Snowmass2021 - Letter of Interest

Cosmology Intertwined II: The Hubble Constant Tension

Thematic Areas: (check all that apply □/■)

■ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
■ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
□ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
□ (Other) *[Please specify frontier/topical group]*

Contact Information:
Eleonora Di Valentino (JBCA, University of Manchester, UK) [eleonora.divalentino@manchester.ac.uk]

Authors:

Eleonora Di Valentino (JBCA, University of Manchester, UK)
Luis A. Anchordoqui (City University of New York, USA)
Özgür Akarsu (Istanbul Technical University, Istanbul, Turkey)
Yacine Ali-Haimoud (New York University, USA)
Luca Amendola (University of Heidelberg, Germany)
Nikki Arendse (DARK, Niels Bohr Institute, Denmark)
Marika Asgari (University of Edinburgh, UK)
Mario Ballardini (Alma Mater Studiorum Università di Bologna, Italy)
Spyros Basilakos (Academy of Athens and Nat. Observatory of Athens, Greece)
Elia Battistelli (Sapienza Università di Roma and INFN sezione di Roma, Italy)
Micol Benetti (Università degli Studi di Napoli Federico II and INFN sezione di Napoli, Italy)
Simon Birrer (Stanford University, USA)
François R. Bouchet (Institut d'Astrophysique de Paris, CNRS & Sorbonne University, France)
Marco Bruni (Institute of Cosmology and Gravitation, Portsmouth, UK, and INFN Sezione di Trieste, Italy)
Erminia Calabrese (Cardiff University, UK)
David Camarena (Federal University of Espirito Santo, Brazil)
Salvatore Capozziello (Università degli Studi di Napoli Federico II, Napoli, Italy)
Angela Chen (University of Michigan, Ann Arbor, USA)
Jens Chluba (JBCA, University of Manchester, UK)
Anton Chudaykin (Institute for Nuclear Research, Russia)
Eoin Ó Colgáin (Asia Pacific Center for Theoretical Physics, Korea)
Francis-Yan Cyr-Racine (University of New Mexico, USA)
Paolo de Bernardis (Sapienza Università di Roma and INFN sezione di Roma, Italy)
Javier de Cruz Pérez (Departament FQA and ICCUB, Universitat de Barcelona, Spain)
Jacques Delabrouille (CNRS/IN2P3, Laboratoire APC, France & CEA/IRFU, France & USTC, China)

Jo Dunkley (Princeton University, USA)
Celia Escamilla-Rivera (ICN, Universidad Nacional Autónoma de México, Mexico)
Agnès Ferté (JPL, Caltech, Pasadena, USA)
Fabio Finelli (INAF OAS Bologna and INFN Sezione di Bologna, Italy)
Wendy Freedman (University of Chicago, Chicago IL, USA)
Noemi Frusciante (Instituto de Astrofísica e Ciências do Espaço, Lisboa, Portugal)
Elena Giusarma (Michigan Technological University, USA)
Adrià Gómez-Valent (University of Heidelberg, Germany)
Julien Guy (Lawrence Berkeley National Laboratory, USA)
Will Handley (University of Cambridge, UK)
Ian Harrison (JBCA, University of Manchester, UK)
Luke Hart (JBCA, University of Manchester, UK)
Alan Heavens (ICIC, Imperial College London, UK)
Hendrik Hildebrandt (Ruhr-University Bochum, Germany)
Daniel Holz (University of Chicago, Chicago IL, USA)
Dragan Huterer (University of Michigan, Ann Arbor, USA)
Mikhail M. Ivanov (New York University, USA)
Shahab Joudaki (University of Oxford, UK and University of Waterloo, Canada)
Marc Kamionkowski (Johns Hopkins University, Baltimore, MD, USA)
Tanvi Karwal (University of Pennsylvania, Philadelphia, USA)
Lloyd Knox (UC Davis, Davis CA, USA)
Suresh Kumar (BITS Pilani, Pilani Campus, India)
Luca Lamagna (Sapienza Università di Roma and INFN sezione di Roma, Italy)
Julien Lesgourgues (RWTH Aachen University)
Matteo Lucca (Université Libre de Bruxelles, Belgium)
Valerio Marra (Federal University of Espirito Santo, Brazil)
Silvia Masi (Sapienza Università di Roma and INFN sezione di Roma, Italy)
Sabino Matarrese (University of Padova and INFN Sezione di Padova, Italy)
Arindam Mazumdar (Centre for Theoretical Studies, IIT Kharagpur, India)
Alessandro Melchiorri (Sapienza Università di Roma and INFN sezione di Roma, Italy)
Olga Mena (IFIC, CSIC-UV, Spain)
Laura Mersini-Houghton (University of North Carolina at Chapel Hill, USA)
Vivian Miranda (University of Arizona, USA)
Cristian Moreno-Pulido (Departament FQA and ICCUB, Universitat de Barcelona, Spain)
David F. Mota (University of Oslo, Norway)
Jessica Muir (KIPAC, Stanford University, USA)
Ankan Mukherjee (Jamia Millia Islamia Central University, India)
Florian Niedermann (CP3-Origins, University of Southern Denmark)
Alessio Notari (ICCUB, Universitat de Barcelona, Spain)
Rafael C. Nunes (National Institute for Space Research, Brazil)
Francesco Pace (JBCA, University of Manchester, UK)
Andronikos Paliathanasis (DUT, South Africa and UACh, Chile)
Antonella Palmese (Fermi National Accelerator Laboratory, USA)
Supriya Pan (Presidency University, Kolkata, India)
Daniela Paoletti (INAF OAS Bologna and INFN Sezione di Bologna, Italy)
Valeria Pettorino (AIM, CEA, CNRS, Université Paris-Saclay, Université de Paris, France)
Francesco Piacentini (Sapienza Università di Roma and INFN sezione di Roma, Italy)
Vivian Poulin (LUPM, CNRS & University of Montpellier, France)

Marco Raveri (University of Pennsylvania, Philadelphia, USA)
Adam G. Riess (Johns Hopkins University, Baltimore, USA)
Vincenzo Salzano (University of Szczecin, Poland)
Emmanuel N. Saridakis (National Observatory of Athens, Greece)
Anjan A. Sen (Jamia Millia Islamia Central University New Delhi, India)
Arman Shafieloo (Korea Astronomy and Space Science Institute (KASI), Korea)
Anowar J. Shajib (University of California, Los Angeles, USA)
Joseph Silk (IAP Sorbonne University & CNRS, France, and Johns Hopkins University, USA)
Alessandra Silvestri (Leiden University, NL)
Martin S. Sloth (CP3-Origins, University of Southern Denmark)
Tristan L. Smith (Swarthmore College, Swarthmore, USA)
Joan Solà Peracaula (Departament FQA and ICCUB, Universitat de Barcelona, Spain)
Carsten van de Bruck (University of Sheffield, UK)
Licia Verde (ICREA, Universidad de Barcelona, Spain)
Luca Visinelli (GRAPPA, University of Amsterdam, NL)
Benjamin D. Wandelt (IAP Sorbonne University & CNRS, France, and CCA, USA)
Deng Wang (National Astronomical Observatories, CAS, China)
Jian-Min Wang (Key Laboratory for Particle Astrophysics, IHEP of the CAS, Beijing, China)
Anil K. Yadav (United College of Engg. & Research, GN, India)
Weiqiang Yang (Liaoning Normal University, Dalian, China)

Abstract: The current cosmological probes have provided a fantastic confirmation of the standard Λ Cold Dark Matter cosmological model, that has been constrained with unprecedented accuracy. However, with the increase of the experimental sensitivity a few statistically significant tensions between different independent cosmological datasets emerged. While these tensions can be in portion the result of systematic errors, the persistence after several years of accurate analysis strongly hints at cracks in the standard cosmological scenario and the need for new physics. In this Letter of Interest we will focus on the 4.4σ tension between the Planck estimate of the Hubble constant H_0 and the SH0ES collaboration measurements. After showing the H_0 evaluations made from different teams using different methods and geometric calibrations, we will list a few interesting new physics models that could solve this tension and discuss how the next decade experiments will be crucial.

State-of-the-art – The 2018 legacy release from the Planck satellite [1] of the Cosmic Microwave Background (CMB) anisotropies, has provided a fantastic confirmation of the standard Λ Cold Dark Matter (ΛCDM) cosmological model. However, the improvement in estimating the uncertainties has led to statistically-significant tensions in the measurement of various quantities between Planck and independent cosmological probes. While some proportion of these discrepancies may have a systematic origin, their magnitude and persistence across probes strongly hint at cracks in the standard cosmological scenario and the need for new physics. The most statistically significant tension is in the estimation of the *Hubble constant* H_0 between the CMB, assuming a ΛCDM model, and the direct local distance ladder measurements. In particular, the Planck collaboration [2] finds $H_0 = (67.27 \pm 0.60)$ km/s/Mpc[1]. This constraint is in tension at about 4.4σ with the 2019 SH0ES collaboration (R19 [3]) constraint, $H_0 = (74.03 \pm 1.42)$ km/s/Mpc, based on the analysis of the Hubble Space Telescope observations using 70 long-period Cepheids in the Large Magellanic Cloud.

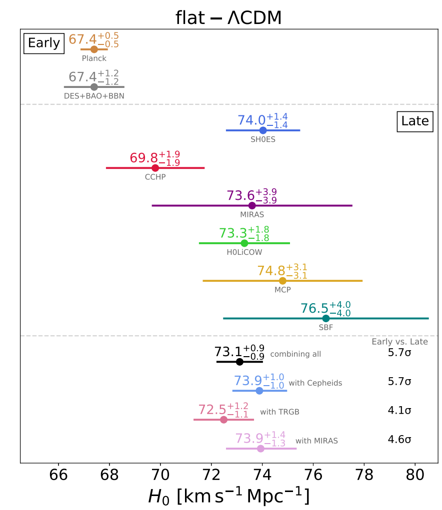

Figure 1: 68% CL constraint on H_0 from different cosmological probes (from Ref. [4]).

