Precision Cosmology for modified gravity

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Cosmology from Home 2020
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- Cosmology and Modified Gravity state-of-art
- Precision Cosmostatistics for Modified Gravity (MG)
- Frontiers in MG using Precision Cosmology

LCDM gravity model

+

Data
(CMB, SN, BAO, GW, RSD…)

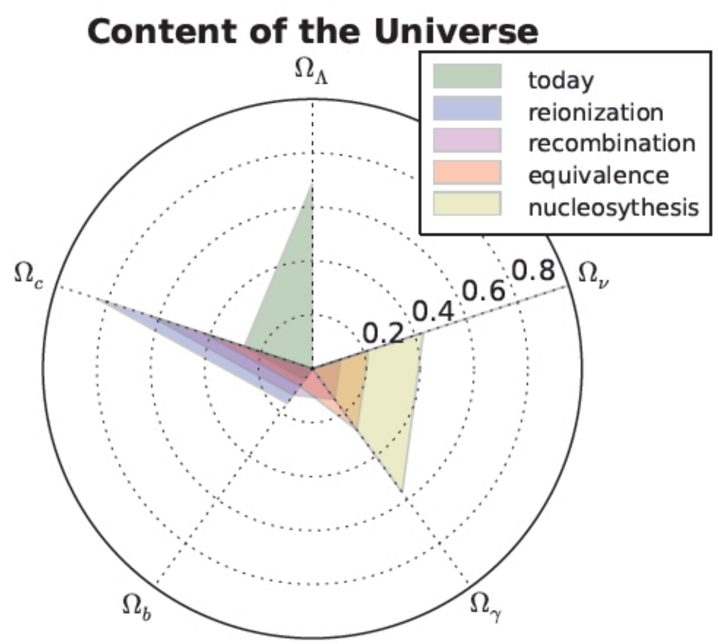
=

Inconsistency : Dark matter + Dark energy

Problems: H_0, and σ_8 tensions

New Physics?

Initial Conditions	Cosmic Structure	Late acceleration
Inflation	Dark Matter	Λ
Primordial GWs?	Ultra-light/Axion? Primordial BHs?	Modified Gravity?



Two main roots to determining H_0

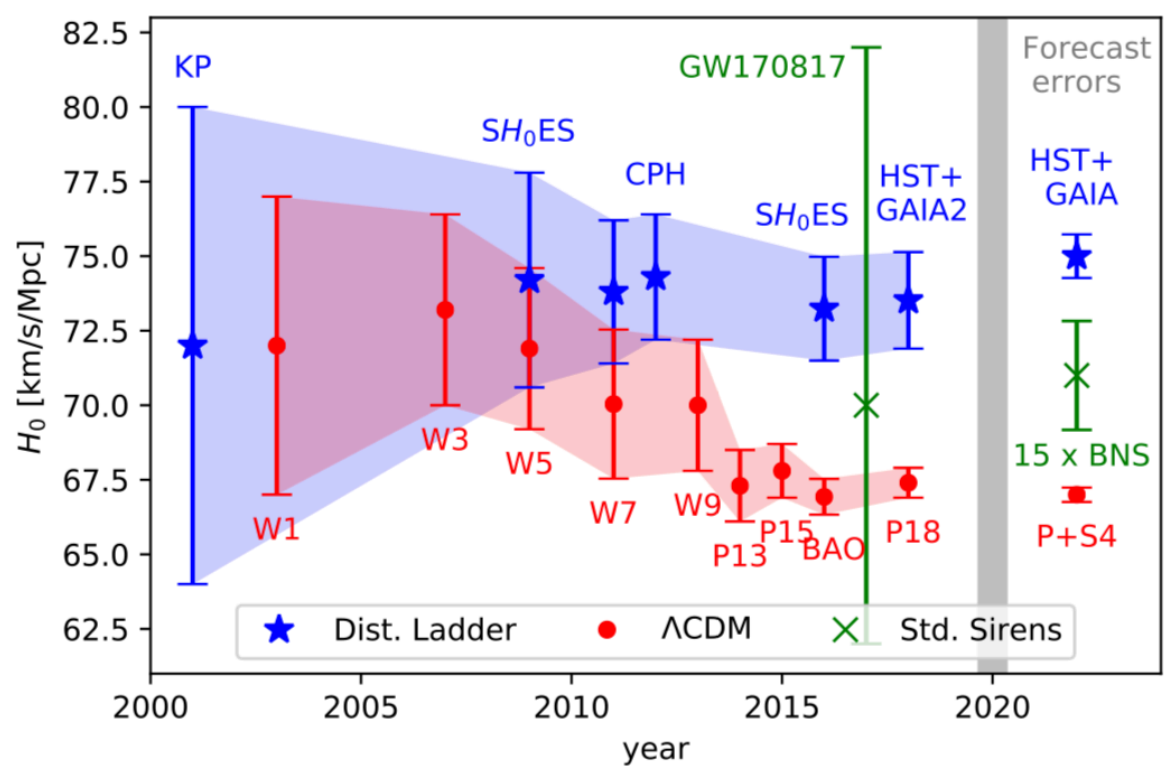
(1) **Distance ladder method**: Cepheids and TRGBs (calibrated to geometric anchor distances)

Improved: from 10% (2001) to < 2% (2019)

Value: $H_0 = 74.03 \pm 1.42$ km/s/Mpc

(2) **Via sound horizon observed from CMB**: not constrained directly. Using data at z ~ 1100 and extrapolated to z ~ 0, based on the physics of the early universe.

