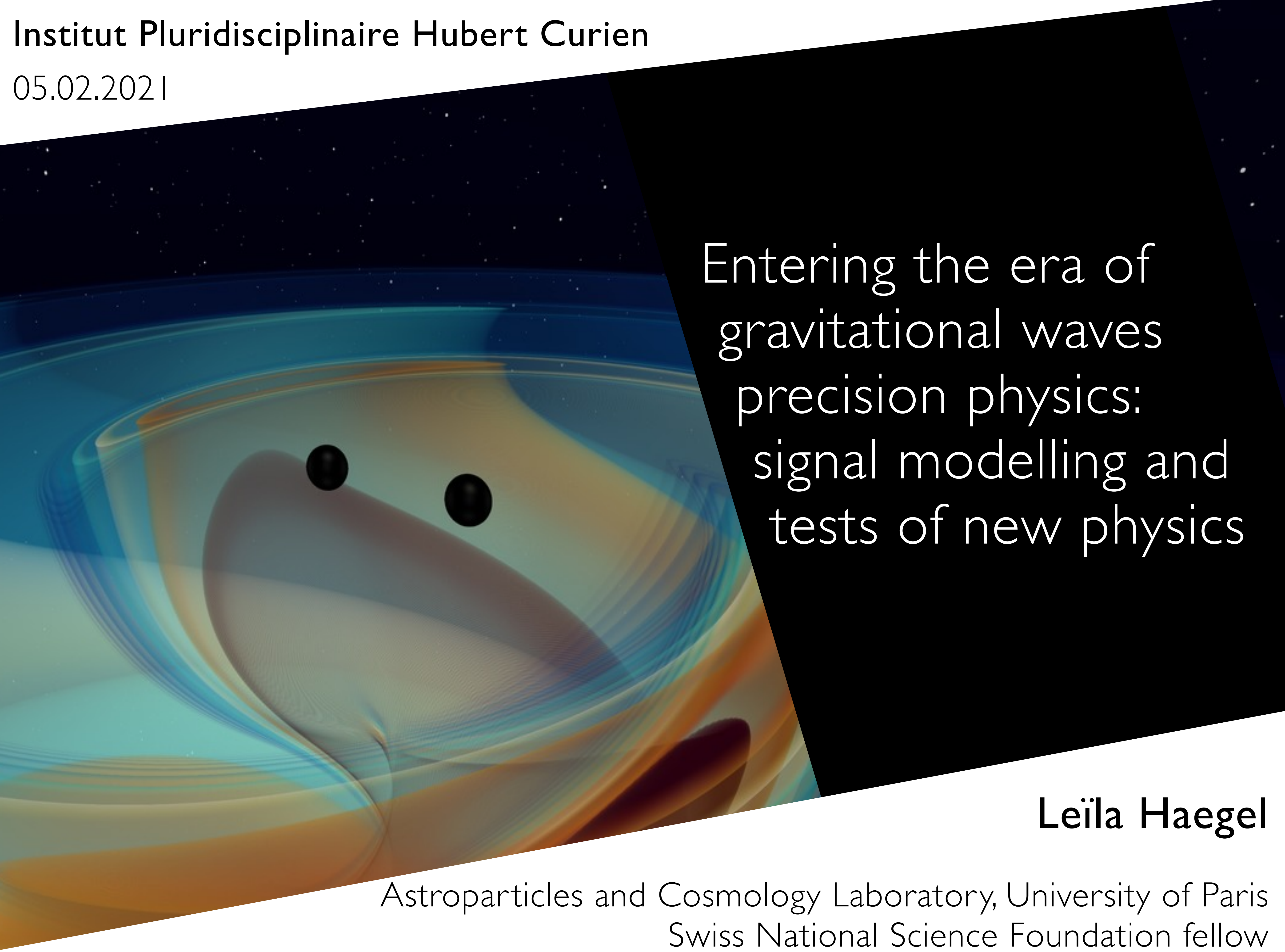
Institut Pluridisciplinaire Hubert Curien

