# Postmerger: a new and dominant contribution to the SGWB from binary neutron stars

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Based on: Lehoucq, Dvorkin, Rezzolla, arXiv:2503.20877

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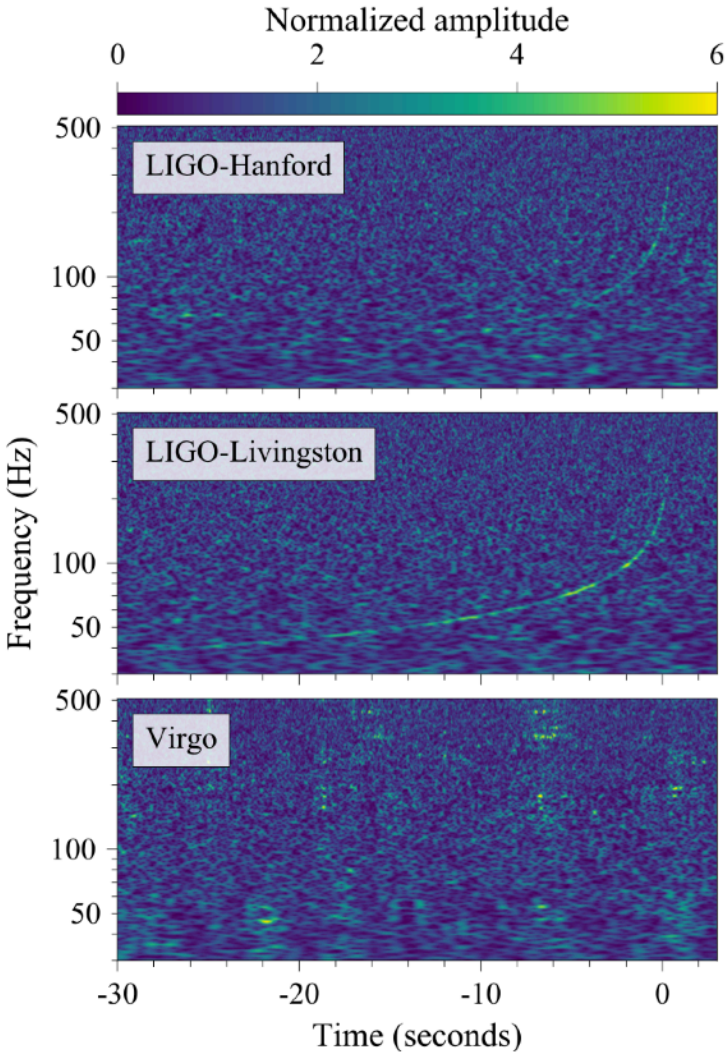
# BNS mergers

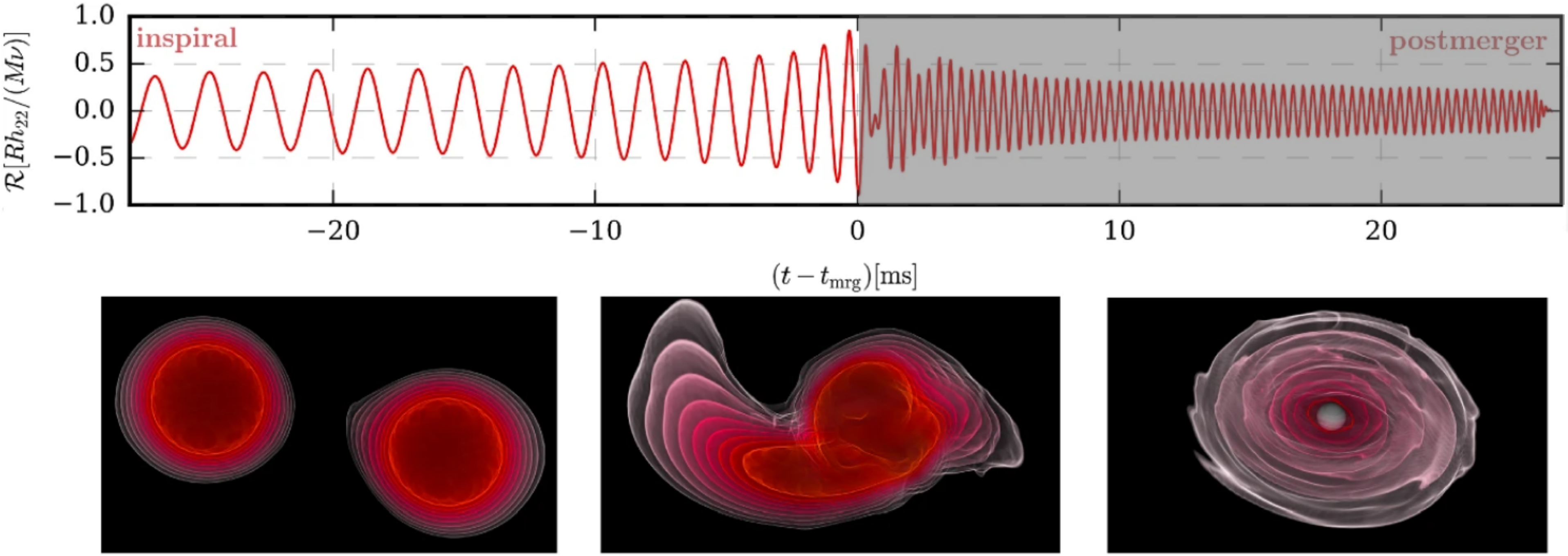
- 2 individual detections so far
- Amazing multi-messenger event
- But LVK sensible only up to ~500Hz, we are not looking at the full GW strain!
- What about higher frequencies > 1kHz that could be detectable with 3G detectors (ET, CE, …)?




*GW170817 chirp, https://www.ligo.org*

# BNS merger waveform

- **Premerger (below ~ 1kHz):**
  - GWs emission including tidal interaction up to merger

