

CONSTRAINTS ON DISSIPATIVE NON-EQUILIBRIUM DARK ENERGY MODELS FROM RECENT SUPERNOVA DATA

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Non-critical string cosmologies may be viewed as the analogue of off-equilibrium models arising within string theory as a result of a cosmically catastrophic event in the early Universe. Such models entail relaxing-to-zero dark energies provided by a rolling dilaton field at late times. We discuss fits of such non-critical models to high-redshift supernovae data, including the recent ones by HST and ESSENCE and compare the results with those of a conventional model with Cold Dark Matter and a cosmological constant and a model invoking super-horizon perturbations.

1. Introduction

There is a plethora of astrophysical evidence today, from supernovae measurements,^{1–5} the cosmic microwave background,⁶ baryon oscillations⁷ and other cosmological data, indicating that the expansion of the Universe is currently accelerating. The energy budget of the Universe seems to be dominated at the present epoch by a mysterious dark energy component. Many theoretical models provide possible explanations for the latter, ranging from a cosmological constant⁸ to super-horizon perturbations⁹ and time-varying quintessence scenarios,¹⁰ in which the dark energy is due to a smoothly varying scalar field dominating cosmology in the present era. In the context of string theory, such a time-dependent ‘quintessence’ field is provided by the scalar dilaton field of the gravitational string multiplet.^{11–13}

2. Dissipative Q-Cosmology Basics

Most of the astrophysical analyses so far are based on effective four-dimensional Robertson-Walker Universes, satisfying on-shell dynamical equations of motion of the Einstein-Friedman form. Even in modern approaches to brane cosmology, described by equations deviating during early

eras of the Universe from the standard Friedman equation, the underlying dynamics is assumed to be of classical equilibrium (on-shell) nature.

However, cosmology may not be an entirely classical equilibrium situation. The initial Big Bang or other catastrophic cosmic event, such as a collision of two brane worlds in the modern approach to strings, which led to the initial rapid expansion of the Universe, may have caused a significant departure from classical equilibrium dynamics in the early Universe, whose signatures may still be present at later epochs including the present era. One specific model for the cosmological dark energy which is of this type, being associated with a rolling dilaton field that is a remnant of this non-equilibrium phase, was formulated^{11,14} in the framework of non-critical string theory.^{12,15} This scenario is called ‘Q-cosmology’. It is of outmost importance to confront the currently available precision astrophysical data with such non-equilibrium stringy cosmologies. The central purpose of this talk is to present a first step towards this direction, namely a confrontation of cosmological data on high-redshift supernovae^{16,17} with Q-cosmologies and compare the results with the predictions of the conventional Λ CDM model⁸ and the super-horizon model.⁹ Care must be taken in interpreting the Q-cosmology scenario. Since such a non-equilibrium, non-classical theory *is not described by the equations of motion derived by extremising an effective space-time Lagrangian*, one must use a more general formalism¹⁶ to make predictions that can be confronted with the current data.

3. Supernova Data Analysis

We use recent type-Ia supernovae (SN) data released by the Hubble Space Telescope (HST)³ and the ESSENCE collaboration.⁴ Among 16 newly discovered high-redshift SNe,³ the so-called ‘gold’ dataset (*Riess07*) embraces SNe from other sets: 14 SNe discovered earlier by HST,¹ 47 SNe reported by SNLS,² and 105 SNe detected by ground-based discoveries, amounting a total of 182 data points. An additional set of 77 SNe tagged as ‘silver’ due to lower quality of photometric and spectroscopic record is also listed. The ESSENCE dataset (*WV07*), on the other hand, consists out of 60 SNe of $0.015 < z < 1.02$ discovered by ESSENCE,⁴ 57 high- z SNe discovered during the first year of SNLS² and 45 nearby SNe. The results presented here were obtained by analysing a compilation of the aforementioned data (*WV07+Riess07*),⁵ normalised to account for the different light-curve-fitters employed.

These data are given in terms of the distance modulus $\mu = 5 \log d_L + 25$,

where the luminosity distance d_L (in megaparsecs) for a flat universe is related to the redshift z via the Hubble rate H : $d_L = c(1+z) \int_0^z \frac{dz'}{H(z')}$. We note that this observable depends on the expansion history of the Universe from z to the present epoch, and recall that, although most of the available supernovae have $z < 1$, there is a handful with larger values of z . In the analysis that follows, the predictions for the Hubble rate $H(z)$ of the following three cosmological models are investigated:

Λ CDM: In a CDM model with a cosmological constant,⁸ we have

$$H(z) = H_0 \left(\Omega_M(1+z)^3 + \Omega_\Lambda(1+z)^{3(1+w_0)} \right)^{1/2}. \quad (1)$$

Super-horizon model: The Universe is assumed to be filled with non-relativistic matter only,⁹ and there is no dark energy of any sort:

$$H(z) = \bar{a}^{-1} \frac{d\bar{a}(t)}{dt} = \frac{\bar{H}_0}{1 - \Psi_{\ell 0}} \left(a^{-3/2} - a^{-1/2} \Psi_{\ell 0} \right), \quad (2)$$

where $(1+z)^{-1} = \bar{a}(t)$, $\Psi(\vec{x}, t)$ is the gravitational potential, and $\Psi_{\ell 0}$ is a free parameter.