05.02.2021

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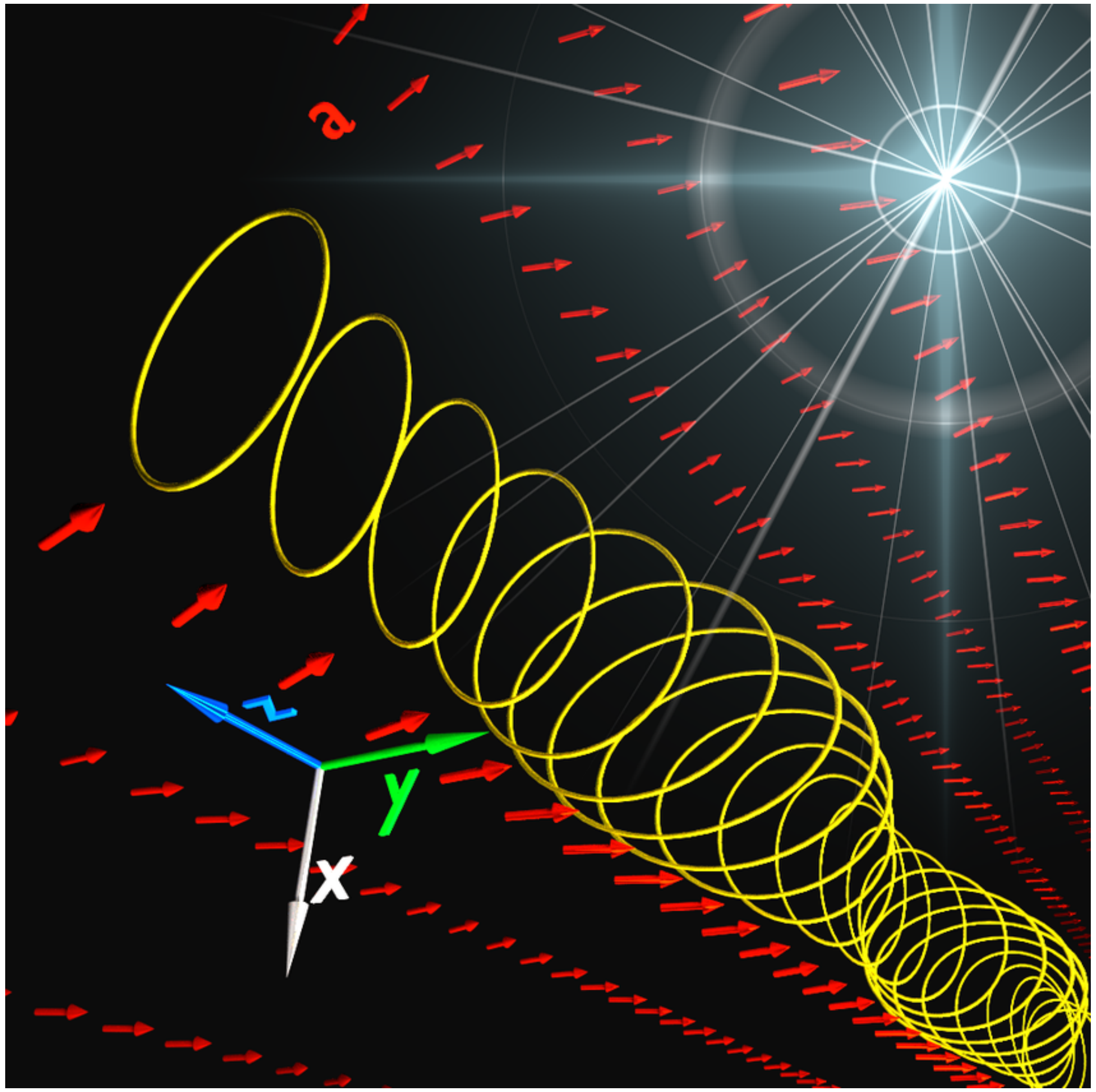
# Overview

- **Searching for new physics during gravitational waves (GW) propagation**
  - Constraints from GW + electromagnetic signal
  - Constraints from the modified GW signal

- **Designing accurate GW signals**
  - Predicting the black holes parameters with increased prediction
  - Using non-parametric method to generate GW templates

# Searching for new physics during GW propagation

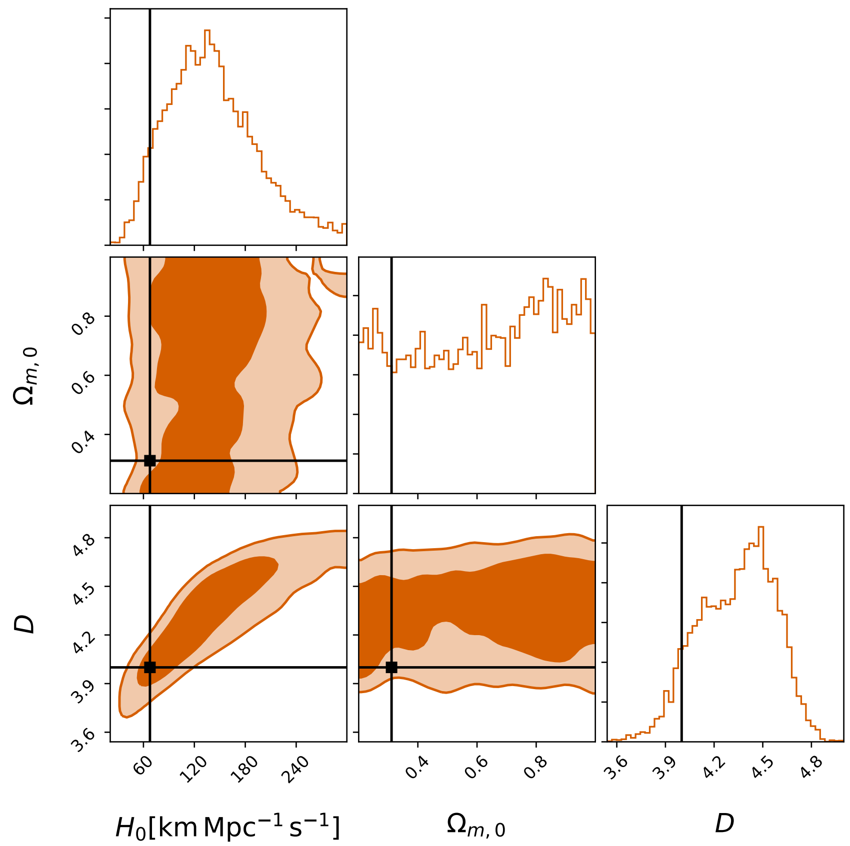
- **In presence of new fields, GW can be dispersed during their propagation.**
  - The dispersion can impact the apparent distance of the GW source.
  - Constraining the dispersion enable to constrain new theories of gravitation, such as massive gravity.



