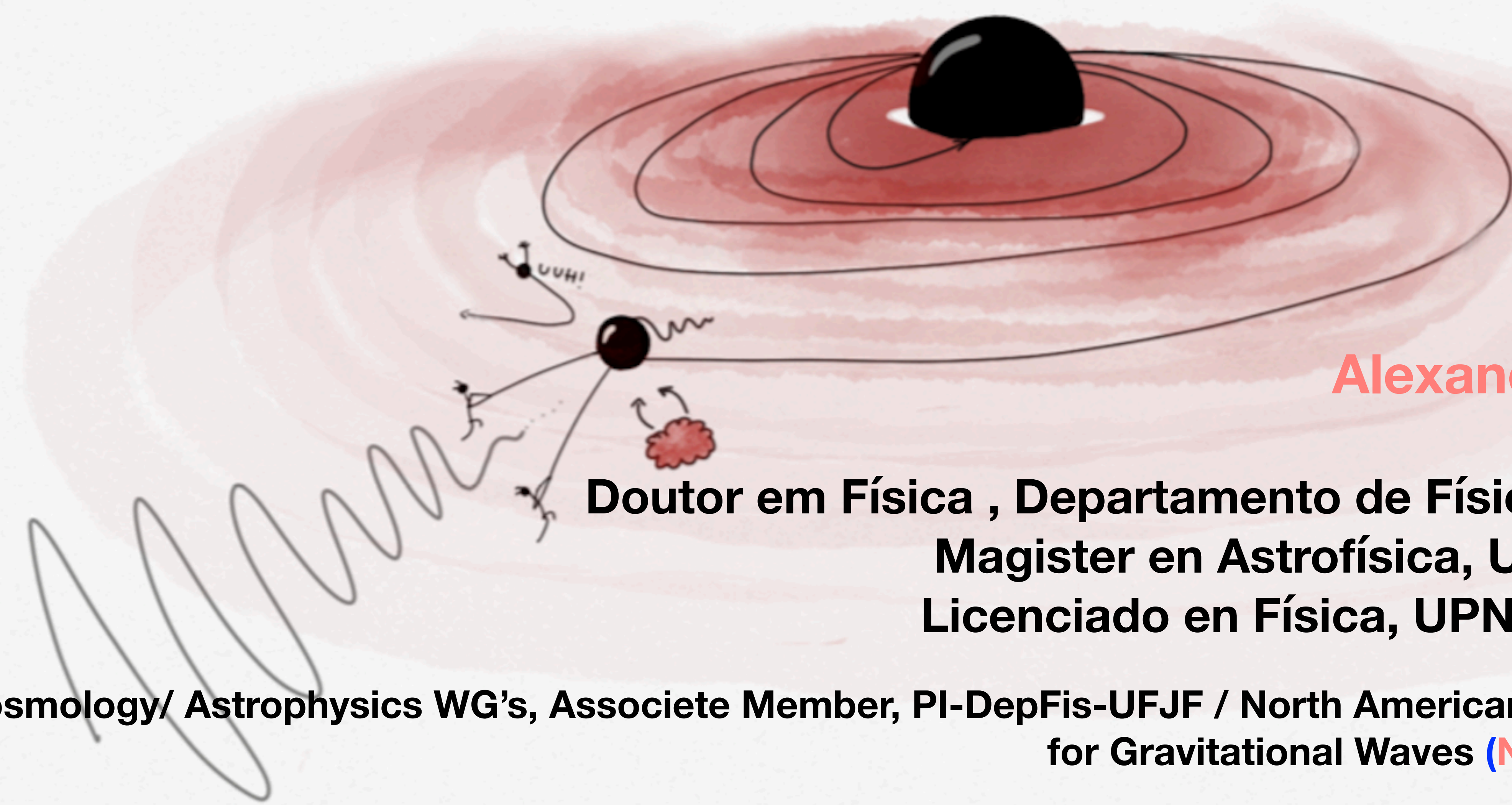
Next Generation Event Horizon Telescope

NANOGrav
NSF-funded Physics Frontiers Center

LISA CONSORTIUM
We will observe gravitational waves in space

Modified Gravity Forecasting with Large Scale Structure in the LISA era, including a Machine Learning analysis



UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

Alexander Bonilla Rivera

Doutor em Física , Departamento de Física, ICE-UFJF, Brasil.
Magister en Astrofísica, UV, Valparaiso, Chile.
Licenciado en Física, UPN, Bogotá, Colombia.

Cosmology/ Astrophysics WG's, Associete Member, PI-DepFis-UFJF / North American Nanohertz Observatory for Gravitational Waves (NANOGrav Collaboration)

Cosmology /Astrophysics & Fundamental Physics, PI-UN-UD/ Laser Interferometer Space Antena (LISA Cosnsortium)

Galaxies /Cosmology & Fundamental Physics SWG's / next generation Event Horizon Telescope (ngEHT)