Value: $H_0 = 67.4 \pm 0.5$ km/s/Mpc



Novel measurements of H_0

- Quasars strongly gravitationally lensed: H0LiCOW collaboration [Bonvin et al 2017]

Value: $H_0 = 73.3^{+1.7}_{-1.8}$ km/s/Mpc

- Geometric distantes measurements to megamaster-hosting galaxies:

  Megamaster Cosmology Project [Pesce et al 2020]

Value: $H_0 = 73.9 \pm 3.0$ km/s/Mpc

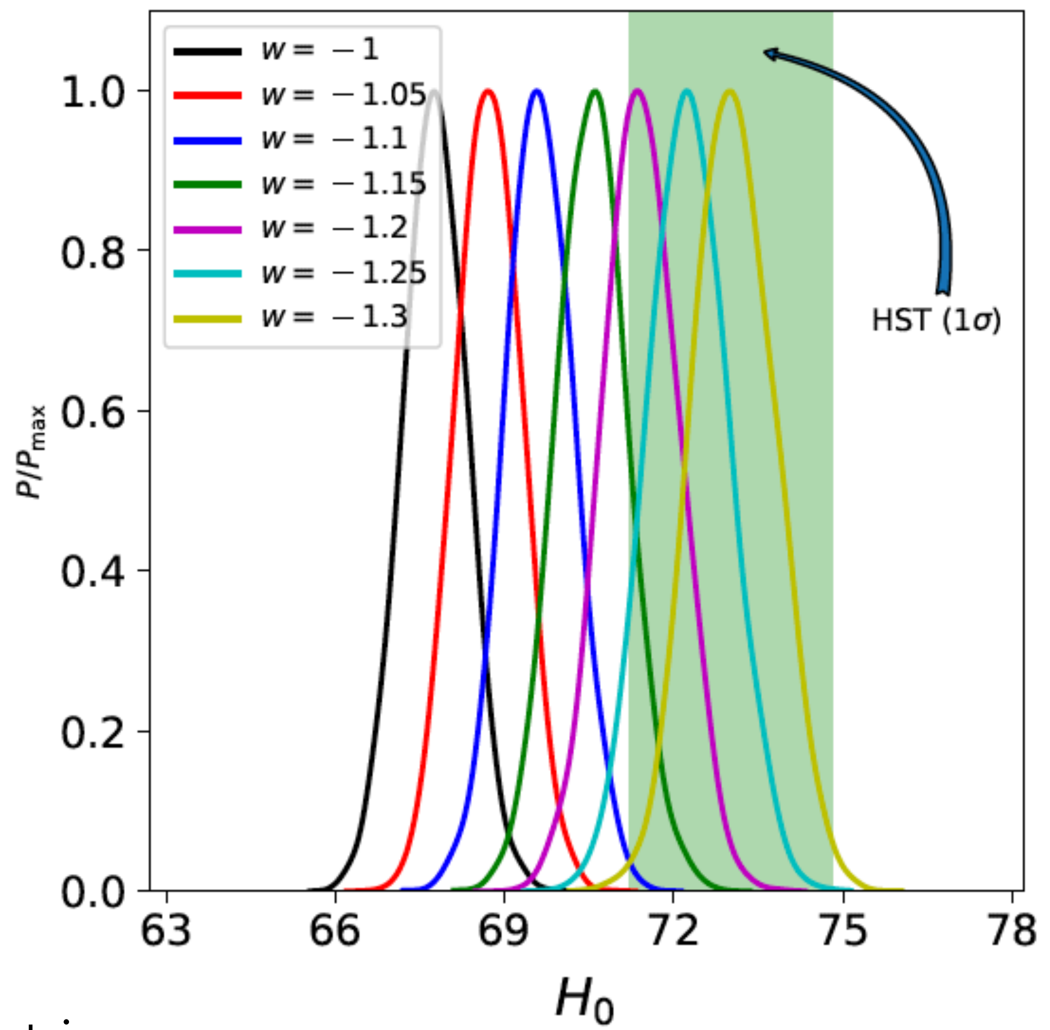
- Standard sirens from merger events detected through GW [Abbott et al 2017]

Value: $H_0 = 70^{+12}_{-8}$ km/s/Mpc

Novel measurements of H_0 : Possible solutions

Physics beyond the canonical LCDM:

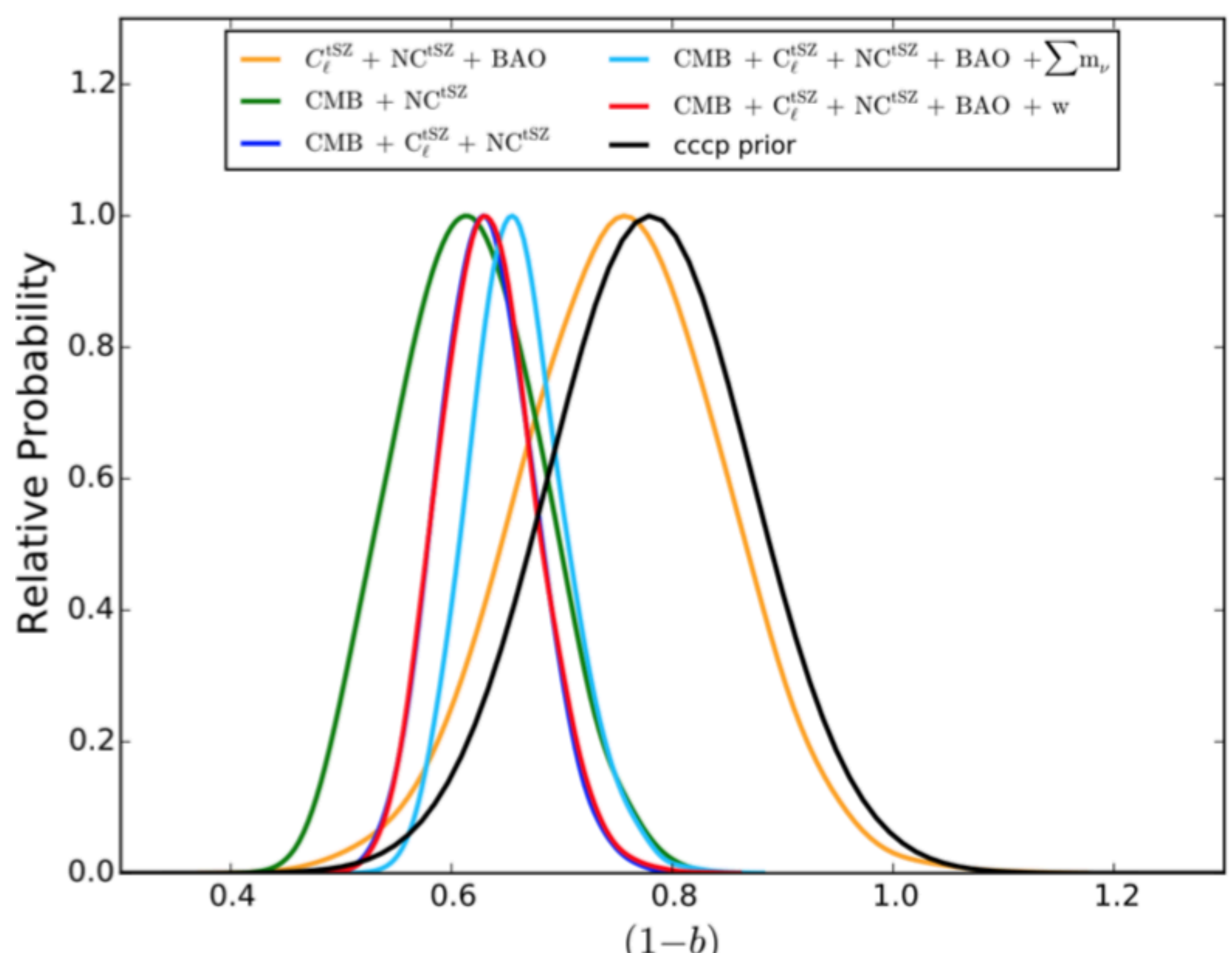
- phantom dark energy,
- dark radiation,
- dynamical dark energy,
- holographic dark energy,
- non-linear parametric dark energy,
- f(T) gravity,
- f(T,B) gravity,
- extended dark energy components with massive neutrinos, …



Tension in the matter fluctuation amplitud σ_8

Interesting since galaxy clusters and weak lensing observations are sensitive to the cosmic matter density.

Powerful complementary probe to CMB data and geometric observables.



[Salvati, L et al (2018) A&A 614, A13]

Lovelock's theorem (1971) [version from T. Clifton, et al Phys.Rept. 513 (2012)]

"The only second-order, local gravitational field equations derivable from an action containing solely the 4D metric tensor (plus related tensors) are the Einstein field equations with a cosmological constant"

$$S_{grav} = \frac{M_{\mathrm{Pl}}^2}{2} \int \sqrt{-g}\, d^4x [R]$$

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$$S_{grav} = \frac{M_{\rm Pl}^2}{2}\int\sqrt{-g}\,d^4x\,\left[\phi R - \frac{\omega(\phi)}{\phi}(\nabla\phi^2) - 2V(\phi)\right]$$

Lovelock's theorem (1971) [version from T. Clifton, et al Phys.Rept. 513 (2012)]

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$$S_{grav} = \frac{M_{\mathrm{D}}^2}{2}\int \sqrt{-\gamma}\, d^D x [\mathscr{R} + \alpha \mathscr{G}]$$

Lovelock's theorem (1971) [version from T. Clifton, et al Phys.Rept. 513 (2012)]

"The only second-order, local gravitational field equations derivable from an action containing solely the 4D metric tensor (plus related tensors) are the Einstein field equations with a cosmological constant"

$$S_{grav} = \frac{M_{\mathrm{Pl}}^2}{2}\int \sqrt{-g}\, d^4x [R + \beta_1 R \nabla_\mu \nabla^\mu R + \beta_2 \nabla_\mu R_{\beta\gamma} \nabla^\mu R^{\beta\gamma}]$$

Lovelock's theorem (1971) [version from T. Clifton, et al Phys.Rept. 513 (2012)]

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$$S_{grav} = \frac{M_{\mathrm{Pl}}^2}{2}\int\sqrt{-g}\,d^4x\left[R + f\left(\frac{1}{\Box}R\right)\right]$$

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"The only second-order, local gravitational field equations derivable from an action containing solely the 4D metric tensor (plus related tensors) are the Einstein field equations with a cosmological constant"