Propagating gravitational wave (yellow rings) that deforms the Lorentz-violating background field a μ (red arrows). Source: Schreck, Marco (2016).

# Constraints from GW + electromagnetic signal

- **The analysis of two types of signals enable to constraint the distance of the source**:
  - GW170817 (BNS merger, $z \simeq 0.01$) and GW190521 (BBH merger in potential AGN disk, $z \simeq 0.44$)
  - Measurement of cosmological parameters (Hubble constant) and alternative theories of gravitation parameters (friction) at the same time



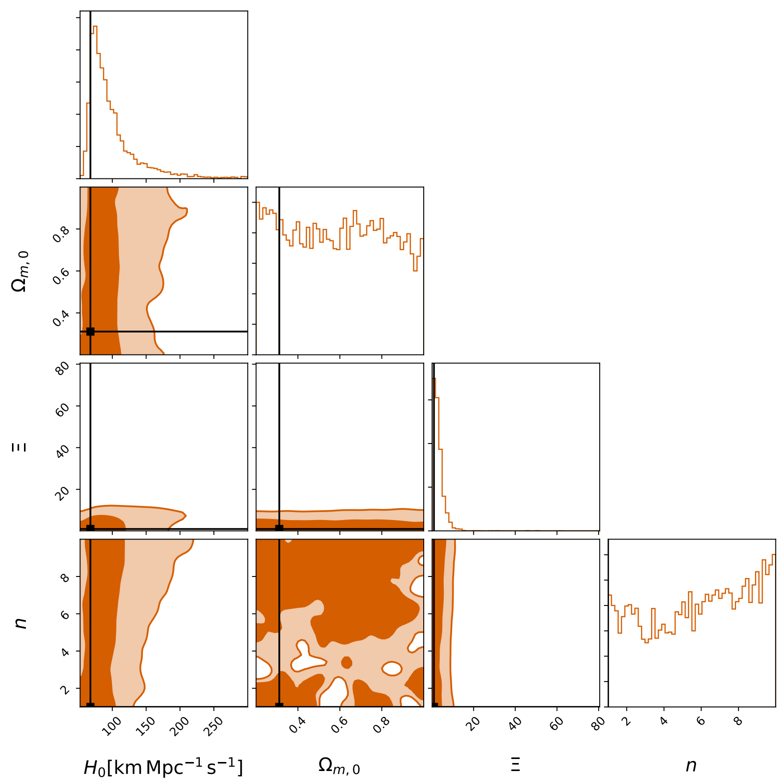

- **Parameterisation**:

$$d_L^{GW}(z) = \left[ 1 + \left( \frac{d_L^{EM}(z)}{R_c} \right)^n \right]^{\frac{D-2}{2n}}$$

- **Compatible theories**:
  - DGP gravity (4+1 dimensions), quantum gravity models of large extra dimensions

Mastrogiovanni, Haegel et al arxiv:2010.04047

# Constraints from GW + electromagnetic signal




- **Parameterisation**:

