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Exploring new physics in the late Universe's expansion through non-parametric inference

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THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Exploring new physics in the late Universe's expansion through non-parametric inference

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Universidad Distrital Francisco José de Caldas, Bogotá, Colombia.
Core Member, LISA Consortium. FPWG, CWG, AWG.
Fourth Workshop on Current Challenges in Cosmology, May 20-22 2026, Cali, Colombia.

INSTITUTO DE FÍSICA Universidade Federal Fluminense

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS Acreditación Institucional de Alta Calidad

Outline

- Introduction
- Theoretical framework
  - Methodology
  - Results
- Final Remarks

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Introduction and Motivation

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? (Frieman, J. A., Turner, M. S., & Huterer, D. 2008).

2. Fine-Tuning PROBLEM: ¿Why is the cosmological constant so small? (Albrecht, A., Bernstein, G., Cahn, R., et al. 2006)

3. QUANTUM VACUUM ENERGY DENSITY: ¿Why the calculated value of the cosmological constant from observations is 120 orders of magnitude larger than the calculated by QFT? (Weinberg S. 1998).

Introduction and Motivation

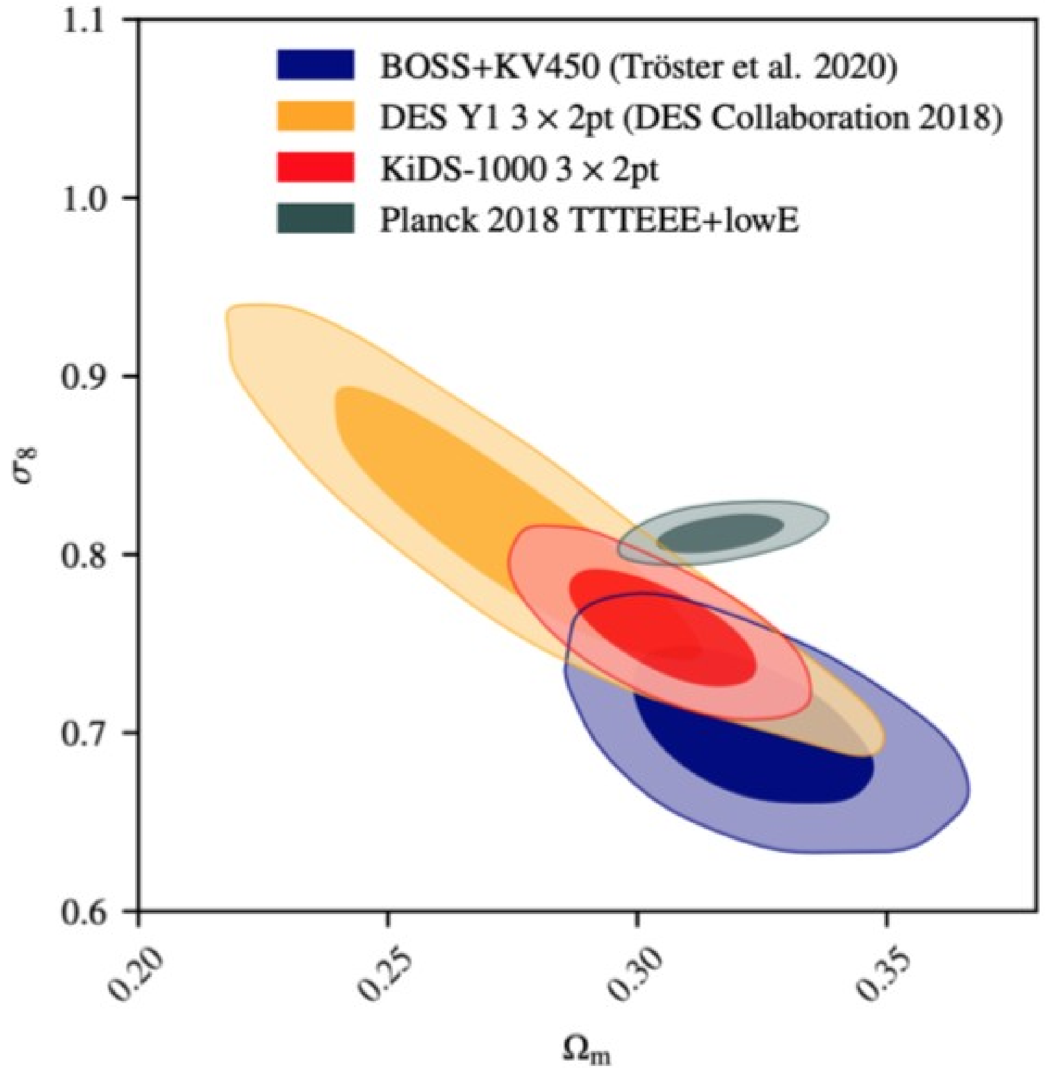
$$G_{\mu\nu} + g_{\mu\nu}\Lambda = \frac{8\pi G}{c^4} T_{\mu\nu}$$

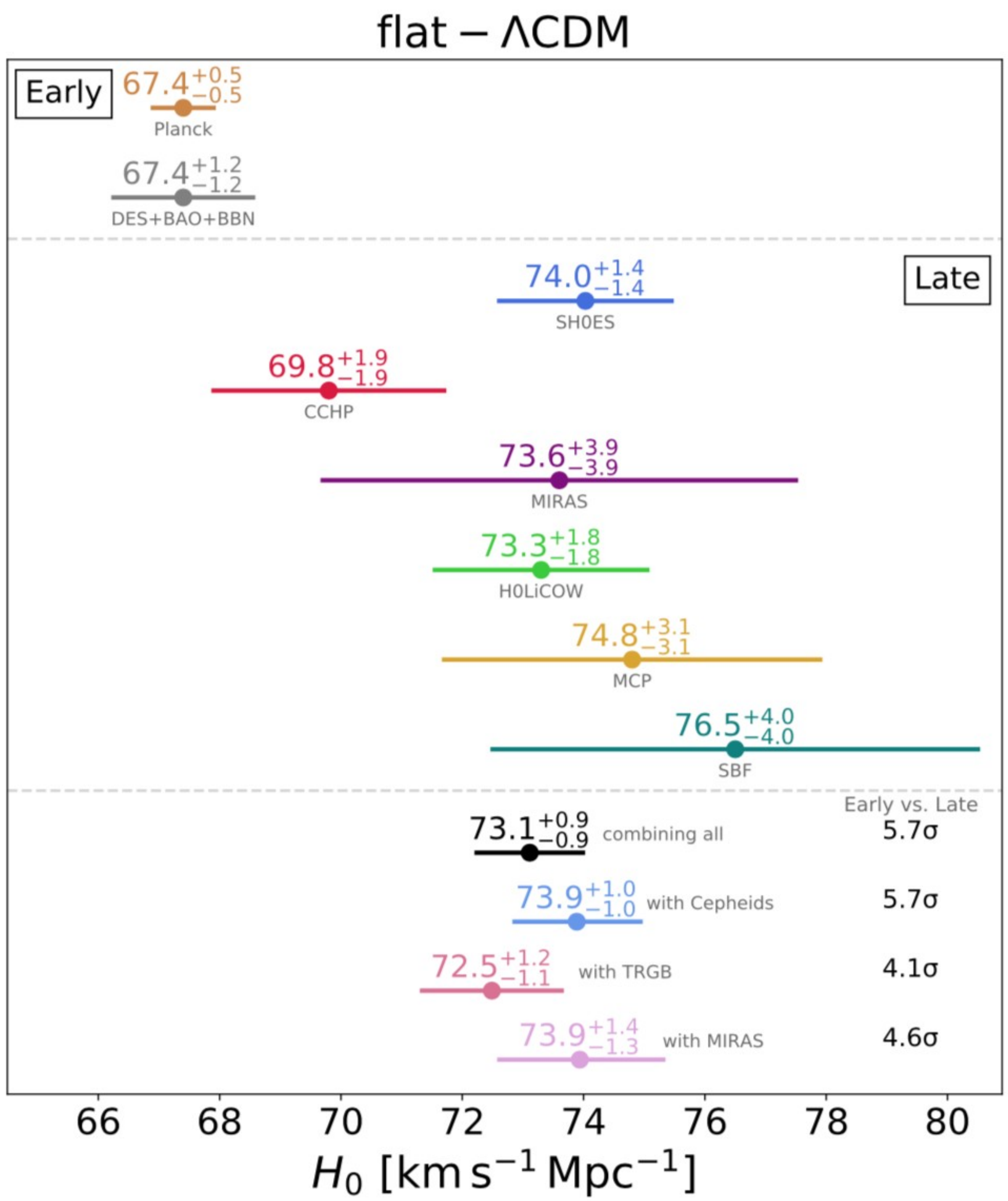
1. Alternative models of dark Energy: wCDM, Chevalier-Polarski-Linder (CPL), Interacting Dark Energy (IDE), Generalized Chapliygin Gas (GCG)..etc. (Bonilla A. et.al. 2013, 2016, 2017)

2. Modified Gravity: f(R), f(T), Massive Gravity, Tensor, Vector, Scalar (Horndeski). (Bonilla A. et.al. 2017, 2019)

3. Holographic Dark Energy: Tsallis' entropy, Kaniadakis statistics, Fluid/Gravity Duality , (Bonilla A. et.al. 2013, 2016, 2017, 2018).

Introduction and Motivation





Hubble and S8 tensións

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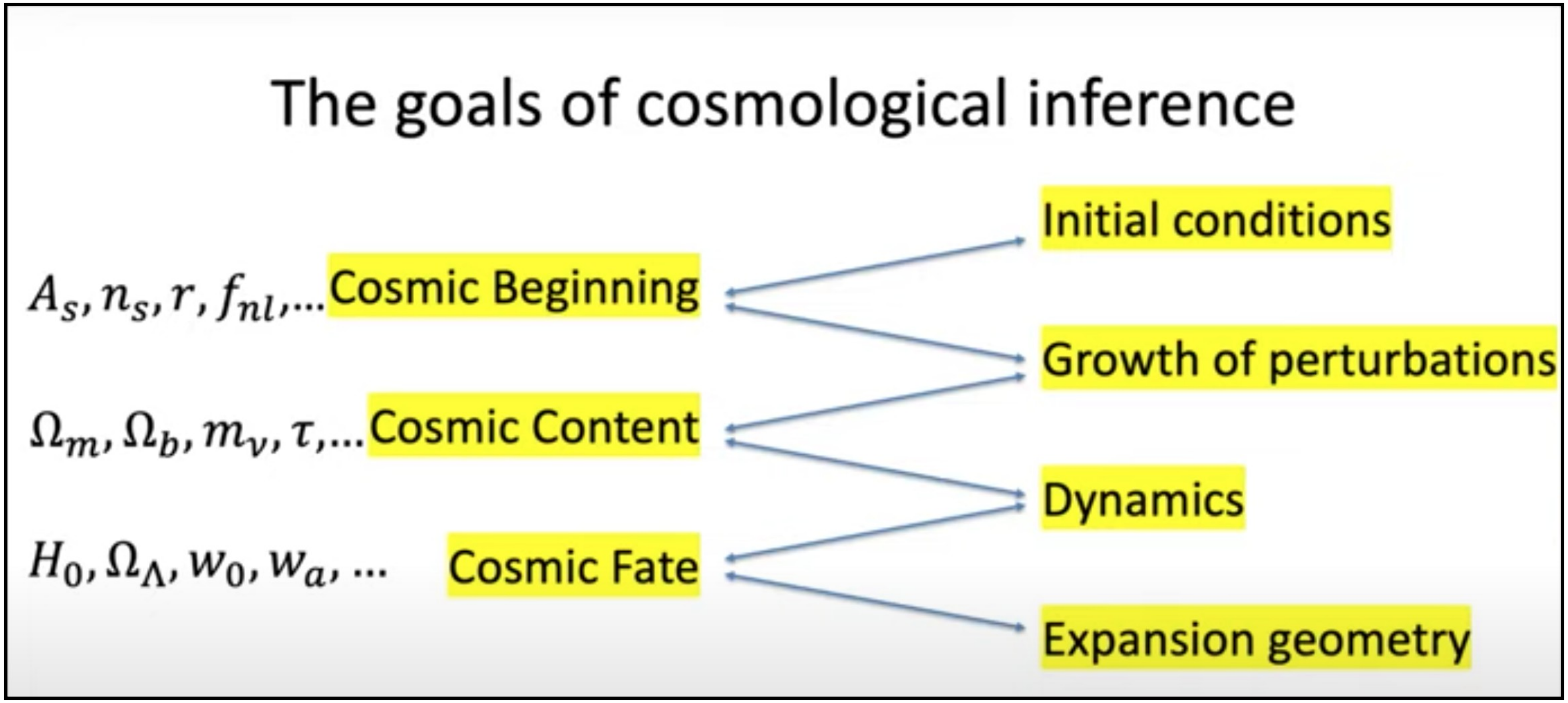
Methodology

