Using machine learning algorithms to enable gravitational-wave detection of short duration binary neutron star remnants

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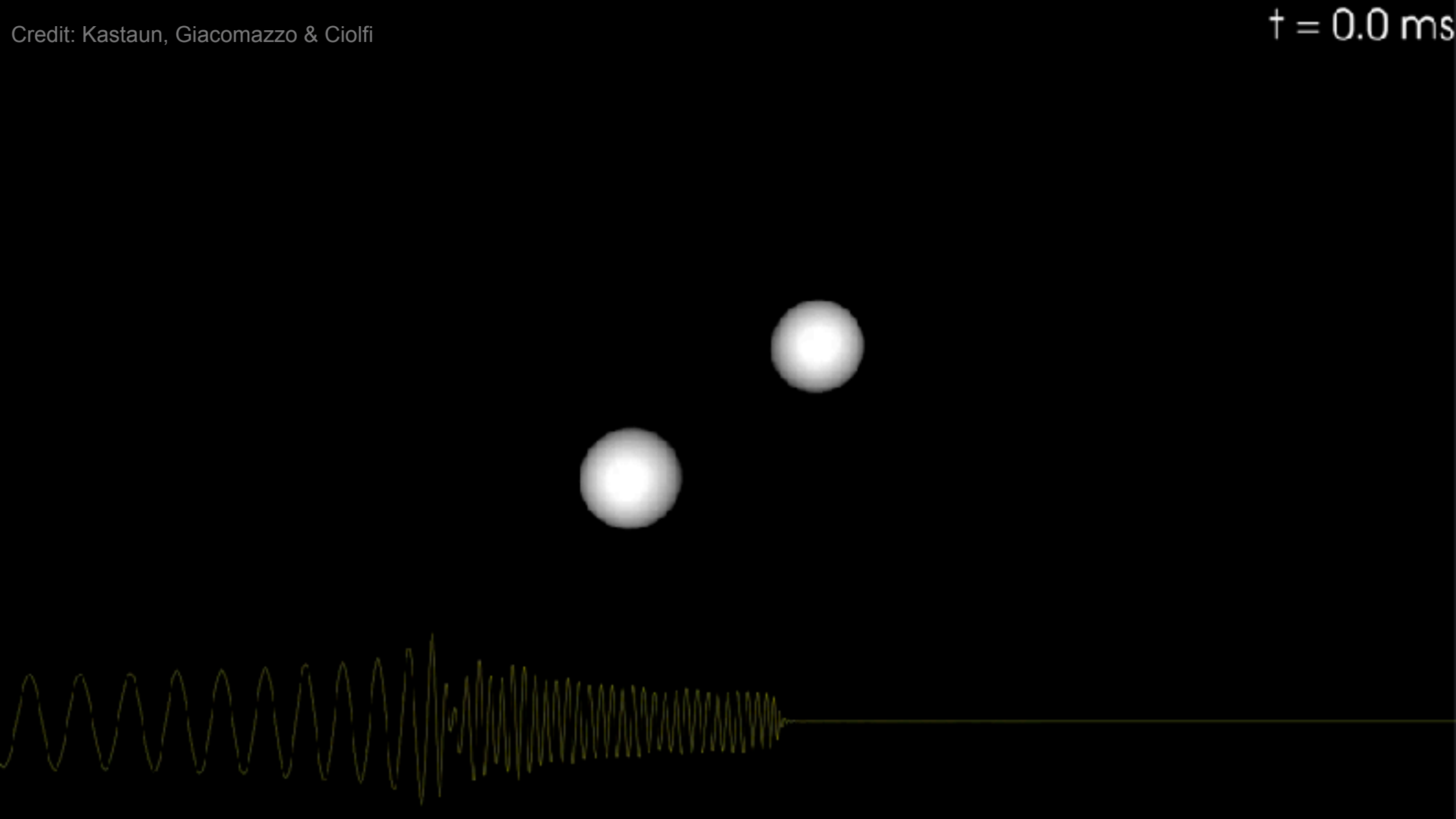
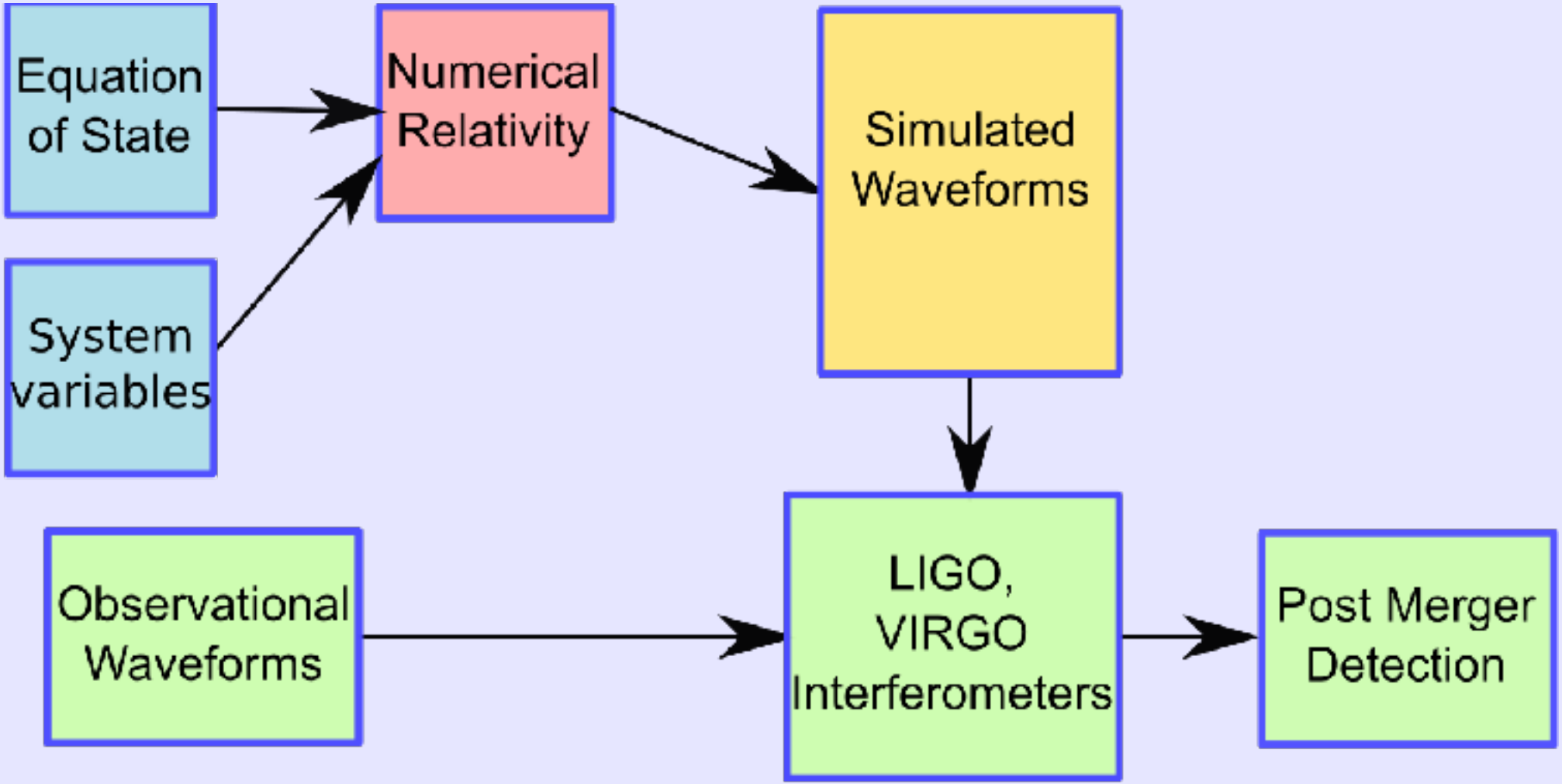
Binary neutron star mergers

