# Tight constraints on EdGB gravity with GW190814

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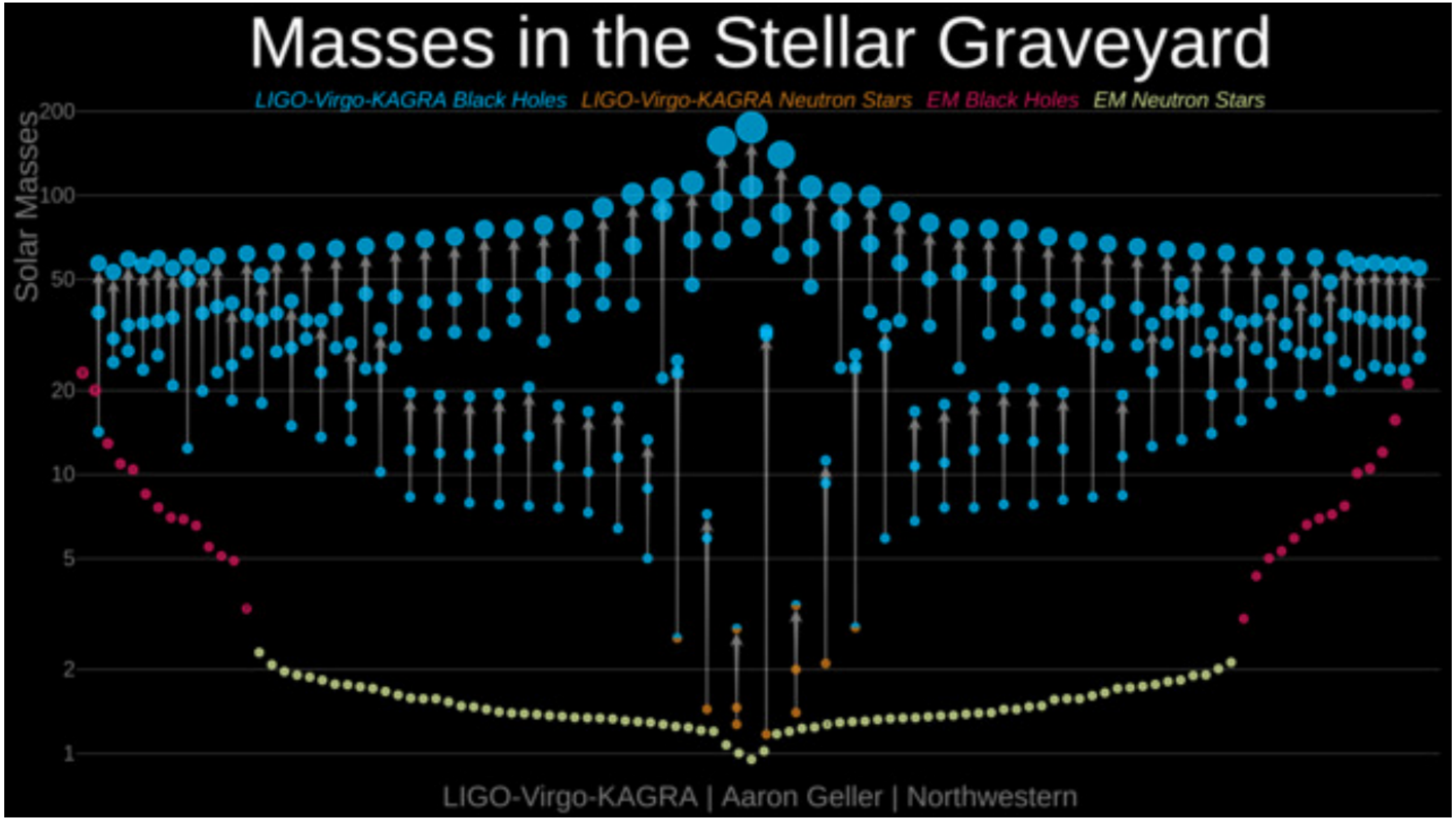
# Background