LISA data analysis: from classical methods to machine learning

21–25 de noviembre de 2022
L2IT Toulouse

Outline

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

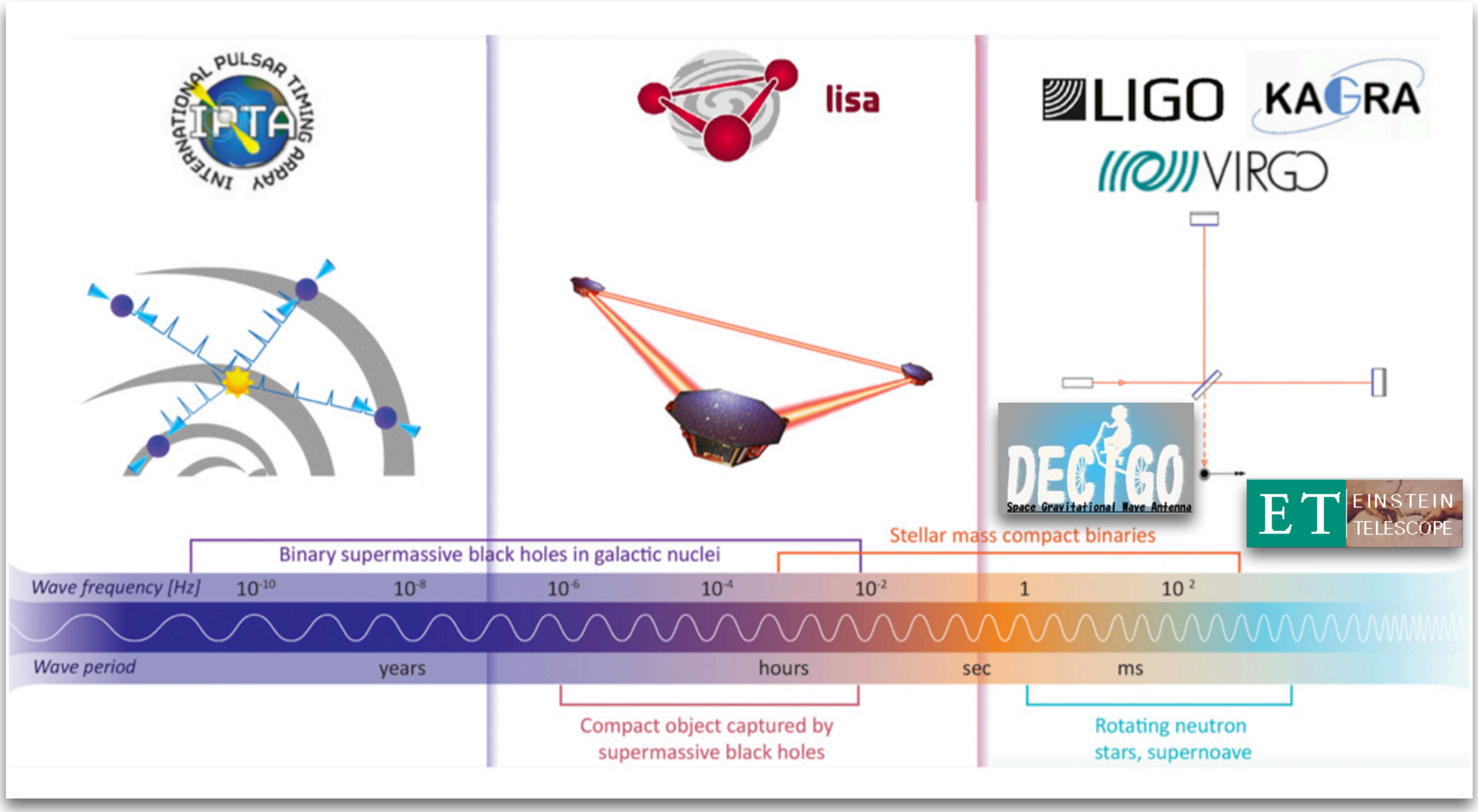
1. Introduction and Motivation
2. Theoretical framework
   2.1. Gravitational waves in modified gravity
   2.2. Methodology and results
3. Summary and conclusions

Outline

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

1. Introduction and Motivation
2. Theoretical framework
    2.1. Gravitational waves in modified gravity
    2.2. Methodology and results
3. Summary and conclusions

Outline



INTERNATIONAL PULSAR TIMING ARRAY
IPTA
lisa
LIGO
KAGRA
VIRGO
DECIGO
Space Gravitational Wave Antenna
ET
EINSTEIN TELESCOPE
Binary supermassive black holes in galactic nuclei
Stellar mass compact binaries
Wave frequency [Hz]
10-10
10-8
10-6
10-4
10-2
1
10 2
Wave period
years
hours
sec
ms
Compact object captured by supermassive black holes
Rotating neutron stars, supernoave

Introduction and Motivation

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

Some theoretical problems with the standard model of cosmology…!

1. COSMIC COINCIDENCE PROBLEM: ¿Why the density of matter and dark energy today are of the same order of magnitude?.

2. Fine-Tuning PROBLEM: ¿Why is the cosmological constant so small?

3. QUANTUM VACUUM ENERGY DENSITY: ¿Why the calculated value of the cosmological constant from quantum field theory is 120 orders of magnitude larger than the observed?

Introduction and Motivation

$$G_{\mu\nu} + g_{\mu\nu}\Lambda = \frac{8\pi G}{c^4} T_{\mu\nu}$$

1. Alternative models of dark Energy: wCDM ($w \neq -1$), Chevalier-Polarski-Linder (CPL), Interacting Dark Energy (IDE), Generalized Chapliygin Gas (GCG)..etc.

