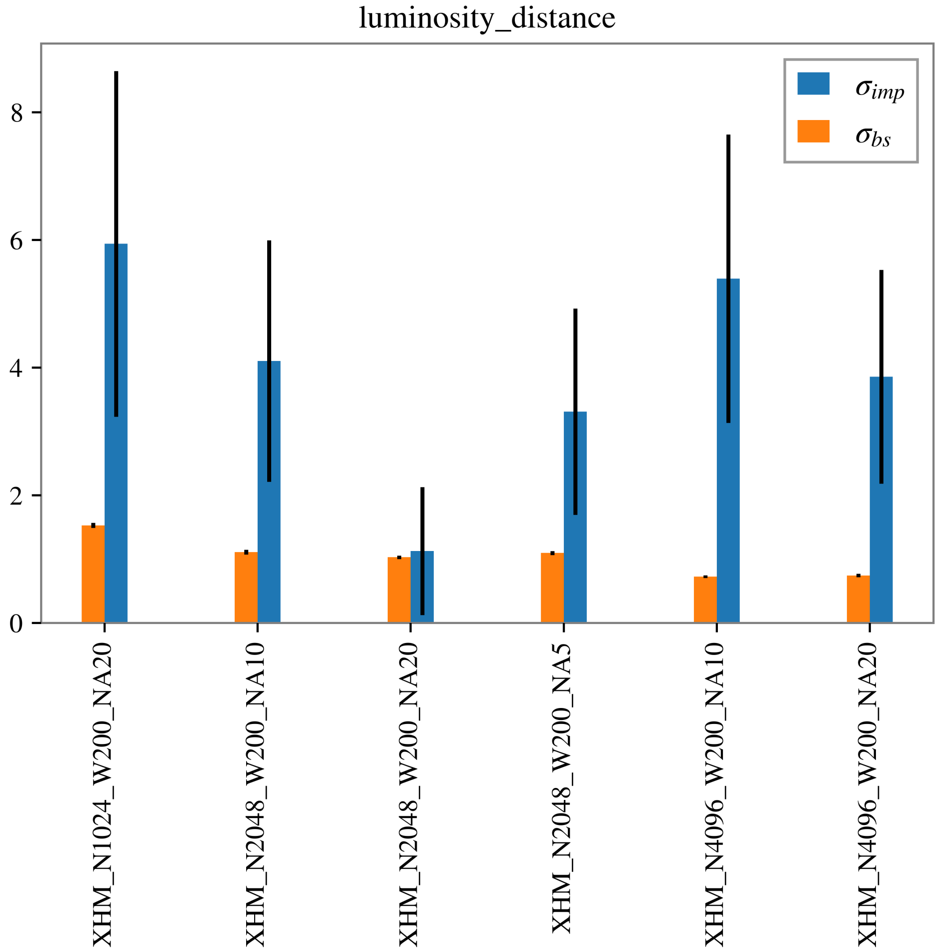


Parameter estimation of **GW190412**:

- Gravitational wave of binary blackhole merger.
- Network signal-to-noise ratio of 19.
- Asymmetric masses – higher order modes contribution.
- Nestcheck results: Not clear convergence depending on the physical parameters.

Results II





- Deeper study is required to have a clear convergence.
- Higher ressolution settings are needed – higher nact ~ (30-50).

Impact and prospects for the future

First gravitational-wave parameter estimation convergence test.

- Better knowledge of the sampler.
- Get the best choice for the sampler settings.
    - ➢ Better convergence in future PE studies.
    - ➢ Lower computational cost.