**GW events of GWTC-3**

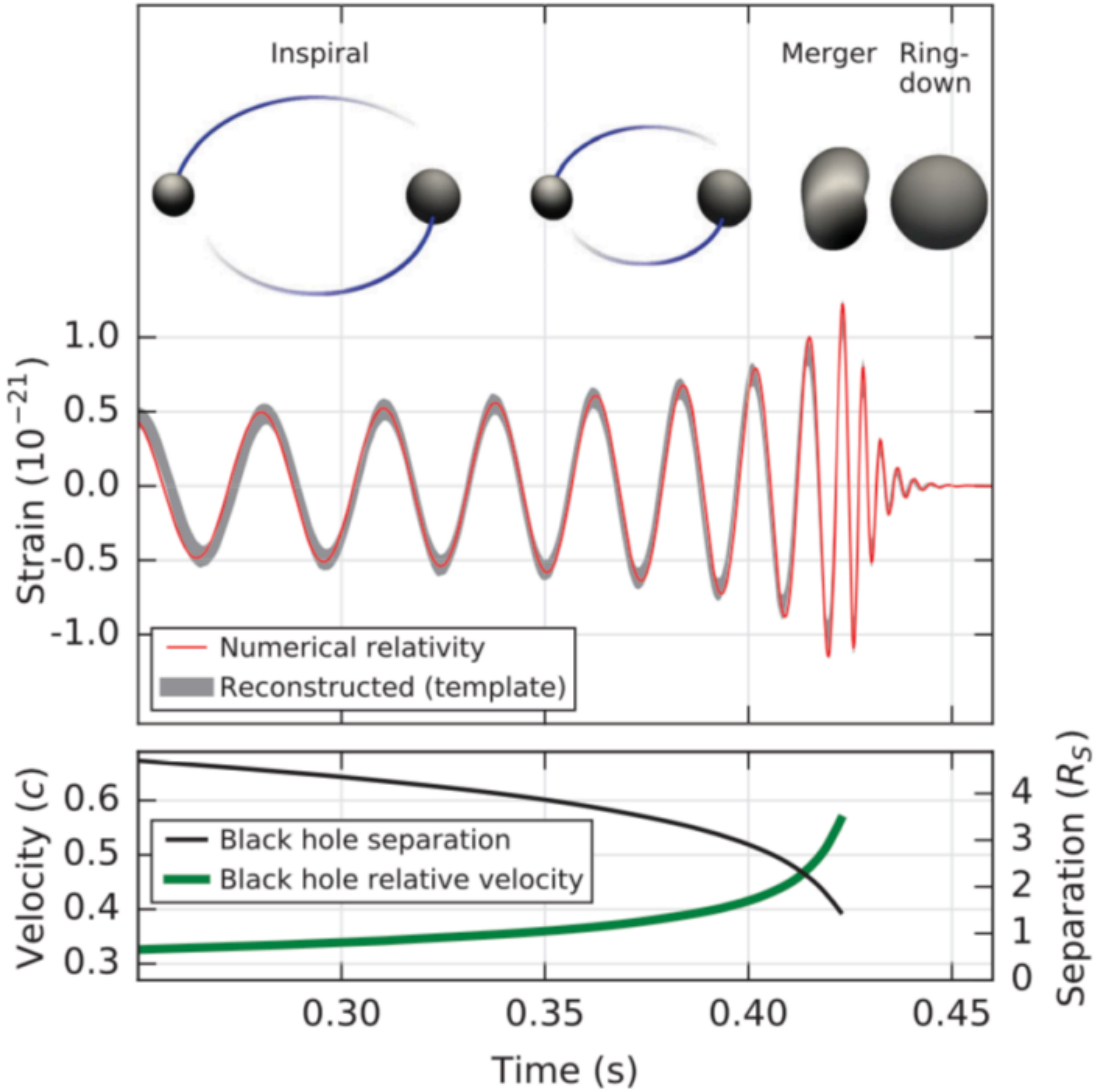



©*https://www.ligo.caltech.edu/image/ligo20211107a*

# Background

## The GW signal of GW150914

- Inspiral: post-Newtonian (PN) theory
- Merger: numerical relativity (NR) simulation
- Ringdown: quasinormal modes (QNMs)




*B. P. Abbott et al. PRL. 2016*

# Background

## The EdGB gravity

$$S = \int d^4x \frac{c^3\sqrt{-g}}{16\pi G}\left[R - 2(\nabla\phi)^2 + \alpha\frac{e^{2\phi}}{4}\mathcal{R}_{\rm GB}\right]$$

The scalar field

The coupling constant: $\sqrt{\alpha_{\rm EdGB}}$

$$\mathcal{R}_{\rm GB} = R^2 - 4R^{\mu\nu}R_{\mu\nu} + R^{\mu\nu\rho\sigma}R_{\mu\nu\rho\sigma}$$

Effects on the GW waveform:

1. NR simulation;
2. The Parameterized Post-Einsteinian (ppE) framework

# Background

## The Parameterized Post-Einsteinian (ppE) framework

The waveform model:

$$h(f) = A(f)e^{i\left(\Phi_{GR}(f) + \delta\Phi(f)\right)}$$

where $\Phi_{GR}(f) = 2\pi f t_c - \phi_c - \frac{\pi}{4} + \frac{3}{128\eta}(\pi m f)^{-5/3}\sum_{i=0}^{7}\phi_i(\pi m f)^{i/3},$

$$\delta\Phi_{\mathrm{I,ppE}}(f) = \frac{3}{128}(\pi\mathcal{M}f)^{-5/3}\sum_{i=0}^{7}\phi_i^{\mathrm{ppE}}(\pi\mathcal{M}f)^{i/3},$$

$$m = m_1 + m_2, \mathcal{M} = (m_1 + m_2)^{0.6}/m^{0.2}$$

*Sharaban Tahura and Kent Yagi. PRD. 2019*

# Background

## The effects of the (scalar) charge

For EdGB gravity (scalar charge):

$$\Delta\Phi_{EdGB} = -\frac{5}{7168}\eta^{-18/5}\zeta_{EdGB}(m_1^2 s_2 - m_2^2 s_1)^2/m^4(\pi\mathcal{M}f)^{-7/3}$$

where $\zeta_{EdGB} = 16\pi\alpha_{EdGB}^2/m$

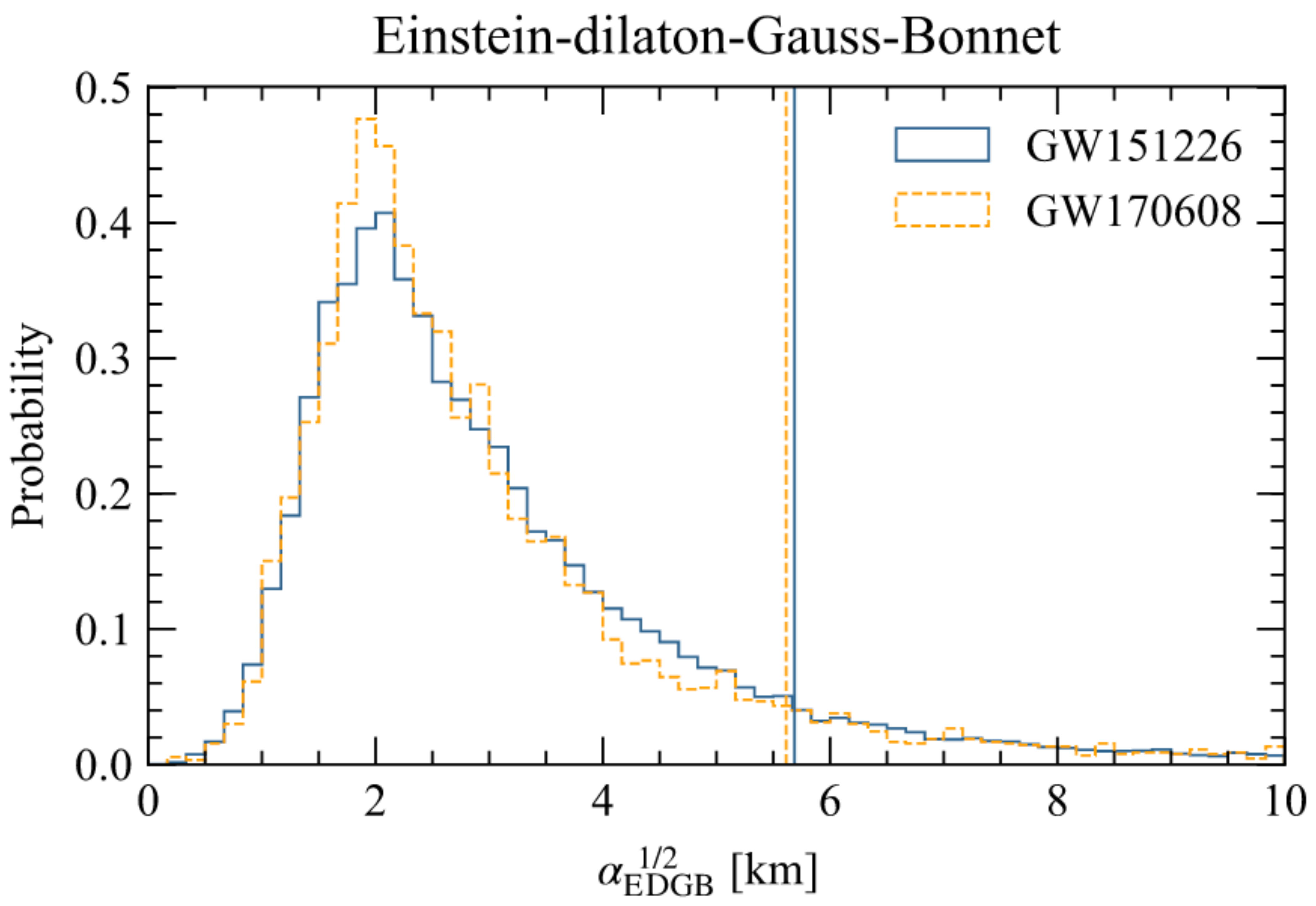
$$s_i = 2\left(\sqrt{1-\chi_i^2} - 1 + \chi_i^2\right)/\chi_i^2$$