2. Modified Gravity: f(R), f(T), Massive Gravity, Tensor, Vector, Scalar (Horndeski).

3. Holographic Dark Energy: Tsallis' entropy, Kaniadakis statistics, Fluid/ Gravity Duality .

Introduction and Motivation

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

Observational Constraints on $f(T)$ gravity from varying fundamental constants

Rafael C. Nunes,[1,*] Alexander Bonilla,[1,†] Supriya Pan,[2,‡] and Emmanuel N. Saridakis[3,4,5,§]

[1] *Departamento de Física, Universidade Federal de Juiz de Fora, 36036-330, Juiz de Fora, MG, Brazil*
[2] *Department of Physical Sciences, Indian Institute of Science Education and Research – Kolkata, Mohanpur – 741246, West Bengal, India*
[3] *Instituto de Física, Pontificia Universidad de Católica de Valparaíso, Casilla 4950, Valparaíso, Chile*
[4] *Physics Division, National Technical University of Athens, 15780 Zografou Campus, Athens, Greece*
[5] *CASPER, Physics Department, Baylor University, Waco, TX 76798-7310, USA*

$$\frac{\Delta\alpha}{\alpha}(z) \approx \frac{\left[1-b\left(\frac{1-\Omega_{m0}}{2b-1}\right)\right]}{\left\{1-b\left(\frac{1-\Omega_{m0}}{2b-1}\right)\left[\frac{H^2(z)}{H_0^2}\right]^{(b-1)}\right\}} - 1,$$

$$G_{eff}(z) = \frac{G_N}{1-b\left(\frac{1-\Omega_{m0}}{2b-1}\right)\left[\frac{H^2(z)}{H_0^2}\right]^{(b-1)}},$$

Cosmological variation of the fine structure constant and the universal constant of gravitation

Introduction and Motivation

Important equations of Universe evolution

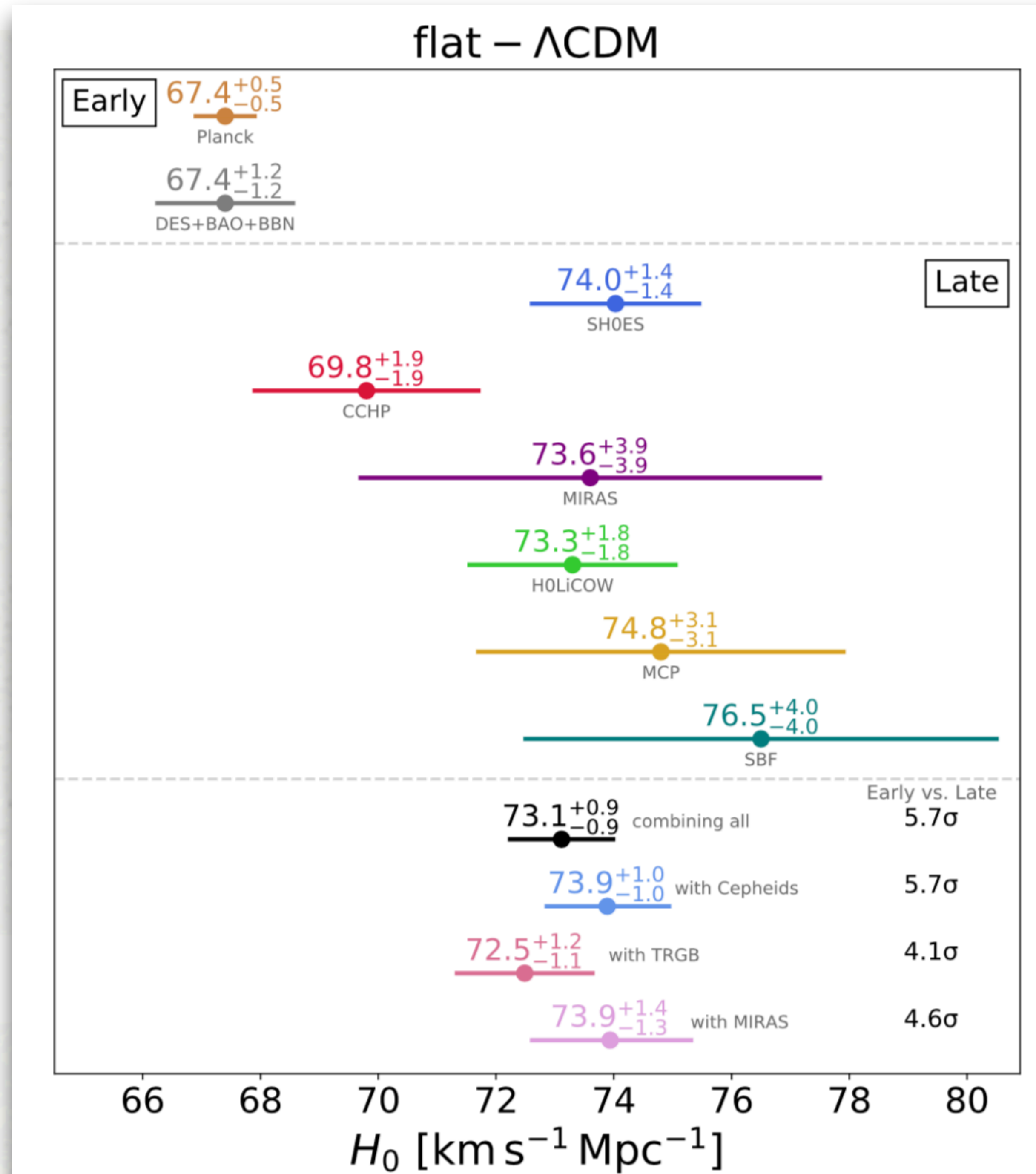
Same equation, new nomenclature:

$$
\begin{aligned}
H &= \dot{a}/a \\
H_0 &= \dot{a}/a)_{\text{today}} \\
\rho_{cr} &= 3H_0^2/8\pi G \\
\Omega_i &= \rho_i/\rho_{cr}
\end{aligned}
$$

and some numbers:

$$H_0 = 67.3 \pm 1.2\,\mathrm{km/s/Mpc}$$

Hubble tensión



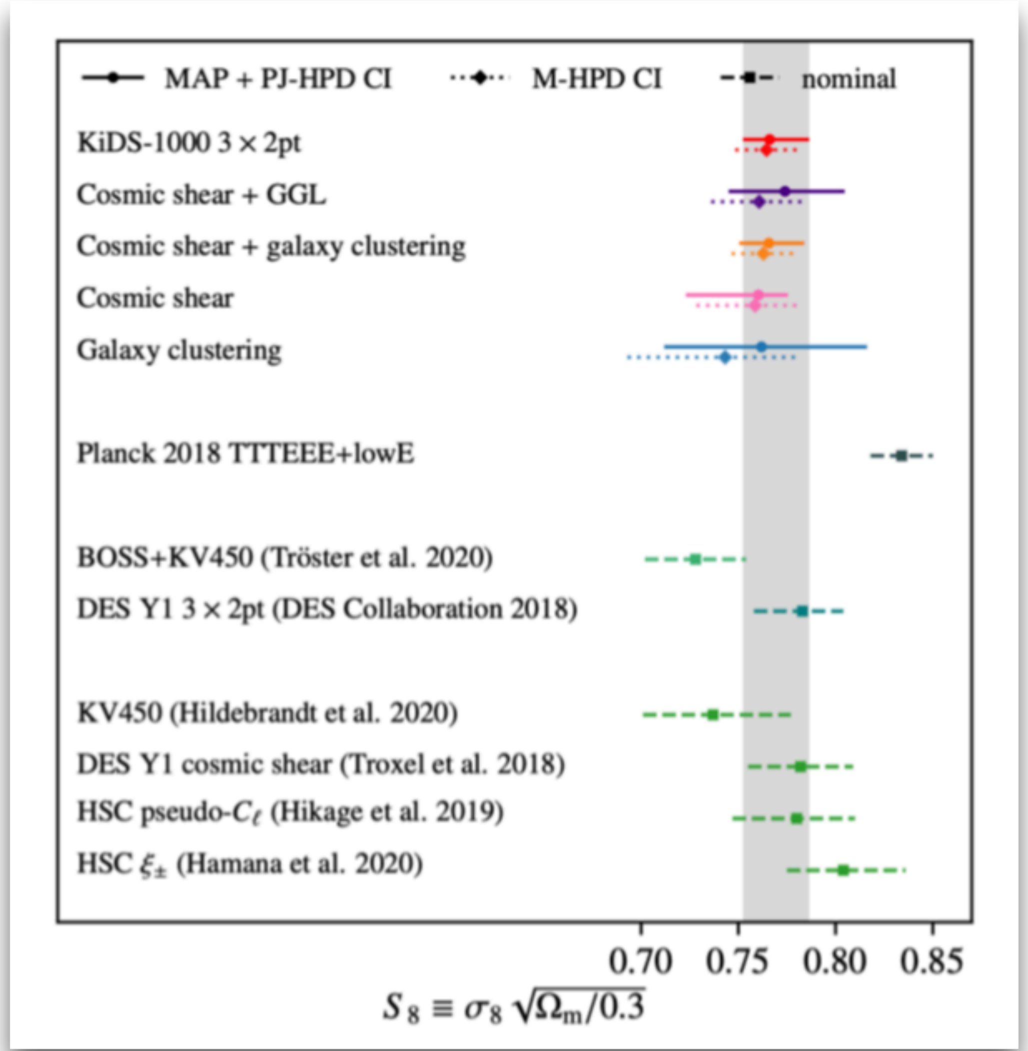
Introduction and Motivation

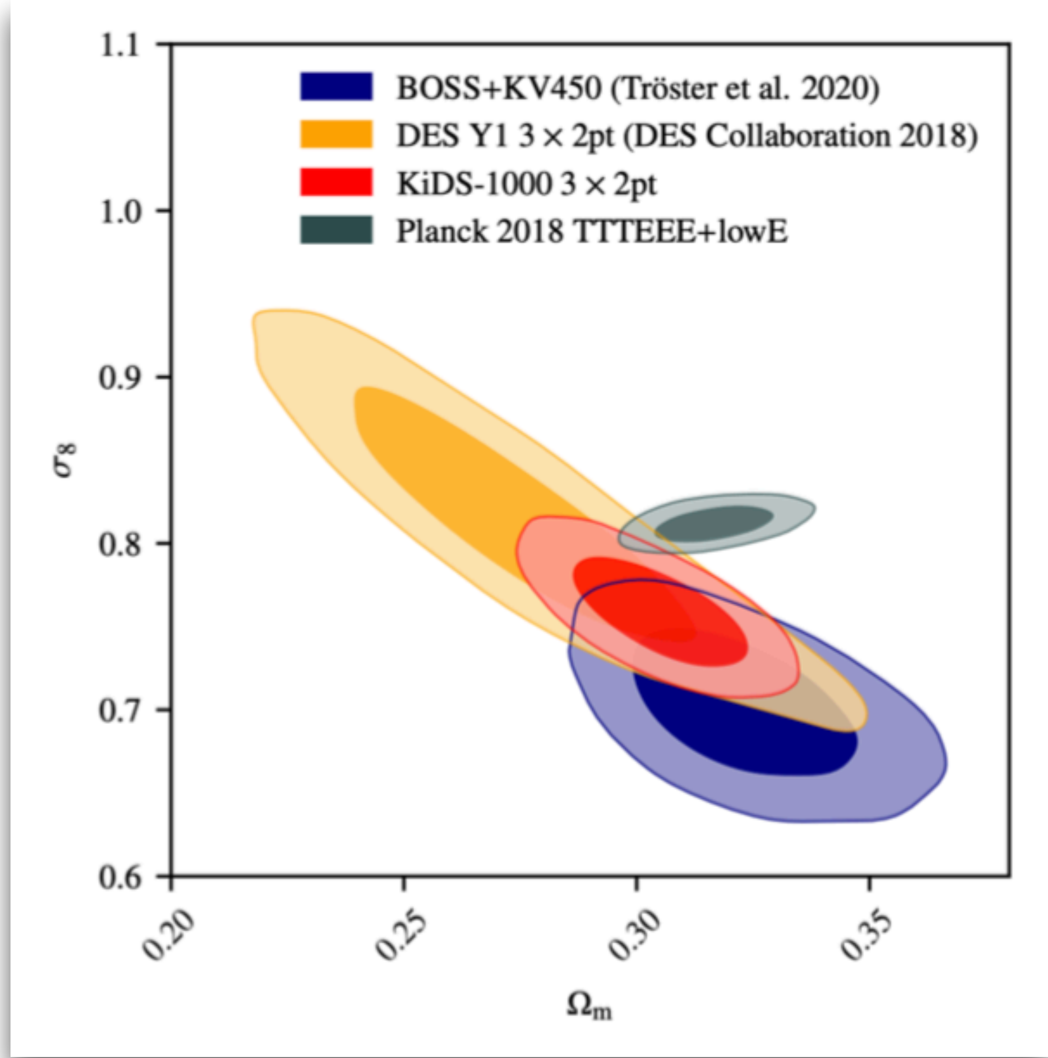
$$\frac{k^3}{2\pi^2}P(k,z) = \delta_H^2 \left(\frac{ck}{H_0}\right)^{3+n} T^2(k,z) D_1^2(z)/D_1^2(0).$$

Power spectrum of matter

$$\sigma_R = \left[\int_0^\infty \frac{dk}{k}\frac{k^3}{2\pi^2}P(k)\left|\tilde{W}_R(k)\right|^2\right]^{1/2},$$