- We have directly observed binary neutron star merger with both gravitational waves and electromagnetic radiation (GW170817)
- Detected inspiral “chirp” of merger
- No detection of post-merger remnant was found (as expected)

Credit: Dana Berry, SkyWorks Digital, Inc.


Credit: Kastaun, Giacomazzo & Ciolfi
t = 0.0 ms

Requirements for post-merger detection



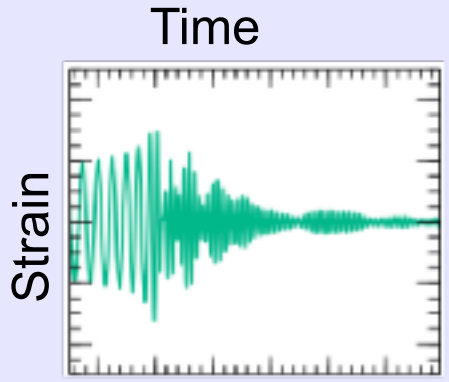
Requirements for post-merger detection

Equation of State

System variables

Numerical Relativity

Simulated Waveforms



~ 10^5 cpu hrs

Observational Waveforms

LIGO, VIRGO Interferometers

Post Merger Detection

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Equation of State

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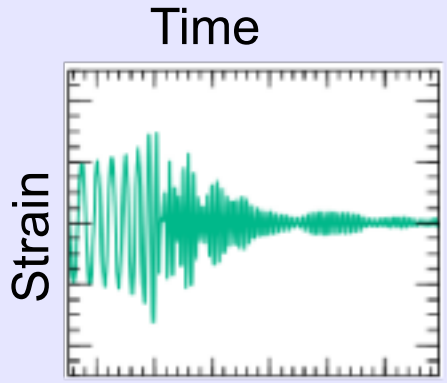
Simulated Waveforms