Q-cosmology: A parametrisation for $H(z)$ in the Q-cosmology framework at late eras, such as the ones pertinent to the supernova and other data ($0 < z < 2$), where some analytic approximations are allowed,¹⁶ is used in the analysis:

$$\frac{H(z)}{H_0} = \sqrt{\Omega_3(1+z)^3 + \Omega_\delta(1+z)^\delta + \Omega_2(1+z)^2}, \quad \Omega_3 + \Omega_\delta + \Omega_2 = 1, \quad (3)$$

with the densities $\Omega_{2,3,\delta}$ corresponding to present-day values ($z = 0$). However, a complete analysis of the non-critical and dilaton effects, which turn out to be important in the present era after the inclusion of matter, requires a numerical treatment.¹⁴ In general, the three parameters to be determined by the fit are Ω_3 , Ω_δ and δ . Here, a fixed value of $\delta = 4$ is assumed for simplicity, justified by earlier results,¹⁶ whilst a more complete analysis is given in Ref. 17.

For illustration purposes, both data and predictions of cosmological models are expressed in the following as residuals, $\Delta\mu$, from the empty-Universe prediction (Milne's model, $\Omega_M = 0$). The VW07+Riess07 dataset, which amounts to a sample of 192 supernovae in total, is shown in Fig. 1, where the predictions of the cosmological models under study are also displayed for the best-fit parameter values, listed in Table 1.

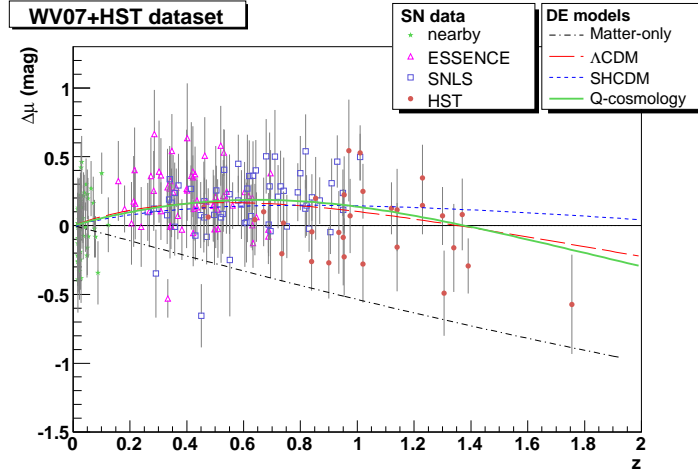


Figure 1. Residual magnitude versus redshift for supernovae from the WV07+HST dataset and model predictions for the best-fit parameter values.

The analysis involves minimisation of the standard χ^2 function with respect to the cosmological model parameters. The best-fit parameter values, the 1σ errors and the corresponding χ^2 values are listed in Table 1 for the three cosmological models.

Table 1. Fit results for the WV07+HST dataset for various models.

Model	Best-fit parameters	χ^2	χ^2/dof
Λ CDM flat	$\Omega_M = 0.259 \pm 0.019$	196	1.02
Λ CDM	$(\Omega_M, \Omega_\Lambda) = (0.33, 0.85)$	195	1.03
Super-horizon	$\Psi_{\ell 0} = -0.90 \pm 0.07$	200	1.05
Q-cosmology	$\Omega_3 = -2.8 \pm 0.5, \Omega_4 = 0.86 \pm 0.22$	195	1.02

It is evident from Fig. 1 and Table 1 that the standard Λ CDM model fits the supernova data *very well*, as expected from earlier analyses. The super-horizon dark matter model also fits the supernova data *quite well*. Both of these models are *on-shell*, i.e., they satisfy the pertinent Einstein's equations. Moreover, *off-shell* cosmology models are also compatible with the data. As we discussed above, off-shell effects are important in our Q-cosmology model. Introducing the appropriate parametrisation Eq. (3) to allow for these off-shell effects, we find that *the Q-cosmology model may fit the supernovae data as well as the standard Λ CDM model*. Further

constraints¹⁷ on cosmological models may be imposed by observations of high- z red galaxies constraining the Hubble parameter, $H(z)$.¹⁸

4. Conclusions

We show that recent high-redshift supernovae data confirm¹⁷ the constraints established in earlier studies¹⁶ which demonstrated that cosmological models with no dark energy may be viable alternatives to the Standard Λ CDM model. As more precision astrophysical data are coming into play, more stringent constraints can be imposed on our non-critical string Q-cosmologies.

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