Methodology



Bayesian inference methods are traditionally used

Methodology

Regression

Bonilla, Kumar and Nunes, EPJC (2021)

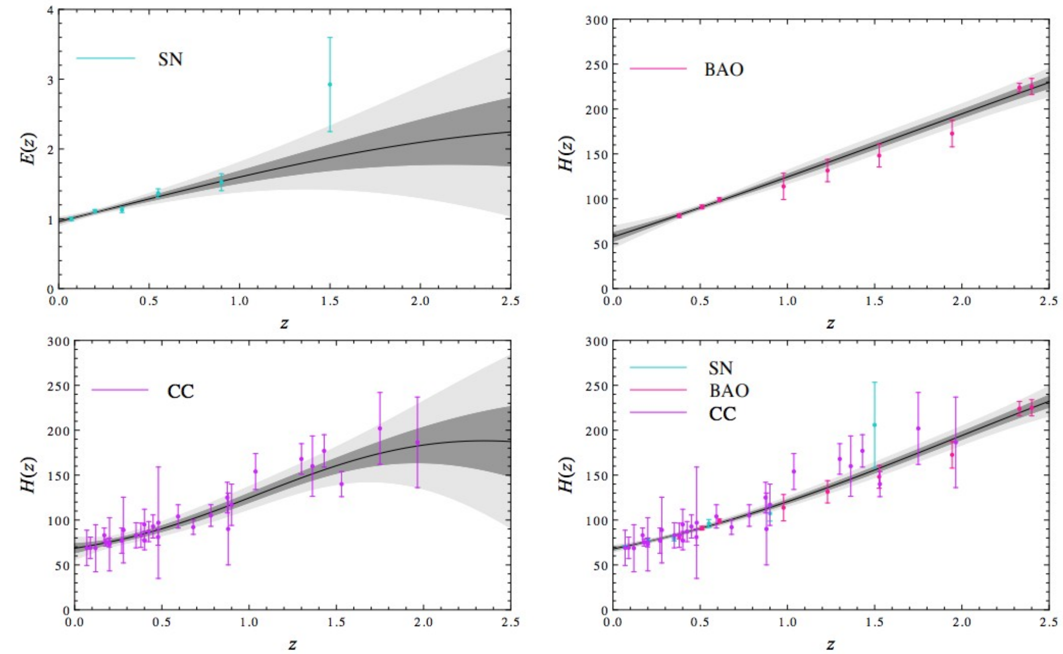


FIG. 1: $H(z)$ (in units of km s^{-1}Mpc^{-1}) vs z ($E(z)$ vs z in case of SN data alone) with 1σ and 2σ CL regions, reconstructed from SN (top-left), BAO (top-right), CC (bottom-left) and SN+BAO+CC data (bottom-right). Data with errorbars in all the panels are the observational data as mentioned in the legend of each panel.

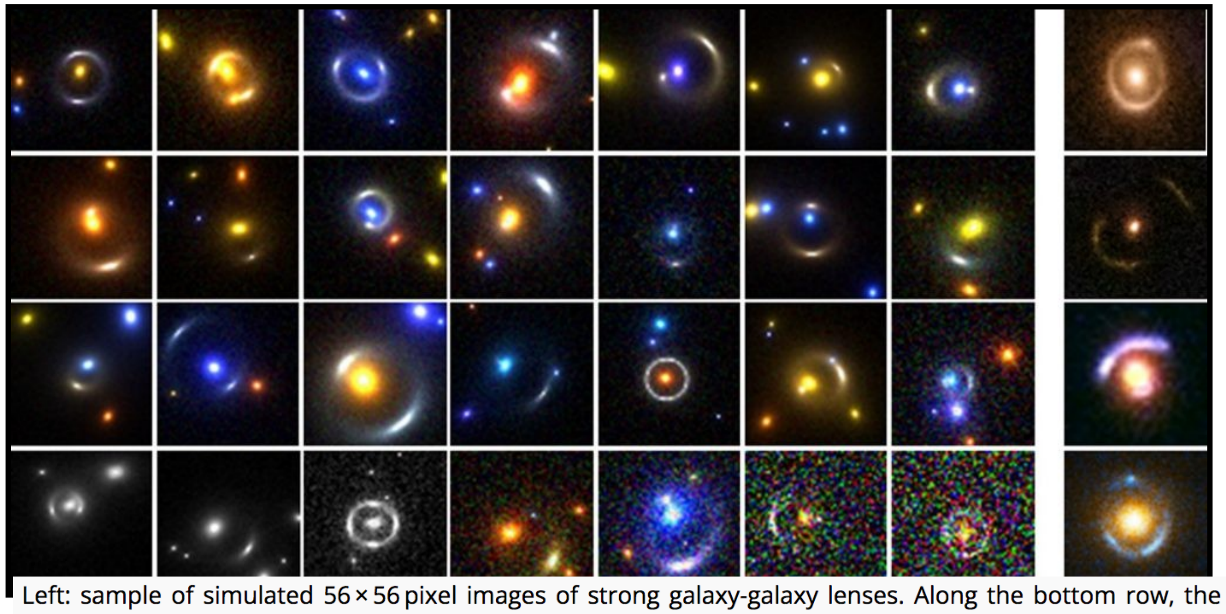
Gaussian Processes (GP’s)

Bonilla, Kumar, Nunes and Pan, MNRAS (2021)

- Independent of the physical model
- Computationally low cost

Classification

Pearson, Pennock and Robinson, MNRAS (2018)



Left: sample of simulated 56×56 pixel images of strong galaxy-galaxy lenses. Along the bottom row, the first three show examples of greyscale images produced compared to the other RGB images, while the others are examples of images with decreasing signal-to-noise ratios. Right: real images of strong galaxy-galaxy lenses. Image Courtesies from top to bottom: NASA, ESA, C. Faure (Zentrum für Astronomie, University of Heidelberg) and J.P. Kneib (Laboratoire d'Astrophysique de Marseille) (top two images); Kavan Ratnatunga (Carnegie Mellon Univ.) and NASA/ESA; and NASA, ESA, A. Bolton (Harvard-Smithsonian CfA) and the SLACS Team.

Neural Networks (NN’s)

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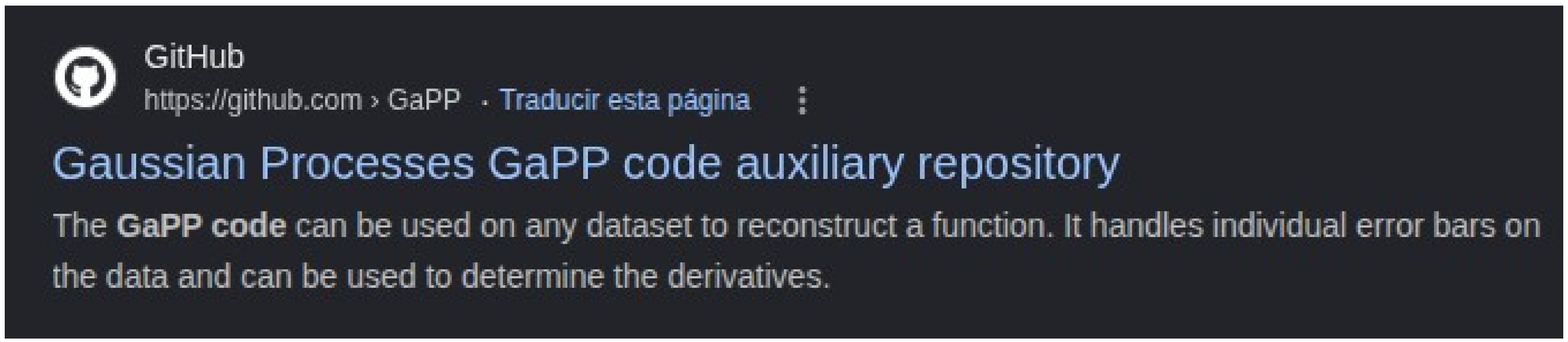
Results



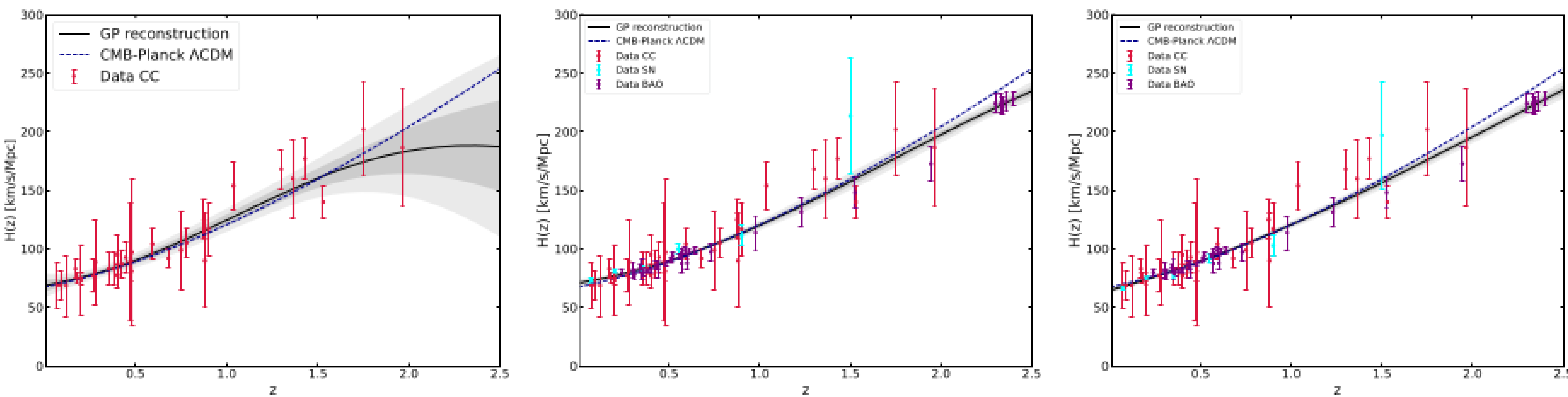
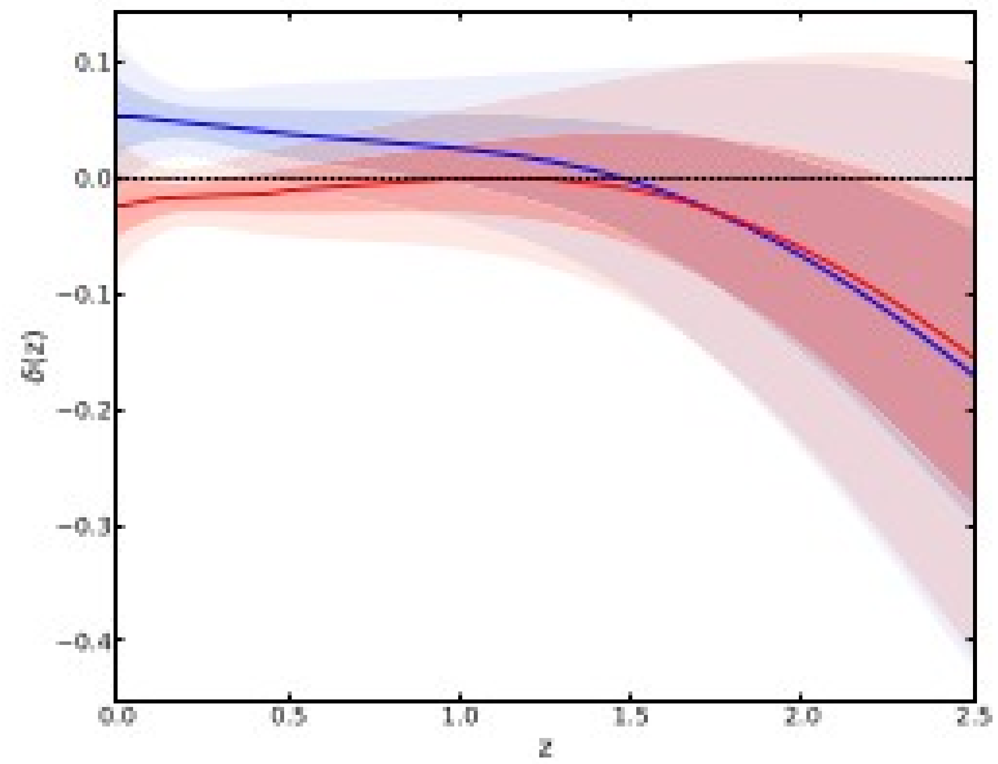