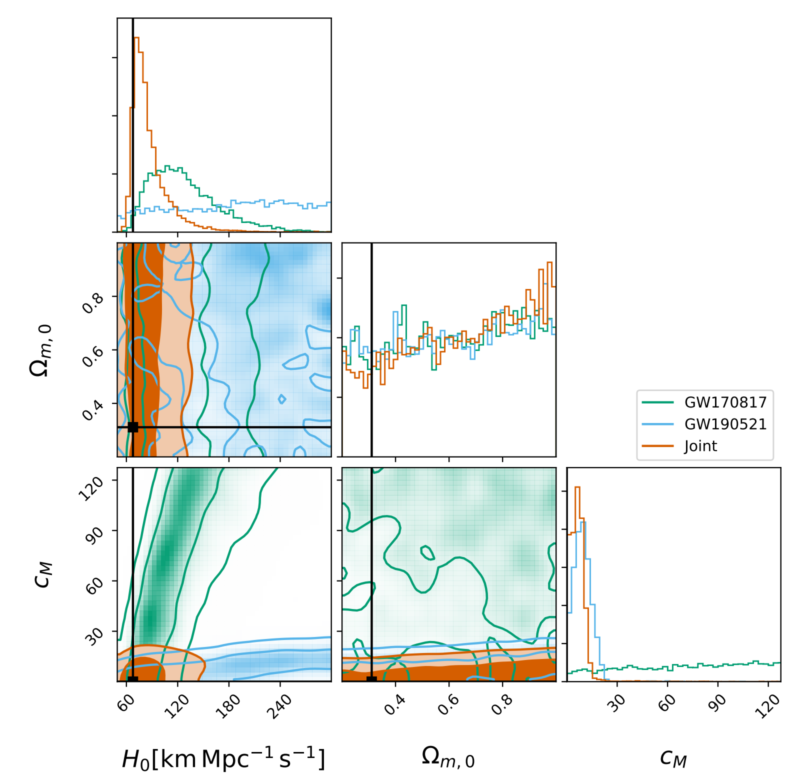
$$d_L^{GW}(z) \;=\; d_L^{EM}(z)\left[\,\Xi + \frac{1-\Xi}{(1+z)^n}\right]$$

- **Compatible theories**:
  - Scalar-tensor theories of gravitation (Brans-Dicke, Horndeski, beyond-Horndeski, DHOST)

- **Parameterisation**:

$$d_L^{GW}(z) \;=\; d_L^{EM}(z)\; exp\left[\,\frac{c_M}{2\Omega_{\Lambda,0}}\; ln\frac{1+z}{\Omega_{m,0}\,(1+z)^3 \;+\; \Omega_{\Lambda,0}}\right]$$

- **Compatible theories**:
  - Modified gravity models where $\alpha_M(z)$ is linked to the evolution of the dark energy content of the Universe