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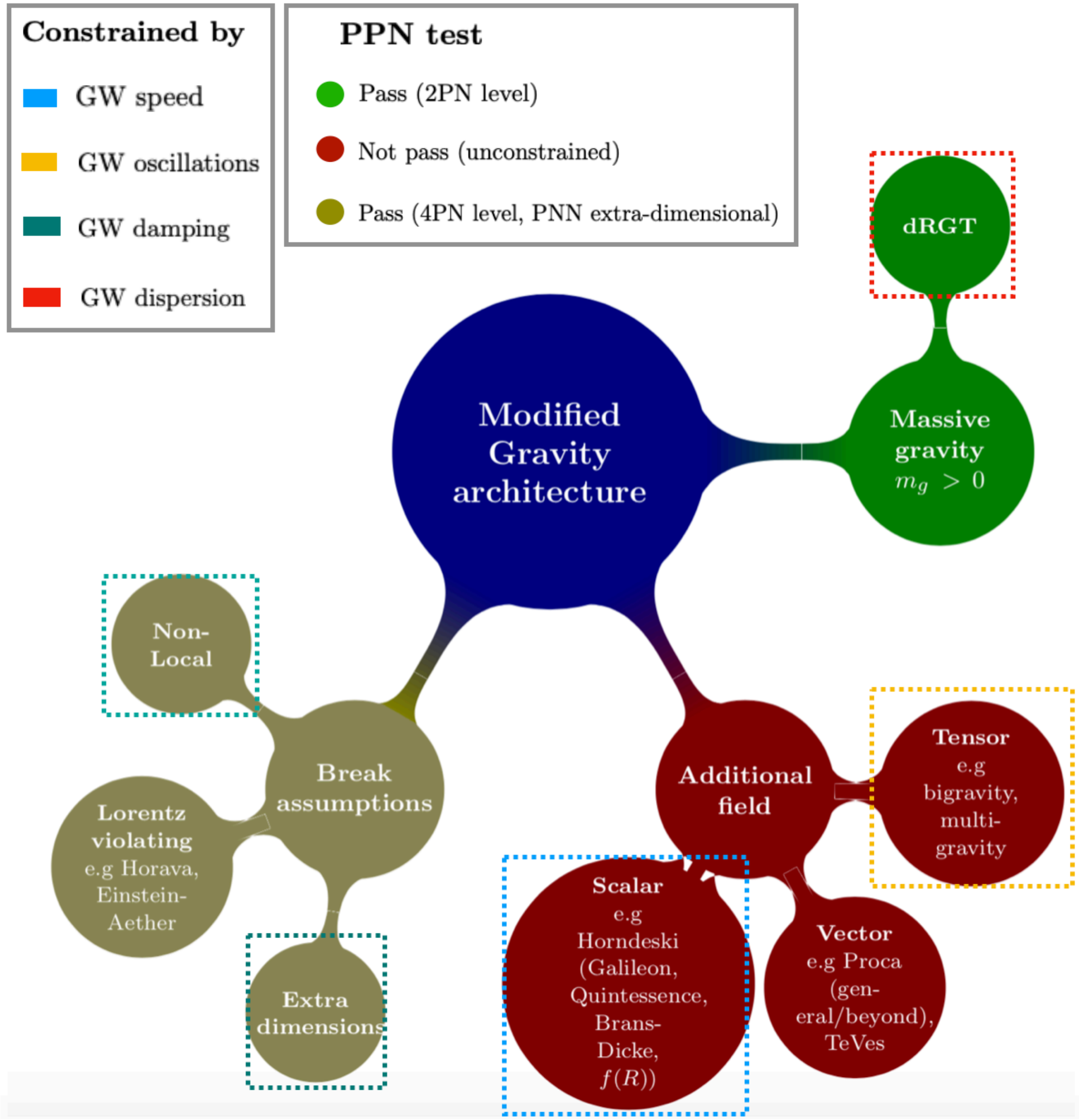
[**C. Escamilla-Rivera**, Júlio Fabris. A non-lagragian theory of gravity. Foundations on Physics (2020)]



[**C. Escamilla-Rivera**, Júlio Fabris. Foundations on Physics (2020)]

	$c_g = c$ (Viable after GW170817)	$c_g \neq c$ (Non-viable after GW170817)
	General Relativity Quintessence/k-essence Brans-Dicke/$f(R)$ Kinetic Gravity Braiding	Quartic/quintic Galileons Fab Four de Sitter Horndeski $G_{\mu\nu}\phi^{\mu}\phi^{\nu}$, $f(\phi)$.Gauss-Bonnet
	Derivative Conformal Disformal Tunning Quadratic DHOST with $A_1 = 0$	Quartic/quintic GLPV Quadratic DHOST with $A_1 \neq 0$ Cubic DHOST

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f(R)-like cosmology parameterisation

[Jaime L., Jaber, M., **Escamilla-R, C**. Phys.Rev D98 (2019)]
[**Escamilla-R, C**. V. Motta, M. Aspeitia and A. Almada. arXiv:2005.13957 (2020)]

$$S[g_{ab},\psi] = \int \frac{f(R)}{2\kappa}\sqrt{-g}\, d^4x + S_{\rm matt}[g_{ab},\psi] \, ,$$