Fig. 1 Left Panel: Reconstruction of the expansion rate of the Universe from the CC sample. Middle Panel: Reconstruction of the expansion rate of the Universe using CC+SN+BAO for the case of H_0-SH0ES. Right Panel: Same as in the middle panel, but with H_0-Λ&CMB. In all panels, the blue dashed line represents the ΛCDM model with parameters fixed at the best-fit values predicted by CMB-Planck [1]

Results

$$\delta(z) = \frac{H(z) - H(z)_{\Lambda\mathrm{CDM}}}{H(z)_{\Lambda\mathrm{CDM}}}$$

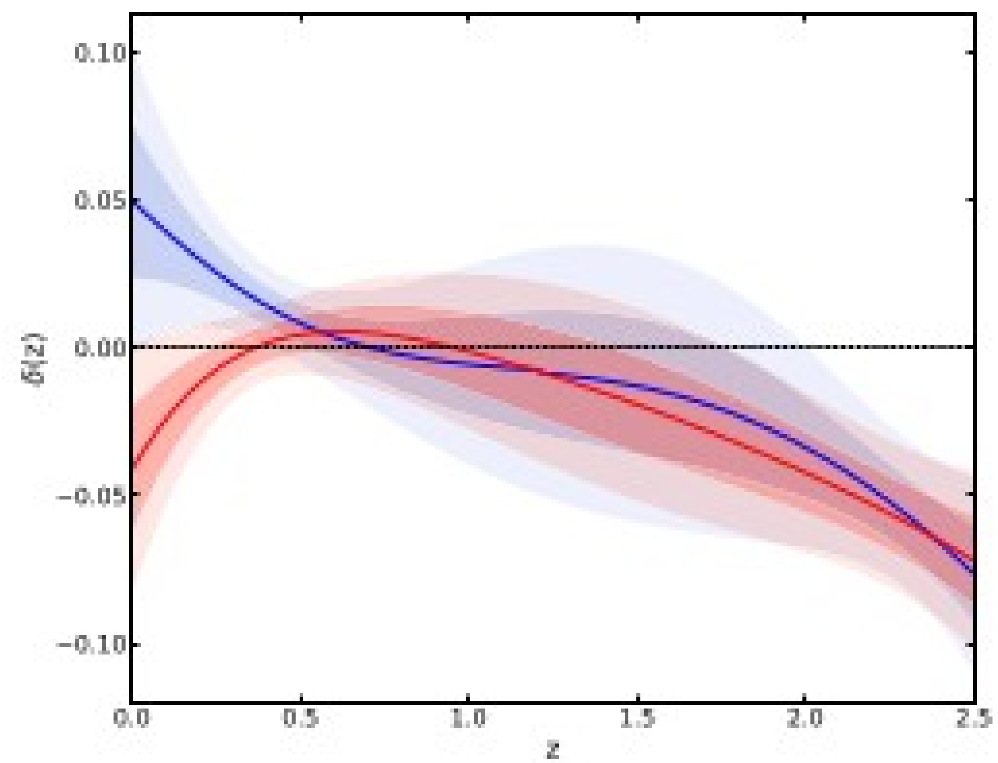
H_0-SH0ES and H_0-Λ&CMB



$\delta = 0$, aligns with Planck-ΛCDM expectations (Null Hypothesis).

$\delta > 0$, implies deviations toward a faster-expanding universe than Planck-ΛCDM predicts.

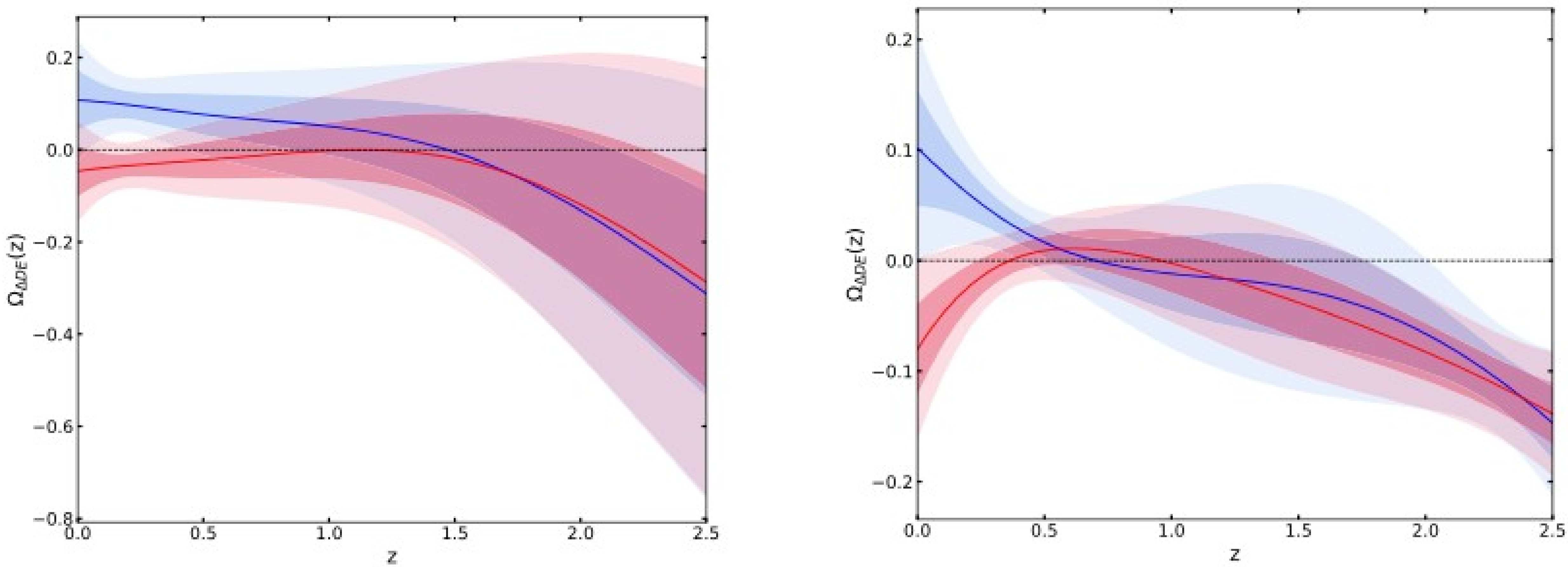
$\delta < 0$, indicates a slower expansion in comparison Planck-ΛCDM.



Results

Our goal is to understand where exploring new physics in the late universe is most relevant. We analyze recent Cosmic

quintessence. We suggest exploring new physics at $z \lesssim 0.5$ and $1.5 \lesssim z \lesssim 2.5$, particularly around $z = 2$, to understand cosmological tensions such as H_0 and S_8.



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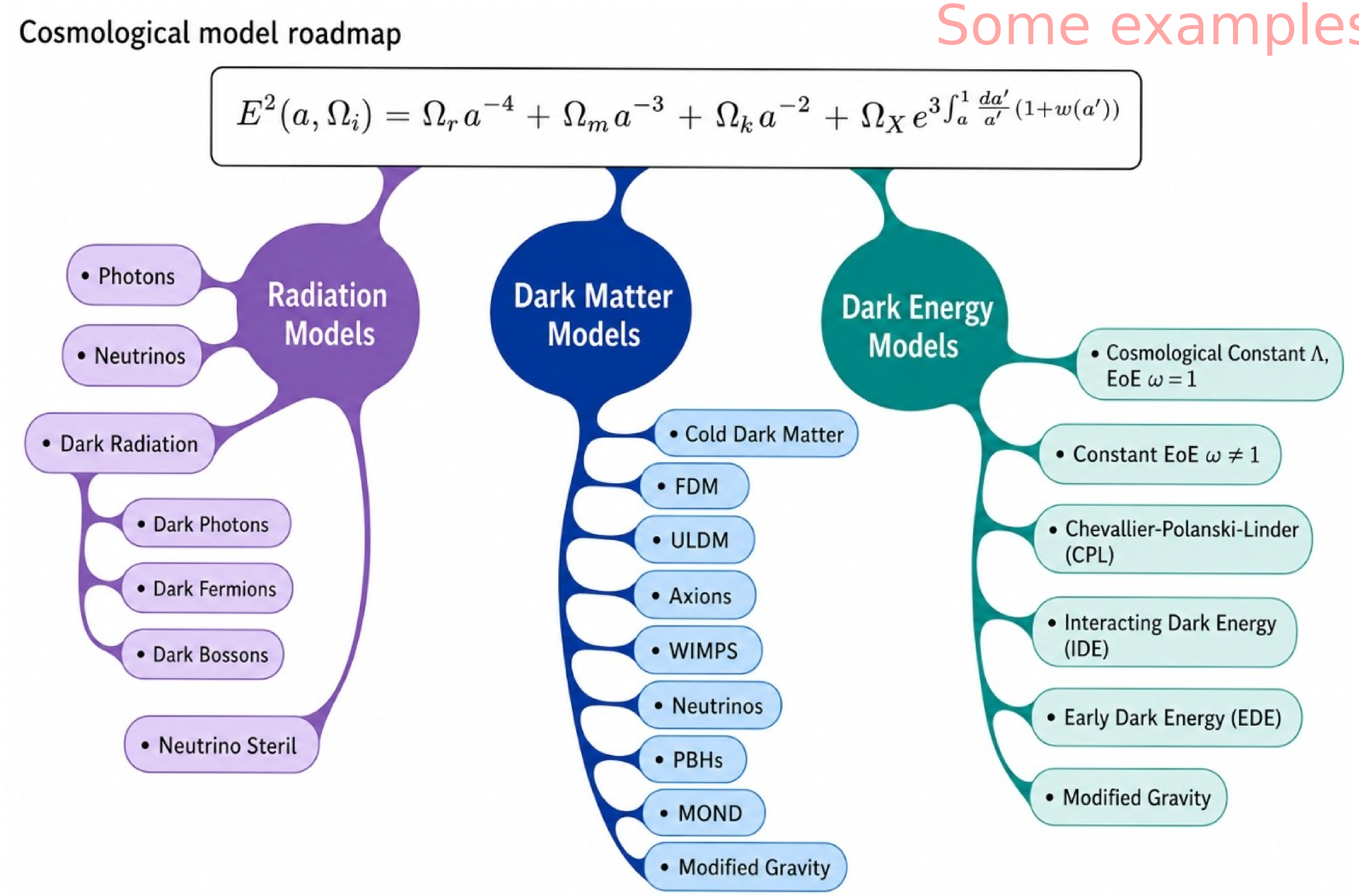
Final Remarks

But what is new physics?