~ 10^5 cpu hrs

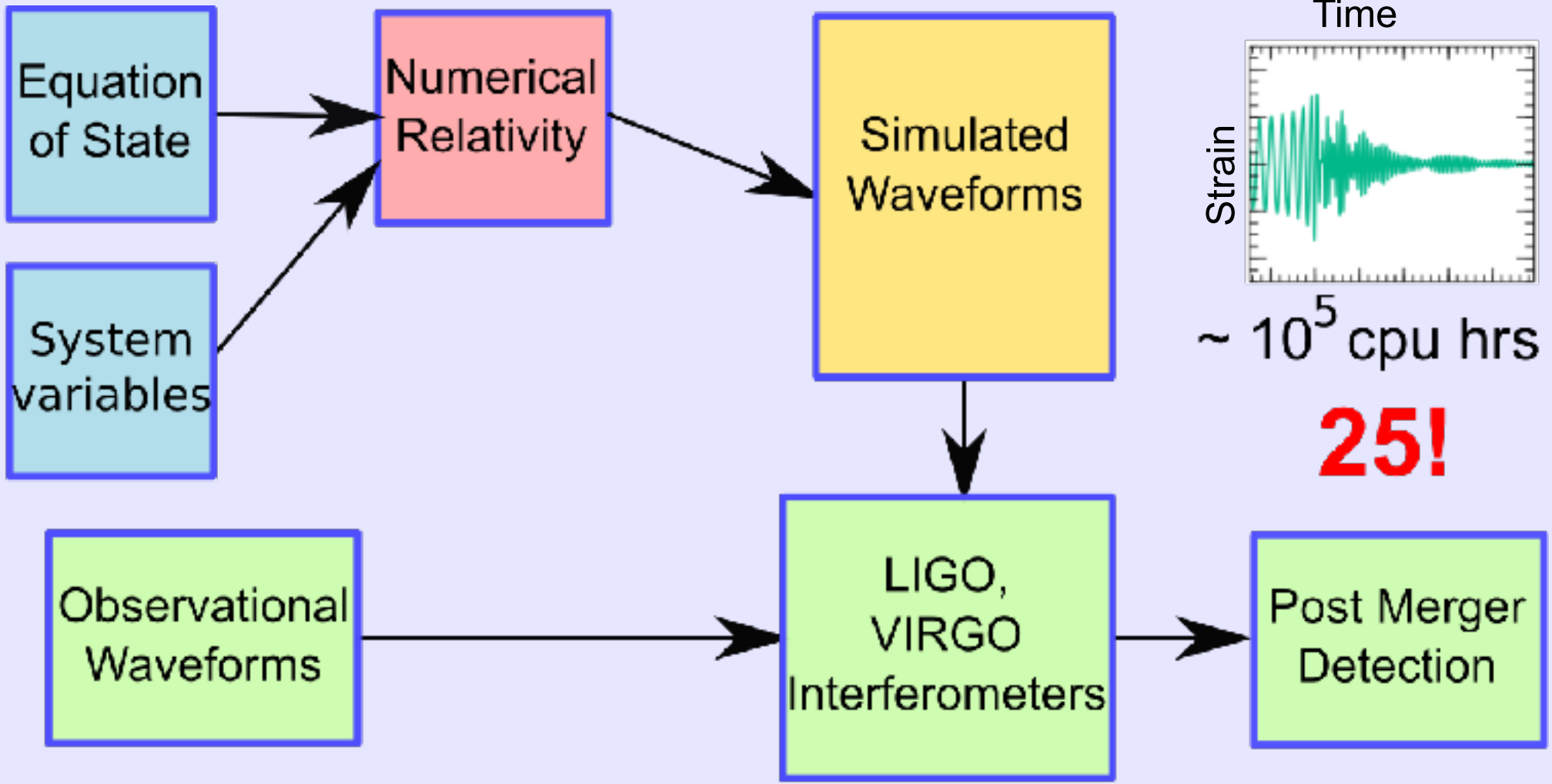
x 10^6

Observational Waveforms

LIGO, VIRGO Interferometers

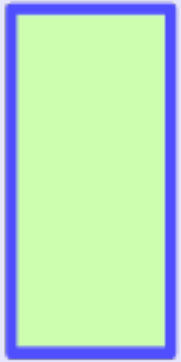
Post Merger Detection

How many do we have?