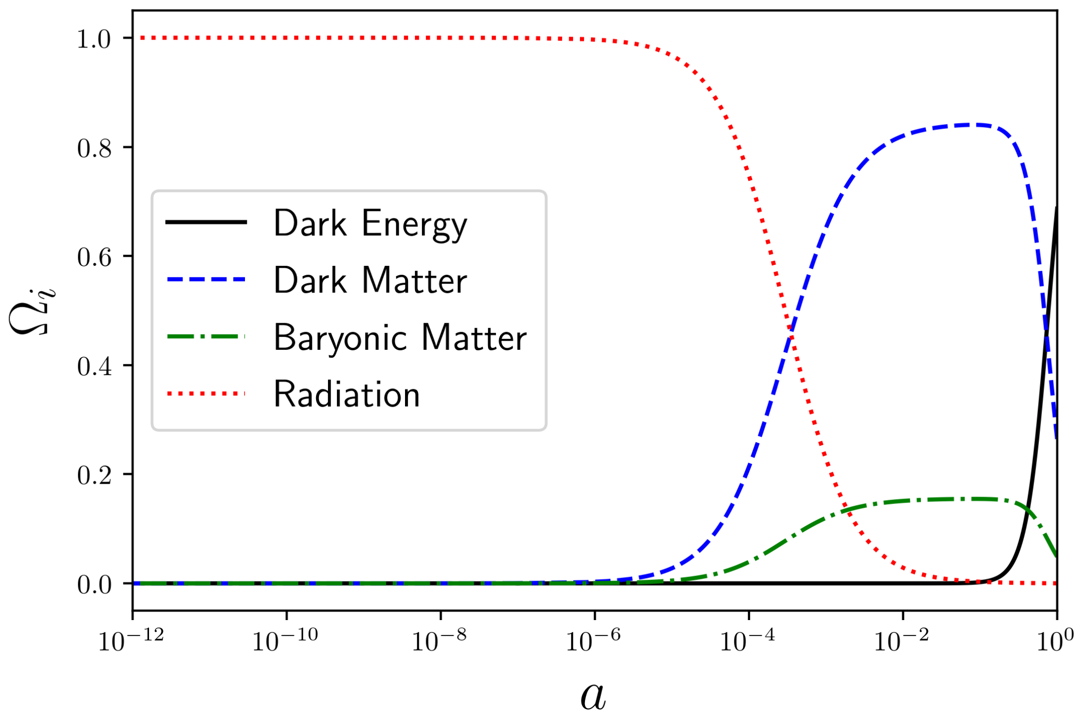
$$\ddot{R} = -3H\dot{R} - \frac{1}{3f_{RR}}\left[3f_{RRR}\dot{R}^2 + 2f - f_R R + \kappa T\right],$$

$$H^2 = -\frac{1}{f_{RR}}\left[f_{RR}H\dot{R} - \frac{1}{6}(Rf_R - f)\right] - \frac{\kappa T_t^t}{3f_R},$$

$$\dot{H} = -H^2 - \frac{1}{f_R}\left[f_{RR}H\dot{R} + \frac{f}{6} + \frac{\kappa T_t^t}{3}\right] \, ,$$

$$\omega_X = \frac{3H^2 - 3\kappa P - R}{3(3H^2 - \kappa\rho)},$$

$$R = 6(\dot{H} + 2H),$$



Hu & Sawicki model $\quad f(R) = R - R_{\rm HS}\dfrac{c_1\left(\frac{R}{R_{\rm HS}}\right)^n}{c_2\left(\frac{R}{R_{\rm HS}}\right)^n + 1} \, ,$

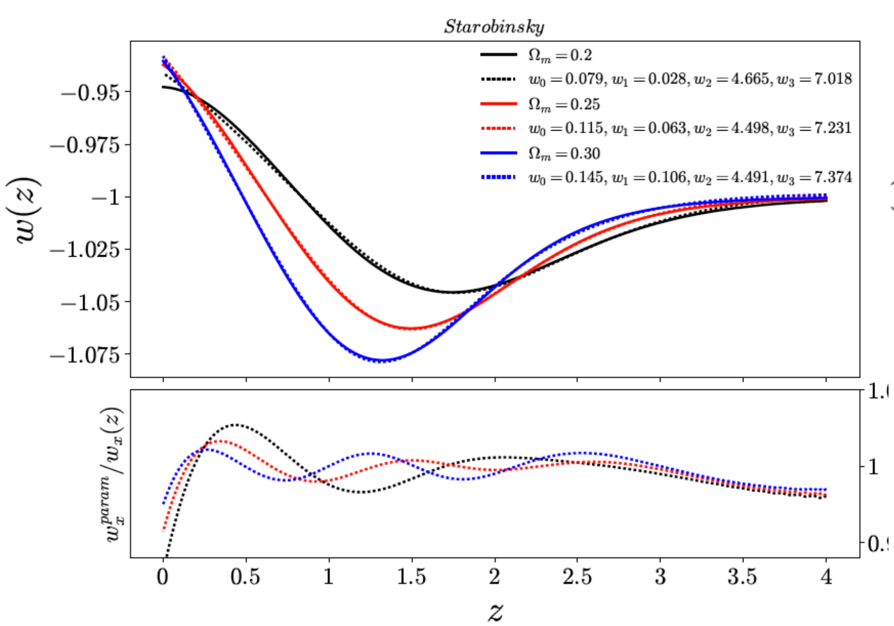
Starobinsky model $\quad f(R) = R + \lambda R_S\left[\left(1 + \frac{R^2}{R_S^2}\right)^{-q} - 1\right],$

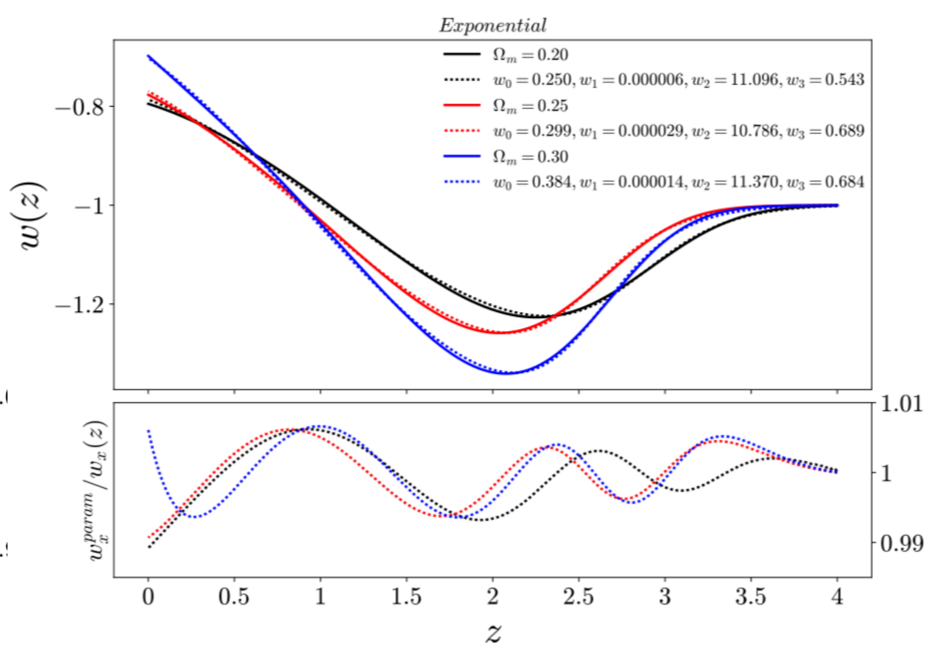
The exponential model $\quad f(R) = R + \beta R_*(1 - e^{-R/R_*}).$