Mass fluctuación R= 8 Mpc





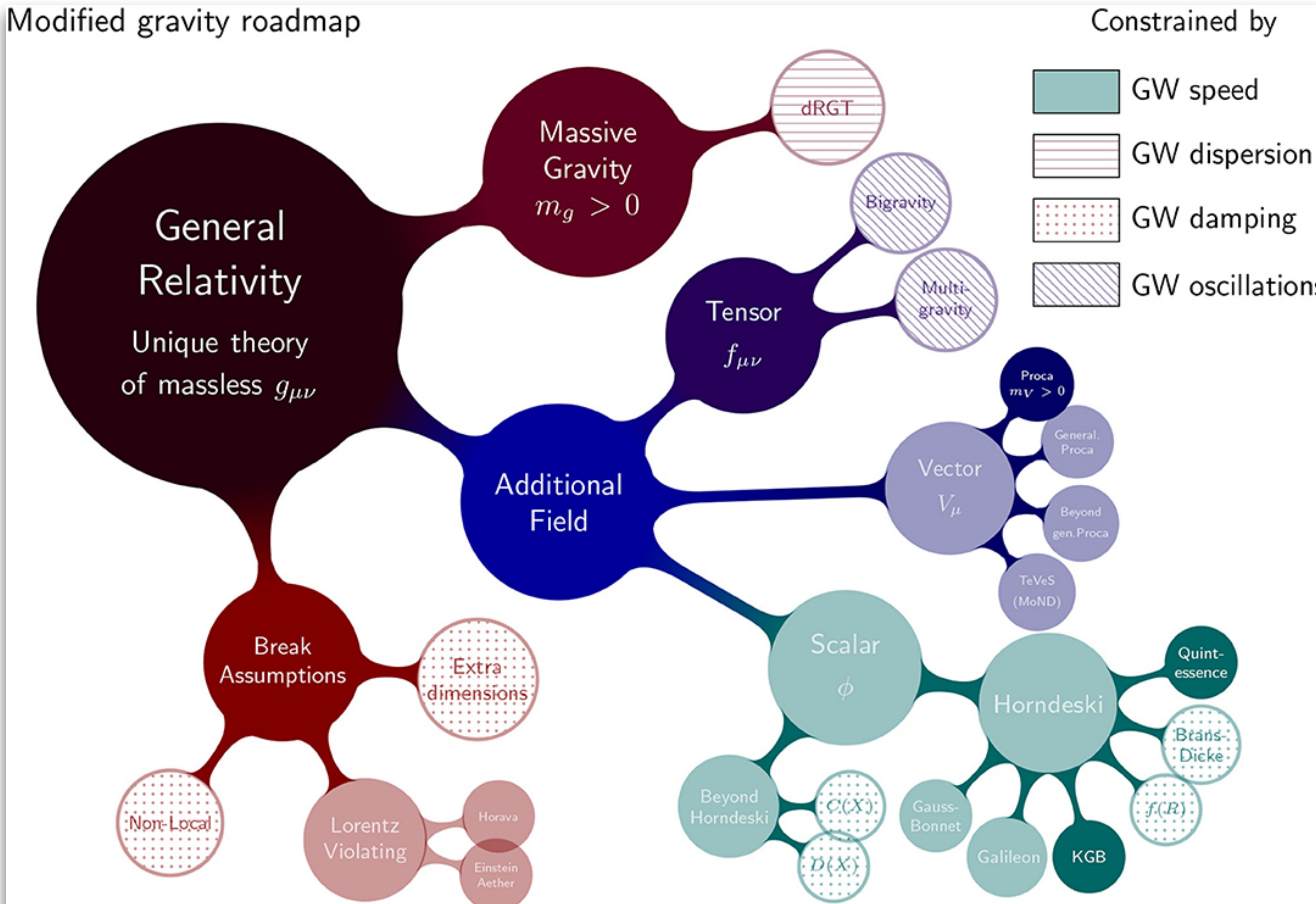
Outline

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

1. Introduction and Motivation
2. Theoretical framework
    2.1. Gravitational waves in modified gravity
    2.2. Methodology and results
3. Summary and conclusions

GravWaves in modified gravity

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad



GravWaves in modified gravity

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

Propagation Equation of GW's in FLRW background

$$\tilde{h}''_A + 2\mathcal{H}[1 - \delta(\eta)]\tilde{h}'_A + k^2\tilde{h}_A = 0$$

k^2 term as they change the speed of GWs

$\mathscr{H}$ Hubble parapetar in conformal time

$\delta(z)$ enter as a fricción term

luminosity distance for the GWs

$$d_L^{\rm gw}(z) = d_L^{\rm em}(z) \exp\left\{-\int_0^z \frac{dz'}{1+z'}\,\delta(z')\right\}$$

Outline

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

1. Introduction and Motivation
2. Theoretical framework
    2.1. Gravitational waves in modified gravity
    2.2. Methodology and results
3. Summary and conclusions