Machine Learning: data set

Set of gravitational-wave spectra

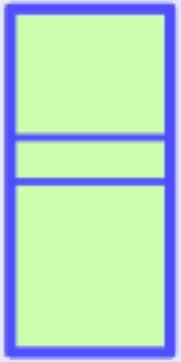


Corresponding system parameters,
eg) mass, equation of state

Machine Learning: cross validation

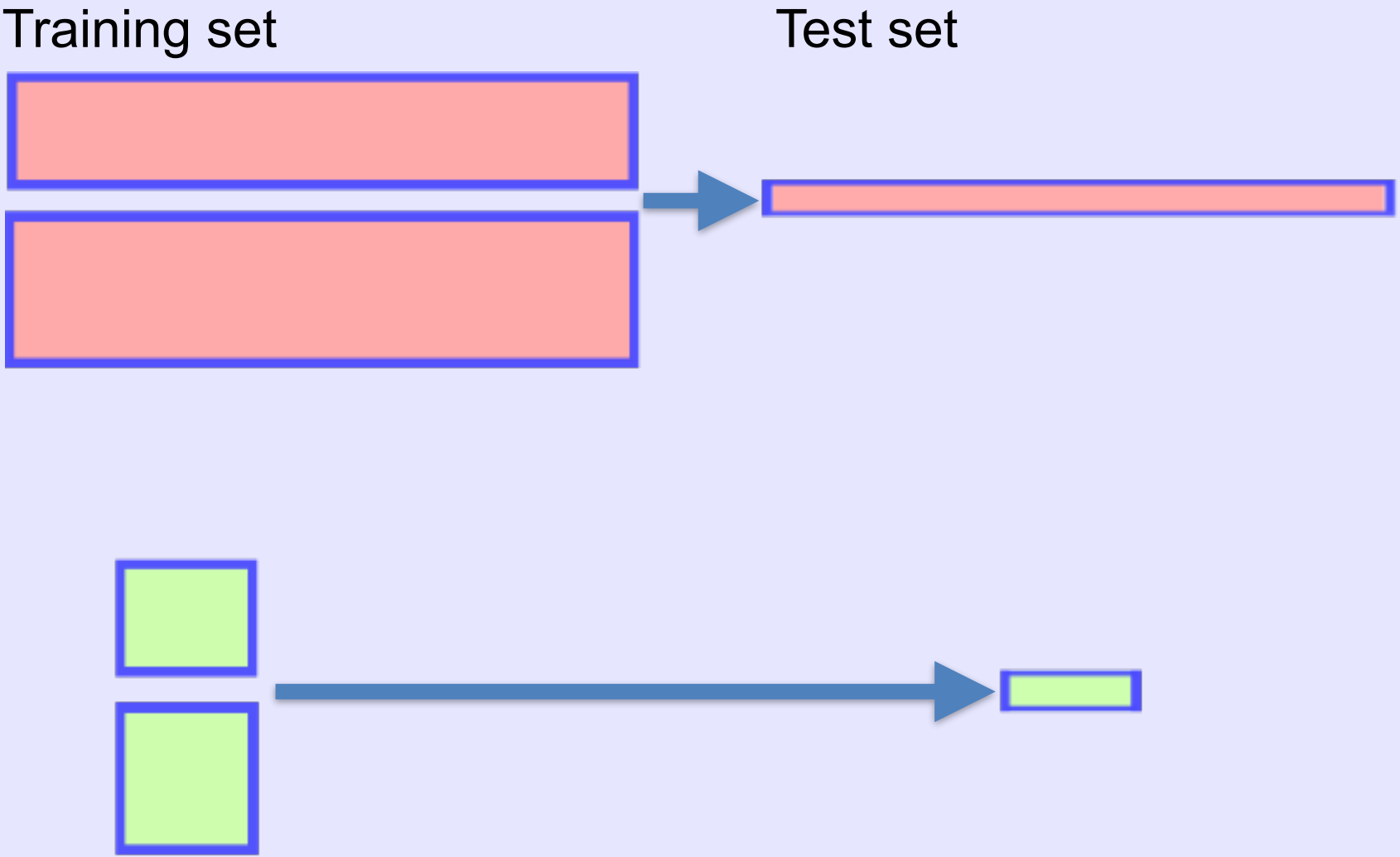
Training set

Cut-out one set of spectra from the training set