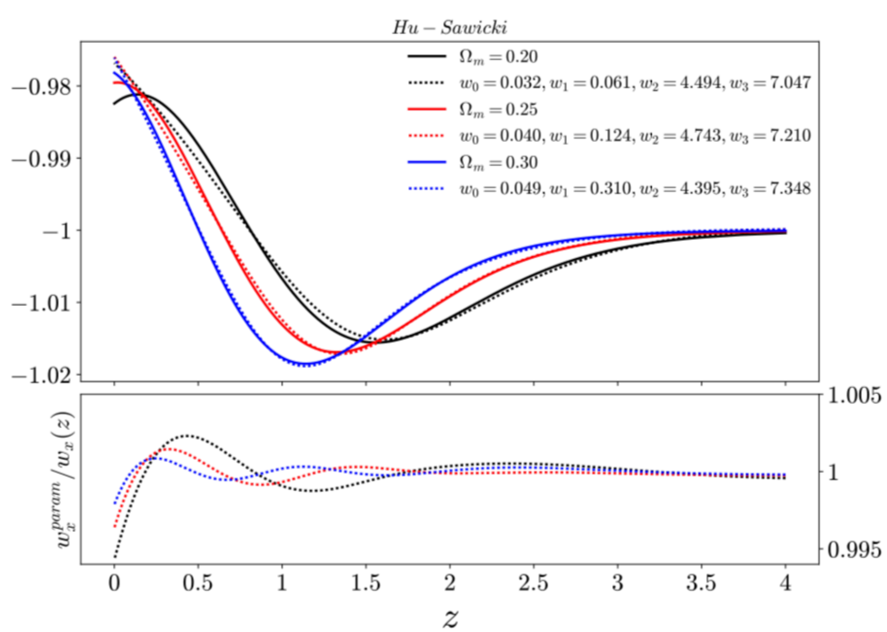
f(R)-like cosmology parameterisation

$$w(z) = -1 + \frac{w_0}{1 + w_1 z^{w_2}} \cos(w_3 + z)$$

[Jaime L., Jaber, M., **Escamilla-R, C**. Phys.Rev D98 (2019)]







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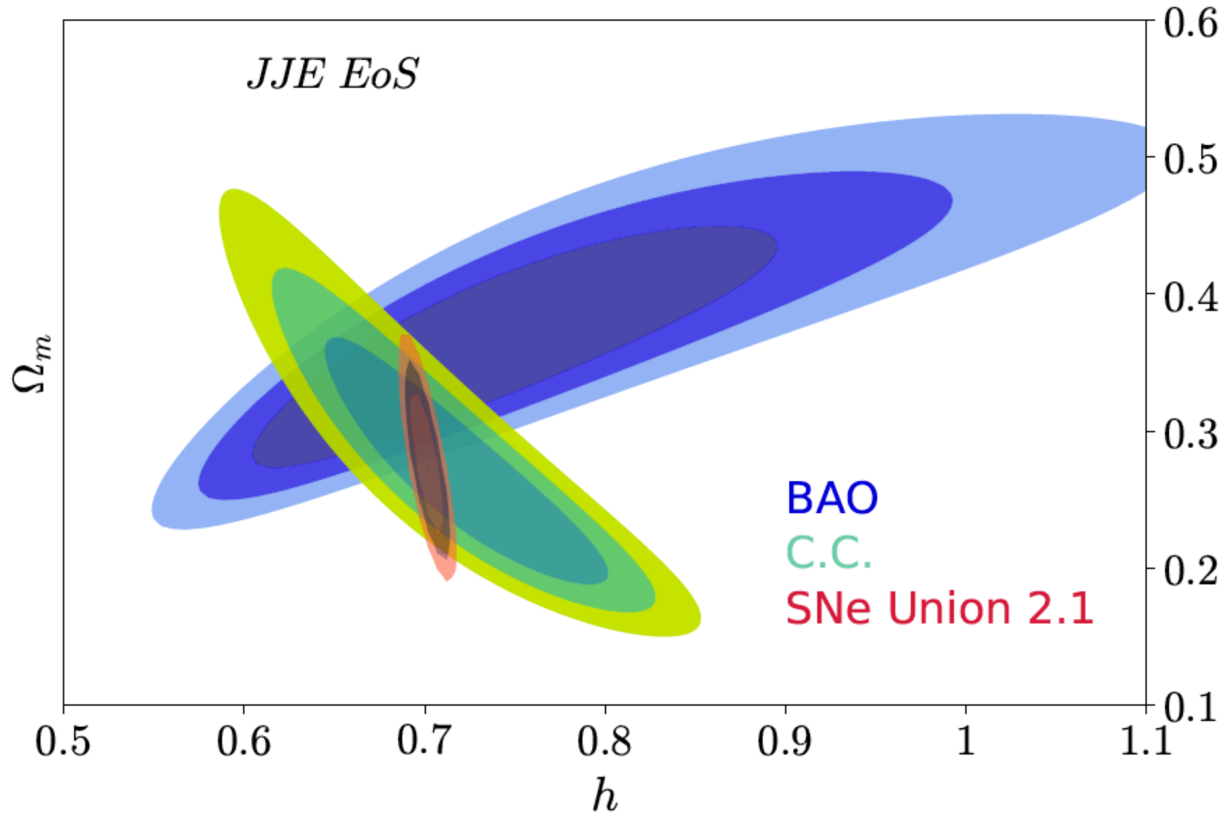