Final Remarks

Some examples



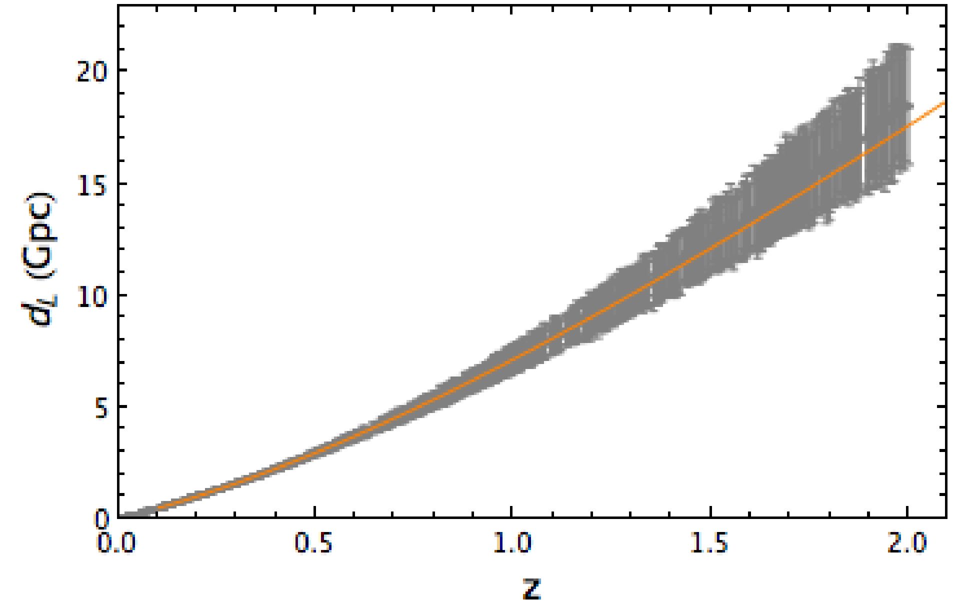
Final Remarks

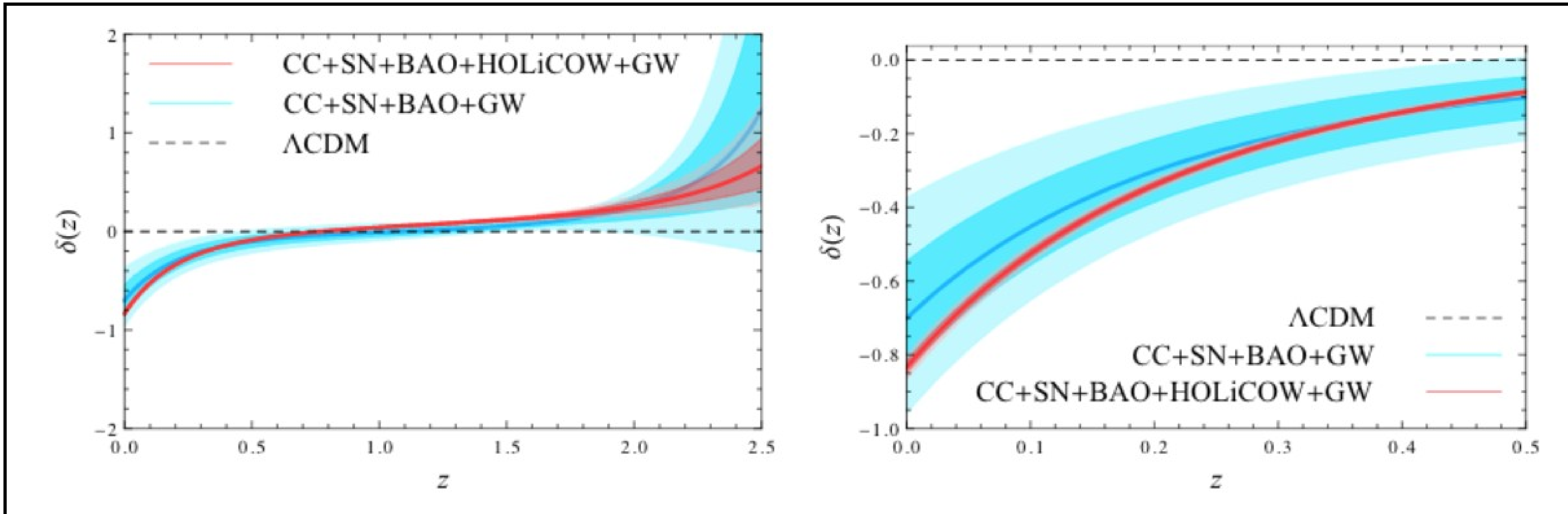
Some specific examples

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **512**, 4231–4238 (2022) https://doi.org/10.1093/mnras/stac687
Advance Access publication 2022 March 12

Reconstruction of the dark sectors' interaction: A model-independent inference and forecast from GW standard sirens

Alexander Bonilla,[1★] Suresh Kumar,[2,3★] Rafael C. Nunes[4★] and Supriya Pan[5]



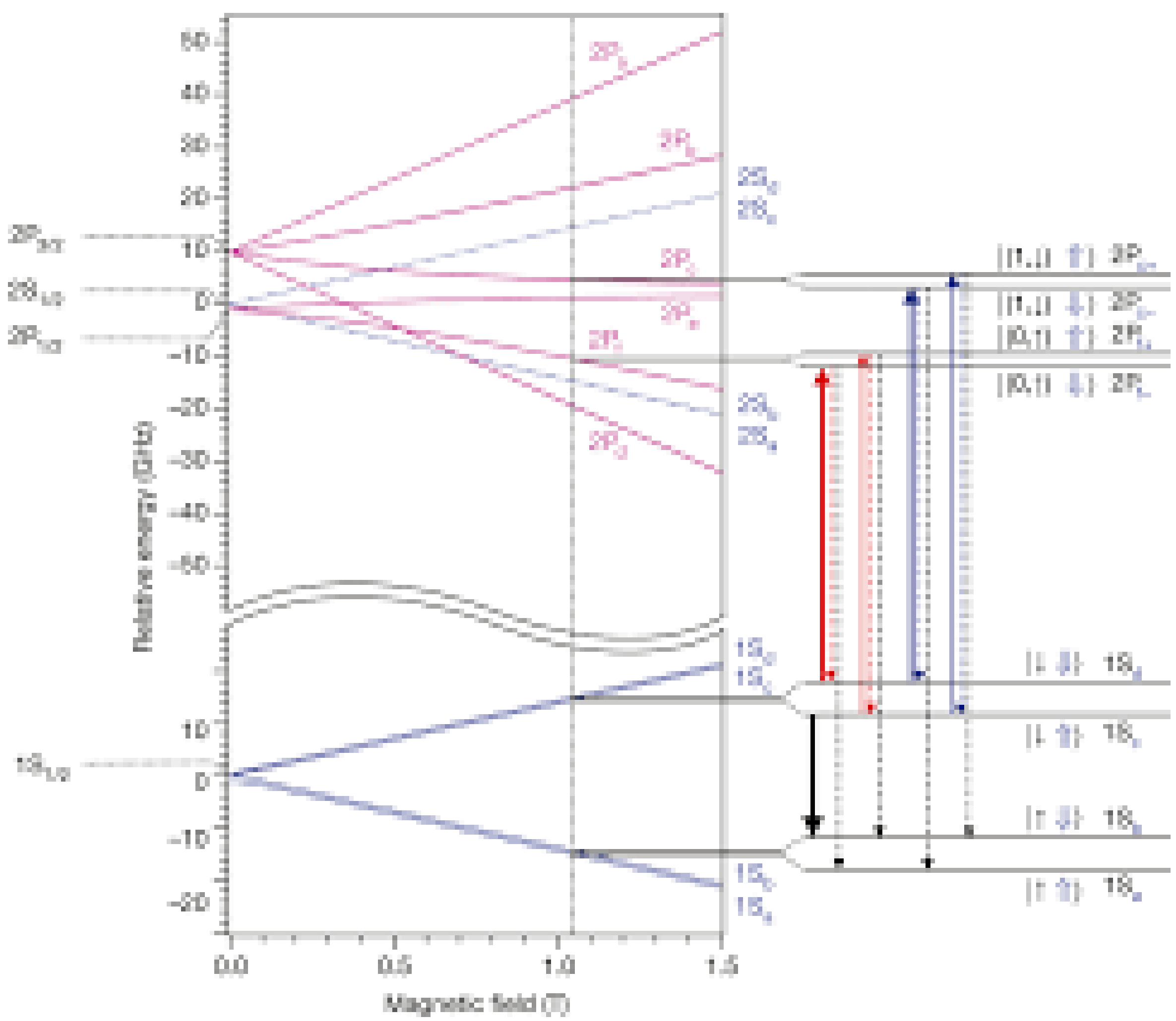


Final Remarks

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **473,** 4404–4409 (2018)
doi:10.1093/mnras/stx2661

Probing the properties of relic neutrinos using the cosmic microwave background, the *Hubble Space Telescope* and galaxy clusters

Rafael C. Nunes★ and Alexander Bonilla
Departamento de Física, Universidade Federal de Juiz de Fora, 36036-330, Juiz de Fora, MG, Brazil



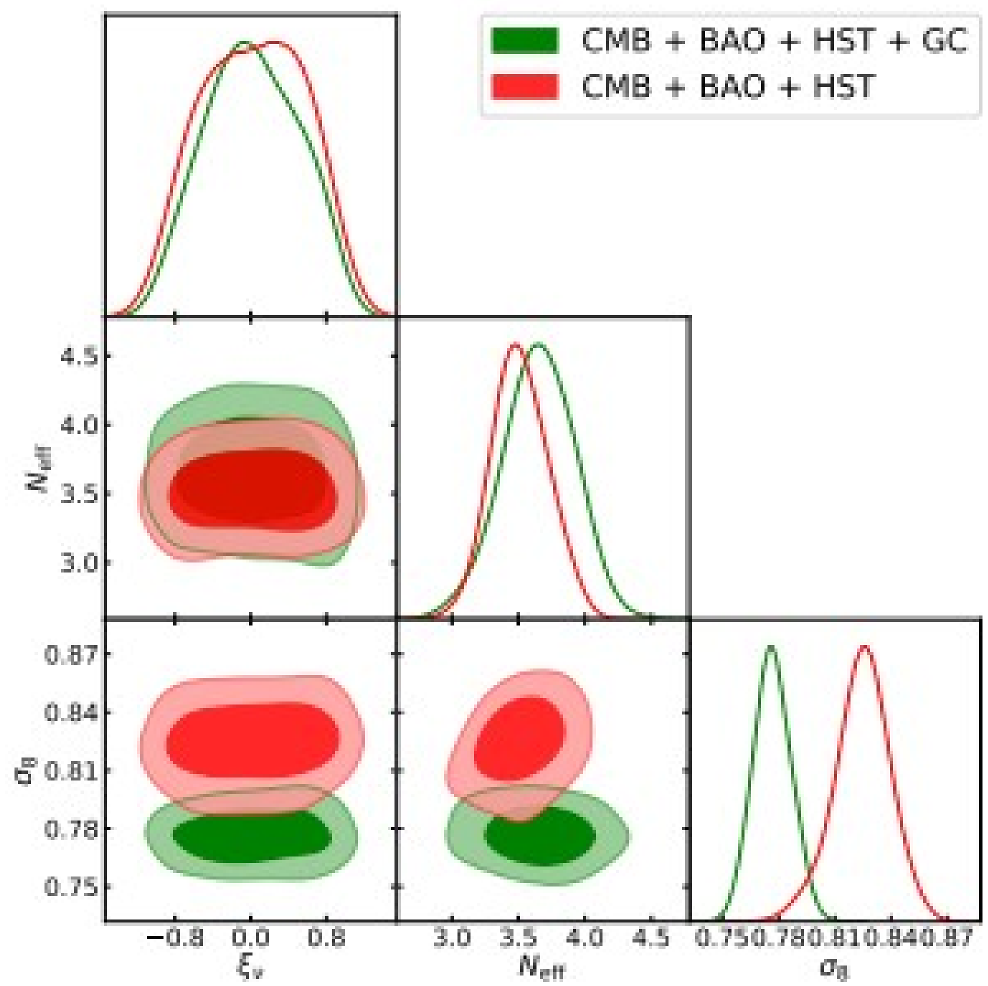


FIG. 2: One-dimensional marginalized distribution and 68 per cent CL and 95 per cent CL regions for some selected parameters of the Model II.