Methodology and results

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

GW strain signal

Simulation: 1000 data points

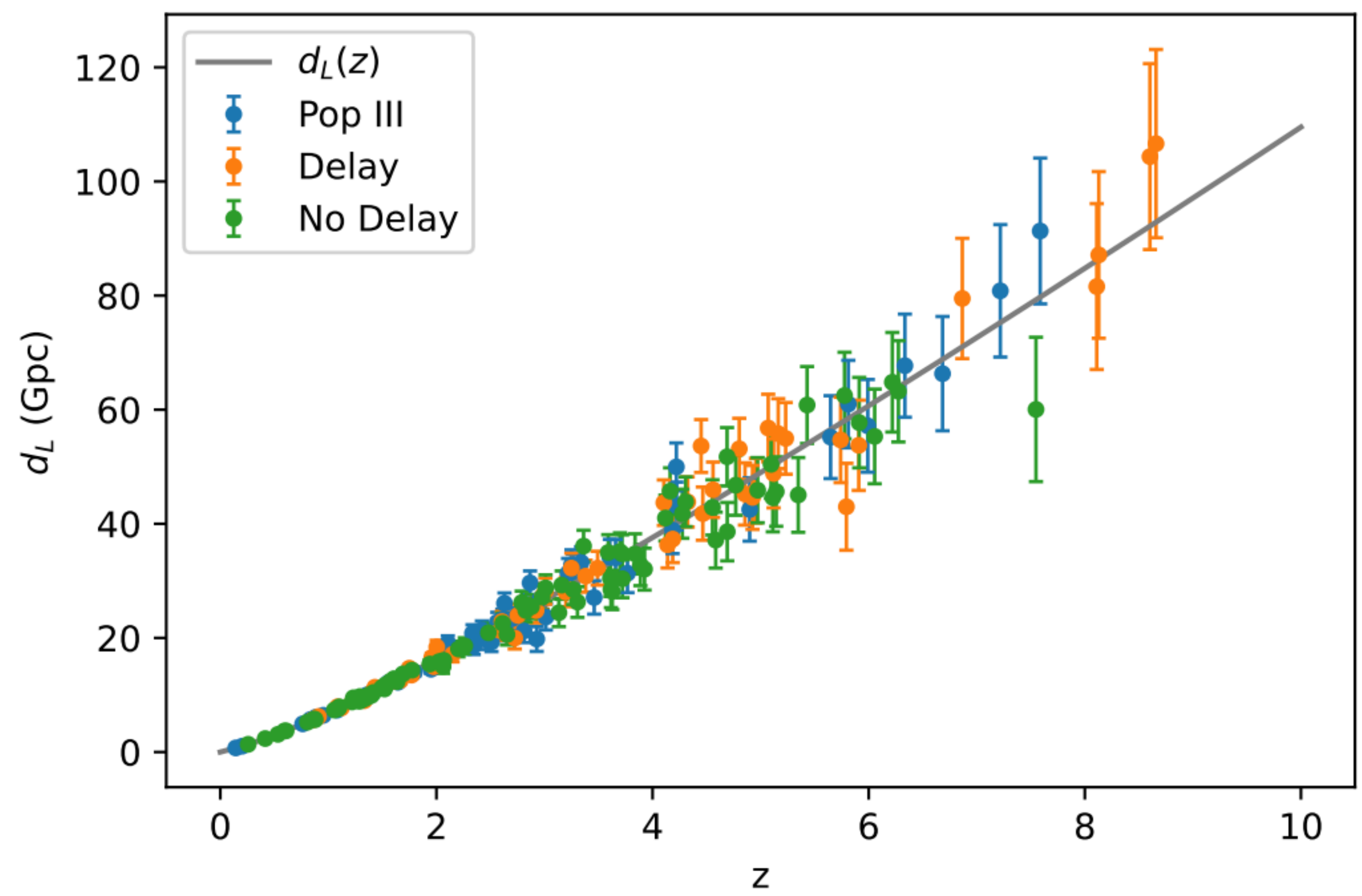


Figure 2. LISA standard sirens at all redshifts from the three population models we consider in this work.

Methodology and results

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

GW strain signal

Simulation: 1000 data points

Parameter	Pop III	Pop III + CMB
