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Little Ado about Everything: ηCDM, a Cosmological Model with Fluctuation-driven Acceleration at Late Times

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Abstract

We propose a model of the Universe (dubbed ηCDM) featuring a controlled stochastic evolution of the cosmological quantities that is meant to render the effects of small deviations from homogeneity/isotropy on scales of 30–50 h^{-1} Mpc at late cosmic times associated with the emergence of the cosmic web. Specifically, we prescribe that the behavior of the matter/radiation energy densities in different patches of the Universe with such a size can be effectively described by a stochastic version of the mass–energy evolution equation. The latter includes, besides the usual dilution due to cosmic expansion, an appropriate noise term that statistically accounts for local fluctuations due to inhomogeneities, anisotropic stresses, and matter flows induced by complex gravitational processes. The evolution of the different patches as a function of cosmic time is rendered via the diverse realizations of the noise term; meanwhile, at any given cosmic time, sampling the ensemble of patches will create a nontrivial spatial distribution of the various cosmological quantities. Finally, the overall behavior of the Universe will be obtained by averaging over the patch ensemble. We assume a simple and physically reasonable parameterization of the noise term, gauging it against a wealth of cosmological data sets in the local and high-redshift Universe. We find that, with respect to standard ΛCDM, the ensemble-averaged cosmic dynamics in the ηCDM model is substantially altered by the stochasticity in three main respects: (i) an accelerated expansion is enforced at late cosmic times without the need for any additional exotic component (e.g., dark energy), (ii) the spatial curvature can stay small even in a low-density Universe constituted solely by matter and radiation, (iii) matter can acquire an effective negative pressure at late times. The ηCDM model is Hubble tension–free, meaning that the estimates of the Hubble constant from early- and late-time measurements do not show marked disagreement as in ΛCDM. We also provide specific predictions for the variance of the cosmological quantities among the different patches of the Universe at late cosmic times. Finally, the fate of the Universe in the ηCDM model is investigated to show that the cosmic coincidence problem is relieved without invoking the anthropic principle.

Unified Astronomy Thesaurus concepts: Cosmology (343); Cosmological models (337); Cosmological principle (2363)

1. Introduction

The standard ΛCDM model of the Universe has proven to be extremely successful in reproducing to a high degree of accuracy many cosmological observations, most noticeably the cosmic microwave background (CMB) temperature and polarization spectra (e.g., Bennett et al. 2003; Planck Collaboration et al. 2013, 2020a), supernova (SN) I*a* cosmography (e.g., Perlmutter et al. 1999; Scolnic et al. 2018; Brout et al. 2022), baryon acoustic oscillation (BAO) measurements (e.g., Eisenstein et al. 2005; Beutler et al. 2011; Zhao et al. 2022), cosmic shear galaxy surveys (e.g., Heymans et al. 2013; Amon et al. 2022; Secco et al. 2022), galaxy clusters (e.g., White et al. 1993; Allen et al. 2011; Mantz et al. 2022), and many others (e.g., see recent review by Turner 2022 and references therein; see also Efstathiou 2023). Despite these astonishing successes, the ΛCDM model maintains a fundamentally empirical character, in that it postulates the existence of a mysterious dark energy component with exotic negative pressure that, at late cosmic times, dominates the energy budget and enforces an accelerated expansion of the Universe.

From an observational perspective, the evidence for dark energy remains mainly related to the interpretation of two occurrences: the accelerated expansion of the Universe at late cosmic times, as mainly indicated by Type Ia SN determinations of the magnitude–redshift diagram, and the nearly zero curvature (flat geometry) of a Universe with a low matter (baryons and dark matter) content, as mainly indicated by CMB and BAO data. From a theoretical perspective, the situation is even more dramatic; the value of the present dark energy density required to explain the aforementioned observations is far below the Planck or any natural scale in particle physics. Nonetheless, it is of the same order of magnitude with respect to the matter density, rather than extremely smaller or fatally larger, thus allowing its observability in this very precise moment of cosmic history (e.g., Zel'dovich 1968; Weinberg 1989). Furthermore, in recent years, some discrepancies with