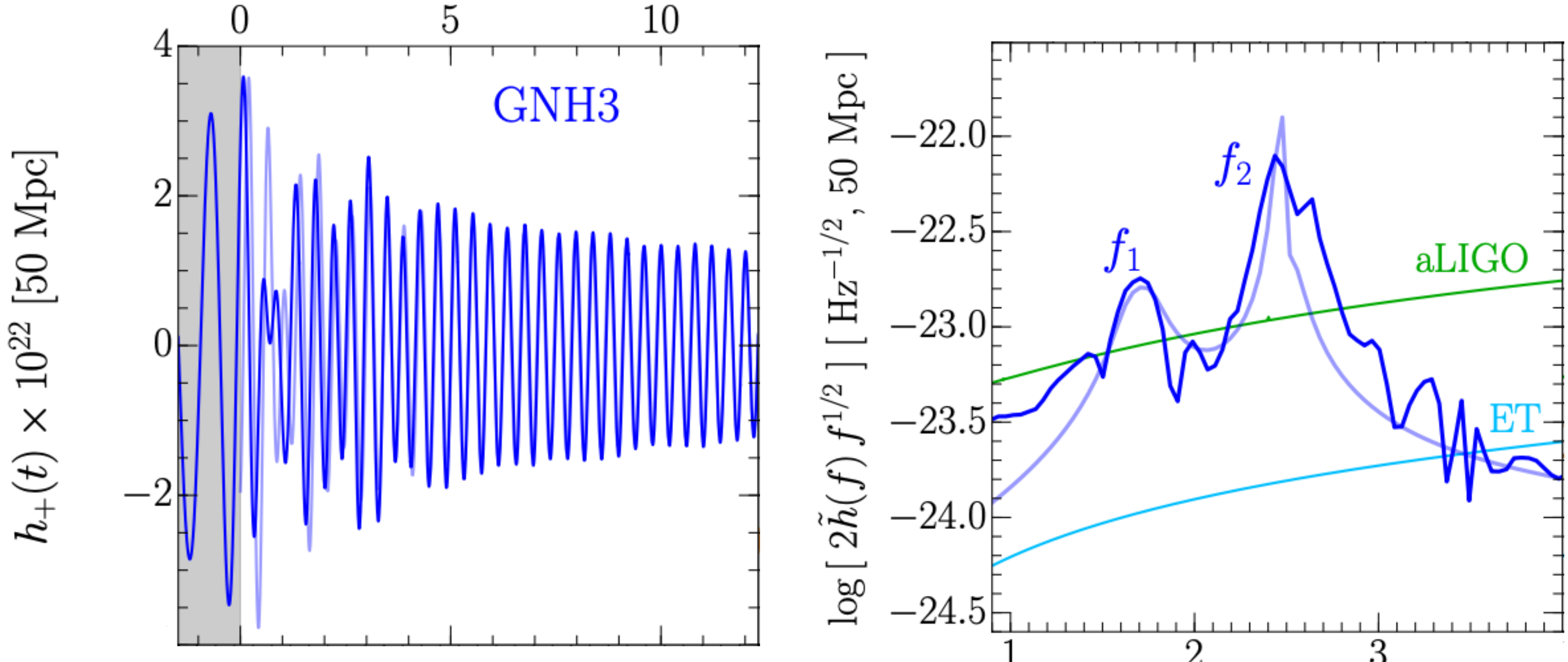



*T.Dietrich et al. 2021*

# BNS merger waveform

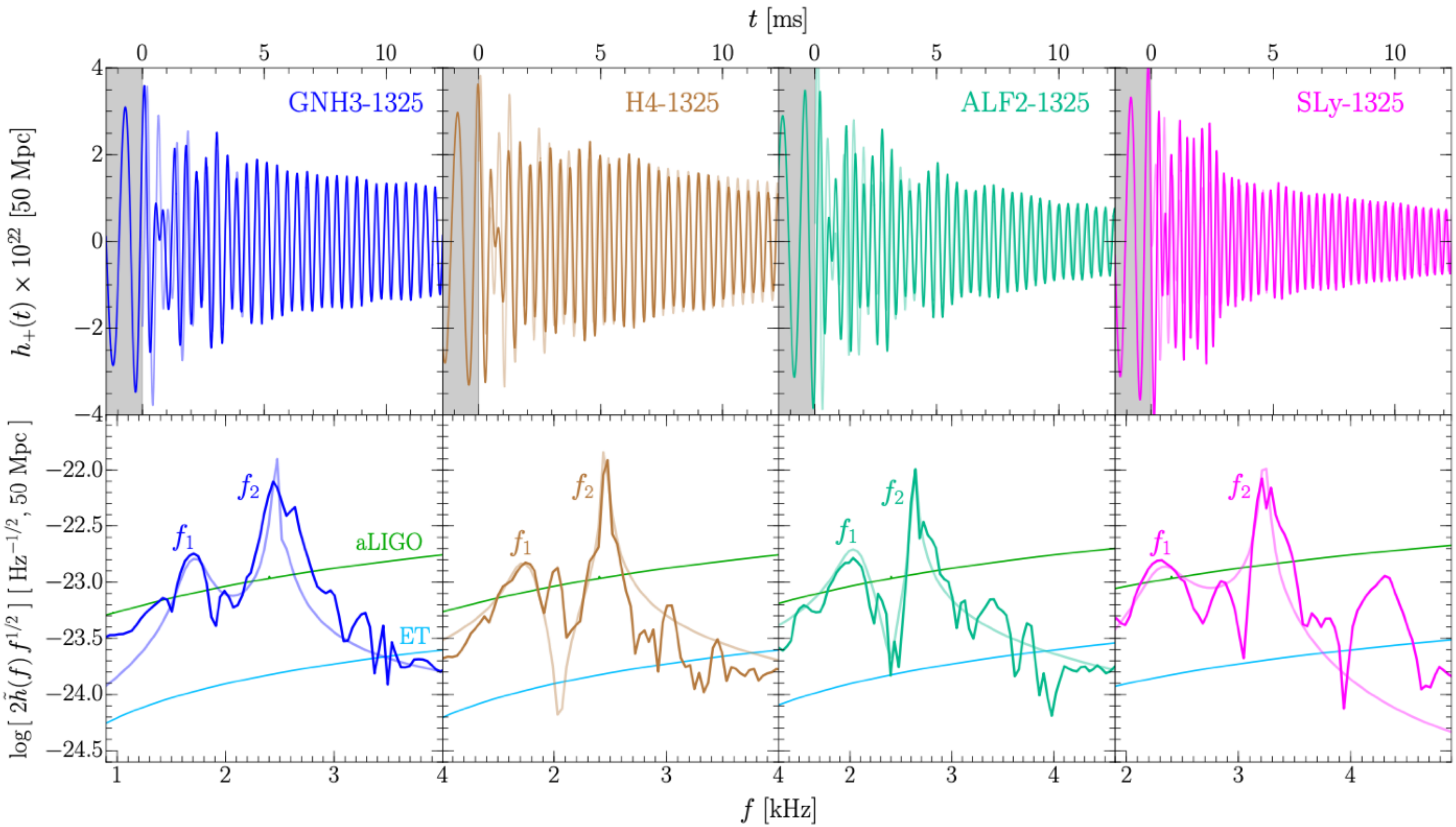
- **Post-merger (Above ~ 1kHz):**
  - Prompt collapse to BH —> little power in the ringdown
  - Formation of a Hyper Massive Neutron Star (HMNS)

  —> emission at $f_1$ and $f_2$ with modes lifetime $\tau_1$ and $\tau_2$.