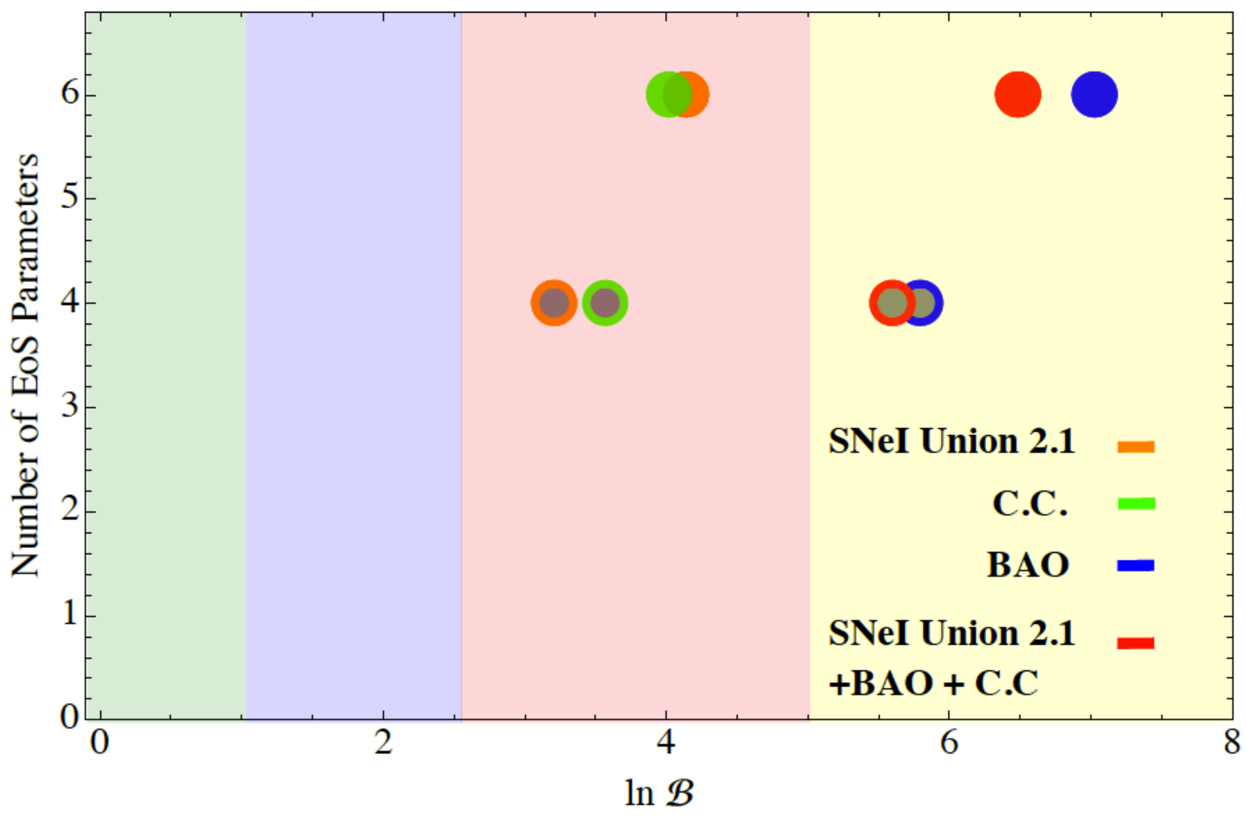

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Current methods: Performing cosmostatistics and statistical diagnostics

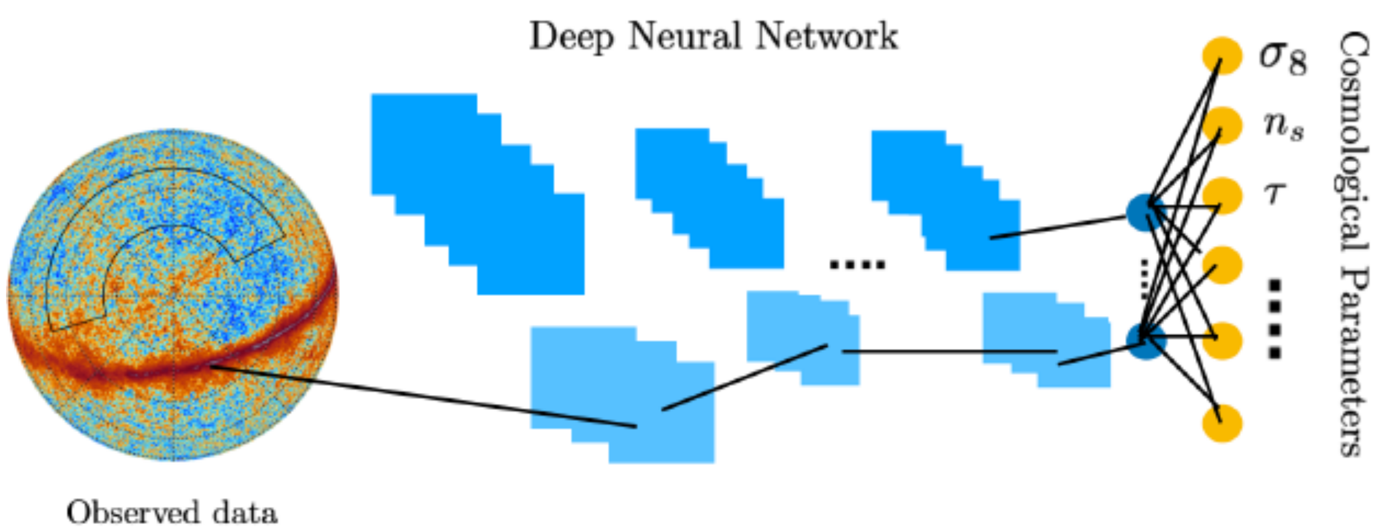
CAMB, CLASS, CosmoMC, MontePython, CosmoSIS, hiCLASS…

