A phenomenological inspiral-merger-postmerger gravitational waveform model for binary neutron star coalescence

Unravel information about supernuclear-dense matter with future generation detectors

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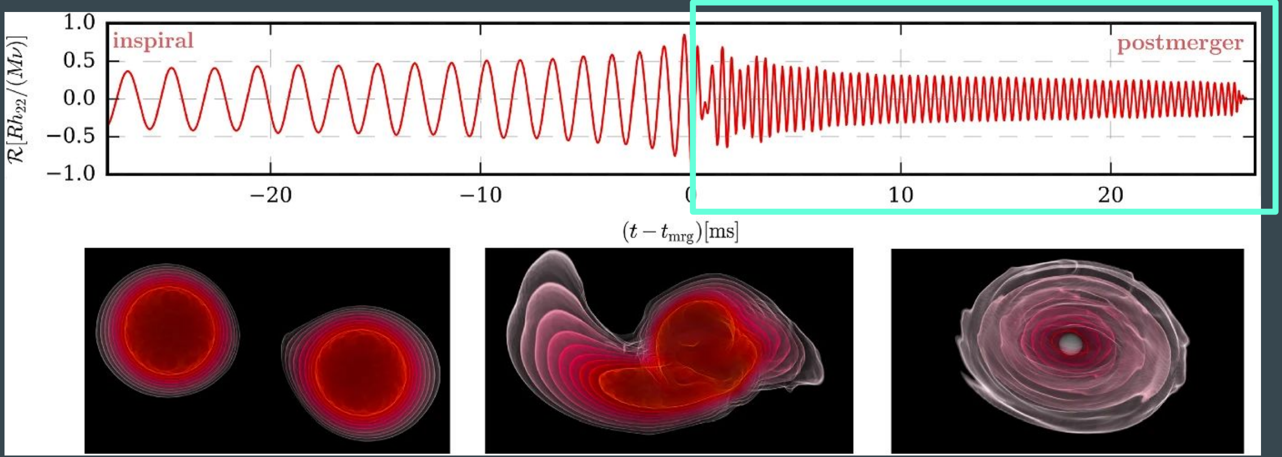
Gravitational Waves from binary neutron stars

Detections: GW170817,GW190425 ⟹ Equation of State



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Postmerger

- different density and temperature regime
- phase transitions?
- remnant

With future generation detectors we will start detecting postmerger signals!

Inspiral-merger-postmerger model

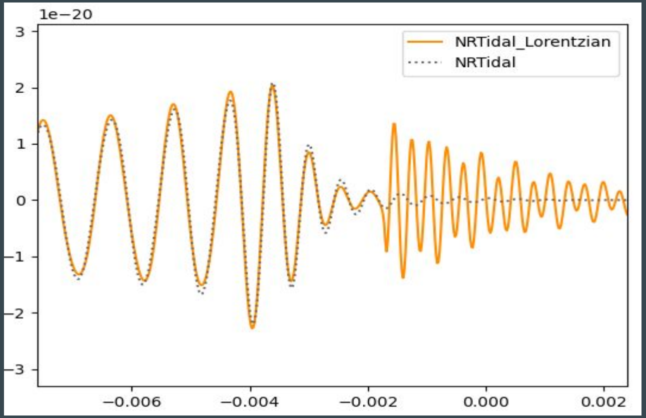
- Inspiral-merger: IMRPhenomD_NRTidalv2
- Postmerger: main emission peak $\Longrightarrow$ 3-parameters Lorentzian (previous work: *Tsang et al. PhysRevD.100.044047*)

$$\boxed{h_{22}(f) = \frac{c_0 c_2}{\sqrt{(f-c_1)^2+c_2^2}} e^{-i \arctan\left(\frac{f-c_1}{c_2}\right)}}$$