and one set of parameters

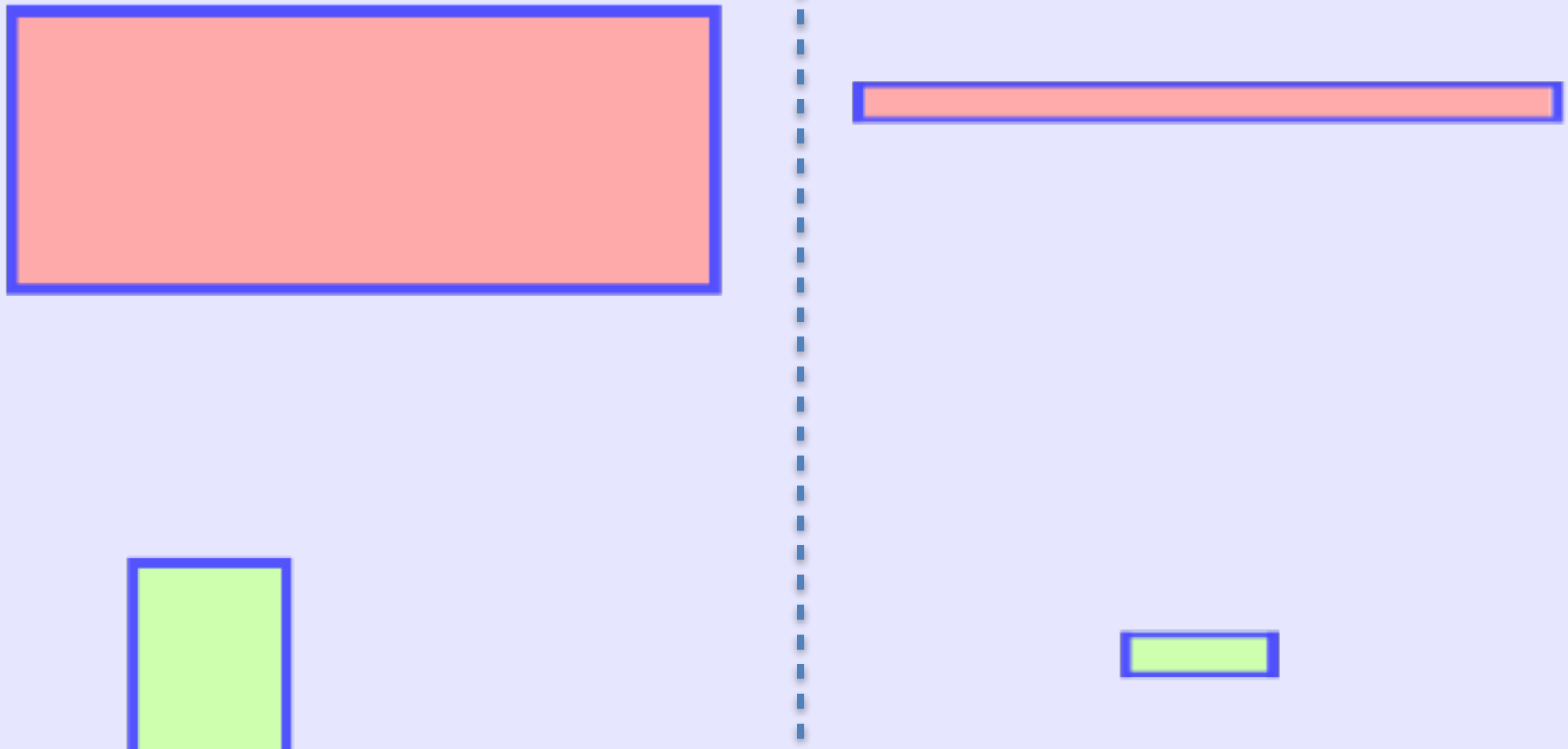
Machine Learning: cross validation



Machine Learning: cross validation

Training set

Test set

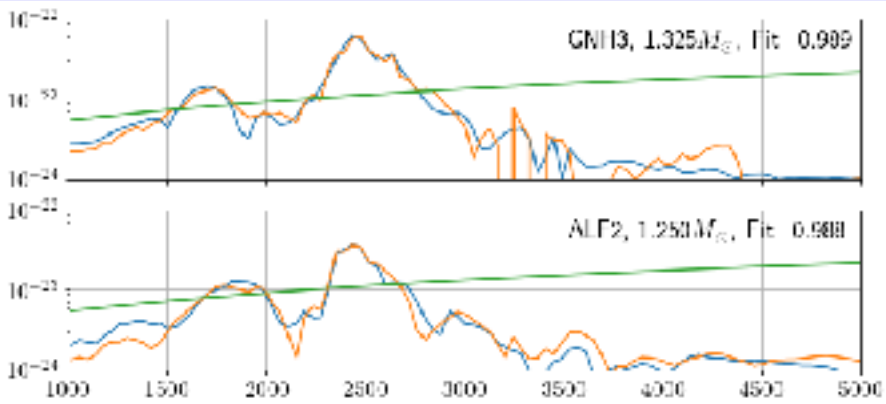


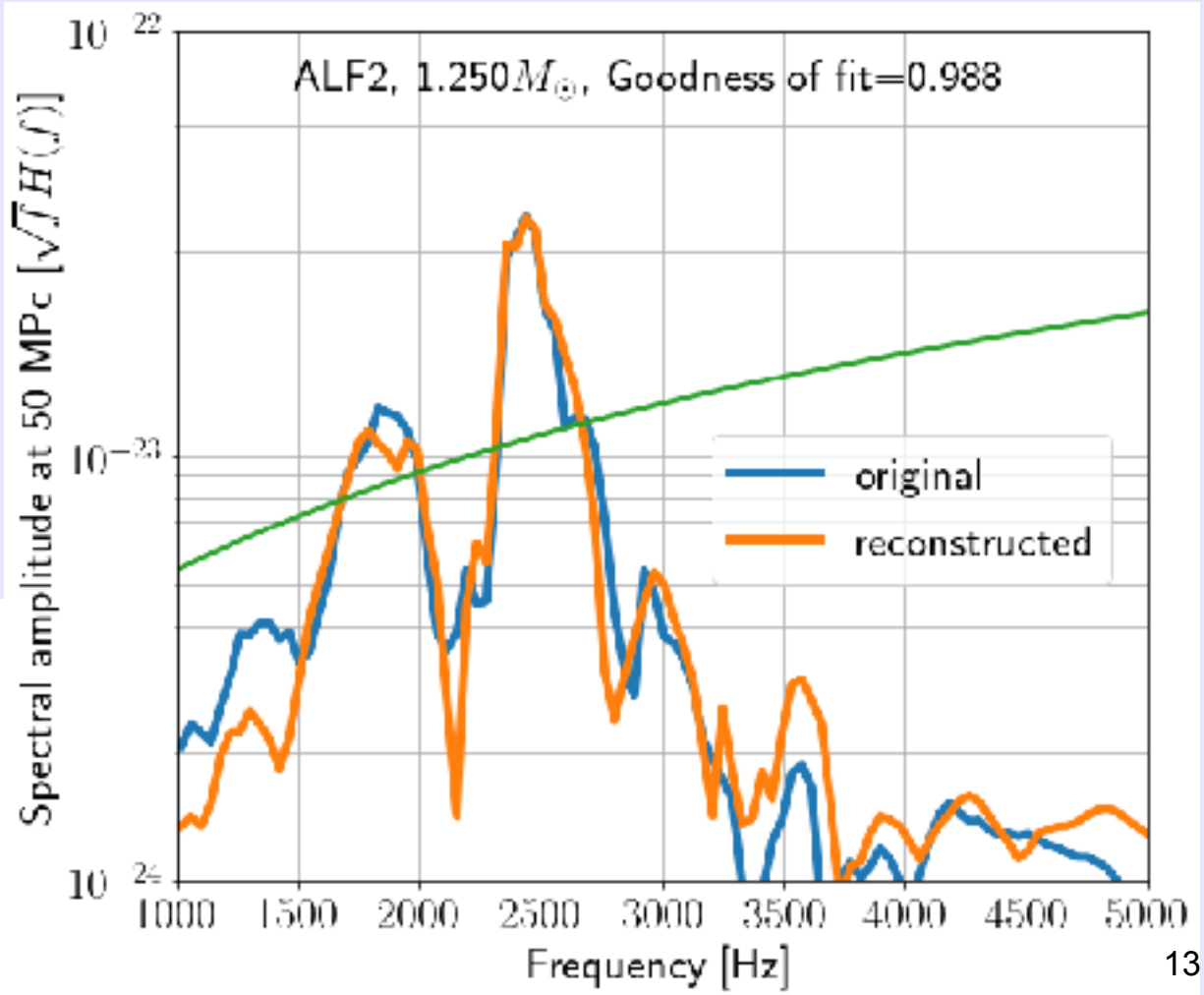
Machine learning – the Cannon 2

- The Cannon 2 (Casey et al 2016) is a machine learning algorithm (supervised regression) used to fit stellar spectra
- We performed cross validation on the gravitational wave strain spectra by comparing predictions with true values
- Waveform prediction takes **a few seconds**
- **8 orders of magnitude improvement!**