$$\chi_i = \vec{S}_i \cdot \hat{L}/m_i^2$$

# Background

## Previous constraints on EdGB

$$\delta\phi_{-2} = \frac{128\beta_{\rm EdGB}}{3\eta^{2/5}}$$

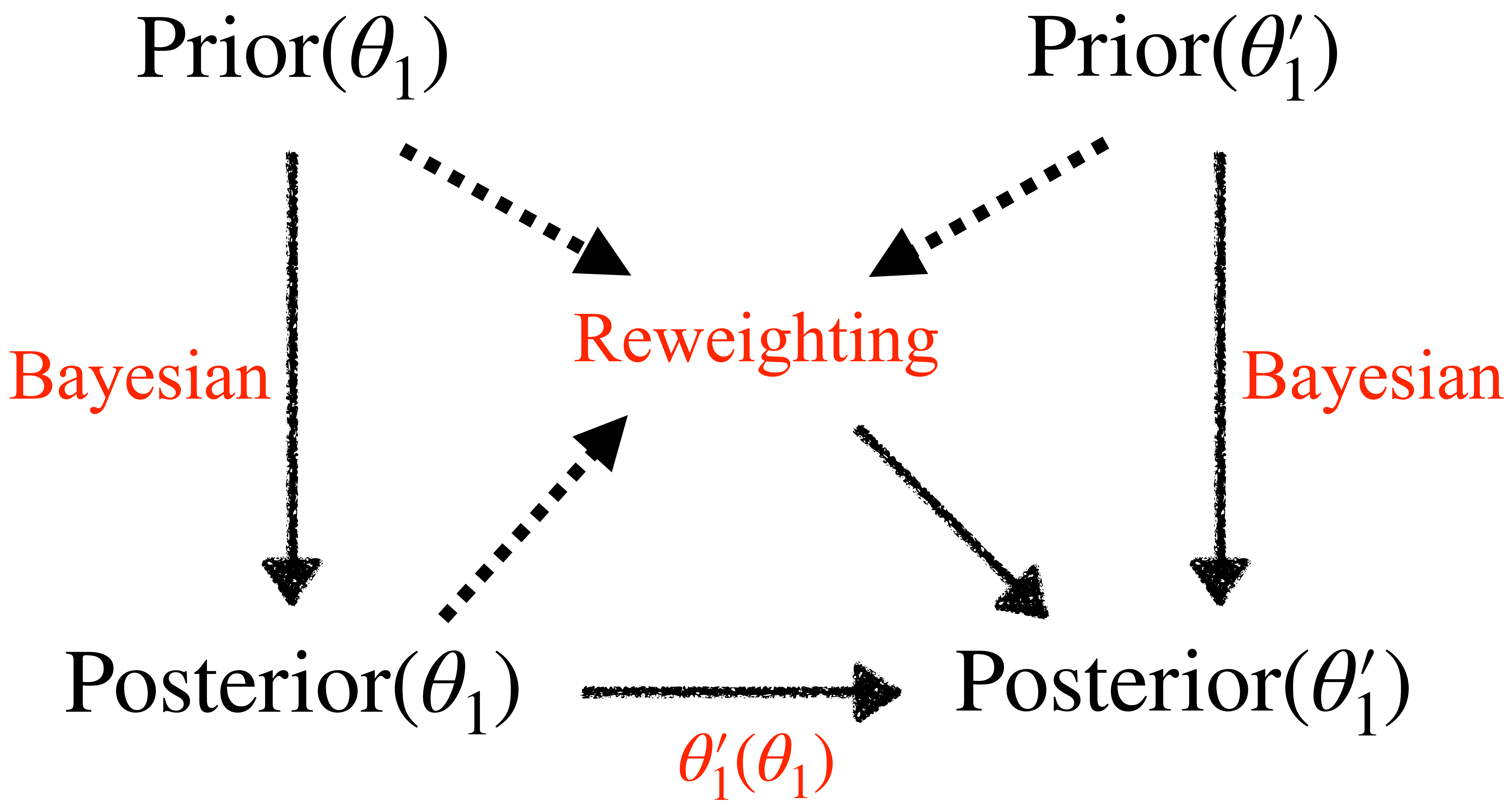



*Remya Nair et al. PRL. 2019*

# Method

### The reweighting method

$$\theta_1 := (\delta\phi_{-2}, m_i, \chi_i)$$
$$\theta_1' := (\sqrt{\alpha_{\rm EdGB}}, m_i, \chi_i)$$