As shown in Fig. 1, preferring smaller values, we have the early universe estimates of H_0, as obtained by Planck or by ACT+WMAP[5] ($H_0 = (67.6 \pm 1.1)$ km/s/Mpc), and their combination with Baryon Acoustic Oscillation (BAO) data [6–8], the Y1 measurements of the Dark Energy Survey [9–11], supernovae from the Pantheon catalog [12], and a prior on the baryon density derived from measurements of primordial deuterium [13] assuming standard Big Bang Nucleosynthesis (BBN). A reanalysis of the BOSS full-shape data [14;15], as well as BAO+BBN [16] from BOSS and eBOSS provides $H_0 = (67.35 \pm 0.97)$, while SPTpol [17] finds $H_0 = (71.3 \pm 2.1)$ km/s/Mpc. In contrast, standard distance ladder and time delay distances agree on a low-z high-H_0 value, as the SH0ES estimate [18] $H_0 = (73.5 \pm 1.4)$ km/s/Mpc, and the H0LiCOW [19] inferred value $H_0 = (73.3^{+1.7}_{-1.8})$ km/s/Mpc, based on strong gravitational lensing effects on quasar systems. However, the strong lensing TDCOSMO+SLACS [20] sample prefers $H_0 = 67.4^{+4.1}_{-3.2}$ km/s/Mpc. Then, we have the reanalysis of the Cepheid data by using Bayesian hyper-parameters [21], the local determination of H_0 [22] considering the cosmographic expansion of the luminosity distance, the independent determination of H_0 based on the Tip of the Red Giant Branch [23–25], and that obtained by using the Surface Brightness Fluctuations method [4;26], or the Cosmic Chronometers [27–30]. Finally, a larger value for H_0 is preferred by MIRAS [31] (variable red giant stars), by STRIDES [32], using the Infrared [33] or Baryonic Tully–Fisher relation [34], or by Standardized Type II supernovae [35]. There is no single type of systematic measurement error in Cepheids which could solve the H_0 crisis, as speculated in [36] (e.g., it would not work for Cepheids calibrated in NGC 4258), and in any case it could not explain the final result from the Maser Cosmology Project [37], completely independent from these considerations, that finds $H_0 = (73.9 \pm 3.0)$ km/s/Mpc. If the late universe estimates are averaged in different combinations, these H_0 values disagree between 4.5σ and 6.3σ with those from Planck [38].

Possible solutions – Models addressing the H_0 tension are extremely difficult to concoct. The simplest possibility is a sample-variance effect, due to an underdense local universe. However, this is a factor of ~ 20 too small to explain the H_0 tension, and thus decisively ruled out [39;40]. This leaves a host of many proposed partial explanations [41–206], but none of them offer a fully satisfactory solution when all other data and parameters are taken into account [207–209]. The models can have a dark energy (DE) explanation or not:

- A DE component with an equation of state $w \neq -1$, i.e. allowing for deviation from the cosmolog-

[1] All the bounds are reported at 68% confidence level in the text.

ical constant Λ, both constant or dynamical with redshift[2;73–79]. These models usually solve the H_0 tension within two standard deviations at the price of a phantom-like DE, i.e. $w < -1$, because of the geometrical degeneracy present with the DE equation of state w.

- Early dark energy (EDE) which behaves like Λ at $z \geq 3000$ and decays away as radiation or faster at later times[80;81;210]. Related models include: *(i)* coupling of the EDE scalar to neutrinos[153]; *(ii)* a first-order phase transition in a dark sector before recombination which leads to a short phase of EDE[112]; *(iii)* an EDE model with an Anti-de Sitter phase around recombination[155;156]; *(iv)* an evolving scalar field asymptotically oscillating or with a non-canonical kinetic term[88;98], *(v)* an axion-like particle sourcing dark radiation[107], *(vi)* a scalar field with a potential inspired by ultra-light axions[96;97].
- Interacting dark energy (IDE) models, where dark matter (DM) and DE share interactions other than gravitational[52–64;211–214]. The IDE model solves the tension with R19 within one standard deviation, leading to a preference for a non-zero DE-DM coupling at more than 5 standard deviations[62;63], fixing the DE equation of state to a cosmological constant. However, this category can be further extended into two classes[63]: *(i)* models with $w < -1$ in which energy flows from DE to DM, *(ii)* models with $w > -1$ in which energy flows from DM to DE. Related models can be realized in string theory[163–165].
- Phenomenologically Emergent Dark Energy[173–178], where the H_0 tension with R19 is alleviated within one standard deviation without additional degrees of freedom with respect to ΛCDM.
- Extra relativistic degrees of freedom at recombination, parametrized by the number of equivalent light neutrino species $N_{\rm eff}$[215]. For three active massless neutrino families, $N_{\rm eff}^{\rm SM} \simeq 3.046$[216–218]. For the well-known degeneracy, we can increase H_0 at the price of additional radiation at recombination. Sterile neutrinos, Goldstone bosons, axions, and neutrino asymmetry are typical examples to enhance the value of $N_{\rm eff}$[138–151;219;220]. Future surveys will detect deviations from $N_{\rm eff}^{\rm SM}$ within $\Delta N_{\rm eff} \lesssim 0.06$ at 95% CL, allowing to probe a vast range of light relic models[221;222].
- Modified recombination and reionization histories through heating processes, variation of fundamental constants, or a non-standard CMB temperature-redshift relation[157–162].
- Modified Gravity models[166] in which gravity changes with redshift, such that the H_0 estimate from CMB can have larger values[167–172;223–226].
- Decaying dark matter[179–188] or interacting neutrinos[45;86;197].

Theoretical efforts to find a dynamic model describing the data have been placed side by side to kinematic models, as the cosmography, where the current expansion is a function of the cosmic time[227–229].

Standard Sirens – In the next decade an important role will be played by standard sirens (GWSS)[230–234], the gravitational-wave (GW) analog of astronomical standard candles. In fact, the observations of the merger of the binary neutron-star system GW170817[235] provided $H_0 = 70^{+12}_{-8}$ km/s/Mpc. While this constraint is significantly relaxed, it does not require any form of cosmic 'distance ladder' and it is model-independent. It can be important in an extended parameter space[236] in which CMB data are unable to strongly constrain H_0. At least 25 additional observations of GWSS[237] are needed to discriminate between Planck and R19. An uncertainty of $1-2\%$ in H_0 is expected in the early(mid)-2020s[232], from the analysis of GW events with electromagnetic counterparts. Finally, complementary dark GWSS, as the GW190814 in[238], are expected to provide a $1-4\%$ constraint on H_0 using the second generation of the detector networks[239;240].

Looking into the future – Solving the H_0 tension is very much an ongoing enterprise. The resolution of this conundrum will likely require a coordinated effort from the side of theory and interpretation (providing crucial tests of the exotic cosmologies), and data analysis and observation (expected to improve methods and disentangle systematics). This agenda will flourish in the next decade with future CMB experiments, as the Simon Observatory or CMB-S4, that combined with gigantic cosmic surveys, as Euclid and LSST, are expected to reach an uncertainty of $\sim 0.15\%$ in the H_0 estimate. In summary, the next decade will test the ΛCDM model and build the next-generation experiments that will usher in a new era of cosmology.

References

[1] **Planck** Collaboration, Y. Akrami *et al.*, "Planck 2018 results. I. Overview and the cosmological legacy of Planck," arXiv:1807.06205 [astro-ph.CO].

[2] **Planck** Collaboration, N. Aghanim *et al.*, "Planck 2018 results. VI. Cosmological parameters," arXiv:1807.06209 [astro-ph.CO].

[3] A. G. Riess, S. Casertano, W. Yuan, L. M. Macri, and D. Scolnic, "Large Magellanic Cloud Cepheid Standards Provide a 1% Foundation for the Determination of the Hubble Constant and Stronger Evidence for Physics beyond ΛCDM," *Astrophys. J.* **876** no. 1, (2019) 85, arXiv:1903.07603 [astro-ph.CO].

[4] L. Verde, T. Treu, and A. Riess, "Tensions between the Early and the Late Universe," arXiv:1907.10625 [astro-ph.CO].

[5] **ACT** Collaboration, S. Aiola *et al.*, "The Atacama Cosmology Telescope: DR4 Maps and Cosmological Parameters," arXiv:2007.07288 [astro-ph.CO].

[6] F. Beutler, C. Blake, M. Colless, D. H. Jones, L. Staveley-Smith, L. Campbell, Q. Parker, W. Saunders, and F. Watson, "The 6dF Galaxy Survey: Baryon Acoustic Oscillations and the Local Hubble Constant," *Mon. Not. Roy. Astron. Soc.* **416** (2011) 3017–3032, arXiv:1106.3366 [astro-ph.CO].

[7] A. J. Ross, L. Samushia, C. Howlett, W. J. Percival, A. Burden, and M. Manera, "The clustering of the SDSS DR7 main Galaxy sample – I. A 4 per cent distance measure at $z = 0.15$," *Mon. Not. Roy. Astron. Soc.* **449** no. 1, (2015) 835–847, arXiv:1409.3242 [astro-ph.CO].