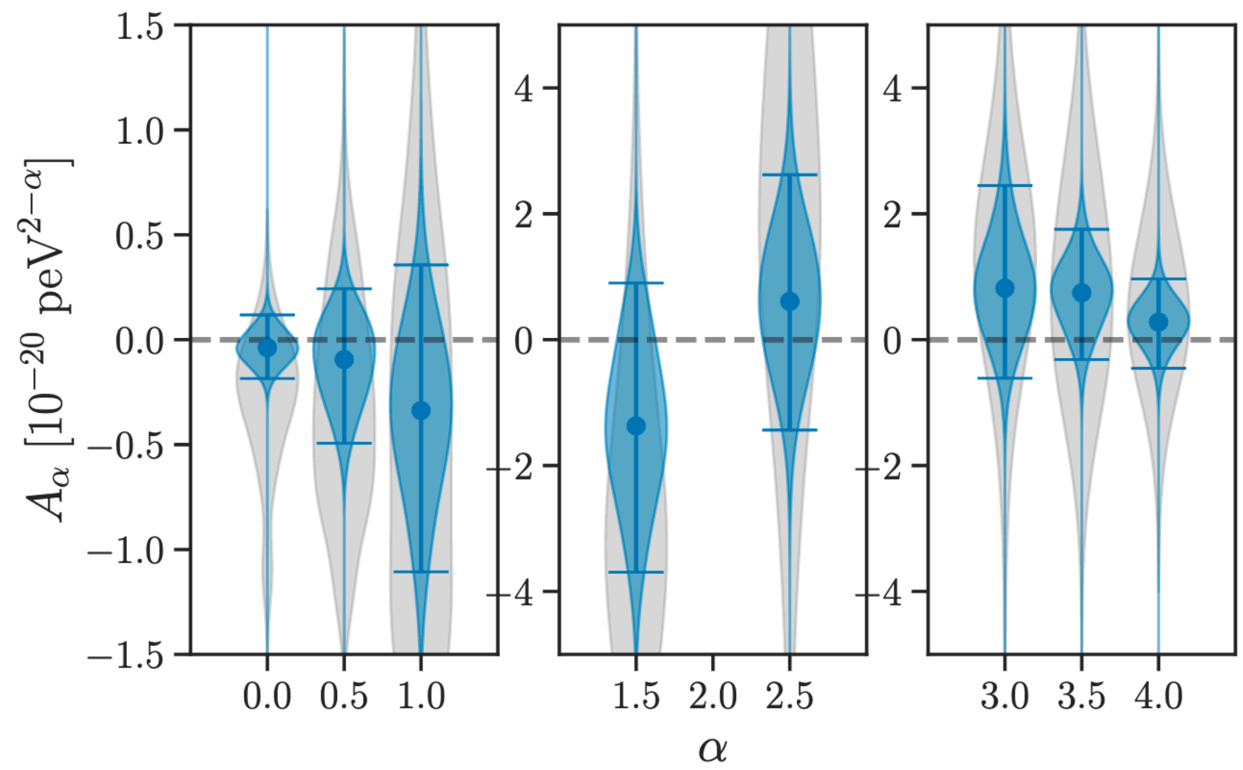



Mastrogiovanni, Haegel et al arxiv:2010.04047

# Constraints from the modified GW signal

- **Dispersion impacts the GW signal detected by the LVC interferometers**:
  - $h^{SME}_{+,\times} = f(A_\alpha)\, h^{GR}_{+,\times} + g(A_\alpha)\, h^{GR}_{\times,+}$
  - The analysis of the GW signal enable to constraint the modified gravity parameters.

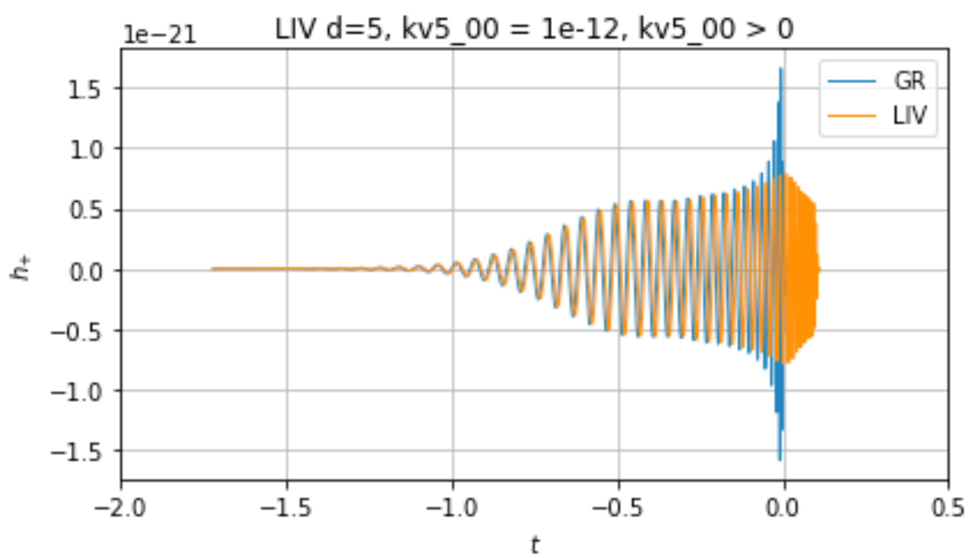
- **Current constraints on polarisation independent dispersion**:
  - Best constraint on the mass of the graviton
  - Constraints on a large range of alternative theories of gravitation (fractal spacetime / doubly special relativity / Hořava-Lifshitz gravity)

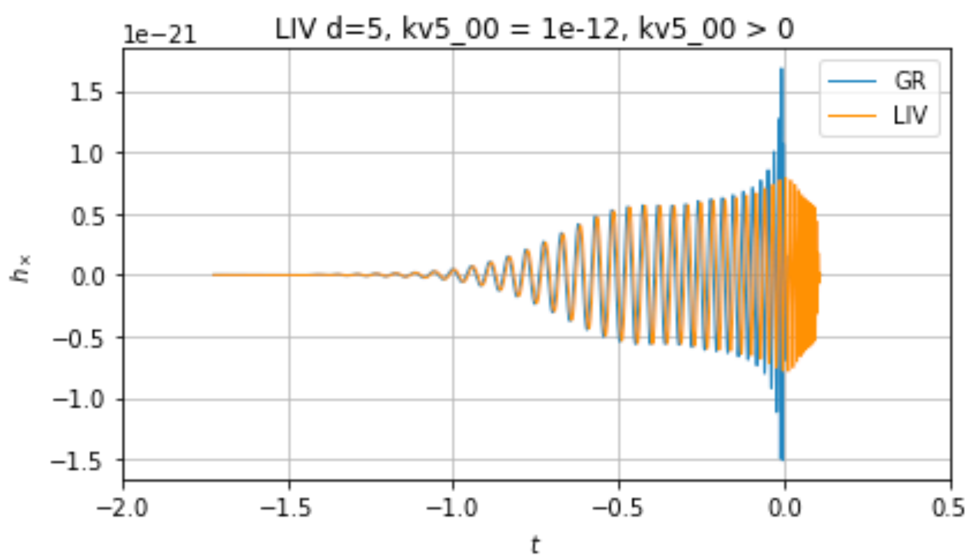



LVC arxiv:2010.14529

# Constraints from the modified GW signal

- **Implementation of polarisation dependent dispersion**:
  - The modified GW signal is derived in the context of the Standard Model Extension effective field theory.
  - Spacetime would be a birefringent medium for GW propagating through it
  - Work in progress (Haegel, Ault-O'Neal, Tasson, Bailey)