# Method

**The reweighting method**

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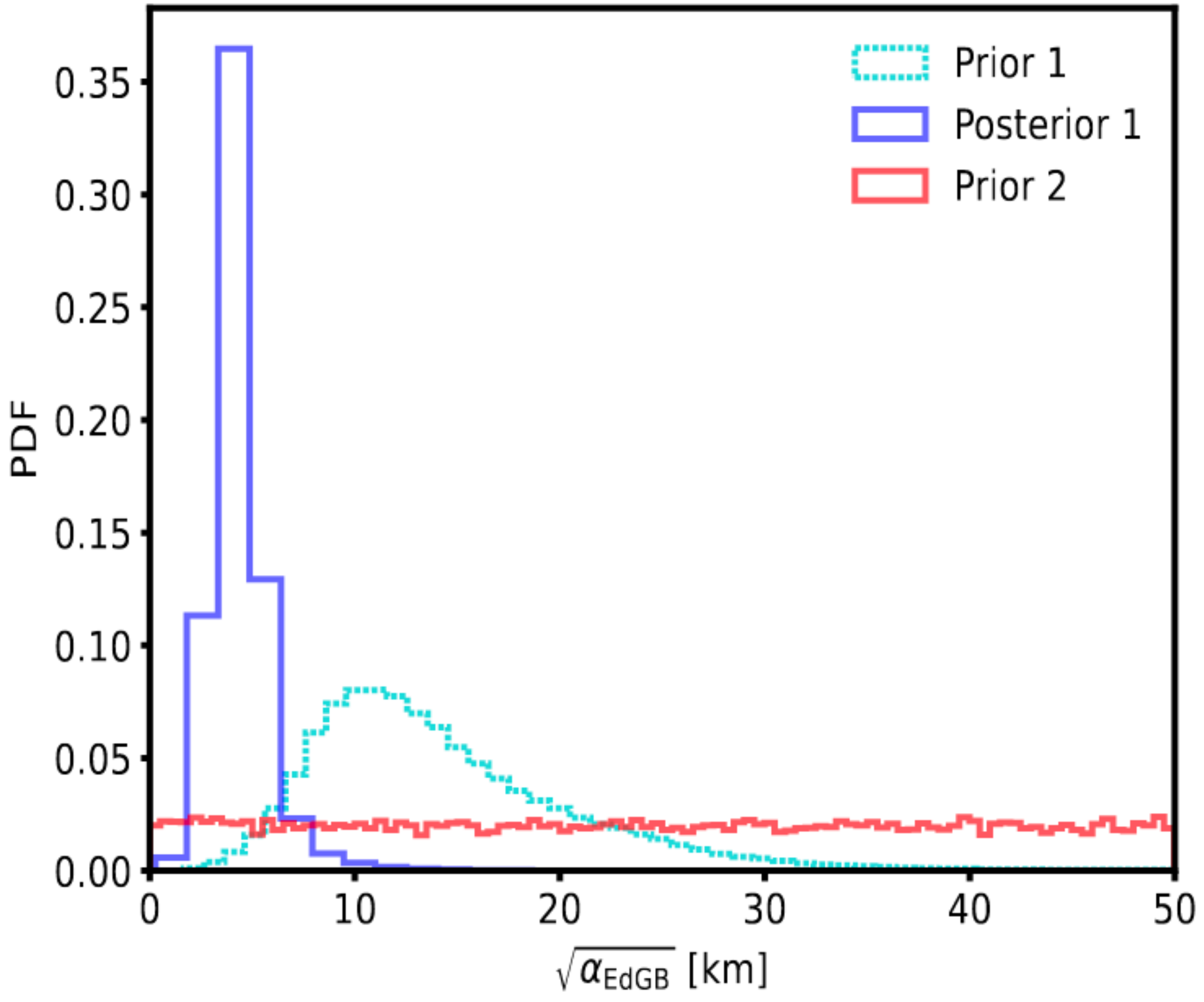
$$\theta_1' := (\sqrt{\alpha_{\rm EdGB}}, m_i, \chi_i)$$



# Method

## The Bayesian inference

- The Bayes theorem:

The likelihood The prior

The posterior

$$P(\theta|d,S)=\frac{P(d|\theta,S)P(\theta|S)}{P(d|S)}$$

The evidence

- For N detectors:

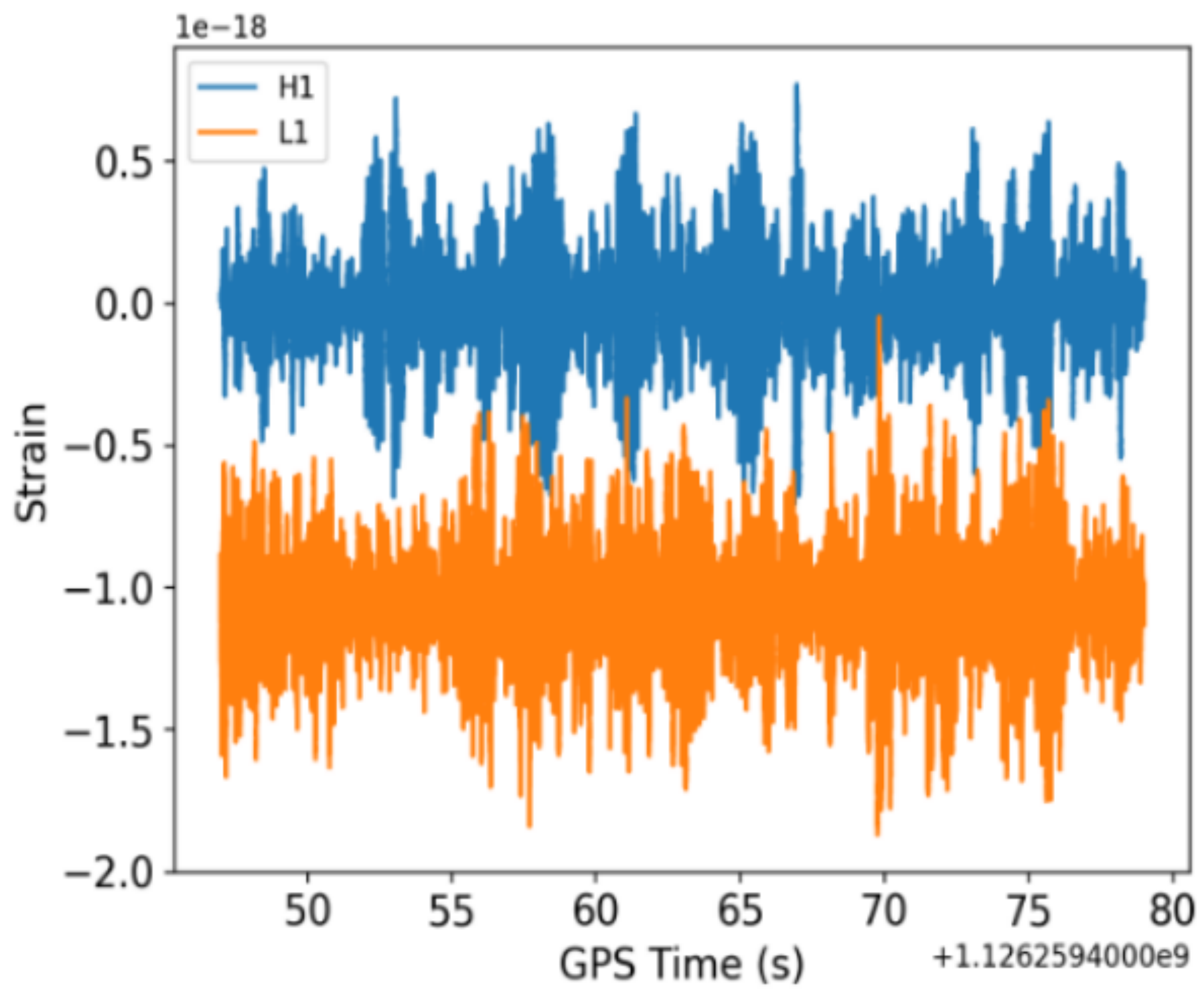
$$P(d|\theta,S)=\exp\left[-\frac{1}{2}\sum_{i=1}^{N}\langle d_i-h_i|d_i-h_i\rangle\right]$$