[8] **BOSS** Collaboration, S. Alam *et al.*, "The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: cosmological analysis of the DR12 galaxy sample," *Mon. Not. Roy. Astron. Soc.* **470** no. 3, (2017) 2617–2652, arXiv:1607.03155 [astro-ph.CO].

[9] **DES** Collaboration, M. A. Troxel *et al.*, "Dark Energy Survey Year 1 results: Cosmological constraints from cosmic shear," *Phys. Rev.* **D98** no. 4, (2018) 043528, arXiv:1708.01538 [astro-ph.CO].

[10] **DES** Collaboration, T. M. C. Abbott *et al.*, "Dark Energy Survey year 1 results: Cosmological constraints from galaxy clustering and weak lensing," *Phys. Rev.* **D98** no. 4, (2018) 043526, arXiv:1708.01530 [astro-ph.CO].

[11] **DES** Collaboration, E. Krause *et al.*, "Dark Energy Survey Year 1 Results: Multi-Probe Methodology and Simulated Likelihood Analyses," arXiv:1706.09359 [astro-ph.CO].

[12] D. M. Scolnic *et al.*, "The Complete Light-curve Sample of Spectroscopically Confirmed SNe Ia from Pan-STARRS1 and Cosmological Constraints from the Combined Pantheon Sample," *Astrophys. J.* **859** no. 2, (2018) 101, arXiv:1710.00845 [astro-ph.CO].

[13] R. J. Cooke, M. Pettini, and C. C. Steidel, "One Percent Determination of the Primordial Deuterium Abundance," *Astrophys. J.* **855** no. 2, (2018) 102, arXiv:1710.11129 [astro-ph.CO].

[14] M. M. Ivanov, M. Simonović, and M. Zaldarriaga, "Cosmological Parameters from the BOSS Galaxy Power Spectrum," *JCAP* **05** (2020) 042, arXiv:1909.05277 [astro-ph.CO].

[15] G. D'Amico, J. Gleyzes, N. Kokron, D. Markovic, L. Senatore, P. Zhang, F. Beutler, and H. Gil-Marín, "The Cosmological Analysis of the SDSS/BOSS data from the Effective Field Theory of Large-Scale Structure," *JCAP* **05** (2020) 005, arXiv:1909.05271 [astro-ph.CO].

[16] **eBOSS** Collaboration, S. Alam *et al.*, "The Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: Cosmological Implications from two Decades of Spectroscopic Surveys at the Apache Point observatory," arXiv:2007.08991 [astro-ph.CO].

[17] **SPT** Collaboration, J. Henning *et al.*, "Measurements of the Temperature and E-Mode Polarization of the CMB from 500 Square Degrees of SPTpol Data," *Astrophys. J.* **852** no. 2, (2018) 97, arXiv:1707.09353 [astro-ph.CO].

[18] M. Reid, D. Pesce, and A. Riess, "An Improved Distance to NGC 4258 and its Implications for the Hubble Constant," *Astrophys. J. Lett.* **886** no. 2, (2019) L27, arXiv:1908.05625 [astro-ph.GA].

[19] K. C. Wong *et al.*, "H0LiCOW XIII. A 2.4% measurement of H_0 from lensed quasars: 5.3σ tension between early and late-Universe probes," arXiv:1907.04869 [astro-ph.CO].

[20] S. Birrer *et al.*, "TDCOSMO IV: Hierarchical time-delay cosmography – joint inference of the Hubble constant and galaxy density profiles," arXiv:2007.02941 [astro-ph.CO].

[21] W. Cardona, M. Kunz, and V. Pettorino, "Determining H_0 with Bayesian hyper-parameters," *JCAP* **1703** no. 03, (2017) 056, arXiv:1611.06088 [astro-ph.CO].

[22] D. Camarena and V. Marra, "Local determination of the Hubble constant and the deceleration parameter," *Phys. Rev. Res.* **2** no. 1, (2020) 013028, arXiv:1906.11814 [astro-ph.CO].

[23] W. L. Freedman *et al.*, "The Carnegie-Chicago Hubble Program. VIII. An Independent Determination of the Hubble Constant Based on the Tip of the Red Giant Branch," arXiv:1907.05922 [astro-ph.CO].

[24] W. Yuan, A. G. Riess, L. M. Macri, S. Casertano, and D. Scolnic, "Consistent Calibration of the Tip of the Red Giant Branch in the Large Magellanic Cloud on the Hubble Space Telescope Photometric System and a Re-determination of the Hubble Constant," *Astrophys. J.* **886** (2019) 61, arXiv:1908.00993 [astro-ph.GA].

[25] W. L. Freedman, B. F. Madore, T. Hoyt, I. S. Jang, R. Beaton, M. G. Lee, A. Monson, J. Neeley, and J. Rich, "Calibration of the Tip of the Red Giant Branch (TRGB)," arXiv:2002.01550 [astro-ph.GA].

[26] N. Khetan *et al.*, "A new measurement of the Hubble constant using Type Ia supernovae calibrated with surface brightness fluctuations," arXiv:2008.07754 [astro-ph.CO].

[27] H. Yu, B. Ratra, and F.-Y. Wang, "Hubble Parameter and Baryon Acoustic Oscillation Measurement Constraints on the Hubble Constant, the Deviation from the Spatially Flat ΛCDM Model, the Deceleration–Acceleration Transition Redshift, and Spatial Curvature," *Astrophys. J.* **856** no. 1, (2018) 3, arXiv:1711.03437 [astro-ph.CO].

[28] A. Gómez-Valent and L. Amendola, "H_0 from cosmic chronometers and Type Ia supernovae, with Gaussian processes and the weighted polynomial regression method," in *15th Marcel Grossmann Meeting on Recent Developments in Theoretical and Experimental General Relativity, Astrophysics, and Relativistic Field Theories*. 5, 2019. arXiv:1905.04052 [astro-ph.CO].

[29] B. S. Haridasu, V. V. Luković, M. Moresco, and N. Vittorio, "An improved model-independent assessment of the late-time cosmic expansion," *JCAP* **10** (2018) 015, arXiv:1805.03595 [astro-ph.CO].

[30] K. Dutta, A. Roy, Ruchika, A. A. Sen, and M. Sheikh-Jabbari, "Cosmology with low-redshift observations: No signal for new physics," *Phys. Rev. D* **100** no. 10, (2019) 103501, arXiv:1908.07267 [astro-ph.CO].

[31] C. D. Huang, A. G. Riess, W. Yuan, L. M. Macri, N. L. Zakamska, S. Casertano, P. A. Whitelock, S. L. Hoffmann, A. V. Filippenko, and D. Scolnic, "Hubble Space Telescope Observations of Mira Variables in the Type Ia Supernova Host NGC 1559: An Alternative Candle to Measure the Hubble Constant," arXiv:1908.10883 [astro-ph.CO].

[32] **DES** Collaboration, A. Shajib *et al.*, "STRIDES: a 3.9 per cent measurement of the Hubble constant from the strong lens system DES J0408-5354," *Mon. Not. Roy. Astron. Soc.* **494** no. 4, (2020) 6072–6102, arXiv:1910.06306 [astro-ph.CO].

[33] E. Kourkchi, R. B. Tully, G. S. Anand, H. M. Courtois, A. Dupuy, J. D. Neill, L. Rizzi, and M. Seibert, "Cosmicflows-4: The Calibration of Optical and Infrared Tully–Fisher Relations," *Astrophys. J.* **896** no. 1, (2020) 3, arXiv:2004.14499 [astro-ph.GA].

[34] J. Schombert, S. McGaugh, and F. Lelli, "Using The Baryonic Tully-Fisher Relation to Measure H_o," *Astron. J.* **160** no. 2, (2020) 71, arXiv:2006.08615 [astro-ph.CO].

[35] T. de Jaeger, B. Stahl, W. Zheng, A. Filippenko, A. Riess, and L. Galbany, "A measurement of the Hubble constant from Type II supernovae," arXiv:2006.03412 [astro-ph.CO].

[36] G. Efstathiou, "A Lockdown Perspective on the Hubble Tension (with comments from the SH0ES team)," arXiv:2007.10716 [astro-ph.CO].

[37] D. Pesce *et al.*, "The Megamaser Cosmology Project. XIII. Combined Hubble constant constraints," *Astrophys. J. Lett.* **891** no. 1, (2020) L1, arXiv:2001.09213 [astro-ph.CO].

[38] A. G. Riess, "The Expansion of the Universe is Faster than Expected," *Nature Rev. Phys.* **2** no. 1, (2019) 10–12, arXiv:2001.03624 [astro-ph.CO].

[39] H.-Y. Wu and D. Huterer, "Sample variance in the local measurements of the Hubble constant," *Mon. Not. Roy. Astron. Soc.* **471** no. 4, (2017) 4946–4955, arXiv:1706.09723 [astro-ph.CO].

[40] W. D. Kenworthy, D. Scolnic, and A. Riess, "The Local Perspective on the Hubble Tension: Local Structure Does Not Impact Measurement of the Hubble Constant," *Astrophys. J.* **875** no. 2, (2019) 145, arXiv:1901.08681 [astro-ph.CO].

[41] T. Tram, R. Vallance, and V. Vennin, "Inflation Model Selection meets Dark Radiation," *JCAP* **01** (2017) 046, arXiv:1606.09199 [astro-ph.CO].

[42] E. Di Valentino and L. Mersini-Houghton, "Testing Predictions of the Quantum Landscape Multiverse 2: The Exponential Inflationary Potential," *JCAP* **03** (2017) 020, arXiv:1612.08334 [astro-ph.CO].

[43] E. Di Valentino, A. Melchiorri, and J. Silk, "Reconciling Planck with the local value of H_0 in extended parameter space," *Phys. Lett.* **B761** (2016) 242–246, arXiv:1606.00634 [astro-ph.CO].