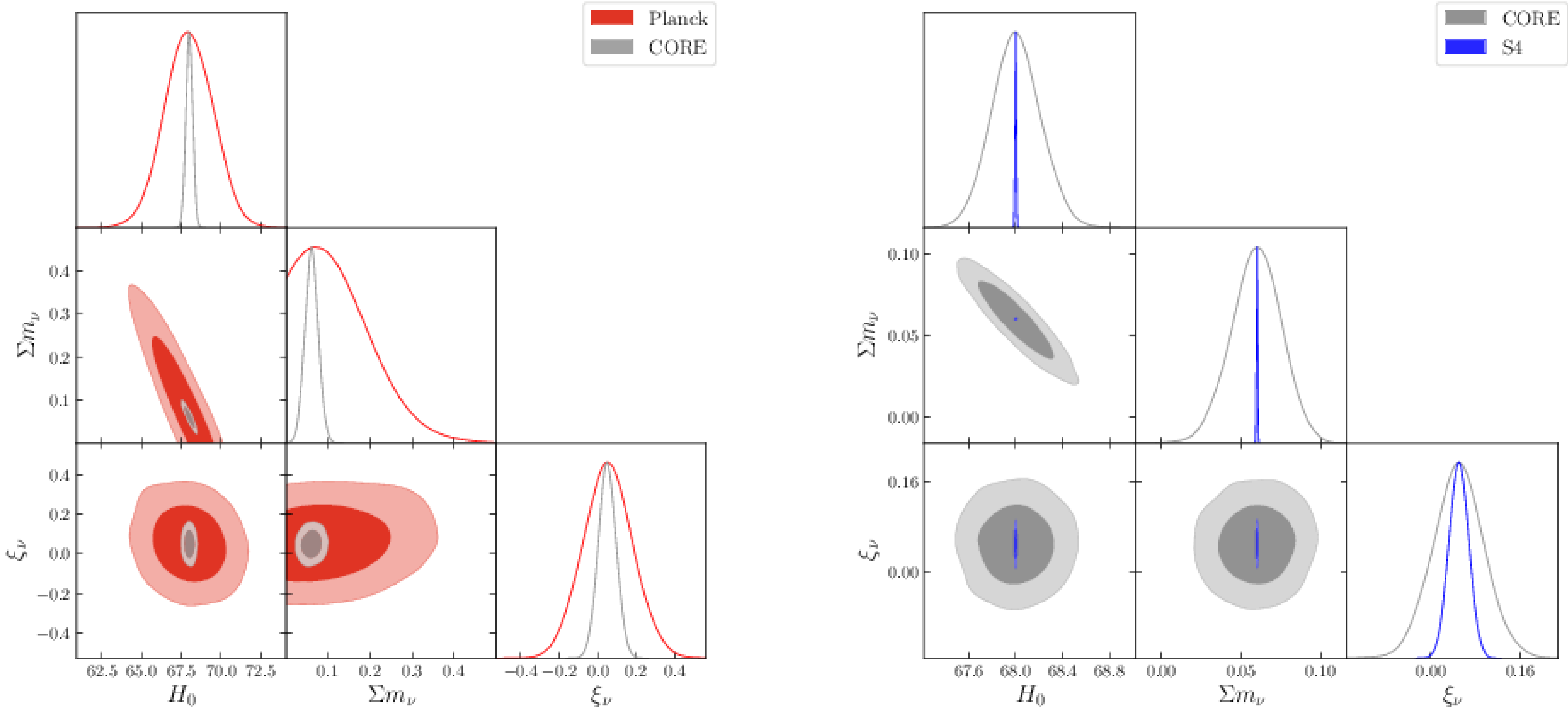
Final Remarks

Forecast on lepton asymmetry from future CMB experiments

Alexander Bonilla (Juiz de Fora U.), Rafael C. Nunes (Sao Jose, INPE), Everton M.C. Abreu (
Rio de Janeiro Federal U. & Juiz de Fora U. & UFRJ, Rio de Janeiro)

Oct 15, 2018 - 6 pages

Mon.Not.Roy.Astron.Soc. 485 (2019) no.2, 2486-2491
(2019-05-11)
DOI: 10.1093/mnras/stz524
e-Print: arXiv:1810.06356 [astro-ph.CO] | PDF



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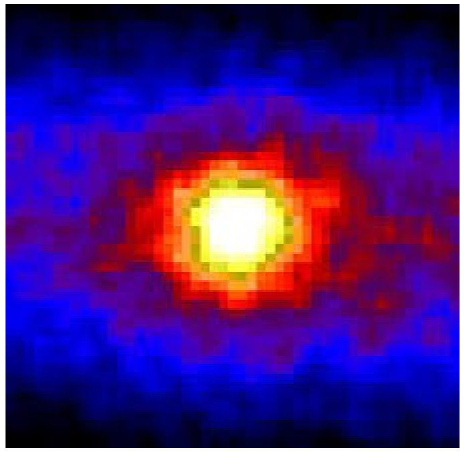


Final Remarks

Unveiling the nature of Dirac's neutrinos in light of the latest cosmological test

Bonilla, Hortua, Di Valentino & Castillo. In preparation

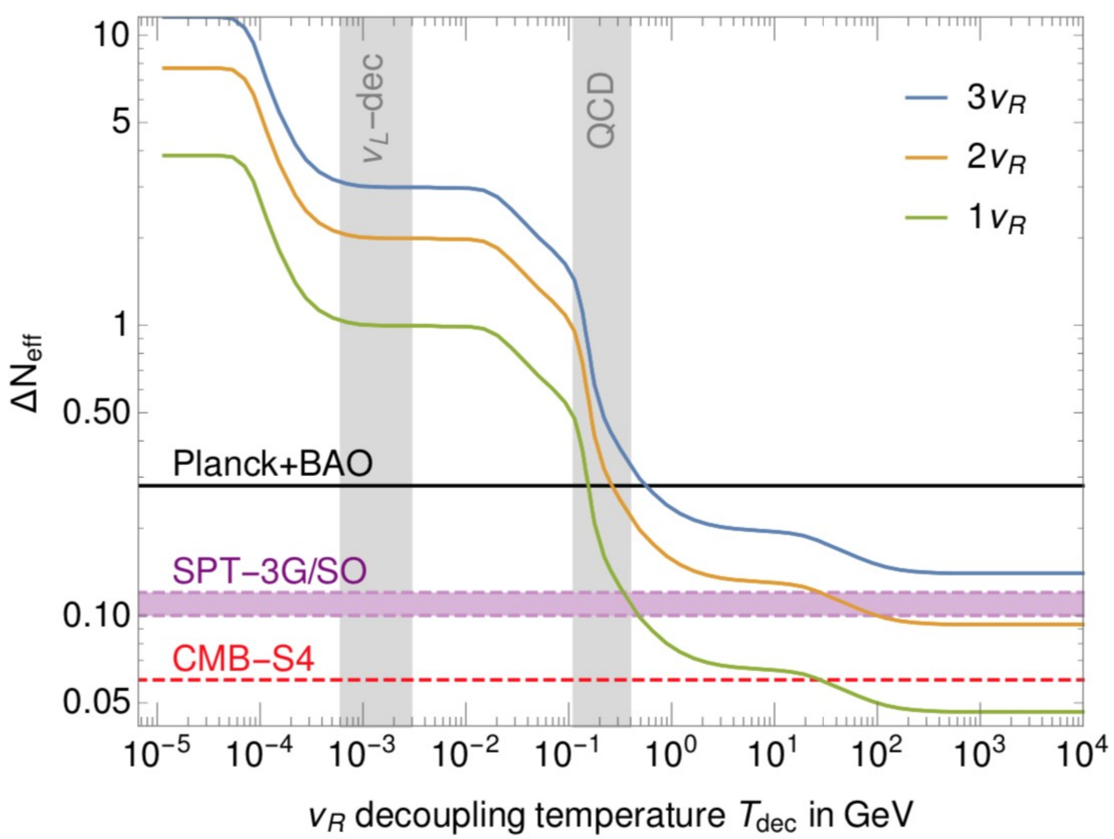
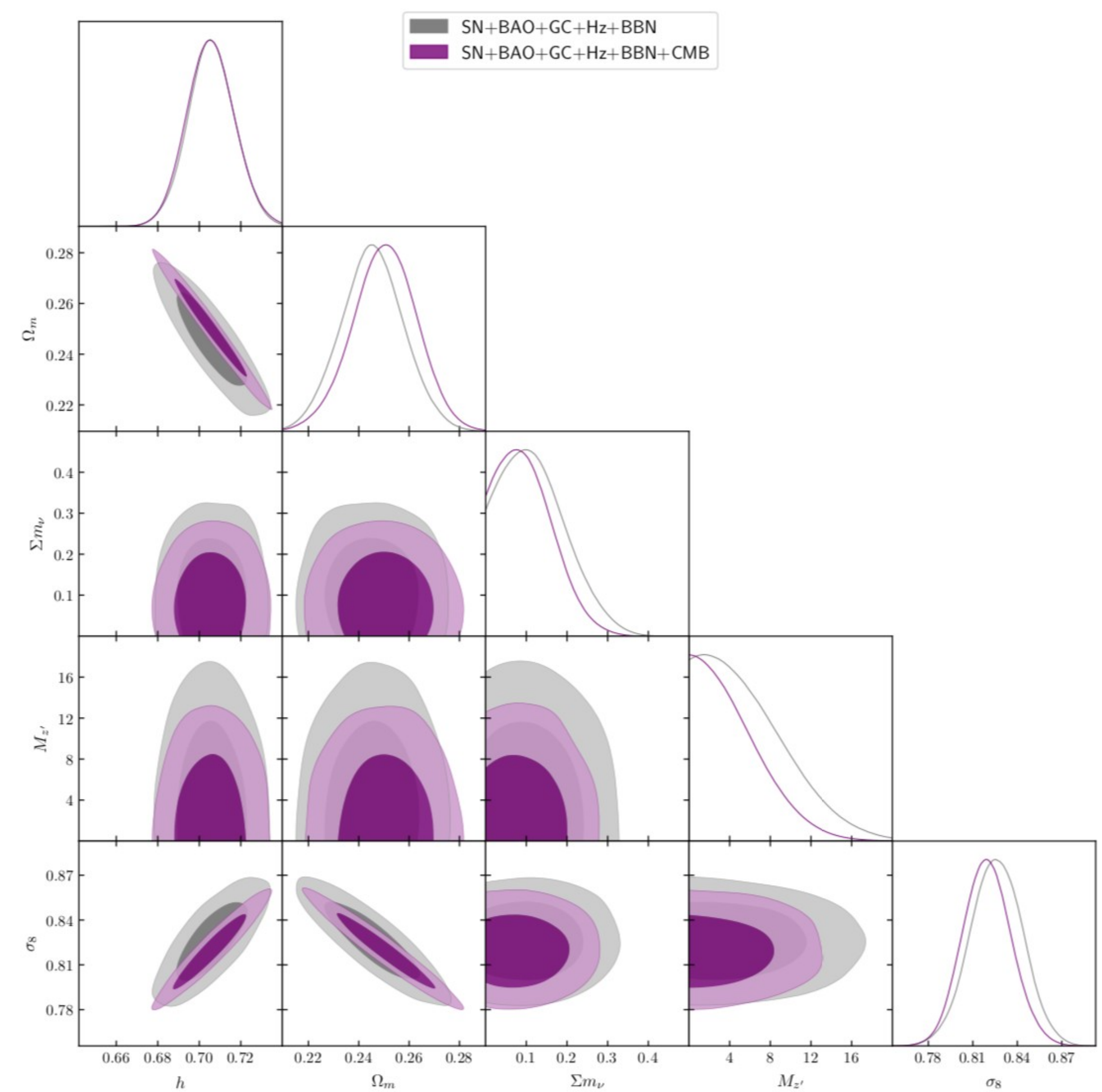


Figure 52 – Contribution of one, two or three right-handed neutrinos ν_R to $\Delta N_{\rm eff}$ as a function of their common decoupling temperature $T_{\rm dec}$. The horizontal lines indicate the current 2σ limit from Planck+BAO as well as the projected reach of SPT-3G, SO, and CMB-S4.