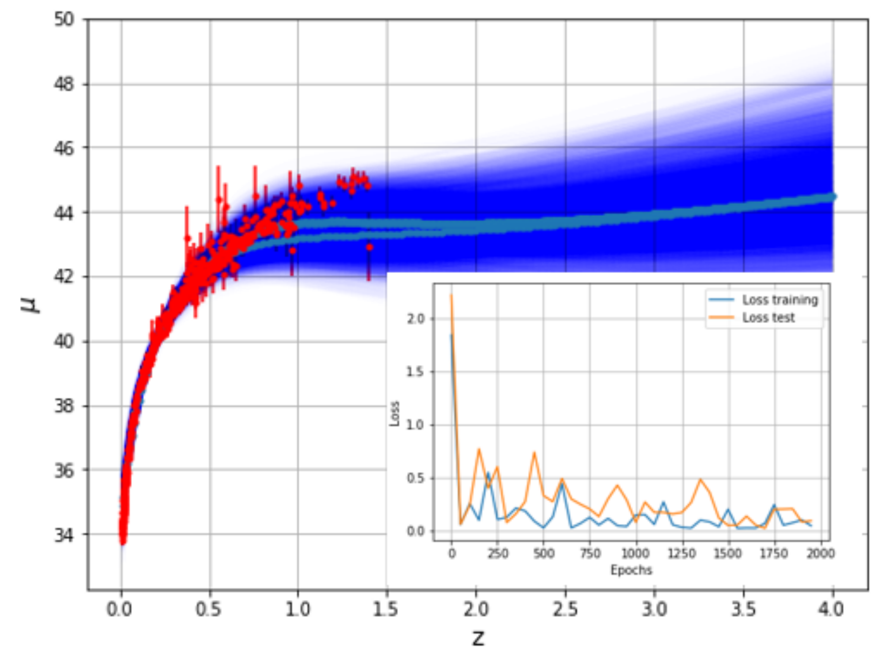
To obtain:

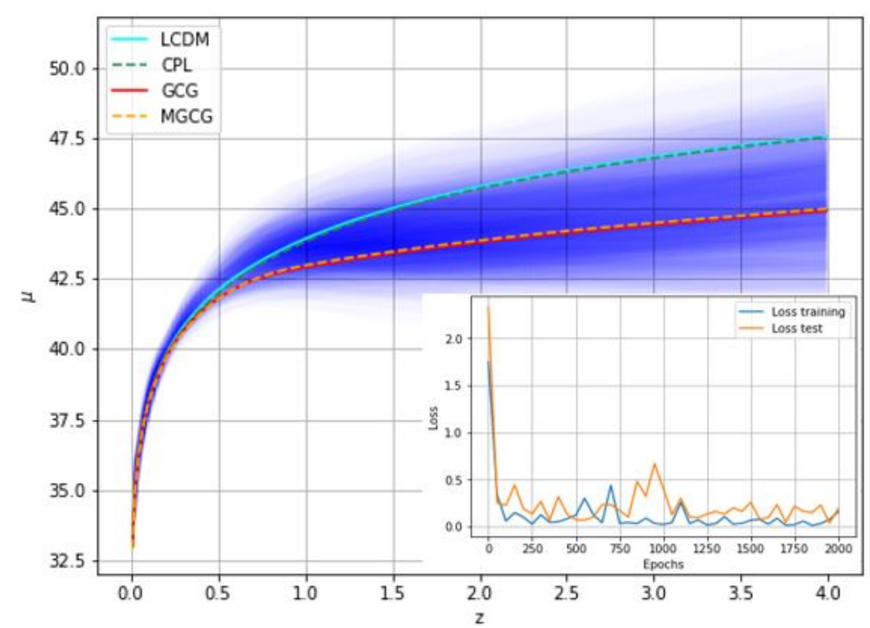
- C.L phase-constraints and likelihoods (evidence) of the cosmological parameters and free model parameters
- Model reconstructions: Gaussian Processs, Principal Component Analysis, Smooting Method [T. Holsclaw et al 2010, Huterer, et al 2010, A. Shafieloo et al 2006]
- Non-parametric approaches: Loess-Simex [Escamilla-Rivera, C et al 2014]
- Power spectra (matter, scalar, tensor)

DLCosmo for gravity: Code for Bayesian Neural Networks Analysis of gravity models

Working Team: ICN-UNAM, U. Glasgow-LIGO/VIRGO/LISA, U. Naples







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Thanks for your kind attention!

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