[44] J. L. Bernal, L. Verde, and A. G. Riess, "The trouble with H_0," *JCAP* **1610** no. 10, (2016) 019, arXiv:1607.05617 [astro-ph.CO].

[45] E. Di Valentino, C. Bøehm, E. Hivon, and F. R. Bouchet, "Reducing the H_0 and σ_8 tensions with Dark Matter-neutrino interactions," *Phys. Rev.* **D97** no. 4, (2018) 043513, arXiv:1710.02559 [astro-ph.CO].

[46] E. Di Valentino, E. V. Linder, and A. Melchiorri, "Vacuum phase transition solves the H_0 tension," *Phys. Rev.* **D97** no. 4, (2018) 043528, arXiv:1710.02153 [astro-ph.CO].

[47] T. Binder, M. Gustafsson, A. Kamada, S. M. R. Sandner, and M. Wiesner, "Reannihilation of self-interacting dark matter," *Phys. Rev.* **D97** no. 12, (2018) 123004, arXiv:1712.01246 [astro-ph.CO].

[48] N. Khosravi, S. Baghram, N. Afshordi, and N. Altamirano, "H_0 tension as a hint for a transition in gravitational theory," *Phys. Rev.* **D99** no. 10, (2019) 103526, arXiv:1710.09366 [astro-ph.CO].

[49] E. Di Valentino, A. Melchiorri, E. V. Linder, and J. Silk, "Constraining Dark Energy Dynamics in Extended Parameter Space," *Phys. Rev.* **D96** no. 2, (2017) 023523, arXiv:1704.00762 [astro-ph.CO].

[50] J. Renk, M. Zumalacárregui, F. Montanari, and A. Barreira, "Galileon gravity in light of ISW, CMB, BAO and H_0 data," *JCAP* **1710** no. 10, (2017) 020, arXiv:1707.02263 [astro-ph.CO].

[51] E. Di Valentino, "Crack in the cosmological paradigm," *Nat. Astron.* **1** no. 9, (2017) 569–570, arXiv:1709.04046 [physics.pop-ph].

[52] S. Kumar and R. C. Nunes, "Probing the interaction between dark matter and dark energy in the presence of massive neutrinos," *Phys. Rev.* **D94** no. 12, (2016) 123511, arXiv:1608.02454 [astro-ph.CO].

[53] E. Di Valentino, A. Melchiorri, and O. Mena, "Can interacting dark energy solve the H_0 tension?," *Phys. Rev.* **D96** no. 4, (2017) 043503, arXiv:1704.08342 [astro-ph.CO].

[54] S. Kumar and R. C. Nunes, "Echo of interactions in the dark sector," *Phys. Rev.* **D96** no. 10, (2017) 103511, arXiv:1702.02143 [astro-ph.CO].

[55] A. Gómez-Valent, V. Pettorino, and L. Amendola, "Update on coupled dark energy and the H_0 tension," *Phys. Rev. D* **101** no. 12, (2020) 123513, arXiv:2004.00610 [astro-ph.CO].

[56] M. Lucca and D. C. Hooper, "Tensions in the dark: shedding light on Dark Matter-Dark Energy interactions," arXiv:2002.06127 [astro-ph.CO].

[57] C. Van De Bruck and J. Mifsud, "Searching for dark matter - dark energy interactions: going beyond the conformal case," *Phys. Rev. D* **97** no. 2, (2018) 023506, arXiv:1709.04882 [astro-ph.CO].

[58] W. Yang, S. Pan, E. Di Valentino, R. C. Nunes, S. Vagnozzi, and D. F. Mota, "Tale of stable interacting dark energy, observational signatures, and the H_0 tension," *JCAP* **1809** no. 09, (2018) 019, arXiv:1805.08252 [astro-ph.CO].

[59] W. Yang, A. Mukherjee, E. Di Valentino, and S. Pan, "Interacting dark energy with time varying equation of state and the H_0 tension," *Phys. Rev.* **D98** no. 12, (2018) 123527, arXiv:1809.06883 [astro-ph.CO].

[60] W. Yang, O. Mena, S. Pan, and E. Di Valentino, "Dark sectors with dynamical coupling," *Phys. Rev.* **D100** no. 8, (2019) 083509, arXiv:1906.11697 [astro-ph.CO].

[61] M. Martinelli, N. B. Hogg, S. Peirone, M. Bruni, and D. Wands, "Constraints on the interacting vacuum–geodesic CDM scenario," *Mon. Not. Roy. Astron. Soc.* **488** no. 3, (2019) 3423–3438, arXiv:1902.10694 [astro-ph.CO].

[62] E. Di Valentino, A. Melchiorri, O. Mena, and S. Vagnozzi, "Interacting dark energy in the early 2020s: a promising solution to the H_0 and cosmic shear tensions," *Phys. Dark Univ.* **30** (2020) 100666, arXiv:1908.04281 [astro-ph.CO].

[63] E. Di Valentino, A. Melchiorri, O. Mena, and S. Vagnozzi, "Nonminimal dark sector physics and cosmological tensions," *Phys. Rev. D* **101** no. 6, (2020) 063502, arXiv:1910.09853 [astro-ph.CO].

[64] G. Benevento, W. Hu, and M. Raveri, "Can Late Dark Energy Transitions Raise the Hubble constant?," arXiv:2002.11707 [astro-ph.CO].

[65] E. Belgacem, Y. Dirian, S. Foffa, and M. Maggiore, "Nonlocal gravity. Conceptual aspects and cosmological predictions," *JCAP* **1803** no. 03, (2018) 002, arXiv:1712.07066 [hep-th].

[66] D. Fernández Arenas, E. Terlevich, R. Terlevich, J. Melnick, R. Chávez, F. Bresolin, E. Telles, M. Plionis, and S. Basilakos, "An independent determination of the local Hubble constant," *Mon. Not. Roy. Astron. Soc.* **474** no. 1, (2018) 1250–1276, arXiv:1710.05951 [astro-ph.CO].

[67] J. Solà, A. Gómez-Valent, and J. de Cruz Pérez, "The H_0 tension in light of vacuum dynamics in the Universe," *Phys. Lett.* **B774** (2017) 317–324, arXiv:1705.06723 [astro-ph.CO].

[68] R. C. Nunes, "Structure formation in $f(T)$ gravity and a solution for H_0 tension," *JCAP* **1805** no. 05, (2018) 052, arXiv:1802.02281 [gr-qc].

[69] E. Ó Colgáin, M. H. P. M. van Putten, and H. Yavartanoo, "de Sitter Swampland, H_0 tension & observation," *Phys. Lett.* **B793** (2019) 126–129, arXiv:1807.07451 [hep-th].

[70] F. D'Eramo, R. Z. Ferreira, A. Notari, and J. L. Bernal, "Hot Axions and the H_0 tension," *JCAP* **1811** no. 11, (2018) 014, arXiv:1808.07430 [hep-ph].

[71] R.-Y. Guo, J.-F. Zhang, and X. Zhang, "Can the H_0 tension be resolved in extensions to ΛCDM cosmology?," *JCAP* **1902** (2019) 054, arXiv:1809.02340 [astro-ph.CO].

[72] M.-X. Lin, M. Raveri, and W. Hu, "Phenomenology of Modified Gravity at Recombination," *Phys. Rev.* **D99** no. 4, (2019) 043514, arXiv:1810.02333 [astro-ph.CO].

[73] W. Yang, S. Pan, E. Di Valentino, E. N. Saridakis, and S. Chakraborty, "Observational constraints on one-parameter dynamical dark-energy parametrizations and the H_0 tension," *Phys. Rev.* **D99** no. 4, (2019) 043543, arXiv:1810.05141 [astro-ph.CO].

[74] S. Vagnozzi, "New physics in light of the H_0 tension: an alternative view," *Phys. Rev. D* **102** no. 2, (2020) 023518, arXiv:1907.07569 [astro-ph.CO].

[75] E. Di Valentino, A. Melchiorri, and J. Silk, "Cosmological constraints in extended parameter space from the Planck 2018 Legacy release," *JCAP* **01** (2020) 013, arXiv:1908.01391 [astro-ph.CO].

[76] E. Di Valentino, A. Mukherjee, and A. A. Sen, "Dark Energy with Phantom Crossing and the H_0 tension," arXiv:2005.12587 [astro-ph.CO].

[77] R. E. Keeley, S. Joudaki, M. Kaplinghat, and D. Kirkby, "Implications of a transition in the dark energy equation of state for the H_0 and σ_8 tensions," *JCAP* **12** (2019) 035, arXiv:1905.10198 [astro-ph.CO].

[78] S. Joudaki *et al.*, "KiDS-450: Testing extensions to the standard cosmological model," *Mon. Not. Roy. Astron. Soc.* **471** no. 2, (2017) 1259–1279, arXiv:1610.04606 [astro-ph.CO].

[79] W. Yang, S. Pan, E. Di Valentino, and E. N. Saridakis, "Observational constraints on dynamical dark energy with pivoting redshift," *Universe* **5** no. 11, (2019) 219, arXiv:1811.06932 [astro-ph.CO].

[80] V. Poulin, T. L. Smith, T. Karwal, and M. Kamionkowski, "Early Dark Energy Can Resolve The Hubble Tension," *Phys. Rev. Lett.* **122** no. 22, (2019) 221301, arXiv:1811.04083 [astro-ph.CO].

[81] T. Karwal and M. Kamionkowski, "Dark energy at early times, the Hubble parameter, and the string axiverse," *Phys. Rev. D* **94** no. 10, (2016) 103523, arXiv:1608.01309 [astro-ph.CO].