*S.Bose et al. 2017*

# BNS merger waveform




$M_1 = M_2 = 1.325\ M_\odot$, D = 50 Mpc taken from *S.Bose et al. 2017*

# Stochastic GW Background

There are two types of stochastic backgrounds:

- The **astrophysical background** (unresolved superposition)
- The **cosmological background** (produced in the primordial universe)

$$\Omega_{\mathrm{GW}} \equiv \frac{1}{\rho_c} \frac{\mathrm{d}\rho_{\mathrm{GW}}}{\mathrm{d}\log f}$$

We are interested in the stochastic **astrophysical** background produced by **binary neutron stars.**

# Calculation of the background

**Background definition:**

$$\Omega_{\rm GW} = \frac{1}{\rho_c}\frac{{\rm d}\rho_{\rm GW}}{{\rm d}\ln f} = \frac{f}{\rho_{\rm c} c}F(f) \quad \text{with} \quad \rho_{\rm c} = 3H_0/8\pi G$$

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**Total GW flux:**

$$F_{\rm tot}(f) = \frac{\pi c^3}{2G}\frac{f^2}{T}\sum_{i=1}^{N}\left[|\tilde{h}_i^{+}(f)|^2 + |\tilde{h}_i^{\times}(f)|^2\right]$$

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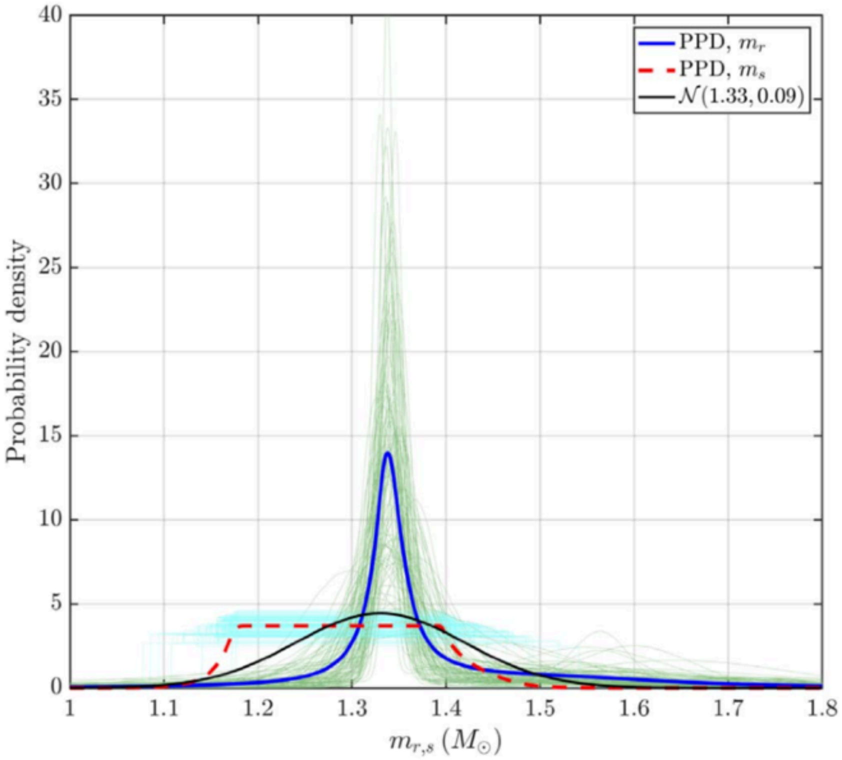
—> To calculate the background, we removed resolved sources based on an $\mathrm{SNR}_{\mathrm{thr}}$ criterion.

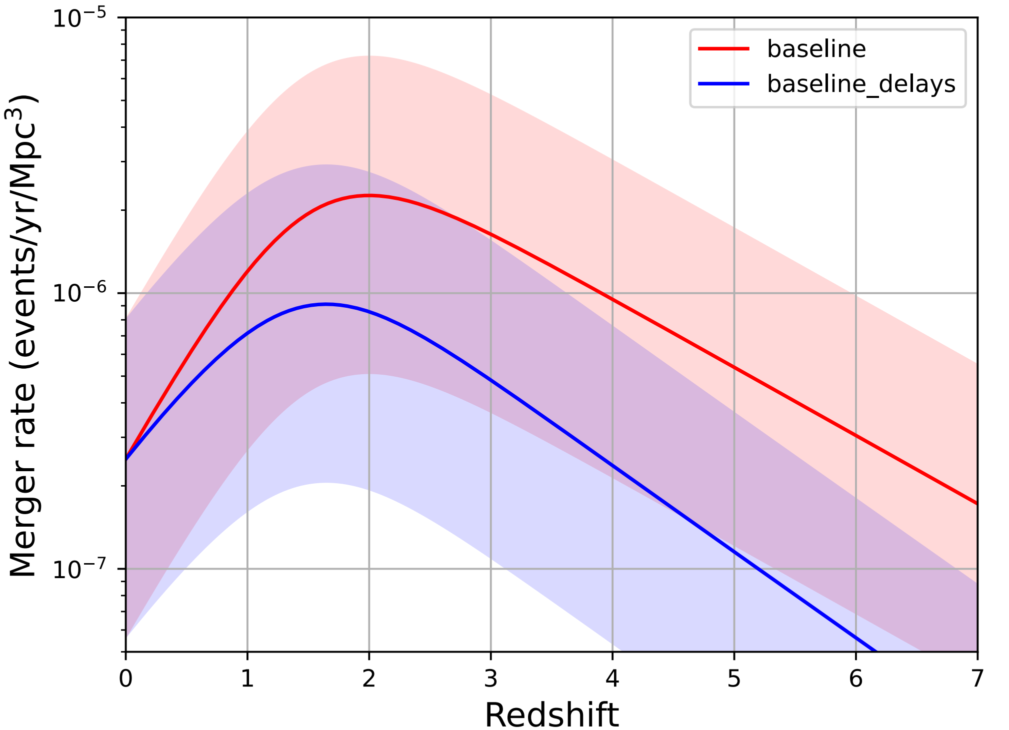
Detectability using the GWFish code *(Dupletsa et al. 2023)*.