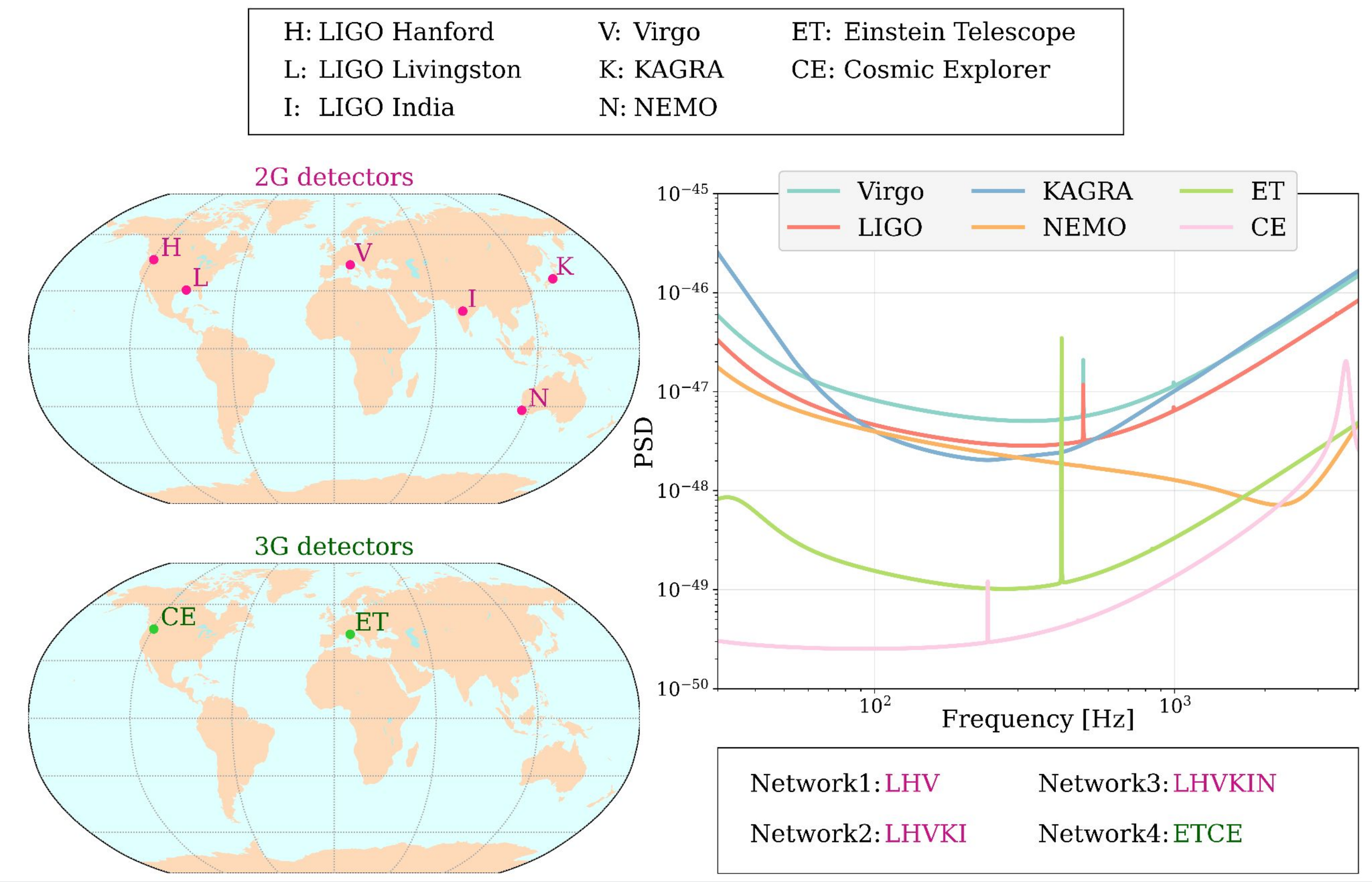
c_0: amplitude
c_1: dominant emission frequency
c_2: width

Postmerger Lorentzian described in two ways:

- c_0, c_1, c_2 as free parameters recover c_1
- Quasi-universal relations: improvements in $\tilde{\Lambda}$ measurements



Detector networks



Parameter estimation runs

We employ our models in **Parameter Estimation** analysis (bilby sampler)

- Very expensive runs ⟶ relative binning

Injections:

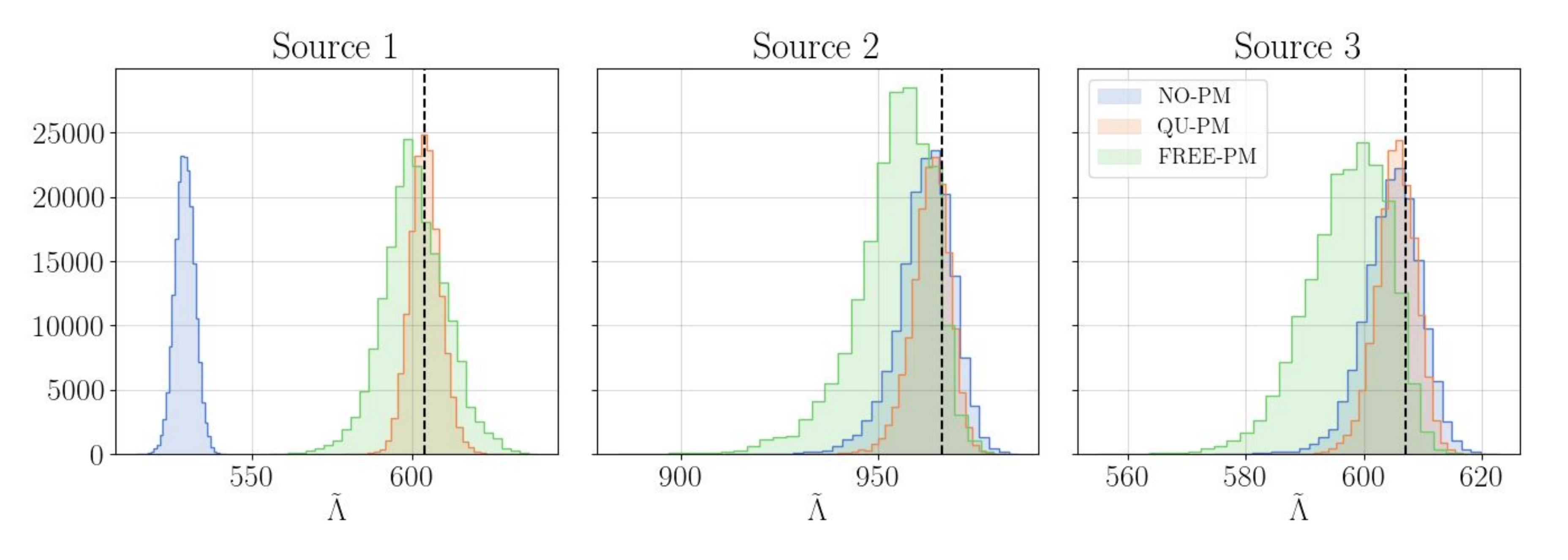
- Simulated signals and numerical-relativity injections (hybrids from SACRA database)
- Three sources, fixed sky location
- Different distances: 68 Mpc, 135 Mpc, 225 Mpc (SNR ~ 100, 50, 30 in LHV)

Investigate:

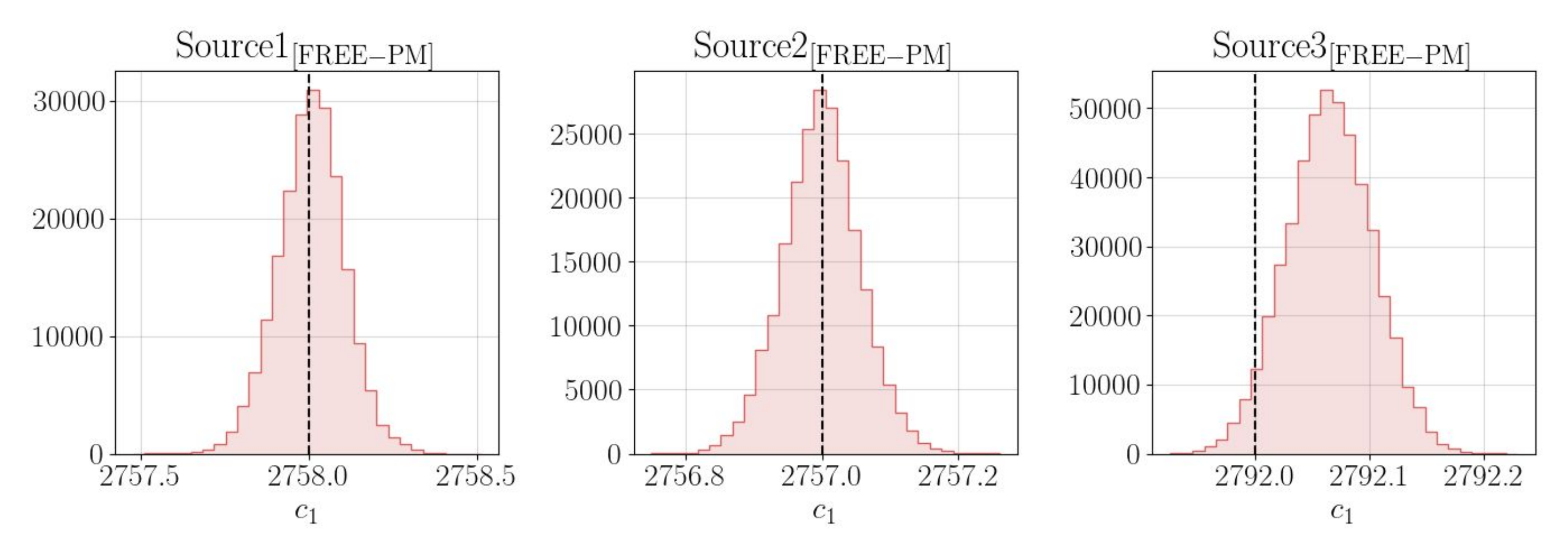
- Model performance
- Effect of noise
- How will future detectors improve our studies?