[82] A. Banihashemi, N. Khosravi, and A. H. Shirazi, "Phase transition in the dark sector as a proposal to lessen cosmological tensions," *Phys. Rev. D* **101** no. 12, (2020) 123521, arXiv:1808.02472 [astro-ph.CO].

[83] A. Banihashemi, N. Khosravi, and A. H. Shirazi, "Ginzburg-Landau Theory of Dark Energy: A Framework to Study Both Temporal and Spatial Cosmological Tensions Simultaneously," *Phys. Rev.* **D99** no. 8, (2019) 083509, arXiv:1810.11007 [astro-ph.CO].

[84] E. Mörtsell and S. Dhawan, "Does the Hubble constant tension call for new physics?," *JCAP* **1809** no. 09, (2018) 025, arXiv:1801.07260 [astro-ph.CO].

[85] X. Zhang and Q.-G. Huang, "Constraints on H_0 from WMAP and BAO Measurements," *Commun. Theor. Phys.* **71** no. 7, (2019) 826–830, arXiv:1812.01877 [astro-ph.CO].

[86] C. D. Kreisch, F.-Y. Cyr-Racine, and O. Doré, "The Neutrino Puzzle: Anomalies, Interactions, and Cosmological Tensions," *Phys. Rev. D* **101** no. 12, (2020) 123505, arXiv:1902.00534 [astro-ph.CO].

[87] S. Kumar, R. C. Nunes, and S. K. Yadav, "Dark sector interaction: a remedy of the tensions between CMB and LSS data," *Eur. Phys. J.* **C79** no. 7, (2019) 576, arXiv:1903.04865 [astro-ph.CO].

[88] P. Agrawal, F.-Y. Cyr-Racine, D. Pinner, and L. Randall, "Rock 'n' Roll Solutions to the Hubble Tension," arXiv:1904.01016 [astro-ph.CO].

[89] W. Yang, S. Pan, A. Paliathanasis, S. Ghosh, and Y. Wu, "Observational constraints of a new unified dark fluid and the H_0 tension," *Mon. Not. Roy. Astron. Soc.* **490** no. 2, (2019) 2071–2085, arXiv:1904.10436 [gr-qc].

[90] W. Yang, S. Pan, E. Di Valentino, A. Paliathanasis, and J. Lu, "Challenging bulk viscous unified scenarios with cosmological observations," *Phys. Rev.* **D100** no. 10, (2019) 103518, arXiv:1906.04162 [astro-ph.CO].

[91] E. Di Valentino, R. Z. Ferreira, L. Visinelli, and U. Danielsson, "Late time transitions in the quintessence field and the H_0 tension," *Phys. Dark Univ.* **26** (2019) 100385, arXiv:1906.11255 [astro-ph.CO].

[92] H. Desmond, B. Jain, and J. Sakstein, "Local resolution of the Hubble tension: The impact of screened fifth forces on the cosmic distance ladder," *Phys. Rev.* **D100** no. 4, (2019) 043537, arXiv:1907.03778 [astro-ph.CO].

[93] W. Yang, S. Pan, S. Vagnozzi, E. Di Valentino, D. F. Mota, and S. Capozziello, "Dawn of the dark: unified dark sectors and the EDGES Cosmic Dawn 21-cm signal," *JCAP* **1911** (2019) 044, arXiv:1907.05344 [astro-ph.CO].

[94] S. Pan, W. Yang, E. Di Valentino, E. N. Saridakis, and S. Chakraborty, "Interacting scenarios with dynamical dark energy: Observational constraints and alleviation of the H_0 tension," *Phys. Rev.* **D100** no. 10, (2019) 103520, arXiv:1907.07540 [astro-ph.CO].

[95] L. Visinelli, S. Vagnozzi, and U. Danielsson, "Revisiting a negative cosmological constant from low-redshift data," *Symmetry* **11** no. 8, (2019) 1035, arXiv:1907.07953 [astro-ph.CO].

[96] T. L. Smith, V. Poulin, and M. A. Amin, "Oscillating scalar fields and the Hubble tension: a resolution with novel signatures," *Phys. Rev. D* **101** no. 6, (2020) 063523, arXiv:1908.06995 [astro-ph.CO].

[97] M. Lucca, "The role of CMB spectral distortions in the Hubble tension: a proof of principle," arXiv:2008.01115 [astro-ph.CO].

[98] M.-X. Lin, G. Benevento, W. Hu, and M. Raveri, "Acoustic Dark Energy: Potential Conversion of the Hubble Tension," *Phys. Rev. D* **100** no. 6, (2019) 063542, arXiv:1905.12618 [astro-ph.CO].

[99] M. Martinelli and I. Tutusaus, "CMB tensions with low-redshift H_0 and S_8 measurements: impact of a redshift-dependent type-Ia supernovae intrinsic luminosity," *Symmetry* **11** no. 8, (2019) 986, arXiv:1906.09189 [astro-ph.CO].

[100] Y.-F. Cai, M. Khurshudyan, and E. N. Saridakis, "Model-independent reconstruction of $f(T)$ gravity from Gaussian Processes," *Astrophys. J.* **888** (2020) 62, arXiv:1907.10813 [astro-ph.CO].

[101] N. Schöneberg, J. Lesgourgues, and D. C. Hooper, "The BAO+BBN take on the Hubble tension," *JCAP* **1910** no. 10, (2019) 029, arXiv:1907.11594 [astro-ph.CO].

[102] A. Shafieloo, D. K. Hazra, V. Sahni, and A. A. Starobinsky, "Metastable Dark Energy with Radioactive-like Decay," *Mon. Not. Roy. Astron. Soc.* **473** no. 2, (2018) 2760–2770, arXiv:1610.05192 [astro-ph.CO].

[103] X. Li, A. Shafieloo, V. Sahni, and A. A. Starobinsky, "Revisiting Metastable Dark Energy and Tensions in the Estimation of Cosmological Parameters," *Astrophys. J.* **887** (4, 2019) 153, arXiv:1904.03790 [astro-ph.CO].

[104] A. Cuceu, J. Farr, P. Lemos, and A. Font-Ribera, "Baryon Acoustic Oscillations and the Hubble Constant: Past, Present and Future," *JCAP* **1910** no. 10, (2019) 044, arXiv:1906.11628 [astro-ph.CO].

[105] E. . Colgáin and H. Yavartanoo, "Testing the Swampland: H_0 tension," *Phys. Lett.* **B797** (2019) 134907, arXiv:1905.02555 [astro-ph.CO].

[106] S. Pan, W. Yang, C. Singha, and E. N. Saridakis, "Observational constraints on sign-changeable interaction models and alleviation of the H_0 tension," *Phys. Rev.* **D100** no. 8, (2019) 083539, arXiv:1903.10969 [astro-ph.CO].

[107] K. V. Berghaus and T. Karwal, "Thermal Friction as a Solution to the Hubble Tension," *Phys. Rev. D* **101** no. 8, (2020) 083537, arXiv:1911.06281 [astro-ph.CO].

[108] L. Knox and M. Millea, "Hubble constant hunter's guide," *Phys. Rev. D* **101** no. 4, (2020) 043533, arXiv:1908.03663 [astro-ph.CO].

[109] K. L. Pandey, T. Karwal, and S. Das, "Alleviating the H_0 and σ_8 anomalies with a decaying dark matter model," *JCAP* **07** (2020) 026, arXiv:1902.10636 [astro-ph.CO].

[110] S. Adhikari and D. Huterer, "Super-CMB fluctuations and the Hubble tension," *Phys. Dark Univ.* **28** (2020) 100539, arXiv:1905.02278 [astro-ph.CO].

[111] L. Lancaster, F.-Y. Cyr-Racine, L. Knox, and Z. Pan, "A tale of two modes: Neutrino free-streaming in the early universe," *JCAP* **1707** no. 07, (2017) 033, arXiv:1704.06657 [astro-ph.CO].

[112] F. Niedermann and M. S. Sloth, "New Early Dark Energy," arXiv:1910.10739 [astro-ph.CO].

[113] S. K. Yadav, "Constraints on Dark Matter-Photon Coupling in the Presence of Time-Varying Dark Energy," *Mod. Phys. Lett.* **A33** (2019) 1950358, arXiv:1907.05886 [astro-ph.CO].

[114] M. Kasai and T. Futamase, "A possible solution to the Hubble constant discrepancy – Cosmology where the local volume expansion is driven by the domain average density," *PTEP* **2019** no. 7, (2019) 073E01, arXiv:1904.09689 [gr-qc].

[115] H. Amirhashchi and A. K. Yadav, "Interacting Dark Sectors in Anisotropic Universe: Observational Constraints and H_0 Tension," arXiv:2001.03775 [astro-ph.CO].

[116] A. Perez, D. Sudarsky, and E. Wilson-Ewing, "Resolving the H_0 tension with diffusion," arXiv:2001.07536 [astro-ph.CO].

[117] S. Pan, W. Yang, and A. Paliathanasis, "Non-linear interacting cosmological models after Planck 2018 legacy release and the H_0 tension," *Mon. Not. Roy. Astron. Soc.* **493** no. 3, (2020) 3114–3131, arXiv:2002.03408 [astro-ph.CO].

[118] R. D'Agostino and R. C. Nunes, "Measurements of H_0 in modified gravity theories," arXiv:2002.06381 [astro-ph.CO].

[119] K. Liao, A. Shafieloo, R. E. Keeley, and E. V. Linder, "Determining H_0 Model-Independently and Consistency Tests," arXiv:2002.10605 [astro-ph.CO].