# BNS population modelling

*N.Farrow et al. 2019*

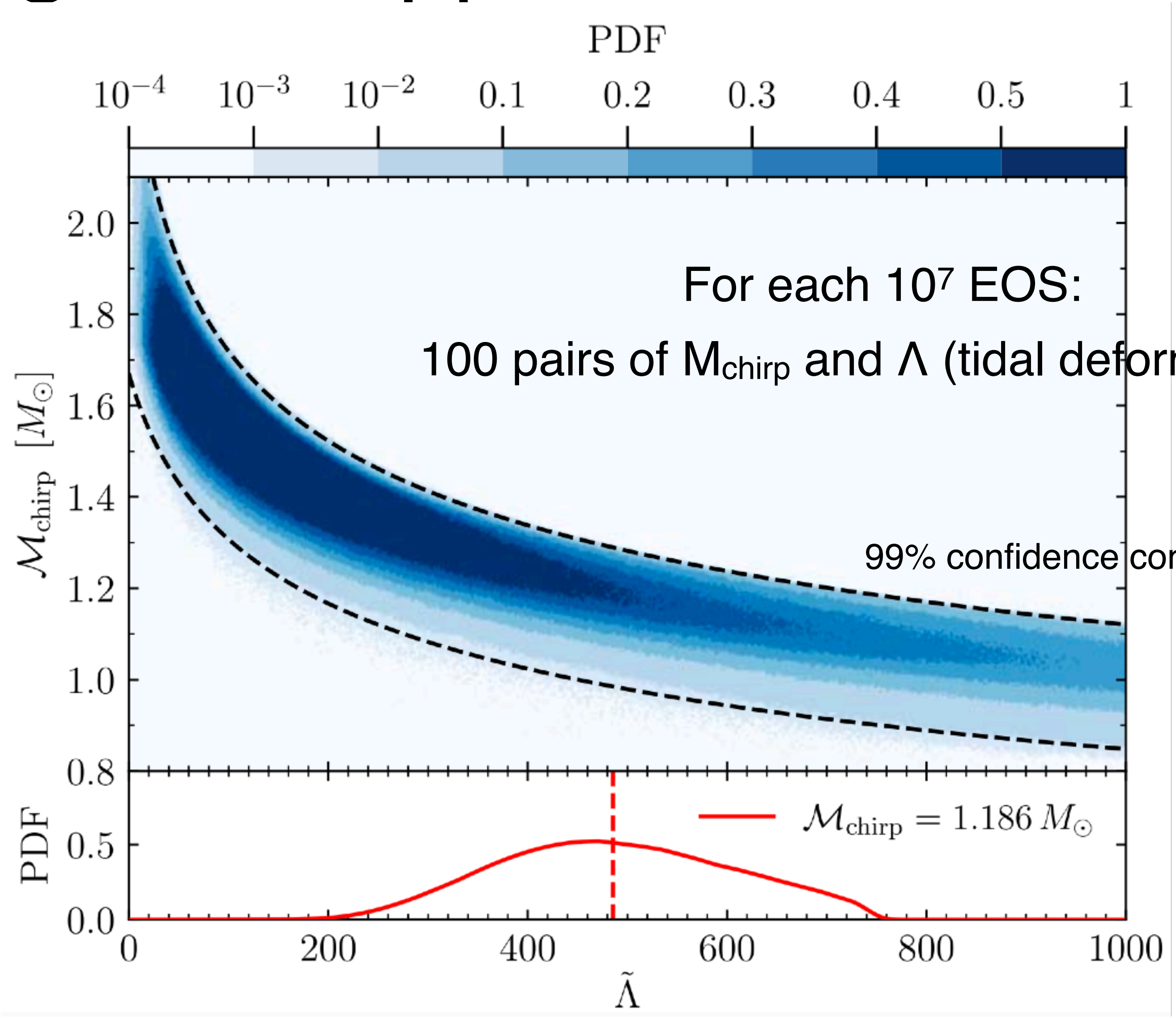



*L.Lehoucq et al. 2023*




We take T = 1 year of observation —> $N_{merger}$ ~ 3.8e5

# Agnostic approach of the EOS



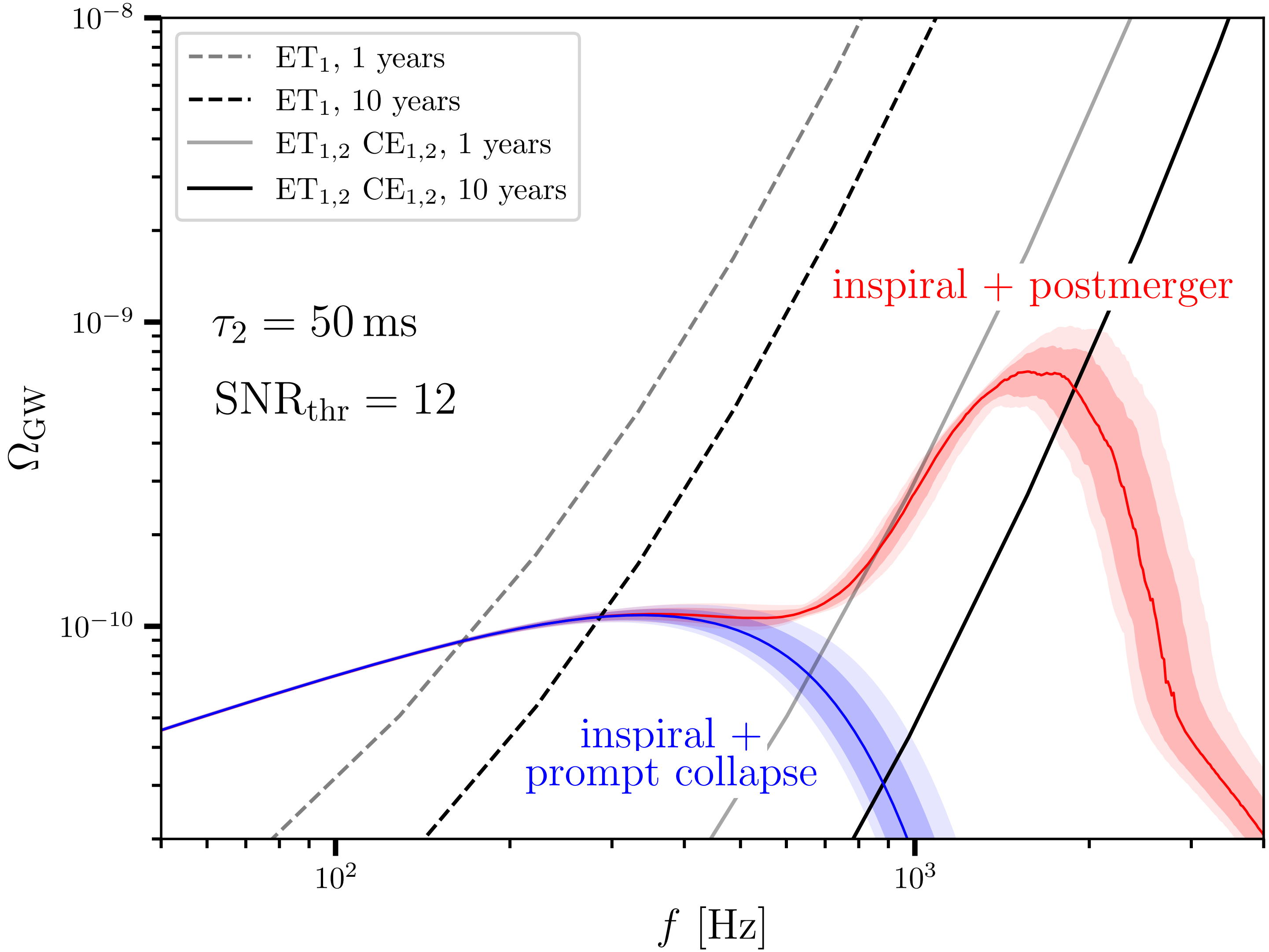

For each $10^7$ EOS:

100 pairs of $M_{chirp}$ and Λ (tidal deformability)