Best case scenario

ETCE network - 68 Mpc - zero noise - simulated signals



Best case scenario



	$\log c_0$	$\log c_{0,\mathrm{inj}}$	c_2	$c_{2,\mathrm{inj}}$
Source1$_{[\mathrm{free-pm}]}$	$-51.40^{+0.04}_{-0.03}$	-51.43	$77.0^{+0.18}_{-0.19}$	74.
Source2$_{[\mathrm{free-pm}]}$	$-51.03^{+0.04}_{-0.03}$	-51.06	$48.0^{+0.1}_{-0.1}$	48.
Source3$_{[\mathrm{free-pm}]}$	$-50.66^{+0.00003}_{-0.0001}$	-50.70	$39.48^{+0.07}_{-0.06}$	39.

Improve the model

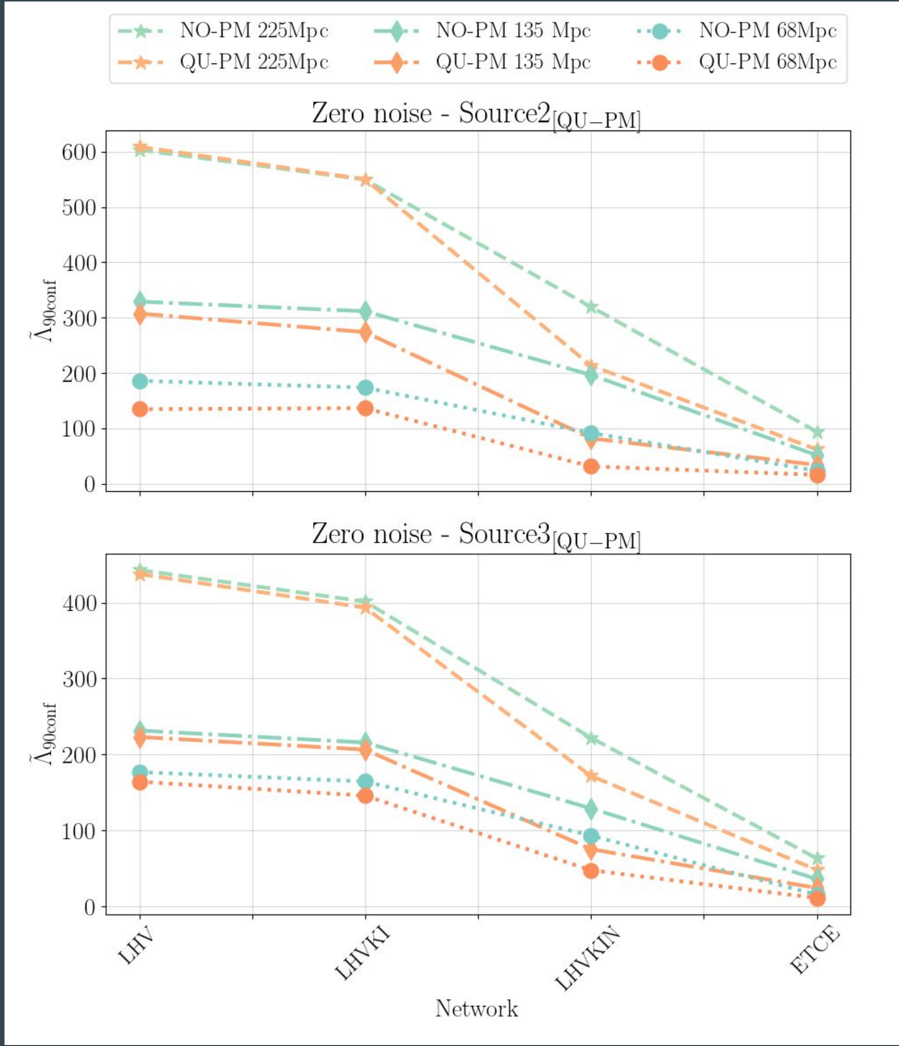
⬇

features beyond the main emission frequency

Detector network performances in zero noise

Zero noise - simulated signals

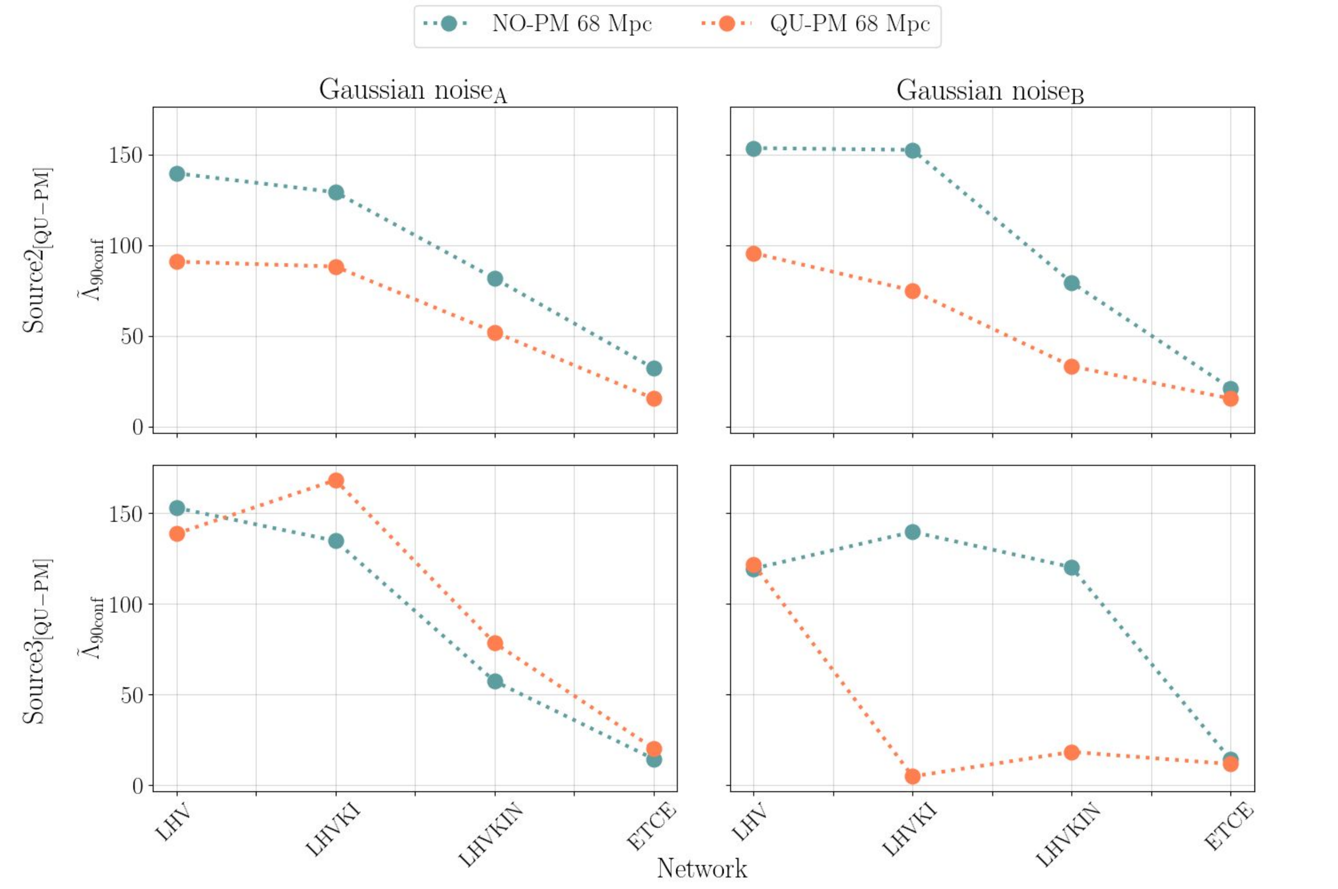
- Best improvement with NEMO



Detector network performances in Gaussian noise

68 Mpc - Gaussian noise - simulated signals

- Strong influence from noise realization!