Final Remarks

Contents lists available at ScienceDirect

Physics Letters B

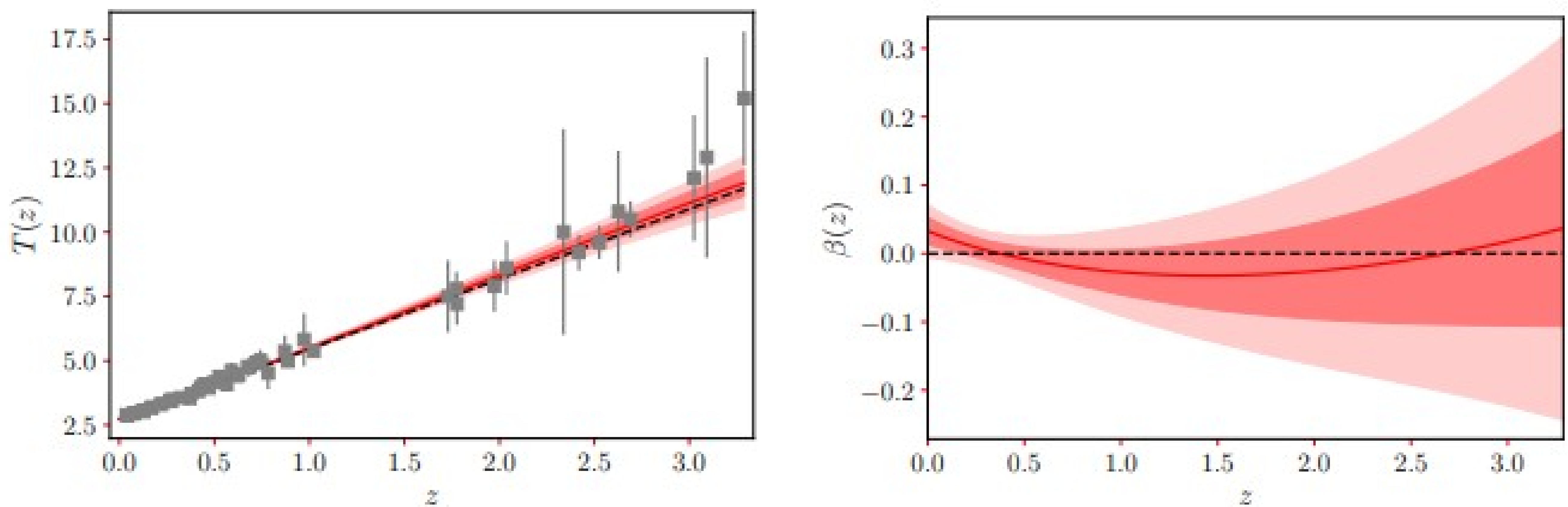
journal homepage: www.elsevier.com/locate/physletb

Letter

Revisiting the temperature evolution law of the CMB with Gaussian processes

Felipe Avila [a,*], Alexander Bonilla Rivera [b], Rafael C. Nunes [c,d], R.F.L. Holanda [c,f], Armando Bernui [a]

$$T_{\mathrm{CMB}}(z) = T_0(1+z)^{1-\beta}$$



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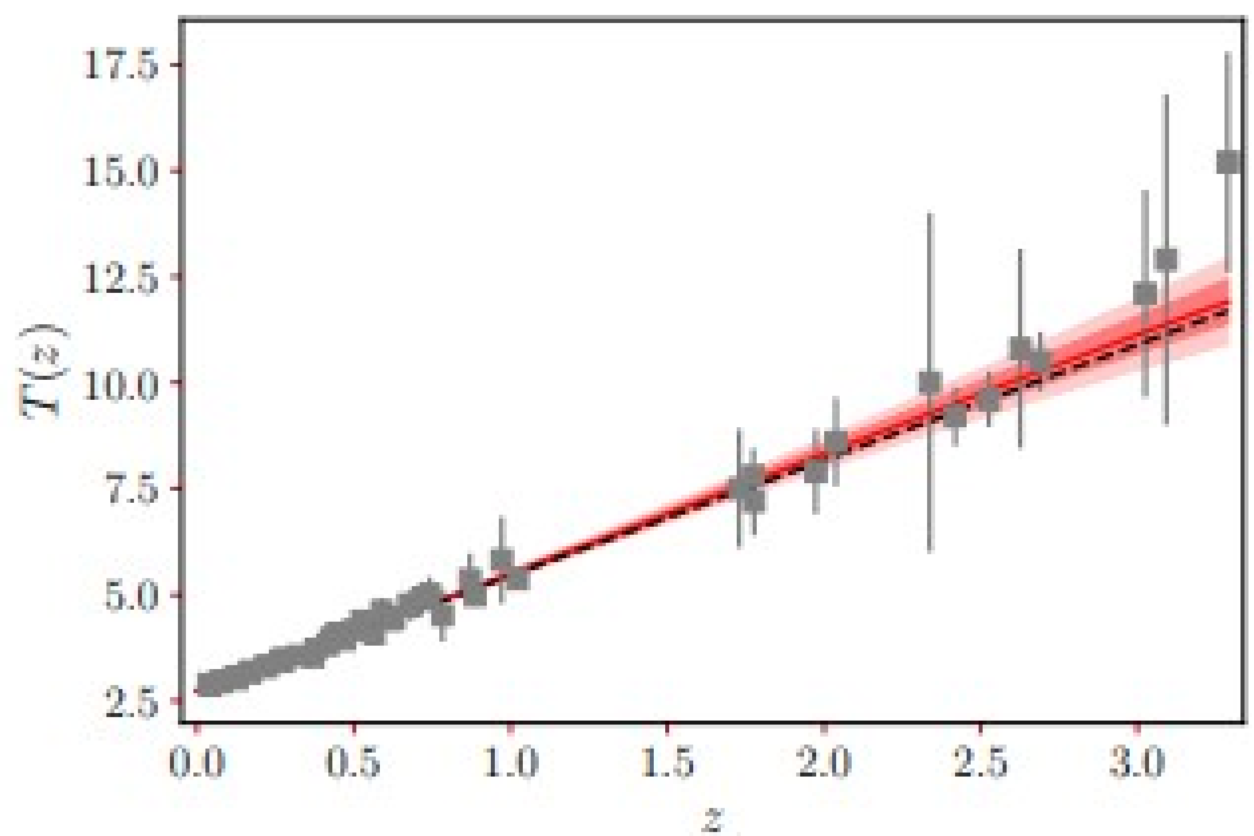
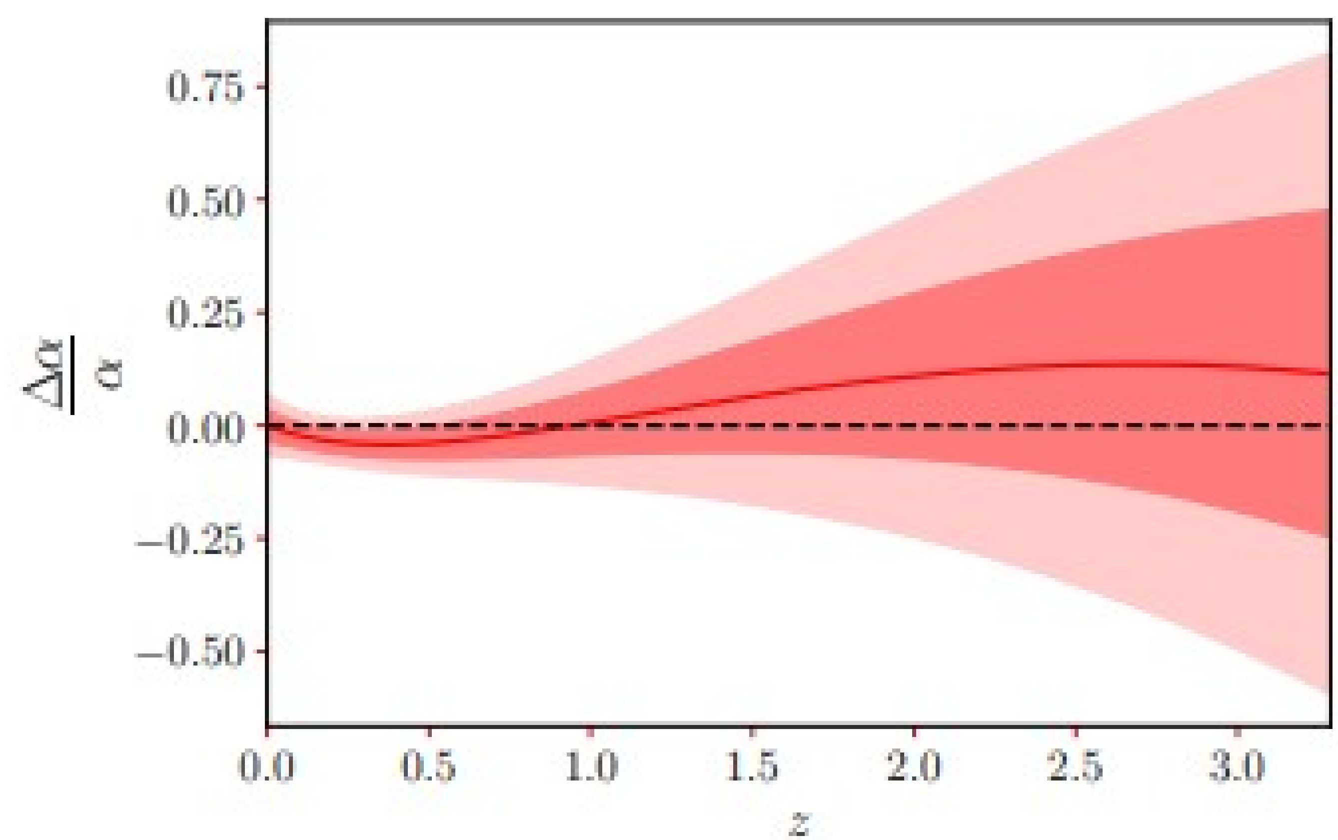
Letter

Revisiting the temperature evolution law of the CMB with Gaussian processes

Felipe Avila [a,*], Alexander Bonilla Rivera [b], Rafael C. Nunes [c,d], R.F.L. Holanda [c,f], Armando Bernui [a]

$$\frac{\Delta\alpha(z)}{\alpha} + 1 = 8.33\,\frac{T_{\rm CMB}(z)}{T_0(1+z)^{-7.33}}$$





Final Remarks

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

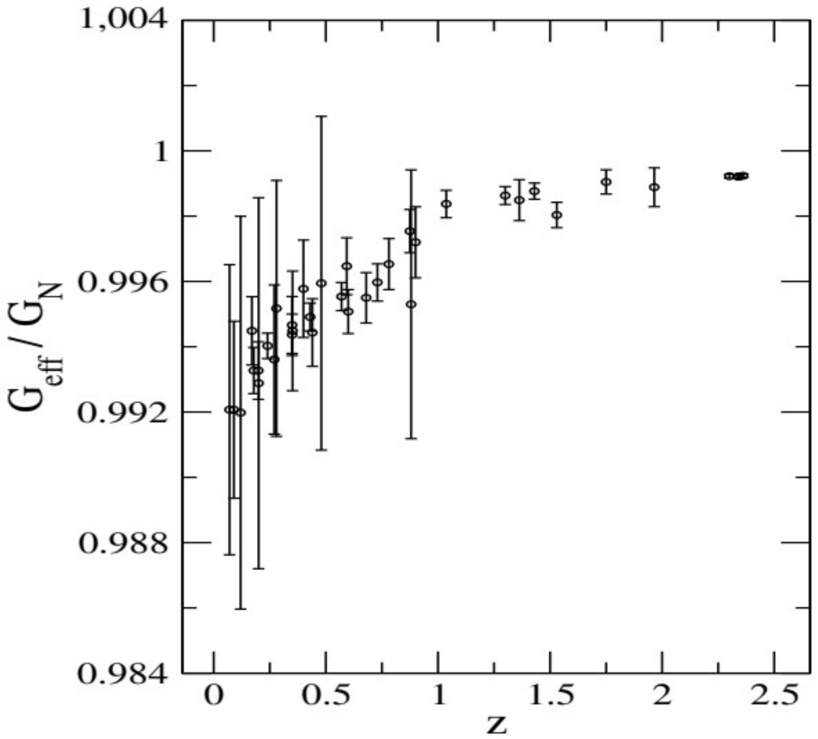
Rafael C. Nunes,[1,*] Alexander Bonilla,[1,†] Supriya Pan,[2,‡] and Emmanuel N. Saridakis[3,4,5,§]