- The inner product:

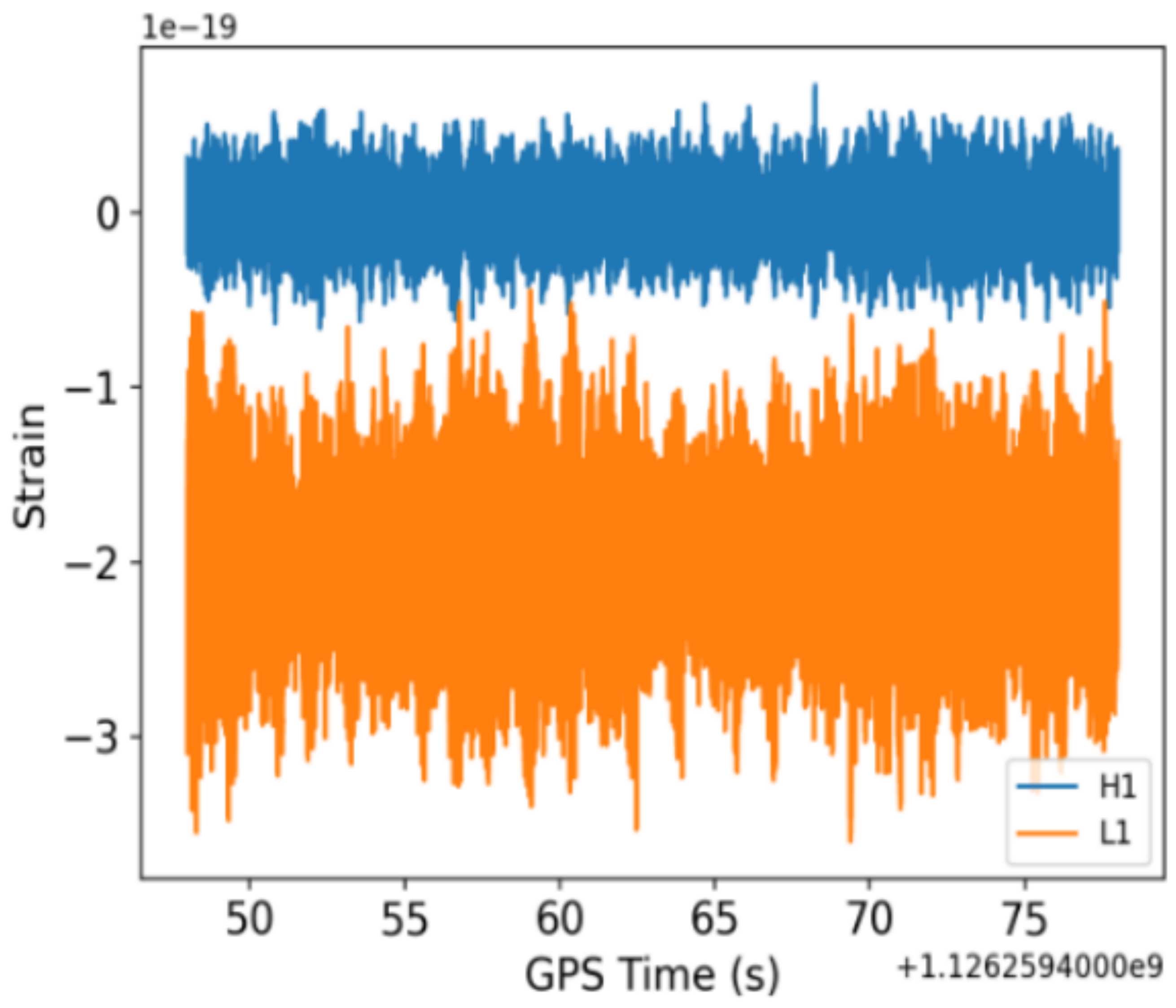
$$\langle h_1(f)|h_2(f)\rangle=4\Re\int_{f_{\rm filter}}^{f_{\rm ISCO}}\frac{h_1(f)h_2^*(f)}{S_n(f)}$$