Detector network performances in Gaussian noise

68 Mpc - Gaussian noise - simulated signals

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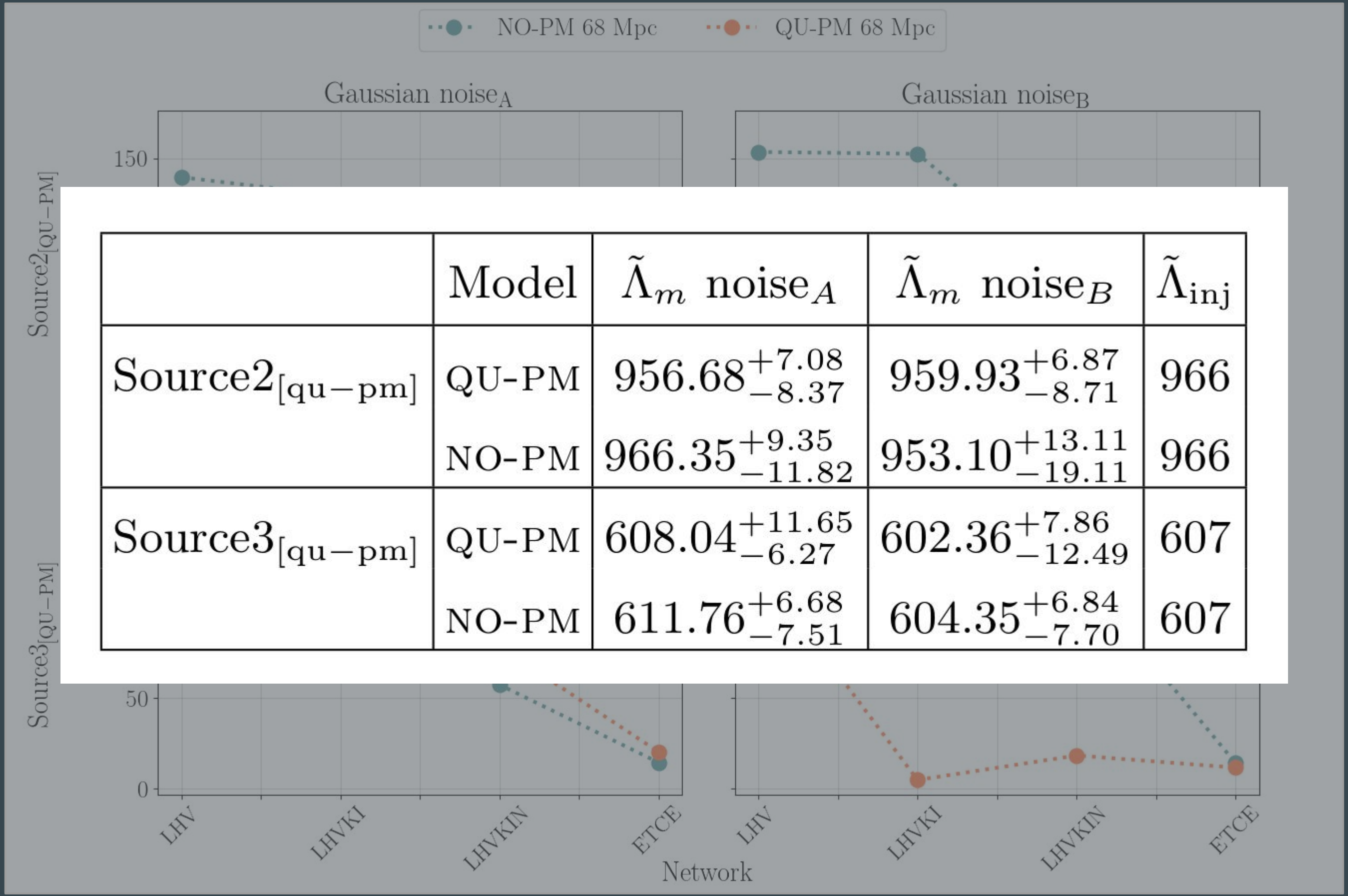
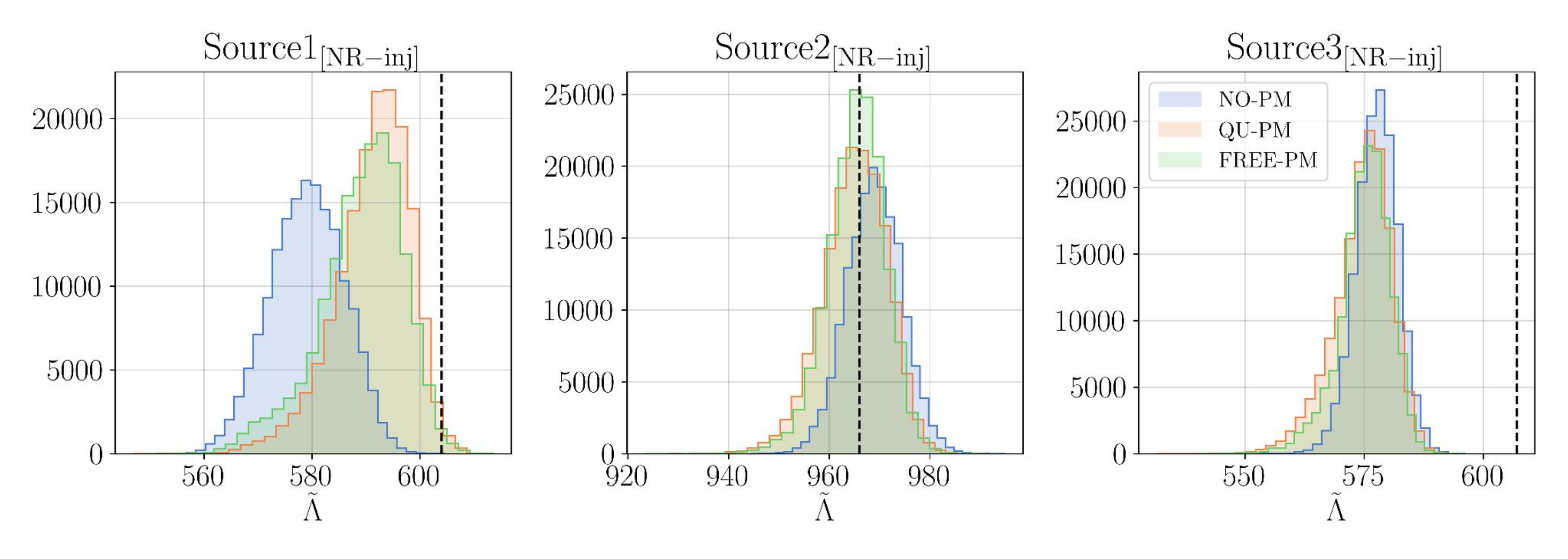