99% confidence contour

*S.Altiparmak, C.Ecker, and L.Rezzolla (2022)*

# Results




*L.Lehoucq, I.Dvorkin and L.Rezzolla, arxiv:2503.20877*

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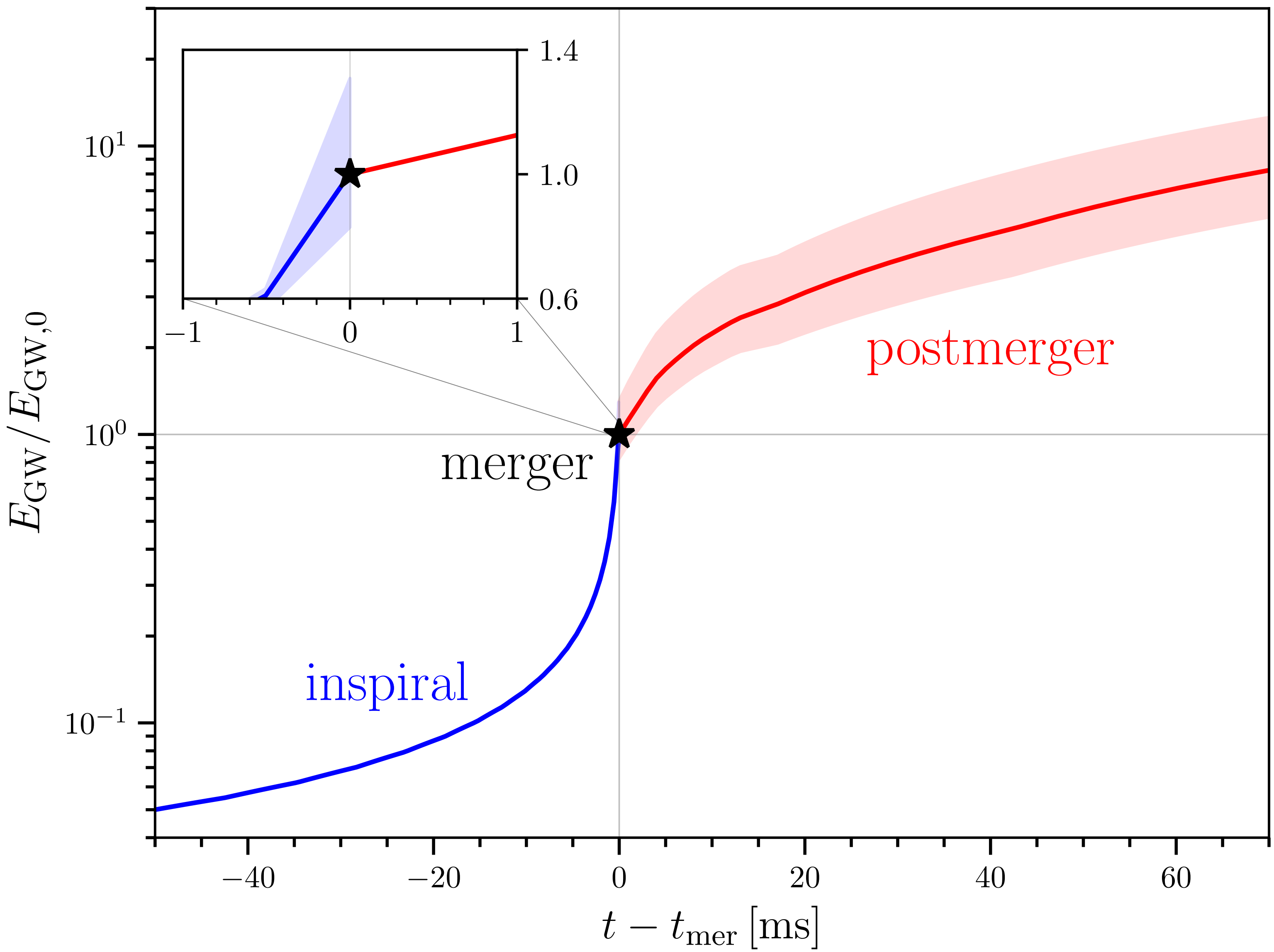


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# Conclusions

- Whatever the EOS, the post-merger phase contributes more to the overall background energy than the inspiral phase.

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# Conclusions

- Whatever the EOS, the post-merger phase contributes more to the overall background energy than the inspiral phase.

- The post-merger peak is located in the 1-2 kHz band and its amplitude is proportional to the lifetime of the proper mode of the HMNS.

- Unfortunately, these lifetimes are not well constrained, but 3G detectors could set interesting upper limits on them and a network could potentially detect the post-merger peak.