# Method

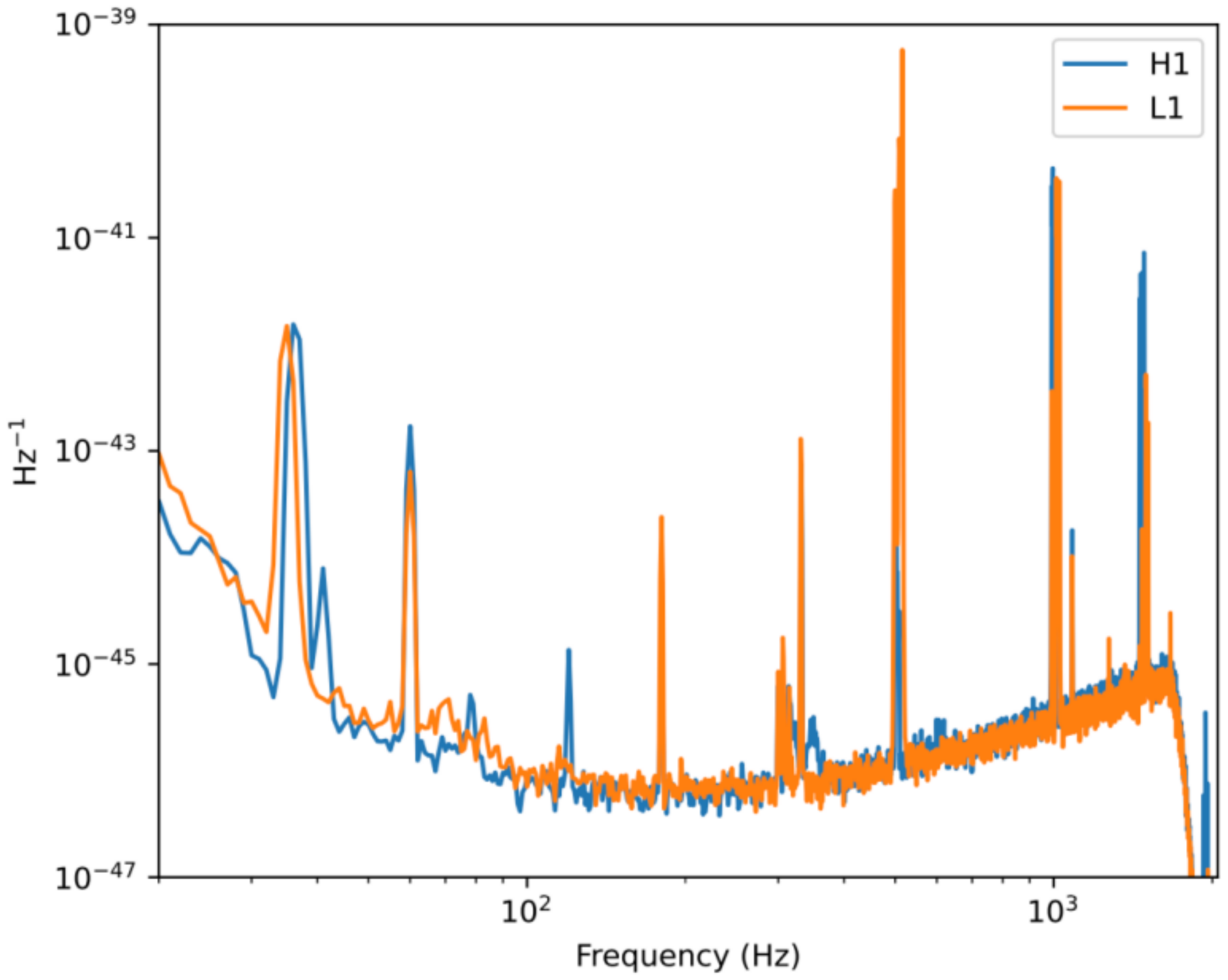
## The estimation on the noise




The raw data around GW150914




GW data after a high-pass filter at $20\,\mathrm{Hz}$




PSDs of GW150914

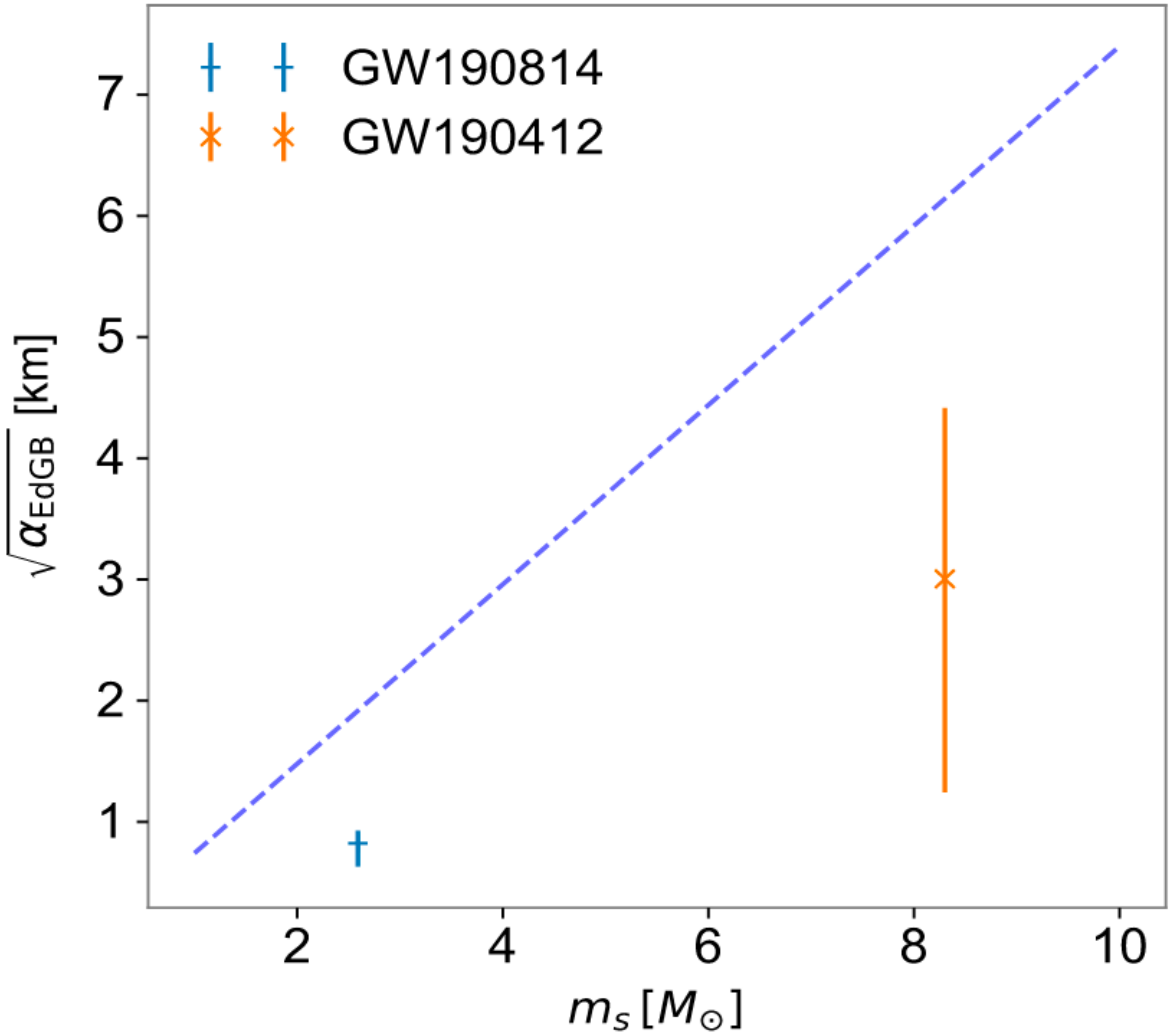
$$S_n(f) = \lim_{T\to\infty} \frac{2}{T}\left(\int_{-T/2}^{T/2} \rho(t) e^{-2\pi i f t} dt\right)^2$$