	Model	$\tilde{\Lambda}_m$ noise$_A$	$\tilde{\Lambda}_m$ noise$_B$	$\tilde{\Lambda}_{\mathrm{inj}}$
Source2$_{[\mathrm{qu-pm}]}$	QU-PM	$956.68^{+7.08}_{-8.37}$	$959.93^{+6.87}_{-8.71}$	966
	NO-PM	$966.35^{+9.35}_{-11.82}$	$953.10^{+13.11}_{-19.11}$	966
Source3$_{[\mathrm{qu-pm}]}$	QU-PM	$608.04^{+11.65}_{-6.27}$	$602.36^{+7.86}_{-12.49}$	607
	NO-PM	$611.76^{+6.68}_{-7.51}$	$604.35^{+6.84}_{-7.70}$	607

Numerical Relativity injections

ETCE network - 68 Mpc - Numerical-relativity waveforms injected in Gaussian noise



Conclusions

Analytical, frequency-domain model to describe gravitational waves from inspiral, merger and postmerger of binary neutron stars:

- PE analysis
  - Both versions perform well with high-SNR and zero-noise injections
  - Noise fluctuations have a large impact on the results (also with model without postmerger!)
  - Model needs improvement (more complicated features, see results for injections with numerical-relativity waveforms)
- Detector network study:
  - NEMO offers a unique possibility to study postmerger signals
  - future detectors will allow us to extract information about equation of state

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Thank you for your attention!