[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*

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

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

z	$\Delta\alpha/\alpha(ppm)$	Ref.
1.08	4.3 ± 3.4	[37]
1.14	-7.5 ± 5.5	[38]
1.15	-0.1 ± 1.8	[39]
1.15	0.5 ± 2.4	[40]
1.34	-0.7 ± 6.6	[38]
1.58	-1.5 ± 2.6	[41]
1.66	-4.7 ± 5.3	[37]
1.69	1.3 ± 2.6	[42]
1.80	-6.4 ± 7.2	[37]
1.74	-7.9 ± 6.2	[38]
1.84	5.7 ± 2.7	[39]



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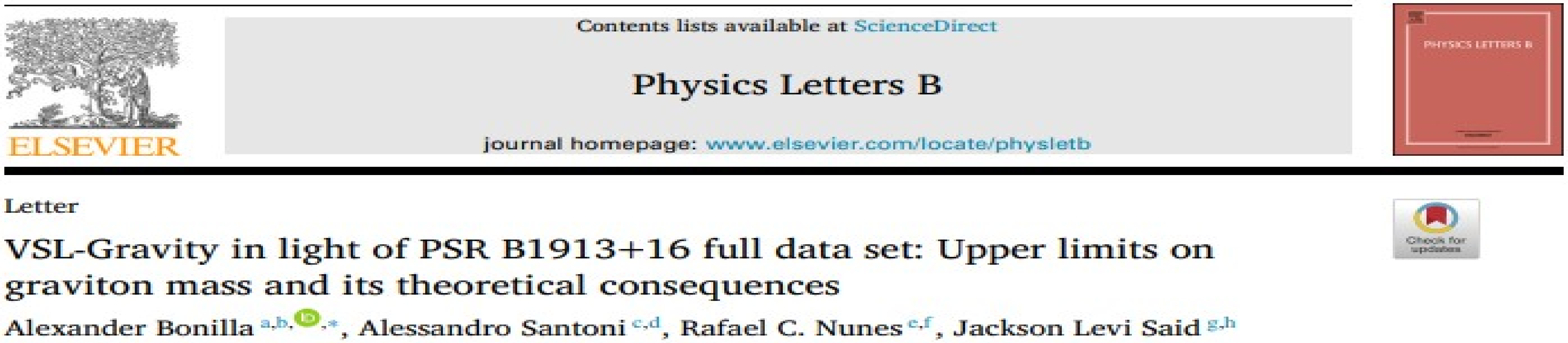

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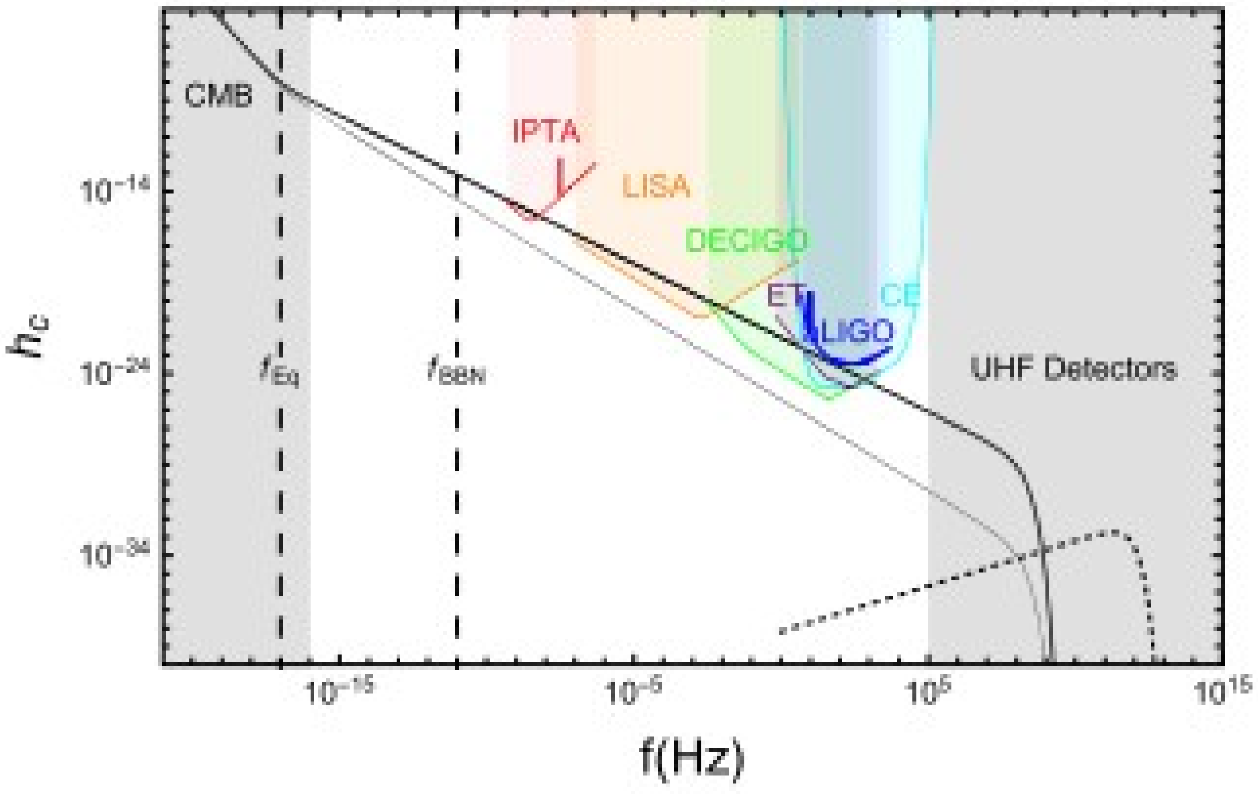
Physics Letters B

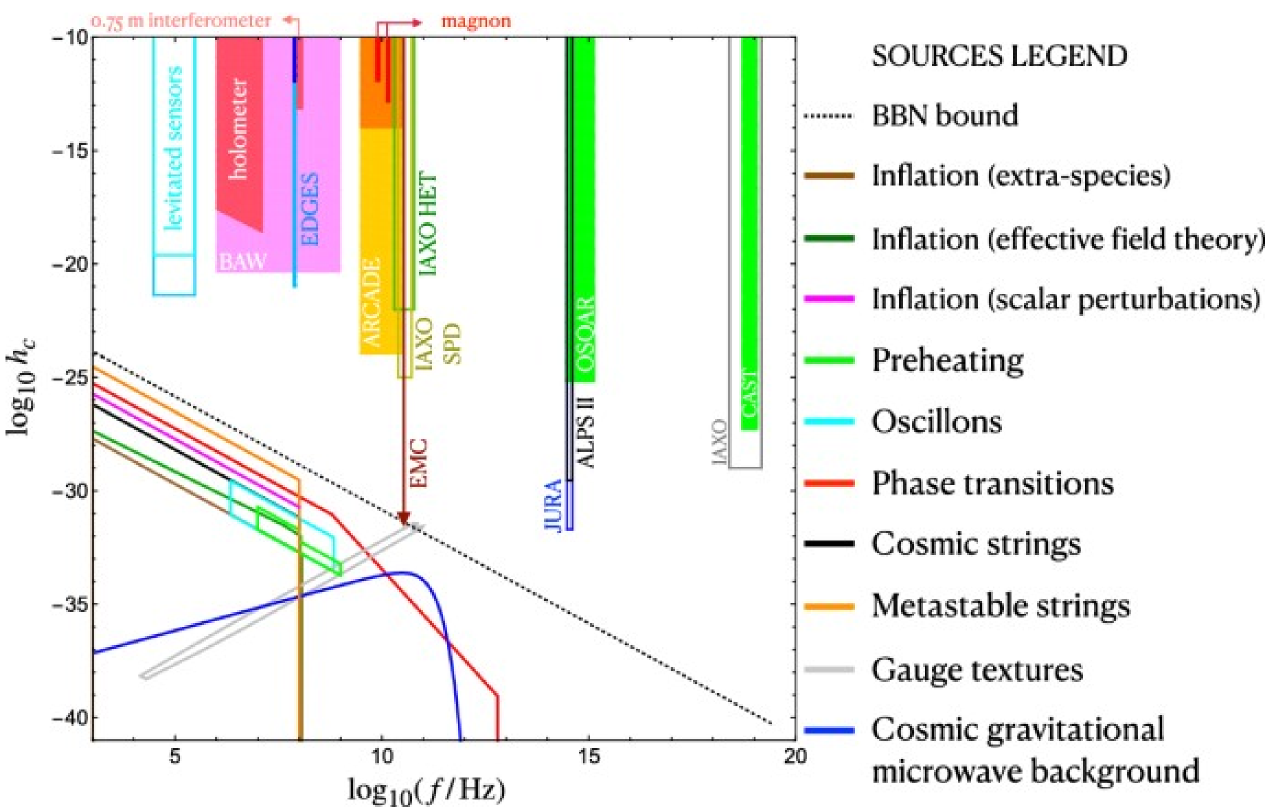
journal homepage: www.elsevier.com/locate/physletb

Letter

VSL-Gravity in light of PSR B1913+16 full data set: Upper limits on graviton mass and its theoretical consequences

Alexander Bonilla [a,b,*], Alessandro Santoni [c,d], Rafael C. Nunes [e,f], Jackson Levi Said [g,h]





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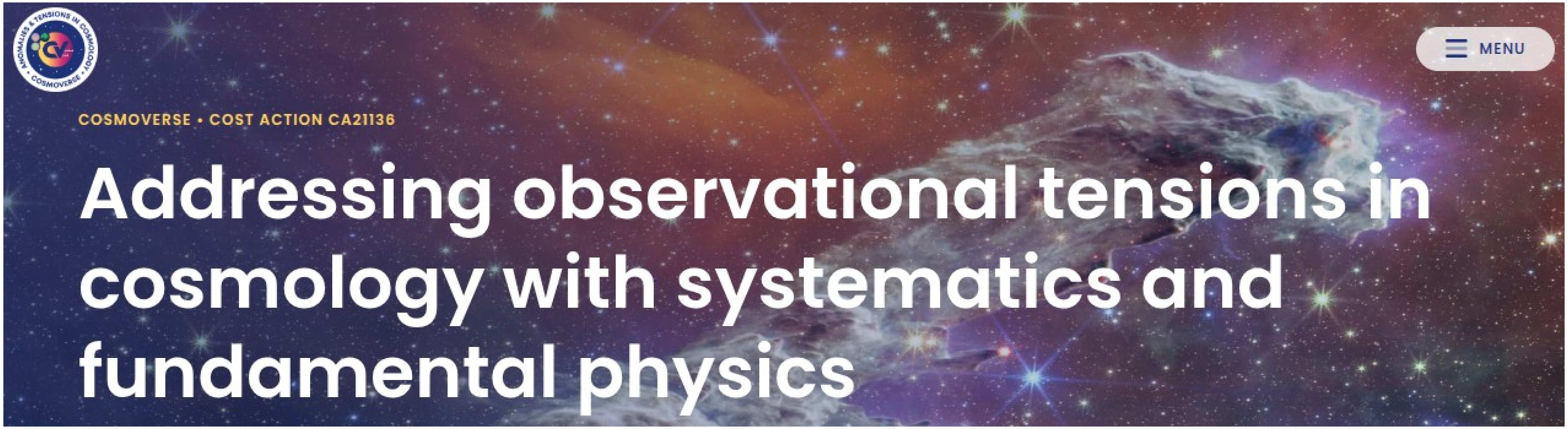

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Physics of the Dark Universe

journal homepage: www.elsevier.com/locate/dark

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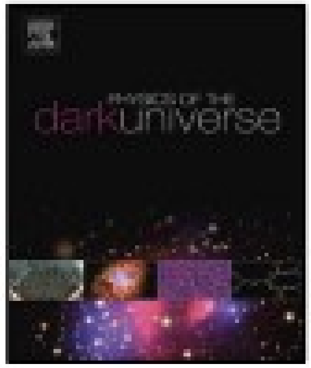

Review article

The CosmoVerse White Paper: Addressing observational tensions in cosmology with systematics and fundamental physics

Eleonora Di Valentino [1,*], Jackson Levi Said [2,3], Adam Riess [4,5], Agnieszka Pollo [6],

Final Remarks

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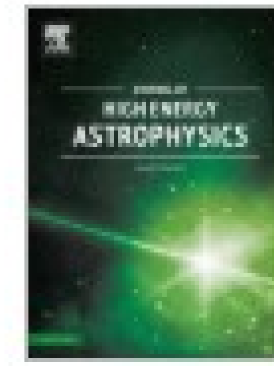
Journal of High Energy Astrophysics