# BACKUP SLIDES

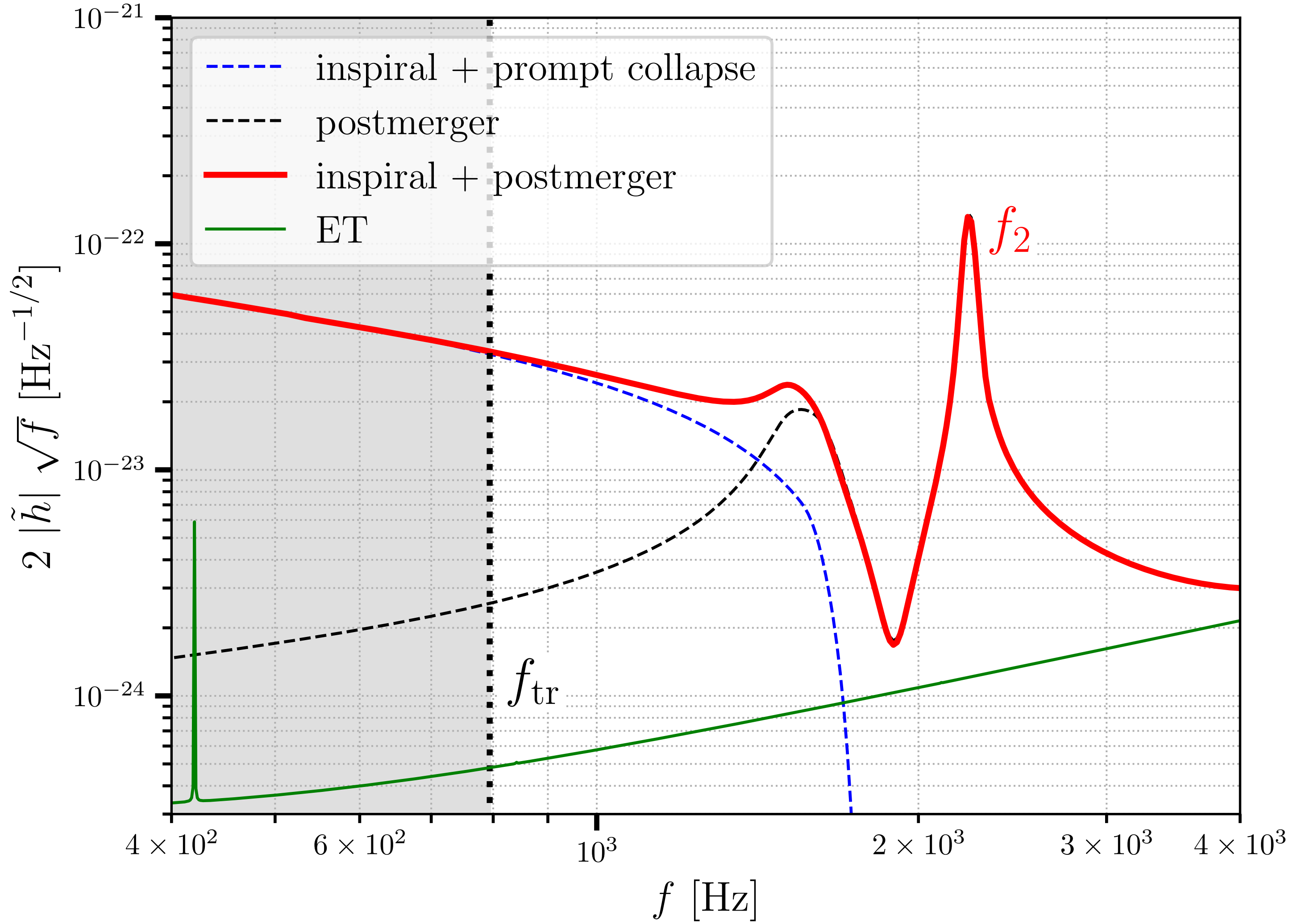
# BNS merger waveform

- **Premerger:**
  - GWs emission including tidal interaction up to merger
  - Below ~ 1kHz
- **Post-merger:** (*2 NS = ?)*
  - Prompt collapse to BH—> few power in the ringdown
  - Formation of a Hyper Massive Neutron Star (HMNS) —> emitting GWs mainly at $f_1$ and $f_2$ with modes lifetime $\tau_1$ and $\tau_2$.
  - Above ~ 1kHz

$$
\begin{aligned}
h_+(t) = \quad & \alpha \quad \mathrm{e}^{-t/\tau_1} \left[\sin(2\pi f_1 t) + \sin(2\pi(f_1 - f_{1\epsilon})t) + \sin(2\pi(f_1 + f_{1\epsilon})t)\right] \\
& + \quad \mathrm{e}^{-t/\tau_2} \sin(2\pi f_2 t + 2\pi\gamma_2 t^2 + 2\pi\xi_2 t^3 + \pi\beta_2)
\end{aligned}
$$

*Analytic WF from S.Bose, K.Chakravarti, L.Rezzolla et al. (2018)*

# BNS merger waveform




$M_1 = M_2 = 1.250 M_\odot$, D = 50 Mpc, for the GNH3 EOS

*L.Lehoucq, I.Dvorkin and L.Rezzolla submitted to PRD Letter*

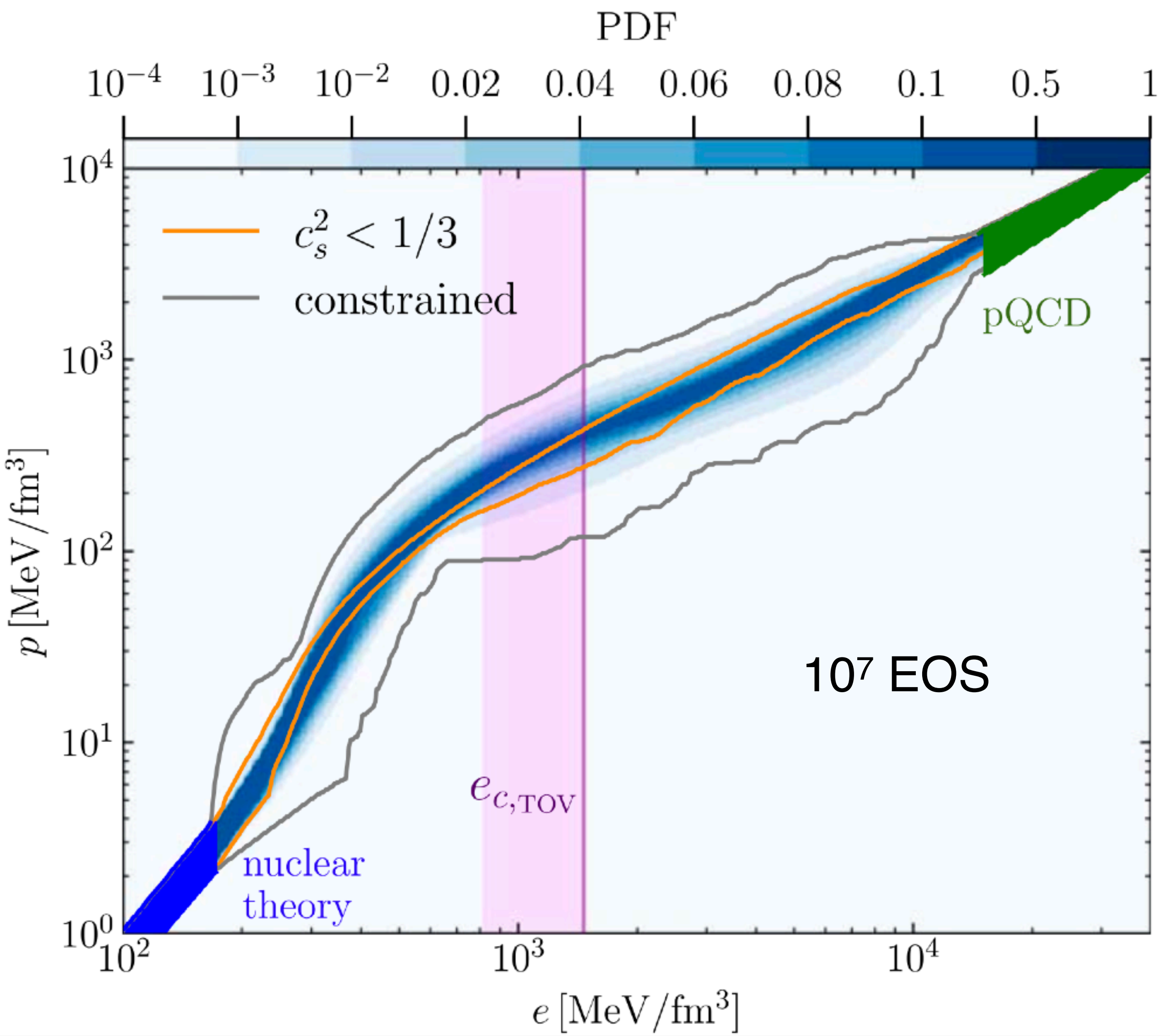
# BNS population modelling

18 —> 9 BNS parameters: non-eccentric, spinless, symmetric

| Parameters | BNS |
|---|---|
| m | Galactic BNS mass distribution (Farrow et al. 2019) |
| $\Lambda$ | Calculated based on $\mathcal{M}$ and the EOS, $\Lambda = a + b\mathcal{M}_{\text{chirp}}{}^{\alpha}$ |
| z | Merger rate model *baseline_delays* (Lehoucq et al. 2023) |
| $\cos\iota$<br>$\cos\delta$ | Uniform in [-1,1] |
| $\alpha$, $\psi$,$\Phi_c$ | Uniform in [0,2$\pi$] |
| $t_c$ | 0 |