# Results

## Constraints on EdGB (the reweighting method)

$$\zeta_{\rm EdGB} = 16\pi\alpha_{\rm EdGB}^2/m_s^4 < 1$$

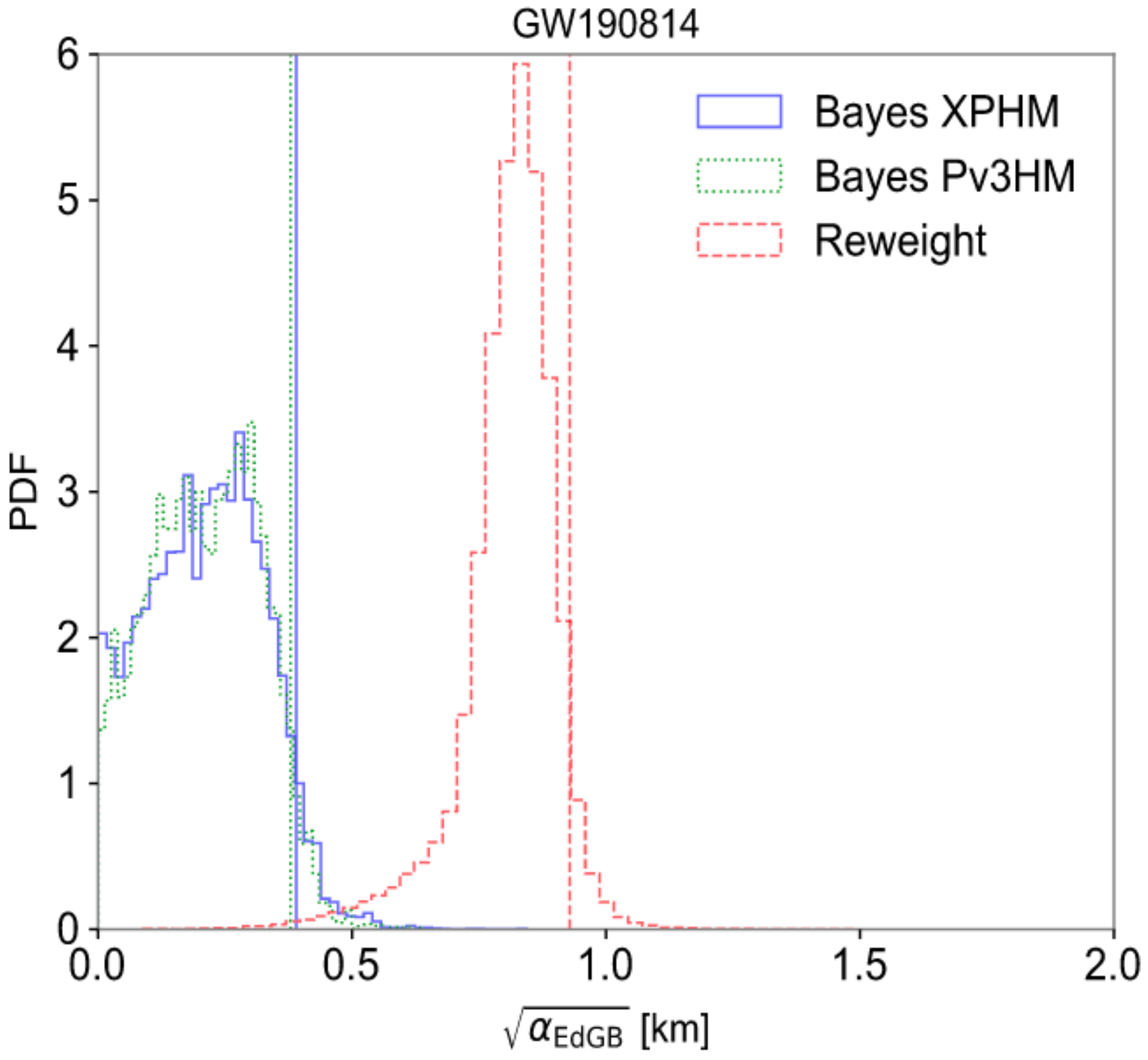
$$\sqrt{\alpha_{\rm EdGB}} < 0.74\frac{m_s}{M_\odot}$$




*H.T. Wang et al. PRD. 2021*

# Results

## Constraints on EdGB (the Bayes method)




*H.T. Wang et al. PRD. 2021*

TABLE I. Constraints on $\sqrt{\alpha_{\mathrm{EdGB}}}$ with reweighting and Bayesian analyses. The Bayesian analyses are performed with both the IMRPhenomPv3HM (Pv3HM) waveform model and IMRPhenomXPHM (XPHM) waveform model. All constraints are presented as the upper limits for each individual event at 90% credibility.

| Events | Methods | $\sqrt{\alpha_{\mathrm{EdGB}}}$ (km) |
|---|---|---|
| GW190412 | Reweighting | 4.41 |
| | Bayes XPHM | 4.46 |
| GW190814 | Reweighting | 0.93 |
| | Bayes XPHM | 0.40 |
| | Bayes Pv3HM | 0.38 |

# Summary

## Constraints on EdGB

| | | |
|---|---|---|
| $\sqrt{\alpha_{EdGB}} \leq 5.6\,\text{km}$ | GW170608 | *Remya Nair et al. PRL. 2019* |
| $\sqrt{\alpha_{EdGB}} \leq 2\,\text{km}$ | X-ray | *Kent yagi. PRD. 2012* |
| $\sqrt{\alpha_{EdGB}} \leq 0.40\,\text{km}$ | GW190814 | *H.T. Wang et al. PRD. 2021* |
| $\sqrt{\alpha_{EdGB}} \leq 0.27\,\text{km}$ | GW190814 | *B.X. Wang et al. arxiv. 2023* |