[120] W. Yang, E. Di Valentino, S. Pan, S. Basilakos, and A. Paliathanasis, "Metastable dark energy models in light of Planck 2018: Alleviating the H_0 tension," arXiv:2001.04307 [astro-ph.CO].

[121] S. Pan, G. S. Sharov, and W. Yang, "Field theoretic interpretations of interacting dark energy scenarios and recent observations," *Phys. Rev. D* **101** no. 10, (2020) 103533, arXiv:2001.03120 [astro-ph.CO].

[122] W. K. Wu, P. Motloch, W. Hu, and M. Raveri, "Hubble constant tension between CMB lensing and BAO measurements," arXiv:2004.10207 [astro-ph.CO].

[123] N. Blinov and G. Marques-Tavares, "Interacting radiation after Planck and its implications for the Hubble Tension," arXiv:2003.08387 [astro-ph.CO].

[124] D. Wang and D. Mota, "Can $f(T)$ gravity resolve the H_0 tension?," arXiv:2003.10095 [astro-ph.CO].

[125] A. Chudaykin, D. Gorbunov, and N. Nedelko, "Combined analysis of Planck and SPTPol data favors the early dark energy models," arXiv:2004.13046 [astro-ph.CO].

[126] G. Alestas, L. Kazantzidis, and L. Perivolaropoulos, "H_0 Tension, Phantom Dark Energy and Cosmological Parameter Degeneracies," *Phys. Rev. D* **101** no. 12, (2020) 123516, arXiv:2004.08363 [astro-ph.CO].

[127] S. J. Clark, K. Vattis, and S. M. Koushiappas, "CMB constraints on late-universe decaying dark matter as a solution to the H_0 tension," arXiv:2006.03678 [astro-ph.CO].

[128] R. E. Keeley, A. Shafieloo, D. K. Hazra, and T. Souradeep, "Inflation Wars: A New Hope," arXiv:2006.12710 [astro-ph.CO].

[129] F. Niedermann and M. S. Sloth, "Resolving the Hubble Tension with New Early Dark Energy," arXiv:2006.06686 [astro-ph.CO].

[130] M. Archidiacono, S. Gariazzo, C. Giunti, S. Hannestad, and T. Tram, "Sterile neutrino self-interactions: H_0 tension and short-baseline anomalies," arXiv:2006.12885 [astro-ph.CO].

[131] E. Di Valentino, E. V. Linder, and A. Melchiorri, "H_0 Ex Machina: Vacuum Metamorphosis and Beyond H_0," arXiv:2006.16291 [astro-ph.CO].

[132] S. Capozziello, M. Benetti, and A. D. Spallicci, "Addressing the cosmological H_0 tension by the Heisenberg uncertainty," arXiv:2007.00462 [gr-qc].

[133] L. A. Anchordoqui and S. E. Perez Bergliaffa, "Hot thermal universe endowed with massive dark vector fields and the Hubble tension," *Phys. Rev. D* **100** no. 12, (2019) 123525, arXiv:1910.05860 [astro-ph.CO].

[134] M. M. Ivanov, Y. Ali-Haïmoud, and J. Lesgourgues, "H0 tension or T0 tension?," arXiv:2005.10656 [astro-ph.CO].

[135] M. Gonzalez, M. P. Hertzberg, and F. Rompineve, "Ultralight Scalar Decay and the Hubble Tension," arXiv:2006.13959 [astro-ph.CO].

[136] A. Hryczuk and K. Jodł owski, "Self-interacting dark matter from late decays and the H_0 tension," arXiv:2006.16139 [hep-ph].

[137] E. J. Baxter and B. D. Sherwin, "Determining the Hubble Constant without the Sound Horizon Scale: Measurements from CMB Lensing," arXiv:2007.04007 [astro-ph.CO].

[138] L. A. Anchordoqui and H. Goldberg, "Neutrino cosmology after WMAP 7-Year data and LHC first Z' bounds," *Phys. Rev. Lett.* **108** (2012) 081805, arXiv:1111.7264 [hep-ph].

[139] T. D. Jacques, L. M. Krauss, and C. Lunardini, "Additional Light Sterile Neutrinos and Cosmology," *Phys. Rev. D* **87** no. 8, (2013) 083515, arXiv:1301.3119 [astro-ph.CO]. [Erratum: Phys.Rev.D 88, 109901 (2013)].

[140] S. Weinberg, "Goldstone Bosons as Fractional Cosmic Neutrinos," *Phys. Rev. Lett.* **110** no. 24, (2013) 241301, arXiv:1305.1971 [astro-ph.CO].

[141] L. A. Anchordoqui, H. Goldberg, and G. Steigman, "Right-Handed Neutrinos as the Dark Radiation: Status and Forecasts for the LHC," *Phys. Lett. B* **718** (2013) 1162–1165, arXiv:1211.0186 [hep-ph].

[142] S. Carneiro, P. C. de Holanda, C. Pigozzo, and F. Sobreira, "Is the H_0 tension suggesting a fourth neutrino generation?," *Phys. Rev.* **D100** no. 2, (2019) 023505, arXiv:1812.06064 [astro-ph.CO].

[143] A. Paul, A. Ghoshal, A. Chatterjee, and S. Pal, "Inflation, (P)reheating and Neutrino Anomalies: Production of Sterile Neutrinos with Secret Interactions," *Eur. Phys. J.* **C79** no. 10, (2019) 818, arXiv:1808.09706 [astro-ph.CO].

[144] E. Di Valentino, E. Giusarma, O. Mena, A. Melchiorri, and J. Silk, "Cosmological limits on neutrino unknowns versus low redshift priors," *Phys. Rev.* **D93** no. 8, (2016) 083527, arXiv:1511.00975 [astro-ph.CO].

[145] D. Green *et al.*, "Messengers from the Early Universe: Cosmic Neutrinos and Other Light Relics," *Bull. Am. Astron. Soc.* **51** no. 7, (2019) 159, arXiv:1903.04763 [astro-ph.CO].

[146] G. Barenboim, W. H. Kinney, and W.-I. Park, "Flavor versus mass eigenstates in neutrino asymmetries: implications for cosmology," *Eur. Phys. J. C* **77** no. 9, (2017) 590, arXiv:1609.03200 [astro-ph.CO].

[147] R. Z. Ferreira and A. Notari, "Observable Windows for the QCD Axion Through the Number of Relativistic Species," *Phys. Rev. Lett.* **120** no. 19, (2018) 191301, arXiv:1801.06090 [hep-ph].

[148] G. B. Gelmini, A. Kusenko, and V. Takhistov, "Hints of Sterile Neutrinos in Recent Measurements of the Hubble Parameter," arXiv:1906.10136 [astro-ph.CO].

[149] E. Di Valentino, E. Giusarma, M. Lattanzi, O. Mena, A. Melchiorri, and J. Silk, "Cosmological Axion and neutrino mass constraints from Planck 2015 temperature and polarization data," *Phys. Lett.* **B752** (2016) 182–185, arXiv:1507.08665 [astro-ph.CO].

[150] V. Poulin, T. L. Smith, D. Grin, T. Karwal, and M. Kamionkowski, "Cosmological implications of ultralight axionlike fields," *Phys. Rev. D* **98** no. 8, (2018) 083525, arXiv:1806.10608 [astro-ph.CO].

[151] D. Baumann, D. Green, and B. Wallisch, "New Target for Cosmic Axion Searches," *Phys. Rev. Lett.* **117** no. 17, (2016) 171301, arXiv:1604.08614 [astro-ph.CO].

[152] L. A. Anchordoqui, "Hubble Hullabaloo and String Cosmology," 5, 2020. arXiv:2005.01217 [astro-ph.CO].

[153] J. Sakstein and M. Trodden, "Early Dark Energy from Massive Neutrinos as a Natural Resolution of the Hubble Tension," *Phys. Rev. Lett.* **124** no. 16, (2020) 161301, arXiv:1911.11760 [astro-ph.CO].

[154] A. Gogoi, P. Chanda, and S. Das, "Dark matter nugget and new early dark energy from interacting neutrino: A promising solution to Hubble anomaly," arXiv:2005.11889 [astro-ph.CO].

[155] Ö. Akarsu, J. D. Barrow, L. A. Escamilla, and J. A. Vazquez, "Graduated dark energy: Observational hints of a spontaneous sign switch in the cosmological constant," *Phys. Rev. D* **101** no. 6, (2020) 063528, arXiv:1912.08751 [astro-ph.CO].

[156] G. Ye and Y.-S. Piao, "Is the Hubble tension a hint of AdS around recombination?," arXiv:2001.02451 [astro-ph.CO].

[157] L. Hart and J. Chluba, "New constraints on time-dependent variations of fundamental constants using Planck data," *Mon. Not. Roy. Astron. Soc.* **474** no. 2, (2018) 1850–1861, arXiv:1705.03925 [astro-ph.CO].

[158] C.-T. Chiang and A. z. Slosar, "Inferences of H_0 in presence of a non-standard recombination," arXiv:1811.03624 [astro-ph.CO].

[159] L. Hart and J. Chluba, "Updated fundamental constant constraints from Planck 2018 data and possible relations to the Hubble tension," *Mon. Not. Roy. Astron. Soc.* **493** no. 3, (2020) 3255–3263, arXiv:1912.03986 [astro-ph.CO].

[160] K. Jedamzik and L. Pogosian, "Relieving the Hubble tension with primordial magnetic fields," arXiv:2004.09487 [astro-ph.CO].

[161] T. Sekiguchi and T. Takahashi, "Early recombination as a solution to the H_0 tension," arXiv:2007.03381 [astro-ph.CO].