*L.Lehoucq, I.Dvorkin and L.Rezzolla submitted to PRD Letter*

# Agnostic approach of the EOS



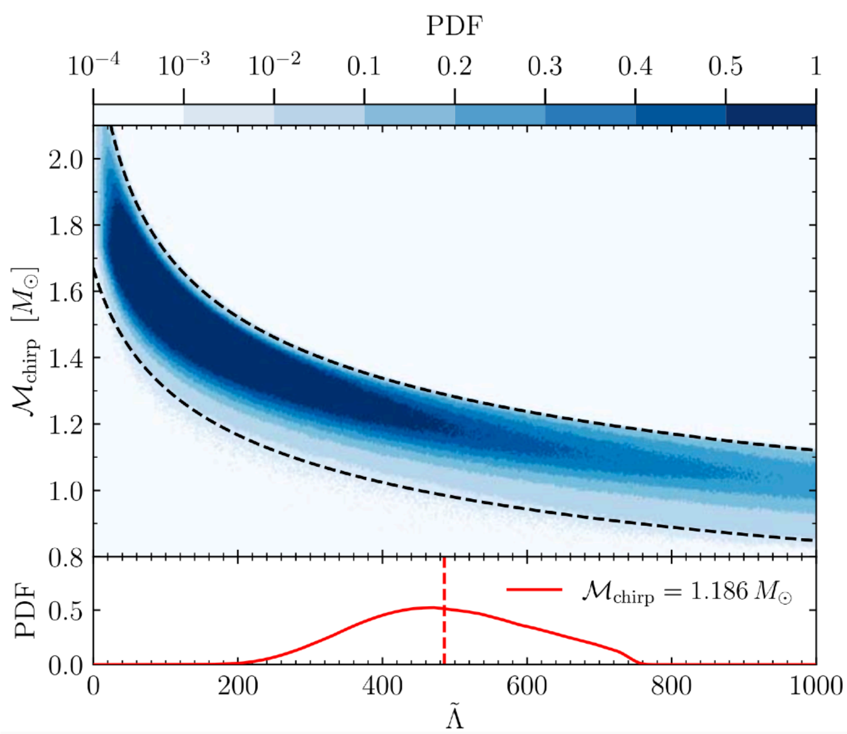

*S.Altiparmak, C.Ecker, and L.Rezzolla (2022)*

# Agnostic approach of the EOS

- A priori, an EOS is not defined by a single $M_{chirp}$-$\Lambda$. relation

- But with only symmetric binaries, there is unicity of the relation

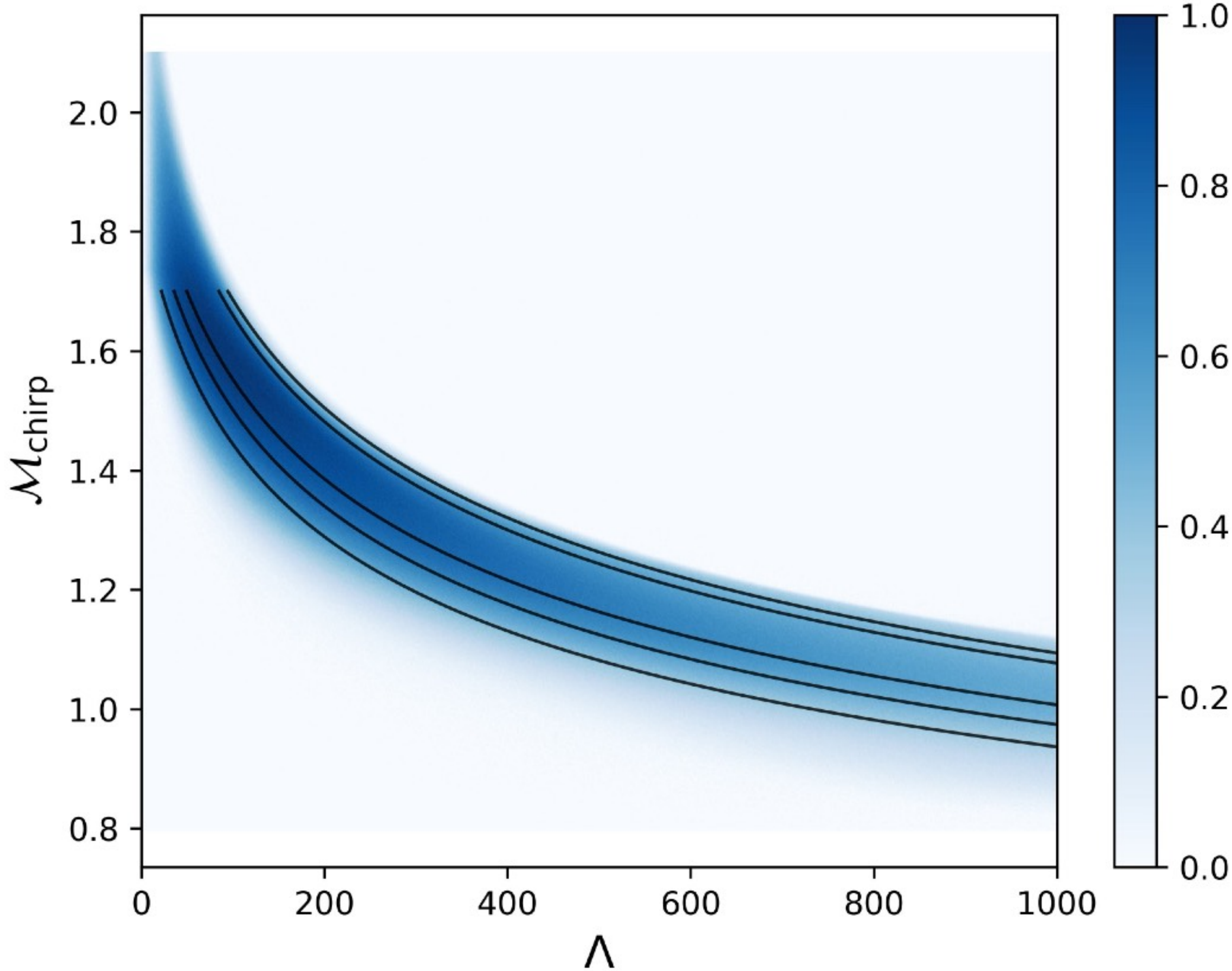
- We can generate a valid EOS in accordance with the PDF, it takes the form of a power-law :