H_0 [km s^{-1} Mpc^{-1}]	66.71 ± 0.95	66.92 ± 0.56
Ω_m	0.31 ± 0.11	0.3160 ± 0.0070

Parameter	No Delay	No Delay + CMB
H_0 [km s^{-1} Mpc^{-1}]	$66.87^{+0.92}_{-0.63}$	67.21 ± 0.47
Ω_m	0.238 ± 0.078	0.3133 ± 0.0062

Parameter	Delay	Delay + CMB
H_0 [km s^{-1} Mpc^{-1}]	70.8 ± 4.5	67.78 ± 0.91
Ω_m	$0.456^{+0.049}_{-0.13}$	0.3098 ± 0.0092

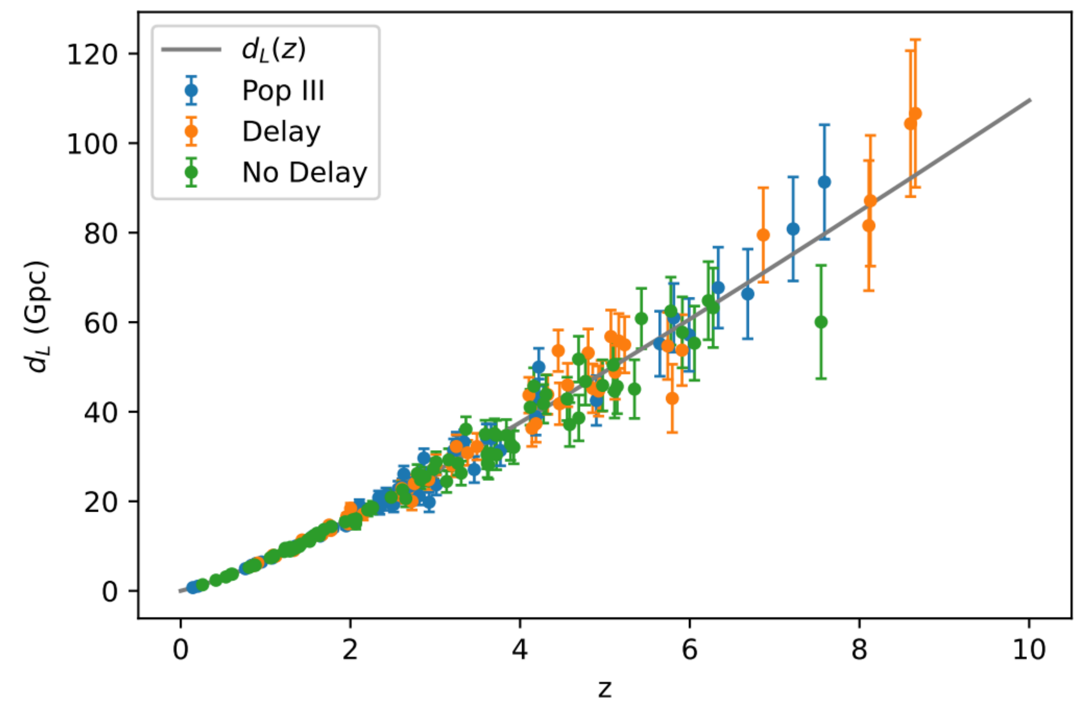
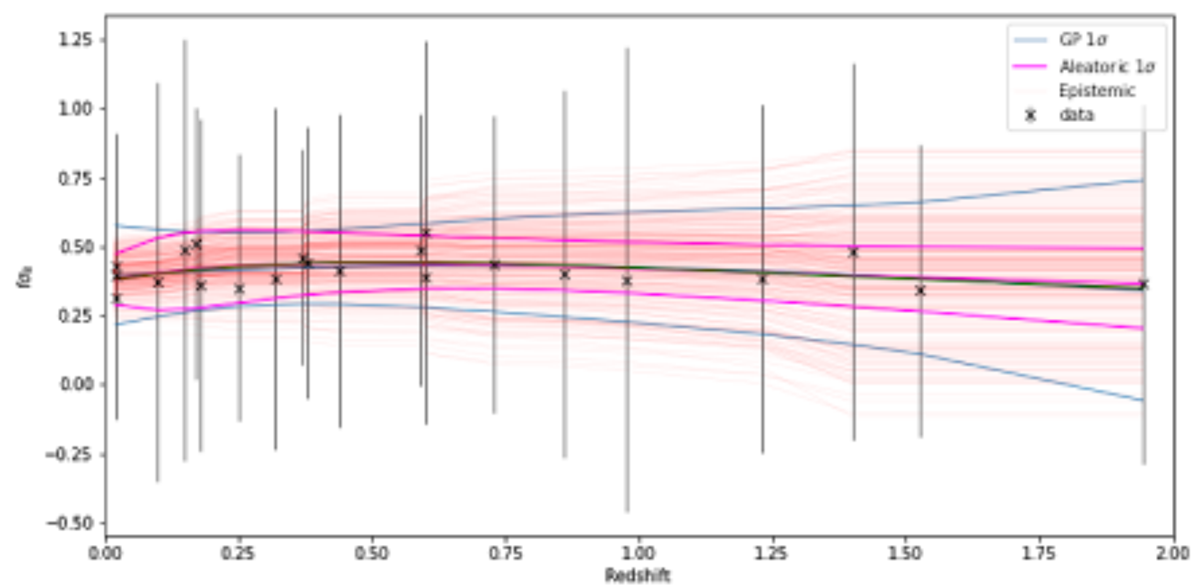


