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Editorial

Focus point on tensions in cosmology from early to late universe: the value of the Hubble constant and the question of dark energy

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Papers included in this Focus Point collection are devoted to one of the hot topics of modern cosmology: the Hubble constant tension. It emerged from observations revealing, with a high degree of confidence, a discrepancy between the value of the Hubble constant, as measured by galaxy distance surveys and standard candles, and the value derived from the Cosmic Microwave Background data. Tension emerges assuming the standard ΛCDM cosmological model [1–3]. This discrepancy is attracting numerous research groups, and it is resulting in hundreds of publications aimed to fix it. From a general point of view, this discrepancy and other ones seem to point out a tension between the current picture of late and early Universe.

A broad range of topics can be considered in searching for a solution of this puzzle. A bunch of them has been considered in this Focus Point. They range from the detailed methods of observational data analysis, up to dark matter and dark energy models dealing with modifications of ΛCDM, general relativity, basic physical principles, or variation of physical constants, including of the gravitational constant (see [4] for a recent review).

The puzzle is, essentially, twofold: from one side, the tension could be addressed by improving measurements and datasets like Cepheids, type Ia supernovae (SNeIa), galaxy sky surveys, gravitational lensing, baryon acoustic oscillations, Big Bang nucleosynthesis, etc. From the other side, the effort is to search for new physics, including possible modifications of general relativity.

Let us illustrate the diversity of the approaches considered in this Focus Point.

There are studies on the very nature of the main observational parameter, the redshift. In the framework of nonlinear-electromagnetism involving the Lorentz–Poincaré symmetry violation, the possibility of additional cosmological expansion-independent frequency shift has been discussed in [5, 6]. The results are compared with observational Pantheon data of SNeIa. Such results allow to conclude that the frequency shift can support an alternative to accelerated expansion accommodating the SNeIa data. Importantly, laboratory tests to investigate additional shifts from extended Electromagnetism can be taken into account. In another study, systematic errors in the cosmological redshift for SNeIa measurements have been studied [7]. As shown, the reduction of the Hubble constant local value is possible up to 5%.

The observational constraints for inflationary models derived from $f(R)$ gravity, including the Starobinski and higher-order Lagrangians, have been derived using Planck satellite and Keck datasets [8]. Remarkably, it appears that although $f(R)$ constant-roll models adopt observationally acceptable values of the parameter r, they do not predict favorable values of the spectral index. In another paper [9], $f(R)$ gravity in Palatini approach is studied as an inverse problem: specifically, models are reconstructed starting from an effective equation of state to be constrained by data. In particular, the Starobinski and power-law models are considered assuming a linear and a quadratic effective equation of state. Namely, using the effective equation of state to constrain cosmological models can become relevant in view of the forthcoming Euclid and other deep observational surveys. Also extended teleparallel $f(T)$ cosmological models can be constrained by the Pantheon dataset and baryonic acoustic oscillation in view to fix the Hubble tension [10]. In particular, higher values of Hubble constant are obtained if compared to equivalent analyses without priors. In [11], a holographic Brans–Dicke dark energy model is derived using the Barrow entropy formula. In this context, the evolution of Hubble constant and other cosmological parameters is taken into account.

The weak-field limit of general relativity, including the cosmological constant, was previously developed in [12]. It is useful to define the Hubble flow as the result of two flows, a local and a global one. Then the fitting of observational data is in quantitative agreement with this picture. The same approach is used in [13] to enable the formation of cosmic web of filaments, clusters and groups of galaxies within a self-consistent gravitational interaction ruled by the Vlasov kinetic technique. The McCrea–Milne description of the local Universe, within the Vlasov technique and the reduced problem of Euler–Courant equations, is analyzed in [14].

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The possible role of modified gravity with cosmological constant is studied for the tidal disruption events (TDE) of stars near massive black holes, also using the adiabatic invariance technique [15, 16]. TDE are considered as the mechanism producing the observed flares from the galactic nuclei. An important observation is that, because of their density, neutron stars' Roche limit can be inside the horizon of a supermassive black hole. Hence, a pulsar may provide timekeeping to track at infalling in galactic nuclei.

In [17], a Yukawa type modified gravity is taken into account in view to detect deviations from the Newtonian gravity in the observed distribution of clusters of galaxies. It appears that a Yukawa potential can provide a useful model to reveal differences between the local and global Universe descriptions.

Discrepancies between early and late Universe are studied in [18] adopting Noether symmetries to select viable models. In this perspective, $f(R)$ gravity can have an important role to solve cosmic tensions. In another study [19], an empirical approach to H_0 tension is adopted. Here the variation of cosmological parameters is considered to improve the standard ΛCDM model.

Non-local gravity corrections are studied in [20] considering data of the IceCube collaboration for high-energy neutrinos. These measurements can be associated to the abundance of dark matter and used to fix the Hubble tension.

Gravitational waves, in view of tracing the evolution of the Universe, are studied in [21]. They have properties as waveguides for electromagnetic radiation. Namely, it is shown that initial perturbations of photon beam, aligned with gravitational waves, decay, so the alignment of both electromagnetic and gravitational waves survives during the propagation. The waveguiding by gravitational waves can affect the interpretation of gravitational and electromagnetic counterparts with direct cosmological consequences. Specifically, the gravitational and electromagnetic counterpart, detected today, can be relevant to determine the distance scale. Hence, it represents a new window for evaluating the Hubble constant on the relevant distance scale of the Universe [22].

The holographic approach to the interacting dark energy and dark matter is considered with a Hubble infrared cutoff [23]. Analytical expressions for the Hubble parameter are obtained and tested by the Pantheon SNeIa and galaxy cluster data. It is shown that they allow cosmic late time acceleration. Piecewise solutions of Friedmann equations, represented via special analytical functions, are studied in [24]. Constraints from observations on these solutions allow to fix the Hubble tension.

As a final remark, we can say that cosmic tensions are one of the main issues of modern cosmology. From a theoretical point of view, they could represent the signature of some new physics. From the point of view of observations, they are a formidable challenge which points out the need to achieve large bulk of data for a comprehensive and self-consistent cosmic history at any epoch.

Data availability This paper has no associated data or the data will not be deposited. There is no data because all obtained results are in the paper. All authors confirm that there is no part of the paper that requires data.

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