*S.Altiparmak, C.Ecker, and L.Rezzolla (2022)*

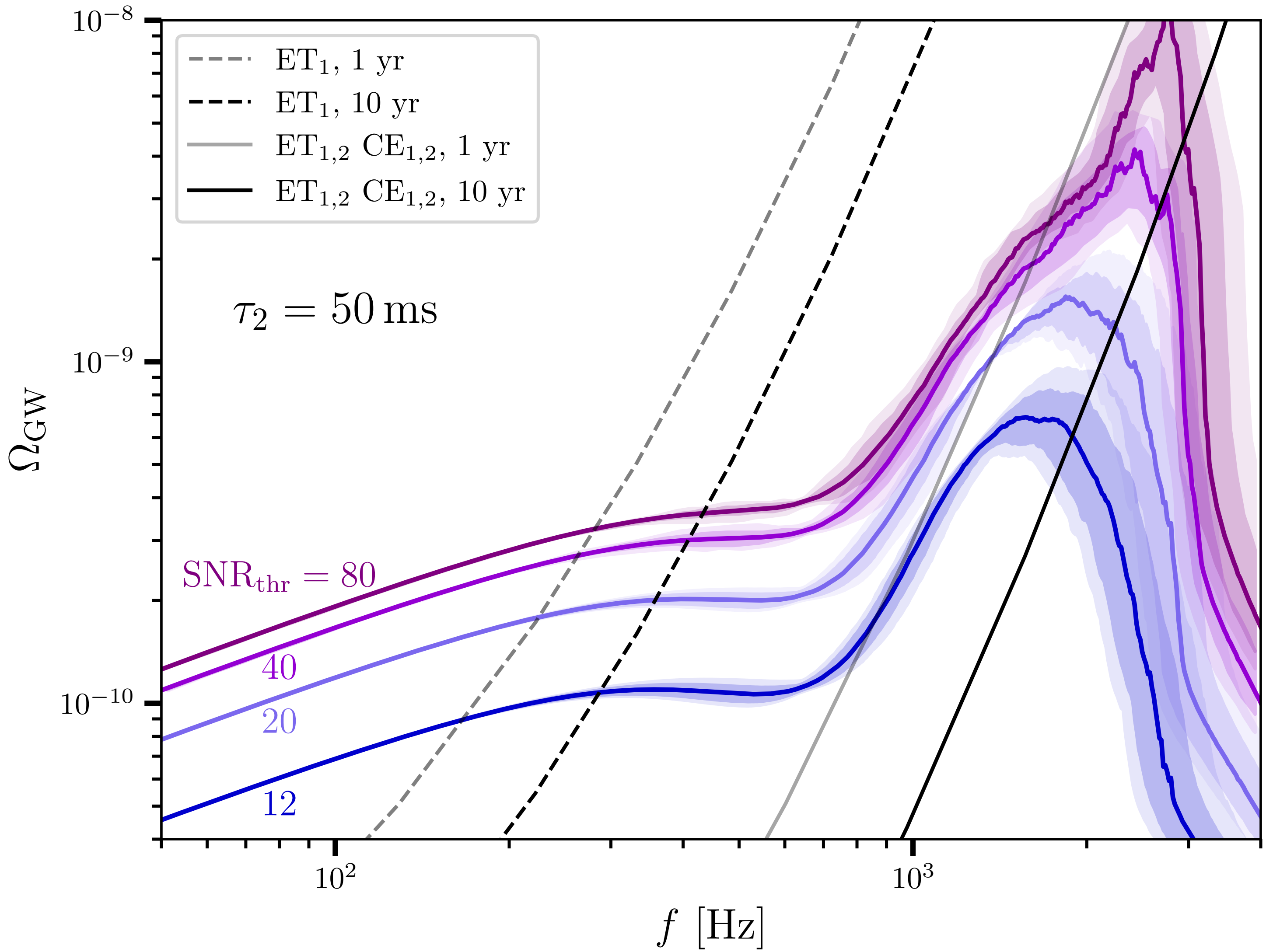
$$\Lambda = a + b\mathcal{M}_{\rm chirp}^{\ \alpha}$$

# Agnostic approach of the EOS




*L.Lehoucq, I.Dvorkin and L.Rezzolla, arxiv:2503.20877*

# Results

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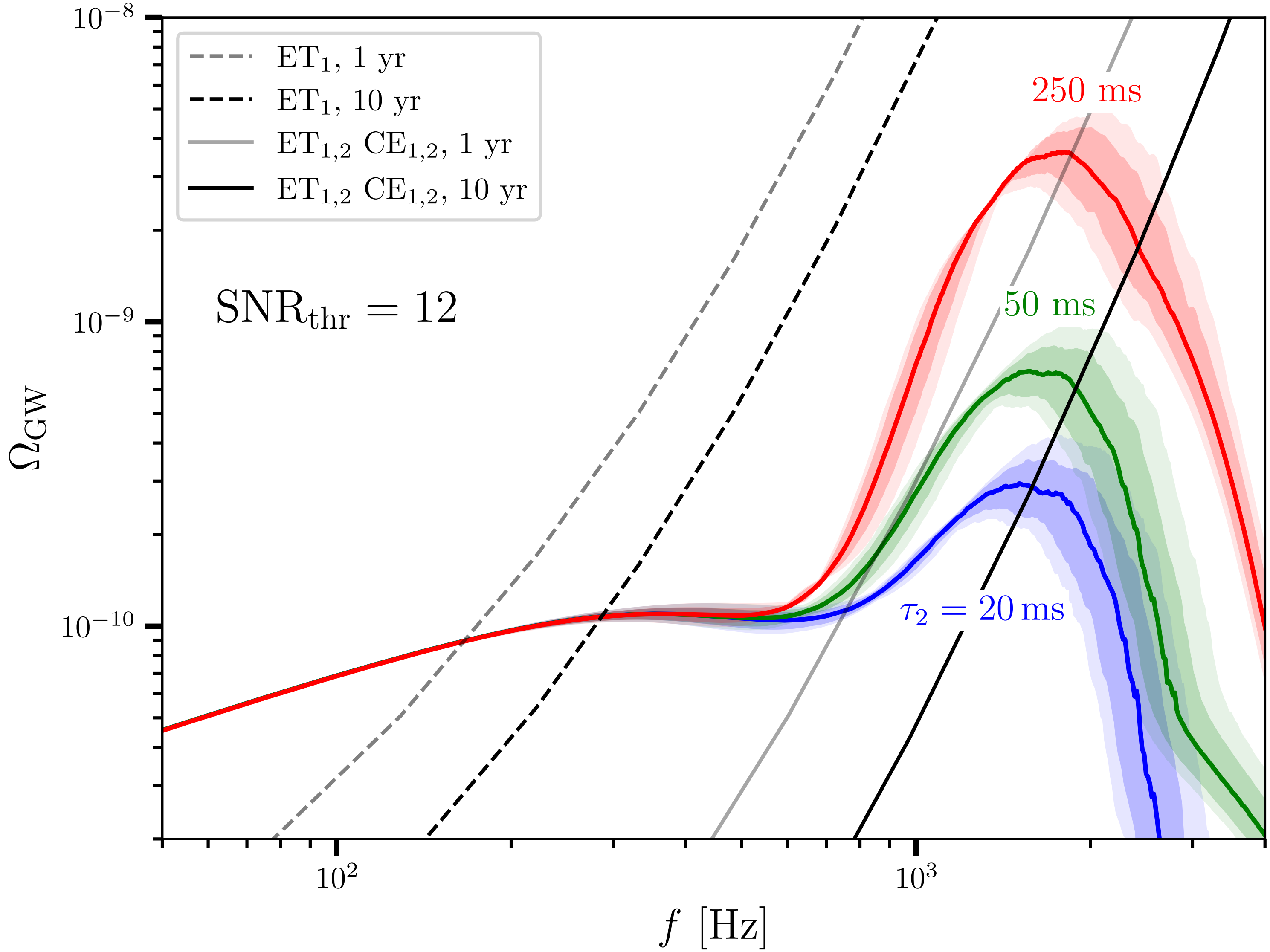


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