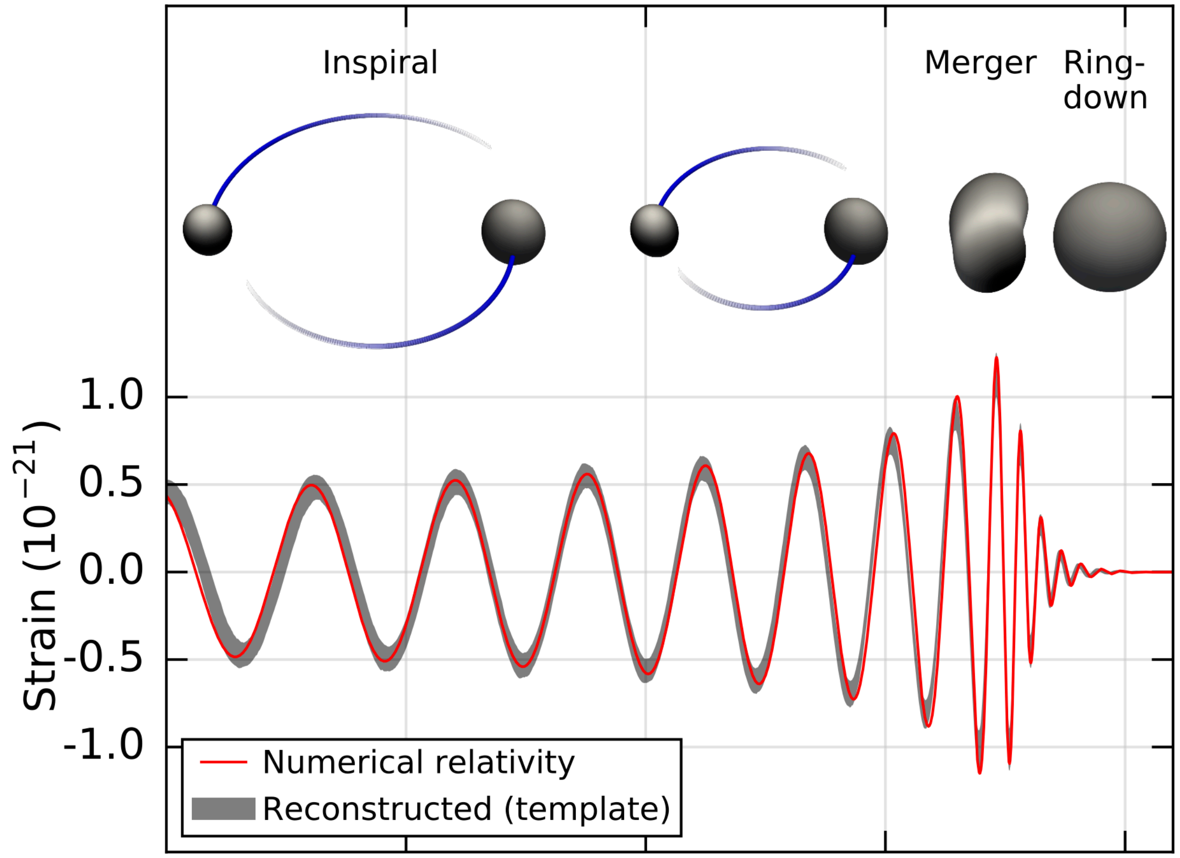

Tasson, Haegel, Ault-O'Neal Snowmass 2021 LOI

# Designing accurate GW signals

- **Necessity of a template bank of GW signals**: matched filtering algorithms and modelled search need to compare the data stream to templates
- **GW modelling**: approximate templates of GW signals as numerical relativity simulations are too computationally intensive