[162] B. Bose and L. Lombriser, "Easing cosmic tensions with an open and hotter universe," arXiv:2006.16149 [astro-ph.CO].

[163] P. Agrawal, G. Obied, and C. Vafa, "H_0 Tension, Swampland Conjectures and the Epoch of Fading Dark Matter," arXiv:1906.08261 [astro-ph.CO].

[164] L. A. Anchordoqui, I. Antoniadis, D. Lüst, J. F. Soriano, and T. R. Taylor, "H_0 tension and the String Swampland," *Phys. Rev. D* **101** (2020) 083532, arXiv:1912.00242 [hep-th].

[165] L. A. Anchordoqui, I. Antoniadis, D. Lüst, and J. F. Soriano, "Dark energy, Ricci-nonflat spaces, and the Swampland," arXiv:2005.10075 [hep-th].

[166] **Planck** Collaboration, P. A. R. Ade *et al.*, "Planck 2015 results. XIV. Dark energy and modified gravity," *Astron. Astrophys.* **594** (2016) A14, arXiv:1502.01590 [astro-ph.CO].

[167] M. Raveri, "Reconstructing Gravity on Cosmological Scales," *Phys. Rev. D* **101** no. 8, (2020) 083524, arXiv:1902.01366 [astro-ph.CO].

[168] S.-F. Yan, P. Zhang, J.-W. Chen, X.-Z. Zhang, Y.-F. Cai, and E. N. Saridakis, “Interpreting cosmological tensions from the effective field theory of torsional gravity,” *Phys. Rev. D* **101** no. 12, (2020) 121301, arXiv:1909.06388 [astro-ph.CO].

[169] N. Frusciante, S. Peirone, L. Atayde, and A. De Felice, “Phenomenology of the generalized cubic covariant Galileon model and cosmological bounds,” *Phys. Rev. D* **101** no. 6, (2020) 064001, arXiv:1912.07586 [astro-ph.CO].

[170] M. Braglia, M. Ballardini, W. T. Emond, F. Finelli, A. E. Gumrukcuoglu, K. Koyama, and D. Paoletti, “A larger value for H_0 by an evolving gravitational constant,” arXiv:2004.11161 [astro-ph.CO].

[171] M. Ballardini, M. Braglia, F. Finelli, D. Paoletti, A. A. Starobinsky, and C. Umiltà, “Scalar-tensor theories of gravity, neutrino physics, and the H_0 tension,” arXiv:2004.14349 [astro-ph.CO].

[172] M. Rossi, M. Ballardini, M. Braglia, F. Finelli, D. Paoletti, A. A. Starobinsky, and C. Umiltà, “Cosmological constraints on post-Newtonian parameters in effectively massless scalar-tensor theories of gravity,” *Phys. Rev. D* **100** no. 10, (2019) 103524, arXiv:1906.10218 [astro-ph.CO].

[173] S. Pan, W. Yang, E. Di Valentino, A. Shafieloo, and S. Chakraborty, “Reconciling H_0 tension in a six parameter space?,” *JCAP* **06** (2020) 062, arXiv:1907.12551 [astro-ph.CO].

[174] X. Li and A. Shafieloo, “A Simple Phenomenological Emergent Dark Energy Model can Resolve the Hubble Tension,” *Astrophys. J. Lett.* **883** no. 1, (2019) L3, arXiv:1906.08275 [astro-ph.CO].

[175] M. Rezaei, T. Naderi, M. Malekjani, and A. Mehrabi, “A Bayesian comparison between ΛCDM and phenomenologically emergent dark energy models,” *Eur. Phys. J. C* **80** no. 5, (2020) 374, arXiv:2004.08168 [astro-ph.CO].

[176] Z. Liu and H. Miao, “Neutrino mass and mass hierarchy in various dark energy,” arXiv:2002.05563 [astro-ph.CO].

[177] X. Li and A. Shafieloo, “Generalised Emergent Dark Energy Model: Confronting Λ and PEDE,” arXiv:2001.05103 [astro-ph.CO].

[178] W. Yang, E. Di Valentino, O. Mena, and S. Pan, “Dynamical Dark sectors and Neutrino masses and abundances,” *Phys. Rev. D* **102** no. 2, (2020) 023535, arXiv:2003.12552 [astro-ph.CO].

[179] P. Di Bari, S. F. King, and A. Merle, “Dark Radiation or Warm Dark Matter from long lived particle decays in the light of Planck,” *Phys. Lett. B* **724** (2013) 77–83, arXiv:1303.6267 [hep-ph].

[180] G. Choi, M. Suzuki, and T. T. Yanagida, “Quintessence Axion Dark Energy and a Solution to the Hubble Tension,” *Phys. Lett. B* **805** (2020) 135408, arXiv:1910.00459 [hep-ph].

[181] G. Choi, M. Suzuki, and T. T. Yanagida, “Degenerate Sub-keV Fermion Dark Matter from a Solution to the Hubble Tension,” *Phys. Rev. D* **101** no. 7, (2020) 075031, arXiv:2002.00036 [hep-ph].

[182] Z. Berezhiani, A. Dolgov, and I. Tkachev, “Reconciling Planck results with low redshift astronomical measurements,” *Phys. Rev. D* **92** no. 6, (2015) 061303, arXiv:1505.03644 [astro-ph.CO].

[183] L. A. Anchordoqui, V. Barger, H. Goldberg, X. Huang, D. Marfatia, L. H. M. da Silva, and T. J. Weiler, "IceCube neutrinos, decaying dark matter, and the Hubble constant," *Phys. Rev. D* **92** no. 6, (2015) 061301, arXiv:1506.08788 [hep-ph]. [Erratum: Phys.Rev.D 94, 069901 (2016)].

[184] K. Vattis, S. M. Koushiappas, and A. Loeb, "Dark matter decaying in the late Universe can relieve the H0 tension," *Phys. Rev.* **D99** no. 12, (2019) 121302, arXiv:1903.06220 [astro-ph.CO].

[185] A. Desai, K. R. Dienes, and B. Thomas, "Constraining Dark-Matter Ensembles with Supernova Data," *Phys. Rev. D* **101** no. 3, (2020) 035031, arXiv:1909.07981 [astro-ph.CO].

[186] J. Alcaniz, N. Bernal, A. Masiero, and F. S. Queiroz, "Light Dark Matter: A Common Solution to the Lithium and H_0 Problems," arXiv:1912.05563 [astro-ph.CO].

[187] A. Chudaykin, D. Gorbunov, and I. Tkachev, "Dark matter component decaying after recombination: Lensing constraints with Planck data," *Phys. Rev. D* **94** (2016) 023528, arXiv:1602.08121 [astro-ph.CO].

[188] A. Chudaykin, D. Gorbunov, and I. Tkachev, "Dark matter component decaying after recombination: Sensitivity to baryon acoustic oscillation and redshift space distortion probes," *Phys. Rev. D* **97** no. 8, (2018) 083508, arXiv:1711.06738 [astro-ph.CO].

[189] J. C. Hill, E. McDonough, M. W. Toomey, and S. Alexander, "Early Dark Energy Does Not Restore Cosmological Concordance," arXiv:2003.07355 [astro-ph.CO].

[190] M. M. Ivanov, E. McDonough, J. C. Hill, M. Simonović, M. W. Toomey, S. Alexander, and M. Zaldarriaga, "Constraining Early Dark Energy with Large-Scale Structure," arXiv:2006.11235 [astro-ph.CO].

[191] M. Rezaei, S. P. Ojaghi, and M. Malekjani, "Cosmography approach to dark energy cosmologies: new constrains using the Hubble diagrams of supernovae, quasars and gamma-ray bursts," arXiv:2008.03092 [astro-ph.CO].

[192] D. Wang, "Can $f(R)$ gravity relieve H_0 and σ_8 tensions?," arXiv:2008.03966 [astro-ph.CO].

[193] R. C. Nunes and A. Bernui, "$\theta_{\rm BAO}$ estimates and the H_0 tension," arXiv:2008.03259 [astro-ph.CO].

[194] U. Leonhardt and D. Berechya, "Observed Hubble constant is consistent with physics of the quantum vacuum," arXiv:2008.04789 [gr-qc].

[195] S. Birrer and T. Treu, "TDCOSMO V: strategies for precise and accurate measurements of the Hubble constant with strong lensing," arXiv:2008.06157 [astro-ph.CO].

[196] G. Ballesteros, A. Notari, and F. Rompineve, "The H_0 tension: ΔG_N vs. $\Delta N_{\rm eff}$," arXiv:2004.05049 [astro-ph.CO].

[197] N. Blinov, K. J. Kelly, G. Z. Krnjaic, and S. D. McDermott, "Constraining the Self-Interacting Neutrino Interpretation of the Hubble Tension," *Phys. Rev. Lett.* **123** no. 19, (2019) 191102, arXiv:1905.02727 [astro-ph.CO].

[198] A. Hernández-Almada, G. Leon, J. Magaña, M. A. García-Aspeitia, and V. Motta, "Generalized Emergent Dark Energy: observational Hubble data constraints and stability analysis," arXiv:2002.12881 [astro-ph.CO].

[199] O. H. Philcox, B. D. Sherwin, G. S. Farren, and E. J. Baxter, "Determining the Hubble Constant without the Sound Horizon: Measurements from Galaxy Surveys," arXiv:2008.08084 [astro-ph.CO].

[200] S. M. Feeney, D. J. Mortlock, and N. Dalmasso, "Clarifying the Hubble constant tension with a Bayesian hierarchical model of the local distance ladder," *Mon. Not. Roy. Astron. Soc.* **476** no. 3, (2018) 3861–3882, arXiv:1707.00007 [astro-ph.CO].