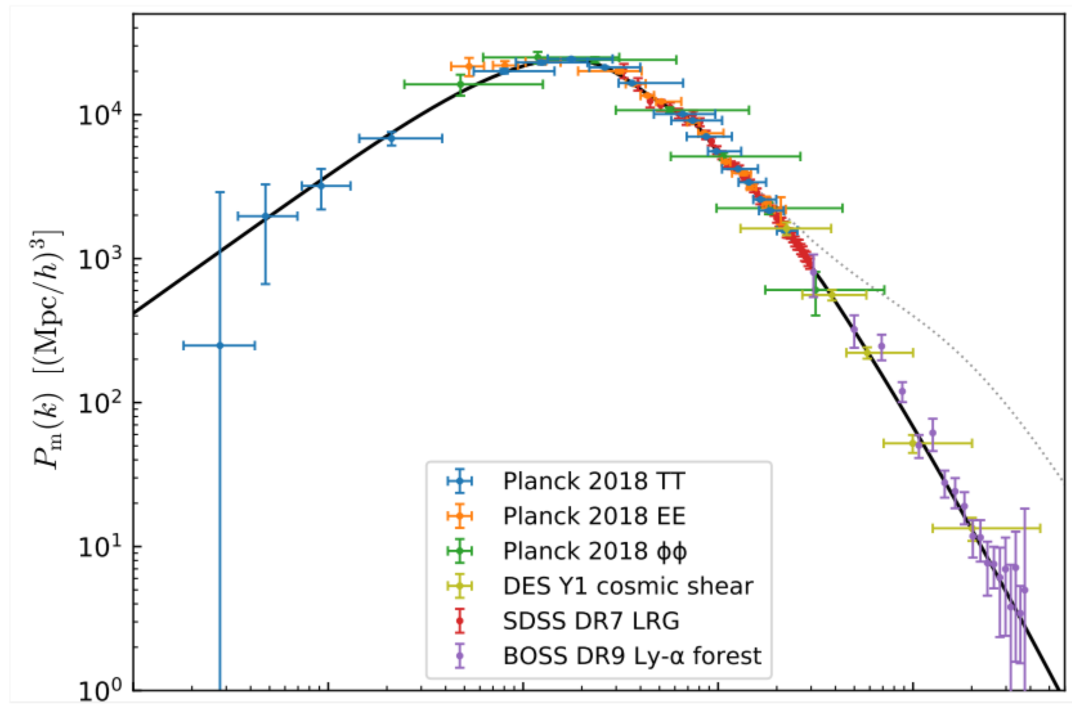
Figure 2. LISA standard sirens at all redshifts from the three population models we consider in this work.

ArXv: 2110.07634

Methodology and results

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad





$$\sigma_8(0) = 0.8153 \pm 0.0854\,(1\sigma) \pm 0.1675\,(2\sigma)$$

$$P(k,z) = \left[\frac{D(z)}{D(z=0)}\right]^2 T^2(k)P(k,z=0),$$

$$\sigma_8(z) \equiv \frac{[f\sigma_8](z)}{f(z)},$$

Work in progress….!

$$\sigma_R^2(z) = \frac{1}{2\pi^2}\int_0^\infty P(k,z)W_R^2(k)dk,$$

We are applying the machine learning technique..!

Outline

1. Introduction and Motivation
2. Theoretical framework
    2.1. Gravitational waves in modified gravity
    2.2. Methodology and results
3. Summary and conclusions

End

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS
Acreditación Institucional de Alta Calidad

CAPES

CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

FAPESP
FUNDAÇÃO DE AMPARO À PESQUISA DO ESTADO DE SÃO PAULO