**merger, strong field**
requires numerical relativity

**inspiral, weak field**
can be modelled with post-Newtonian formalism or effective one-body approach

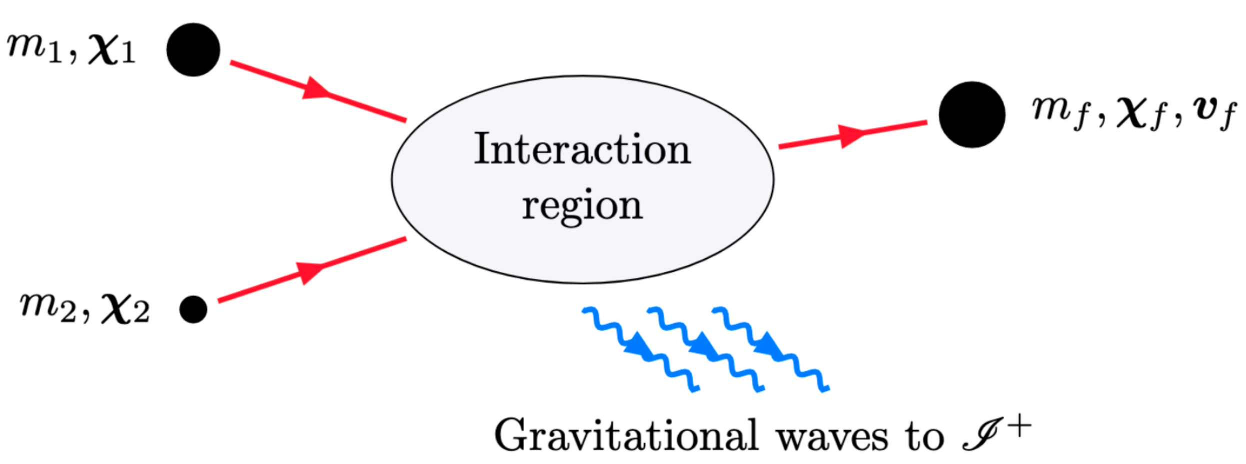



**ringdown, strong to weak field**
can be modelled as a sum of damped sin waves

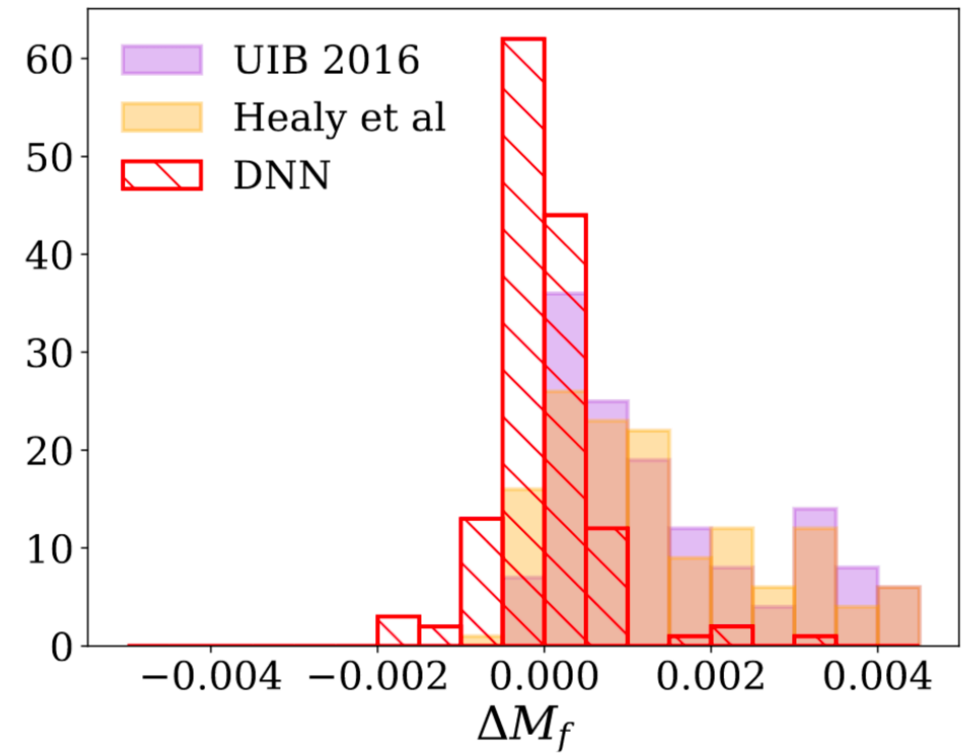
*Source: LVC*

# Predicting the remnant black holes parameters

- **Training a neural network to predict the remnant black holes properties:**
  - Final black holes properties (mass, spin) are important for GW modelling
  - Current predictions approximate the black hole spin effects (precession)
  - Neural networks are powerful to predict the final properties for large-dimension systems