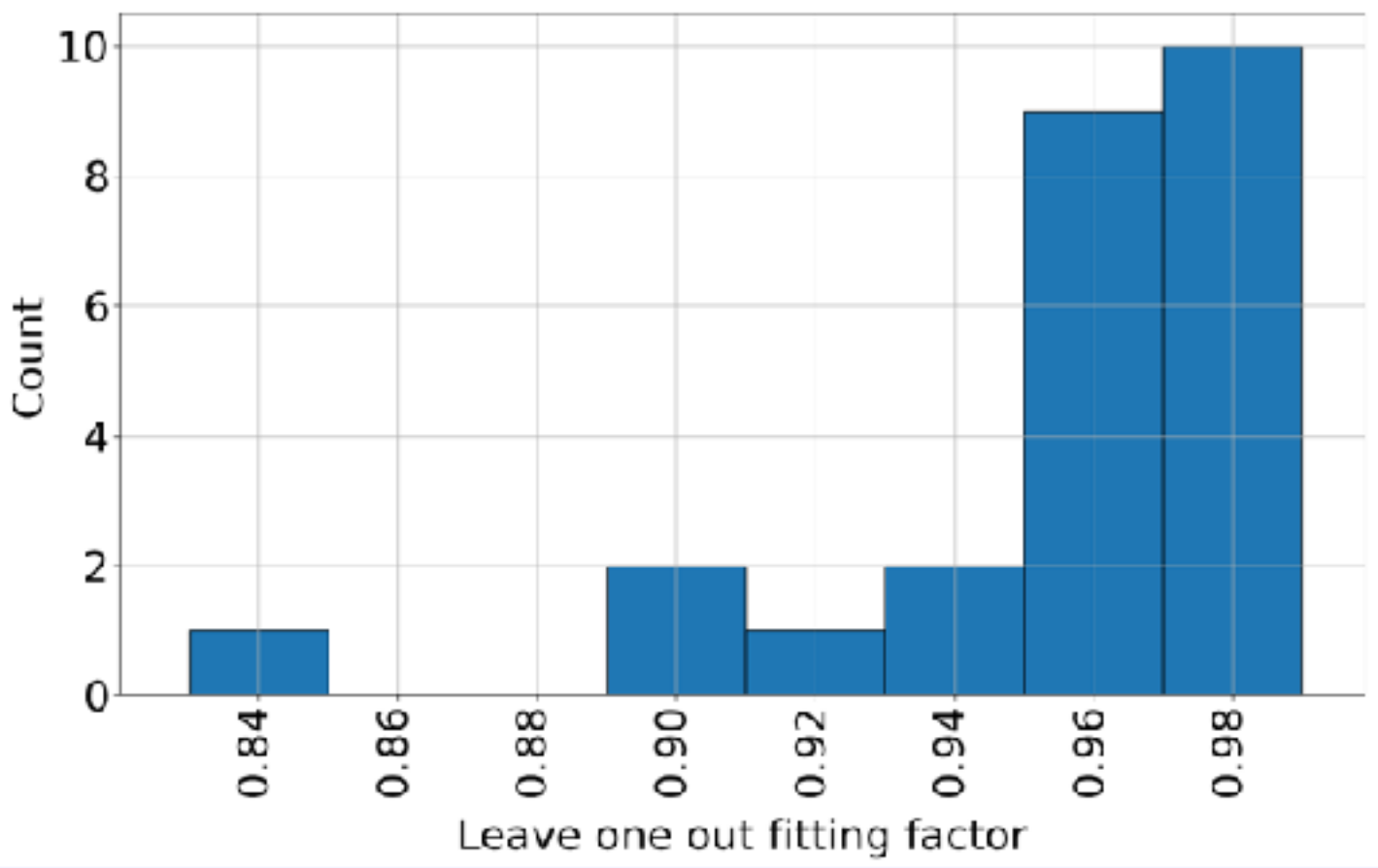
Spectral reconstruction

- Blue curve: original spectra
- Orange curve: best fit
- Green curve advanced LIGO sensitivity