# Summary

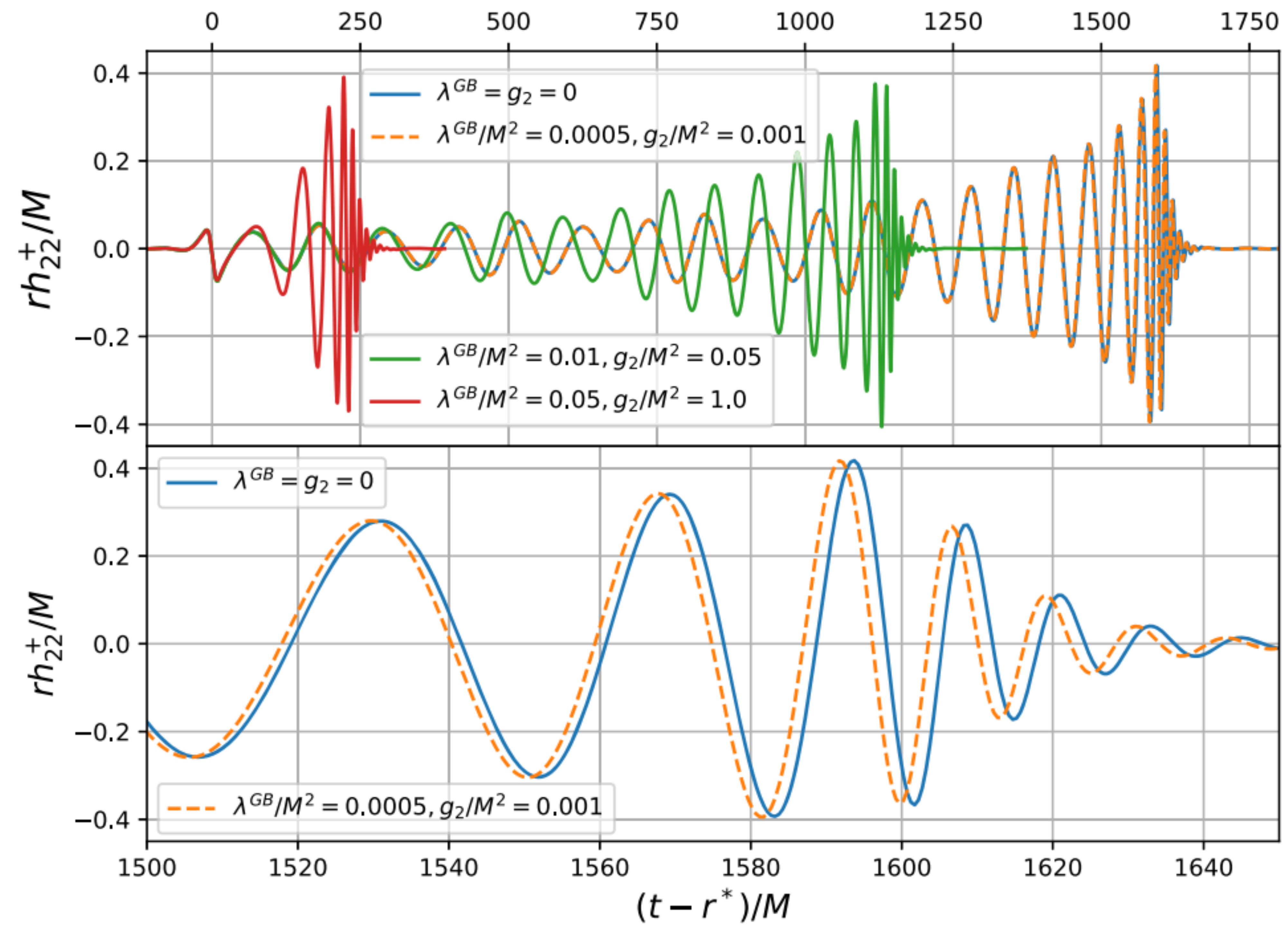
- We compare the reweighting method and the Bayesian inference;

- We update the constraint on EdGB gravity to be $\sqrt{\alpha_{EdGB}} \leq 0.40\,\mathrm{km}$

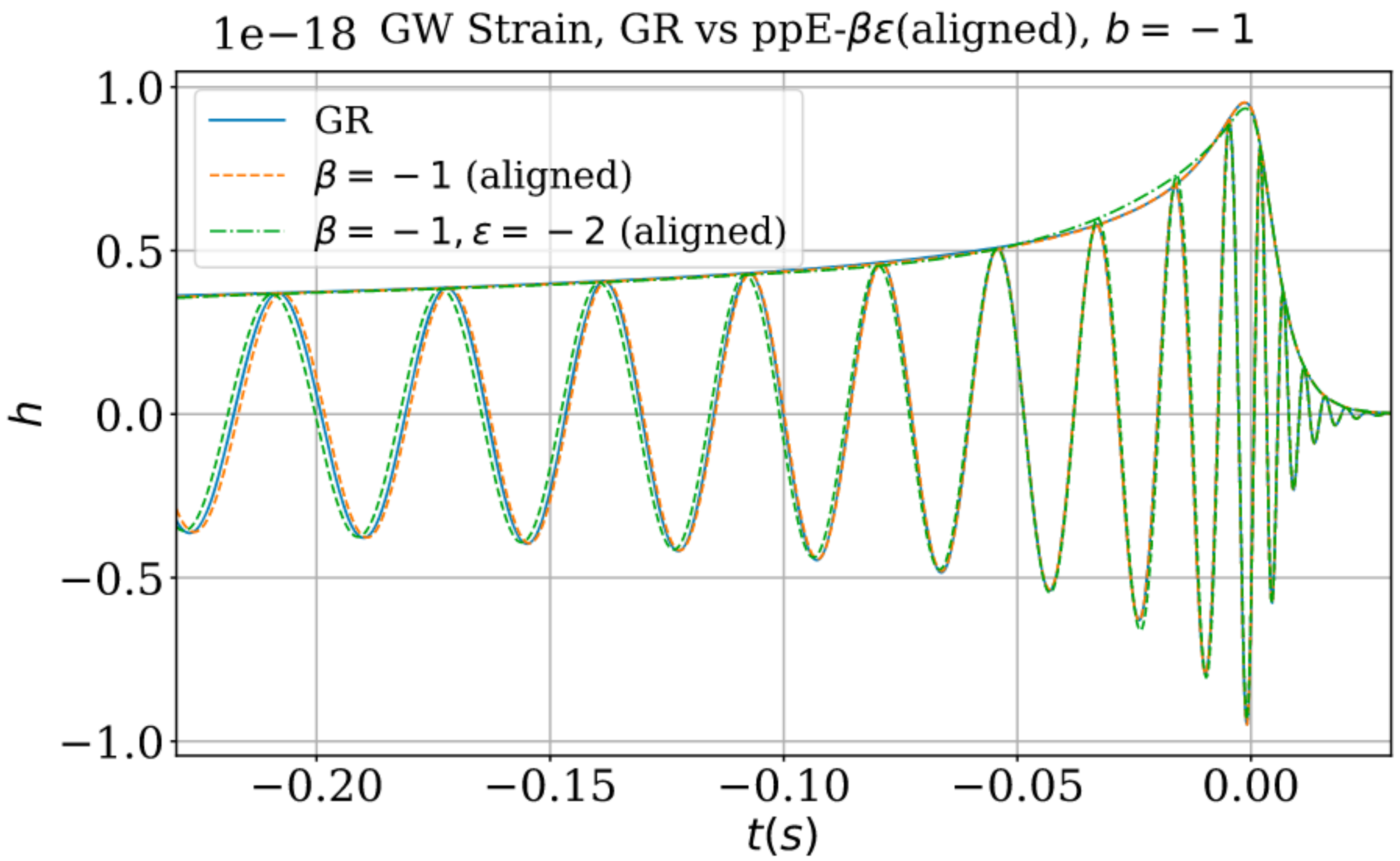
# Thanks

# Background

## The EdGB gravity




*Llibert Aresté Saló et al. PRL. 2022*




*Gabriel S. Bonilla et al. PRD. 2023*