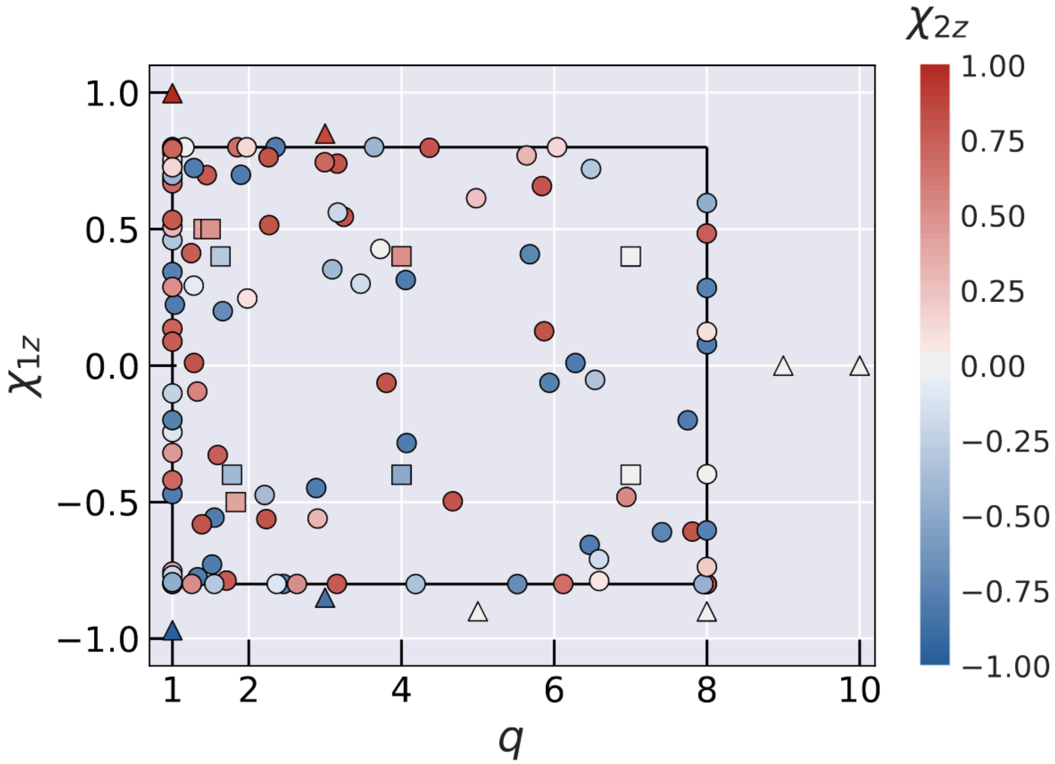

Varma et al arXiv:1809.09125

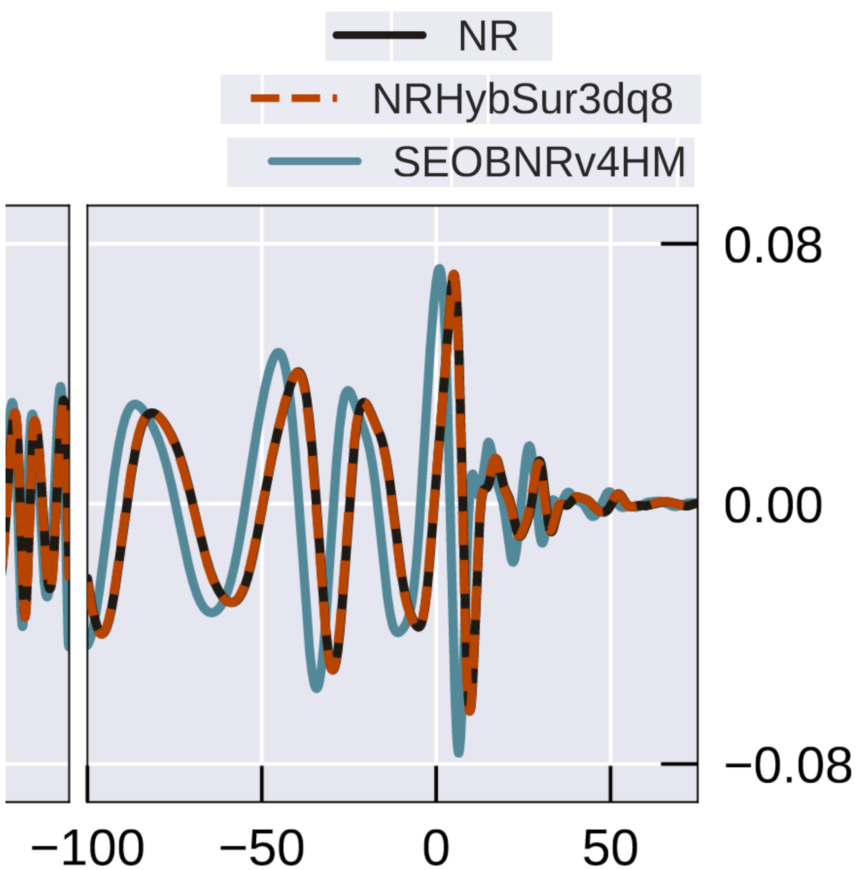



Haegel & Husa arXiv:1911.01496

# Generating GW templates with non-parametric methods

- **Novel methods present accurate generation of GW template signals:**
  - Use non-parametric methods such as Gaussian Processes to interpolate numerical relativity simulations
  - Current applications offer precise templates for precessing binary systems, models to be developed further
  - Important for a large range of GW astrophysics analyses




Varma et al arXiv:1809.09125

# Thank you for your attention