Volume 34, June 2022, Pages 49-211

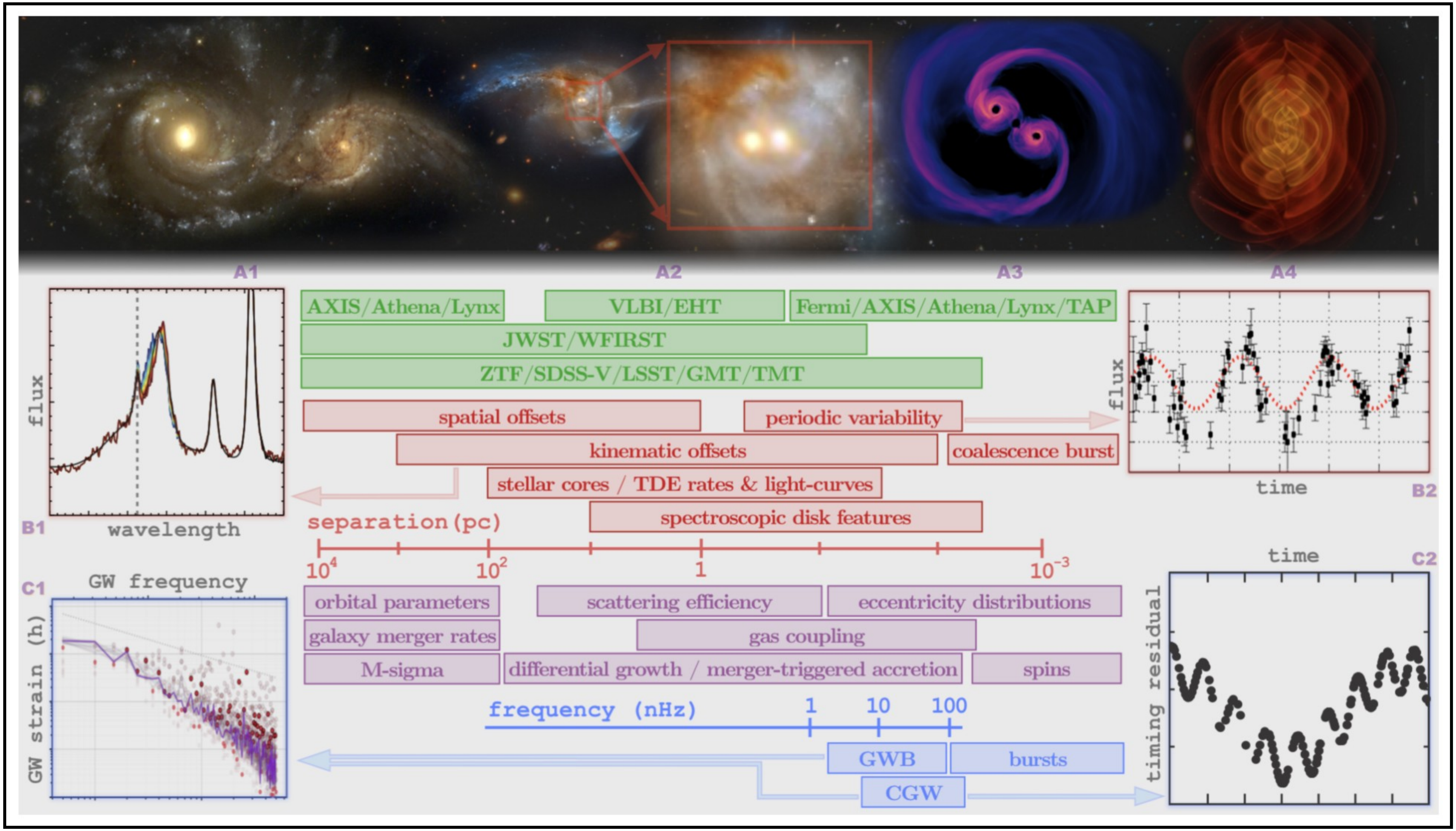


Review

Cosmology intertwined: A review of the particle physics, astrophysics, and cosmology associated with the cosmological tensions and anomalies

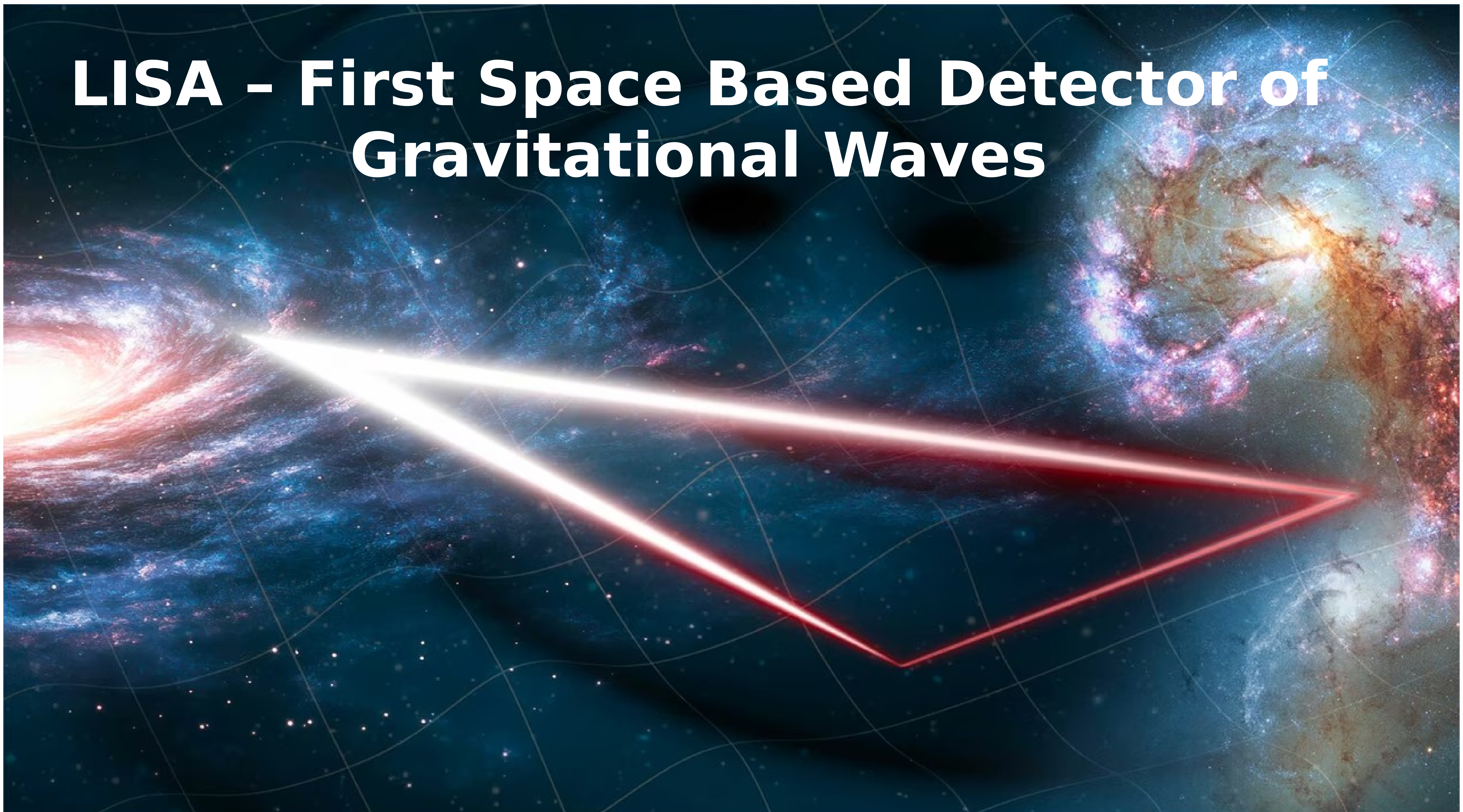
Elcio Abdalla [a], Guillermo Franco Abellán [b], Amin Aboubrahim [c], Adriano Agnello [d], Özgür Akarsu [e], Yashar Akrami [f g h i], George Alestas [j], Daniel Aloni [k], Luca Amendola [l],

Final Remarks The era of multi-messenger astronomy



Final Remarks

LISA CONSORTIUM We will observe gravitational waves in space



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Latinamerican proposal for a gravitational wave observatory

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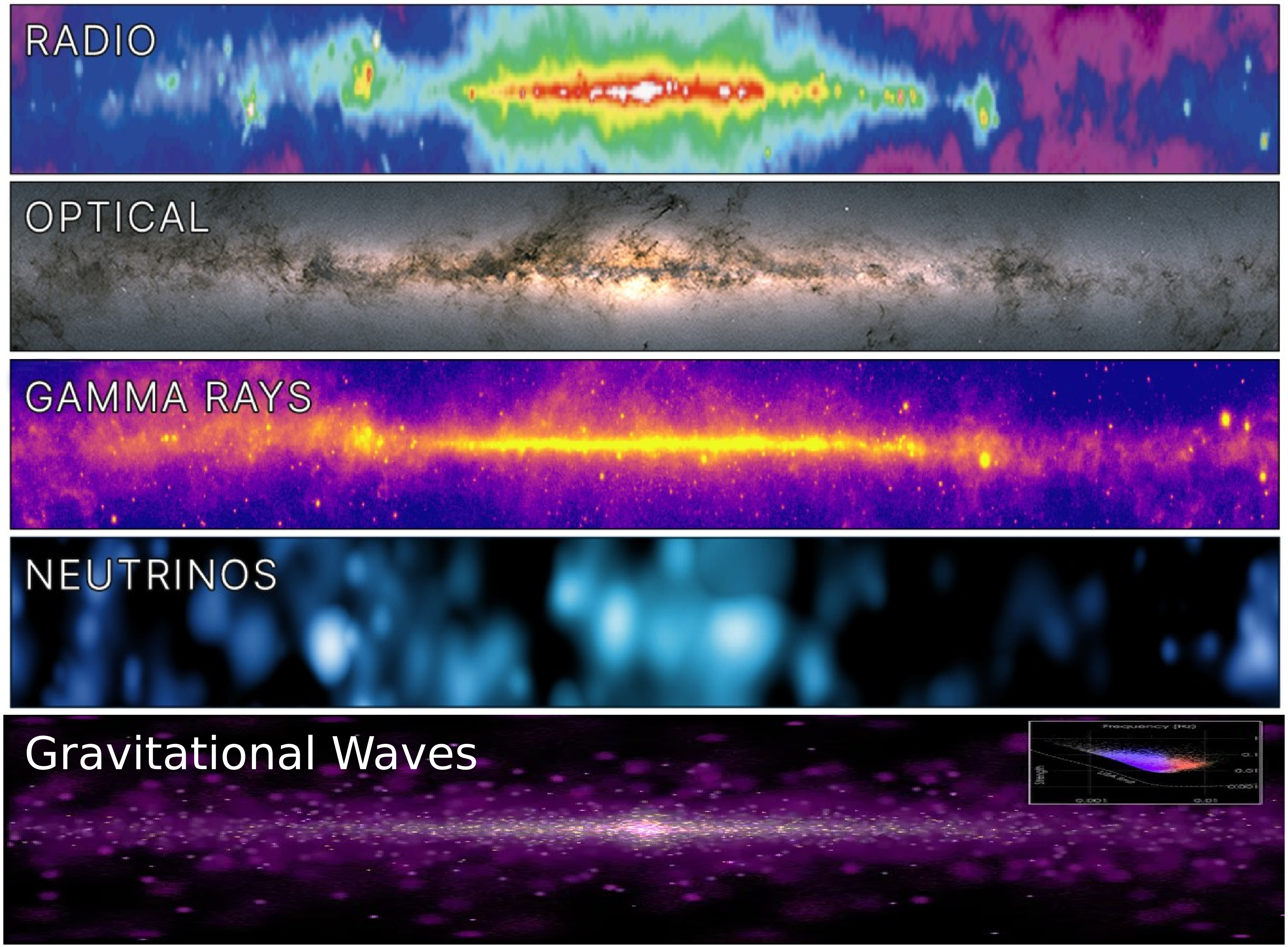

End...!

C A P E S

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FAPESP
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