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Backup slides - model

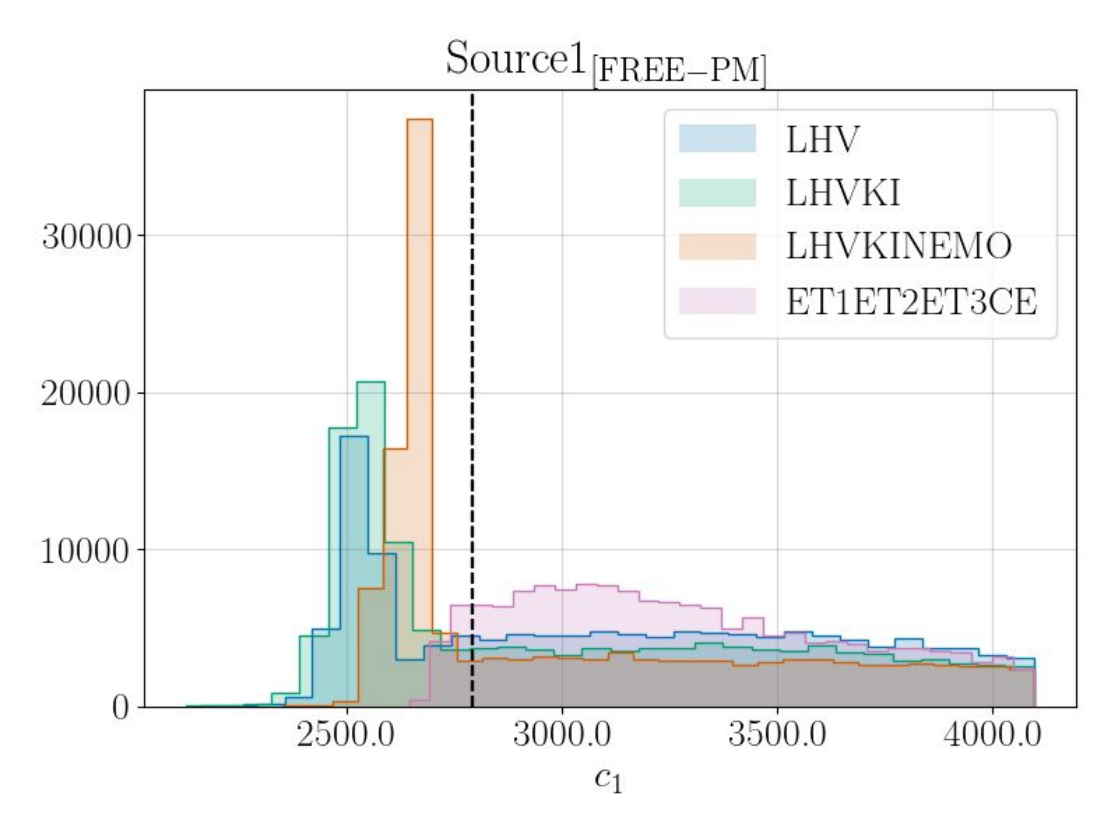
Inspiral-merger: IMRPhenomDNRTidalv2 + Postmerger: Lorentzian

- **Amplitude**: Planck taper window between 0.75 f_2 and 0.9 f_2 (f_2 = postmerger main emission peak frequency)
- **Phase**: we introduce two coefficients in order to ensure C^1-continuity
- term to reduce Lorentzian contribution to pre-merger and merger phase (dt = time of first minimum in *Tsang et al. PhysRevD.100.044047*)

Quasi-universal relations postmerger model, parameters:

$$\begin{cases} M c_1(\zeta) = \alpha \frac{1+A\zeta}{1+B\zeta} \text{ with} \zeta = \frac{3}{18}\tilde{\Lambda} + a\frac{M}{M_{TOV}} \\ c_0 = \gamma A_{NRTidal}(f_{merg}) \\ c_2 = 2 + \beta \frac{1-C\kappa_T q^2}{1+D\kappa_T q^2} \end{cases}$$

Backup slides - free parameters model



68 Mpc - Gaussian noise - injections