[201] S. M. Feeney, H. V. Peiris, A. R. Williamson, S. M. Nissanke, D. J. Mortlock, J. Alsing, and D. Scolnic, "Prospects for resolving the Hubble constant tension with standard sirens," *Phys. Rev. Lett.* **122** no. 6, (2019) 061105, arXiv:1802.03404 [astro-ph.CO].

[202] D. J. Mortlock, S. M. Feeney, H. V. Peiris, A. R. Williamson, and S. M. Nissanke, "Unbiased Hubble constant estimation from binary neutron star mergers," *Phys. Rev. D* **100** no. 10, (2019) 103523, arXiv:1811.11723 [astro-ph.CO].

[203] A. Banerjee, H. Cai, L. Heisenberg, E. O. Colgáin, M. Sheikh-Jabbari, and T. Yang, "Hubble Sinks In The Low-Redshift Swampland," arXiv:2006.00244 [astro-ph.CO].

[204] S. L. Adler, "Implications of a frame dependent dark energy for the spacetime metric, cosmography, and effective Hubble constant," *Phys. Rev. D* **100** no. 12, (2019) 123503, arXiv:1905.08228 [astro-ph.CO].

[205] Y. Gu, M. Khlopov, L. Wu, J. M. Yang, and B. Zhu, "Light gravitino dark matter for Hubble tension and LHC," arXiv:2006.09906 [hep-ph].

[206] Ö. Akarsu, S. Kumar, S. Sharma, and L. Tedesco, "Constraints on a Bianchi type I spacetime extension of the standard ΛCDM model," *Phys. Rev. D* **100** no. 2, (2019) 023532, arXiv:1905.06949 [astro-ph.CO].

[207] E. Di Valentino *et al.*, "Cosmology Intertwined I: Perspectives for the Next Decade," arXiv:2008.11283 [astro-ph.CO].

[208] E. Di Valentino *et al.*, "Cosmology Intertwined III: $f\sigma_8$ and S_8," arXiv:2008.11285 [astro-ph.CO].

[209] E. Di Valentino *et al.*, "Cosmology Intertwined IV: The Age of the Universe and its Curvature," arXiv:2008.11286 [astro-ph.CO].

[210] V. Pettorino, L. Amendola, and C. Wetterich, "How early is early dark energy?," *Phys. Rev. D* **87** (2013) 083009, arXiv:1301.5279 [astro-ph.CO].

[211] V. Pettorino, "Testing modified gravity with Planck: the case of coupled dark energy," *Phys. Rev. D* **88** (2013) 063519, arXiv:1305.7457 [astro-ph.CO].

[212] W. Yang, E. Di Valentino, O. Mena, S. Pan, and R. C. Nunes, "All-inclusive interacting dark sector cosmologies," *Phys. Rev. D* **101** no. 8, (2020) 083509, arXiv:2001.10852 [astro-ph.CO].

[213] W. Yang, S. Pan, R. C. Nunes, and D. F. Mota, "Dark calling Dark: Interaction in the dark sector in presence of neutrino properties after Planck CMB final release," *JCAP* **04** (2020) 008, arXiv:1910.08821 [astro-ph.CO].

[214] W. Yang, S. Pan, L. Xu, and D. F. Mota, "Effects of anisotropic stress in interacting dark matter – dark energy scenarios," *Mon. Not. Roy. Astron. Soc.* **482** no. 2, (2019) 1858–1871, arXiv:1804.08455 [astro-ph.CO].

[215] G. Steigman, D. Schramm, and J. Gunn, "Cosmological Limits to the Number of Massive Leptons," *Phys. Lett. B* **66** (1977) 202–204.

[216] G. Mangano, G. Miele, S. Pastor, T. Pinto, O. Pisanti, and P. D. Serpico, "Relic neutrino decoupling including flavor oscillations," *Nucl. Phys.* **B729** (2005) 221–234, arXiv:hep-ph/0506164 [hep-ph].

[217] P. F. de Salas and S. Pastor, "Relic neutrino decoupling with flavour oscillations revisited," *JCAP* **1607** no. 07, (2016) 051, arXiv:1606.06986 [hep-ph].

[218] K. Akita and M. Yamaguchi, "A precision calculation of relic neutrino decoupling," *JCAP* **08** (2020) 012, arXiv:2005.07047 [hep-ph].

[219] Z. Zeng, S. Yeung, and M.-C. Chu, "Effects of neutrino mass and asymmetry on cosmological structure formation," *JCAP* **03** (2019) 015, arXiv:1808.00357 [astro-ph.CO].

[220] R. Allahverdi, M. Cicoli, B. Dutta, and K. Sinha, "Correlation between Dark Matter and Dark Radiation in String Compactifications," *JCAP* **10** (2014) 002, arXiv:1401.4364 [hep-ph].

[221] **CMB-S4** Collaboration, K. N. Abazajian *et al.*, "CMB-S4 Science Book, First Edition," arXiv:1610.02743 [astro-ph.CO].

[222] K. Abazajian *et al.*, "CMB-S4 Science Case, Reference Design, and Project Plan," arXiv:1907.04473 [astro-ph.IM].

[223] J. Solà Peracaula, A. Gómez-Valent, J. de Cruz Pérez, and C. Moreno-Pulido, "Brans–Dicke Gravity with a Cosmological Constant Smoothes Out ΛCDM Tensions," *Astrophys. J. Lett.* **886** no. 1, (2019) L6, arXiv:1909.02554 [astro-ph.CO].

[224] J. Solà, A. Gómez-Valent, J. de Cruz Pérez, and C. Moreno-Pulido, "Brans-Dicke cosmology with a Λ- term: a possible solution to ΛCDM tensions," arXiv:2006.04273 [astro-ph.CO].

[225] C. Umiltà, M. Ballardini, F. Finelli, and D. Paoletti, "CMB and BAO constraints for an induced gravity dark energy model with a quartic potential," *JCAP* **08** (2015) 017, arXiv:1507.00718 [astro-ph.CO].

[226] M. Ballardini, F. Finelli, C. Umiltà, and D. Paoletti, "Cosmological constraints on induced gravity dark energy models," *JCAP* **05** (2016) 067, arXiv:1601.03387 [astro-ph.CO].

[227] V. Sahni, A. Shafieloo, and A. A. Starobinsky, "Model independent evidence for dark energy evolution from Baryon Acoustic Oscillations," *Astrophys. J. Lett.* **793** no. 2, (2014) L40, arXiv:1406.2209 [astro-ph.CO].

[228] S. Capozziello, R. D'Agostino, and O. Luongo, "Extended Gravity Cosmography," *Int. J. Mod. Phys. D* **28** no. 10, (2019) 1930016, arXiv:1904.01427 [gr-qc].

[229] M. Benetti and S. Capozziello, "Connecting early and late epochs by f(z)CDM cosmography," *JCAP* **12** (2019) 008, arXiv:1910.09975 [astro-ph.CO].

[230] B. F. Schutz, "Determining the Hubble Constant from Gravitational Wave Observations," *Nature* **323** (1986) 310–311.

[231] D. E. Holz and S. A. Hughes, "Using gravitational-wave standard sirens," *Astrophys. J.* **629** (2005) 15–22, arXiv:astro-ph/0504616.

[232] H.-Y. Chen, M. Fishbach, and D. E. Holz, "A two per cent Hubble constant measurement from standard sirens within five years," *Nature* **562** no. 7728, (2018) 545–547, arXiv:1712.06531 [astro-ph.CO].

[233] E. Di Valentino, D. E. Holz, A. Melchiorri, and F. Renzi, "The cosmological impact of future constraints on H_0 from gravitational-wave standard sirens," *Phys. Rev.* **D98** no. 8, (2018) 083523, arXiv:1806.07463 [astro-ph.CO].

[234] A. Palmese *et al.*, "Gravitational Wave Cosmology and Astrophysics with Large Spectroscopic Galaxy Surveys," arXiv:1903.04730 [astro-ph.CO].

[235] **LIGO Scientific, Virgo, 1M2H, Dark Energy Camera GW-E, DES, DLT40, Las Cumbres Observatory, VINROUGE, MASTER** Collaboration, B. P. Abbott *et al.*, "A gravitational-wave standard siren measurement of the Hubble constant," *Nature* **551** no. 7678, (2017) 85–88, arXiv:1710.05835 [astro-ph.CO].

[236] E. Di Valentino and A. Melchiorri, "First cosmological constraints combining Planck with the recent gravitational-wave standard siren measurement of the Hubble constant," *Phys. Rev.* **D97** no. 4, (2018) 041301, arXiv:1710.06370 [astro-ph.CO].

[237] S. Nissanke, D. E. Holz, N. Dalal, S. A. Hughes, J. L. Sievers, and C. M. Hirata, "Determining the Hubble constant from gravitational wave observations of merging compact binaries," arXiv:1307.2638 [astro-ph.CO].

[238] **DES** Collaboration, A. Palmese *et al.*, "A statistical standard siren measurement of the Hubble constant from the LIGO/Virgo gravitational wave compact object merger GW190814 and Dark Energy Survey galaxies," arXiv:2006.14961 [astro-ph.CO].

[239] J. Yu, Y. Wang, W. Zhao, and Y. Lu, "Hunting for the host galaxy groups of binary black holes and the application in constraining Hubble constant," arXiv:2003.06586 [astro-ph.CO].

[240] S. Borhanian, A. Dhani, A. Gupta, K. Arun, and B. Sathyaprakash, "Dark Sirens to Resolve the Hubble-Lemaître Tension," arXiv:2007.02883 [astro-ph.CO].