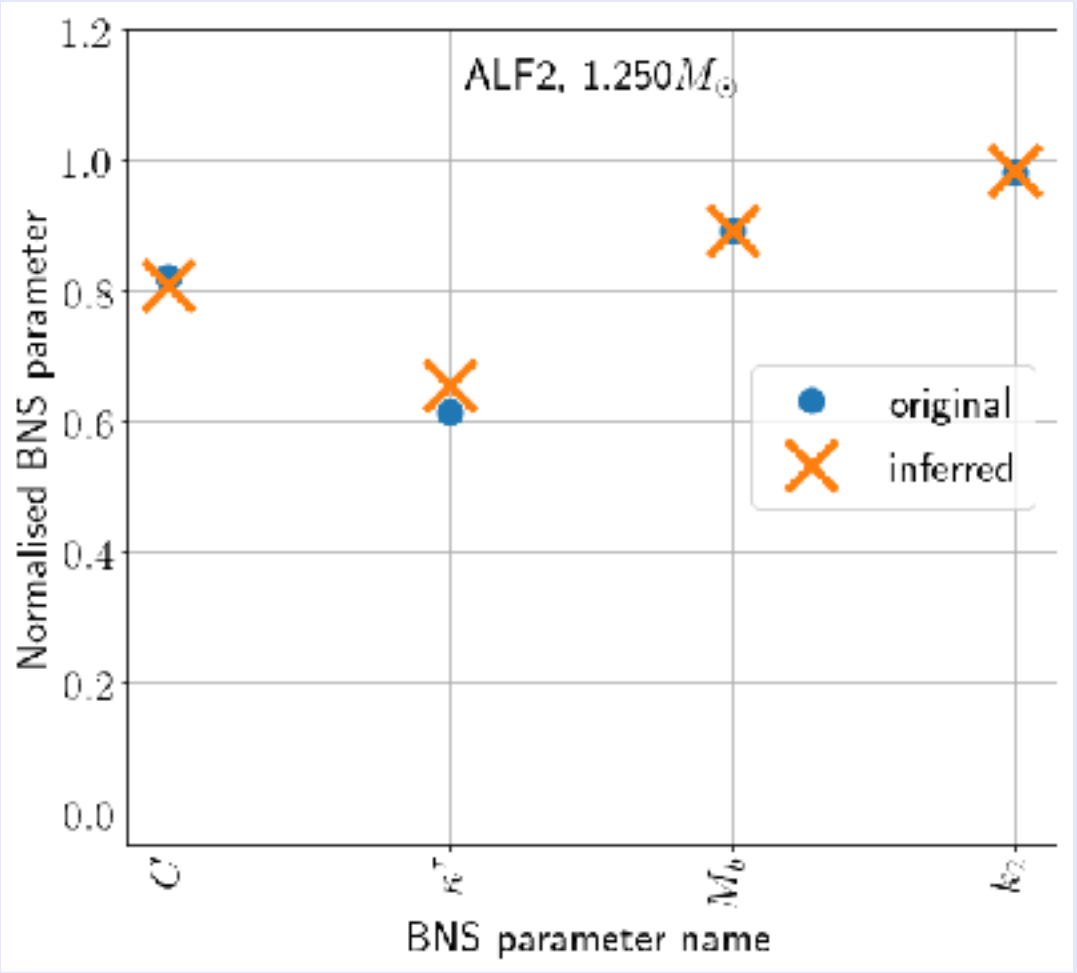


Spectral reconstruction



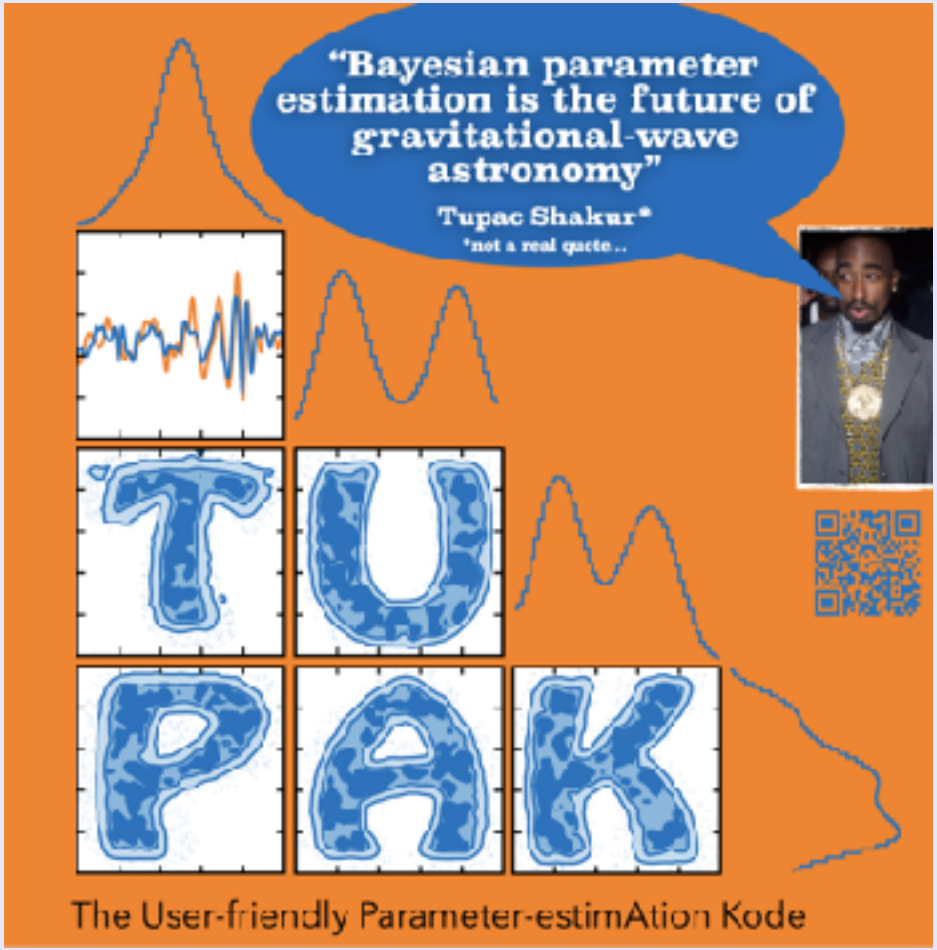
Parameter inference

- Blue dots: original parameters
- Orange crosses: inferred parameters



Future tasks

- Need more NR simulations
- Perform parameter estimation with TUPAK
- Detect post-merger signal
- Infer equation of state 😀



Conclusion

- We achieved good matches with the original spectra, typically above 95%
- 8 orders of magnitude time improvement in comparison to NR simulated waveforms
- We were limited to 25 numerical relativity waveforms across five equations of state
- The numerical relativity simulations should be robust