Constraints on Induced Gravity Dark Energy Models

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Abstract

We study the predictions for structure formation in an induced gravity dark energy model (or Brans-Dicke-like model by a redefinition of the scalar field) with a monomial potential. By developing a dedicated Einstein-Boltzmann code, we study self-consistently the dynamics of homogeneous cosmology and of linear perturbations without using any parametrization. We use CMB anisotropies data and a compilation of BAO data to constrain the coupling γ to the Ricci curvature and the standard cosmological parameters. By connecting the gravitational constant in the Einstein equation to the one measured in a Cavendish-like experiment, we find $10^3\ \gamma < 1.2$ at 95 % CL with *Planck* 2013 temperature and BAO data, $10^3\ \gamma < 0.89$ at 95 % CL with *Planck* 2015 temperature and the same BAO data, for a quartic potential. We also extend the analysis to *Planck* lensing and polarization.

1 Introduction

Several dark energy/modified gravity models alternative to ΛCDM model have been compared extensively to the most recent *Planck* data [1] with no compelling evidence in favour of alternative models to ΛCDM, in particular when *Planck* lensing is included.

We considered the case where the modification of gravity is embedded by adding a scalar degree of freedom. The scalar-tensor theories of gravity are some of the most established and well studied alternative theories of gravity, where deviations from GR are under control and is often possible to find exact solutions to the field equations.

We studied the simplest scalar-tensor dark energy models based on induced gravity (IG) [2] with a monomial potential [3], extending previous works based on a quartic potential [4, 5]. We extend our self-consistent approach in which we solve simultaneously the background and the linear perturbation dynamics in IG previously applied to a quartic potential [5], without any approximation on the background or on the perturbations.

*Speaker

2 Dark energy within induced gravity

IG models can be described by the following action [4]:

$$\mathcal{S} = \int d^4x\sqrt{-g}\left[\frac{\gamma\sigma^2 R}{2} - \frac{g^{\mu\nu}}{2}\partial_\mu\sigma\partial_\nu\sigma - V(\sigma) + \mathcal{L}_{\rm m}\right] \tag{1}$$

where R is the Ricci constant, σ a scalar field, γ a constant coupling between the extra degree of freedom and the Ricci constant and $\mathcal{L}_{\rm m}$ denotes the contribution of matter and radiation. We considered the following class of potentials:

$$V(\sigma) = \lambda_{\rm n}\sigma^{\rm n}\,. \tag{2}$$

Eq. 1 can be rewritten as a action Brans-Dicke-like field $\phi_{\rm BD}$ [6], plus a potential, after a redefinition of the field $\phi_{\rm BD} = 8\pi\gamma\sigma^2$ and $\omega_{\rm BD} = 1/(4\gamma)$.

We considered IG in the original Jordan frame, were the theory is formulated. Here, the evolution of the background cosmology can be compared with an effective DE component in Einstein gravity with a Newtonian's constant $\tilde{G}_{\rm N} = 1/(8\pi\gamma\sigma_0^2)$, whose energy density and pressure are [5]:

$$\rho_{\rm DE} = \frac{\sigma_0^2}{\sigma^2}\left[\frac{\dot\sigma}{2} - 6\gamma H\dot\sigma\sigma + V(\sigma)\right] + \sum_i \rho_i\left(\frac{\sigma_0^2}{\sigma^2} - 1\right) \tag{3}$$

$$p_{\rm DE} = \frac{\sigma_0^2}{\sigma^2}\left[\frac{\dot\sigma}{2} - 2\gamma H\dot\sigma\sigma - V(\sigma) + \sum_i \frac{2\gamma\rho_i + p_i}{1+6\gamma}\right] - \sum_i p_i\,. \tag{4}$$

We show in Fig. 1 the evolution of the different cosmological species with the relative abundances in the various radiation/matter/dark energy dominated era. Moreover, at low redshift the potential drive the model in different future attractor solutions as shown in Fig. 1, due to the evolution of the scalar field σ driven by the non-relativistic matter, and it could lead an imprint on other cosmological probes.

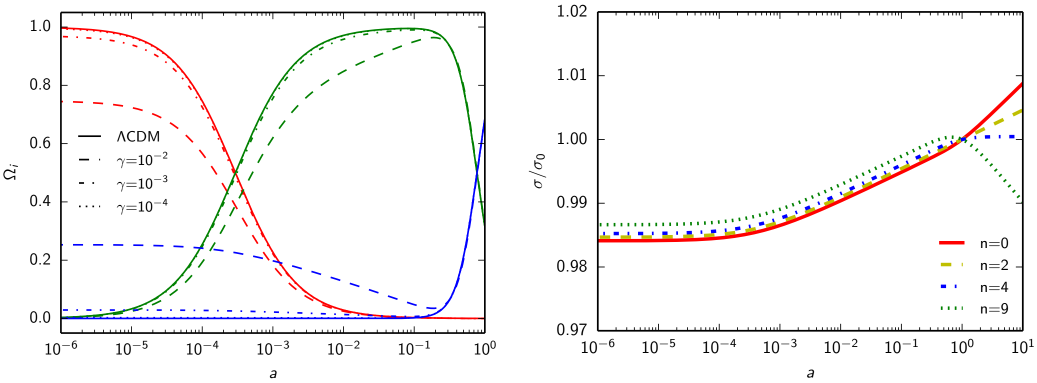

Figure 1: Left: evolution of the critical densities $\Omega_{\rm i}$ for $n = 4$ and different values of γ: radiation in red, matter in green and effective dark energy in blue, figure from [5]. Right: evolution of σ/σ_0 as function of the scale factor a for $10^3\ \gamma = 1$ and different values of n, figure from [3].

To be consistent with laboratory experiments and Solar System constraints, we fix the value of σ at present day to be:

$$\gamma\sigma_0^2 = \frac{1}{8\pi G}\frac{1+8\gamma}{1+6\gamma} \tag{5}$$

where $G = 6.67\times10^{-8}$ cm^3 g^{-1} s^{-2} is the gravitational constant measured in a laboratory Cavendish-type.

3 Cosmological constraints

This class of models leads to distinctive effects compared to ΛCDM for different values of the coupling γ. As explained in [5], the main effect is a shift to the right of the acoustic peaks in the CMB angular power spectra, both in temperature and in polarization, see [5, 3] for details. This shift induces a degeneracy between γ and H_0, as shown in Fig. 2.

We studied also the effects of different exponents of the monomial potential on the CMB angular power spectra in [3]. For the CMB temperature anisotropies, the imprint of different potentials is relegated to low multipoles, i.e. $\ell < 20$.

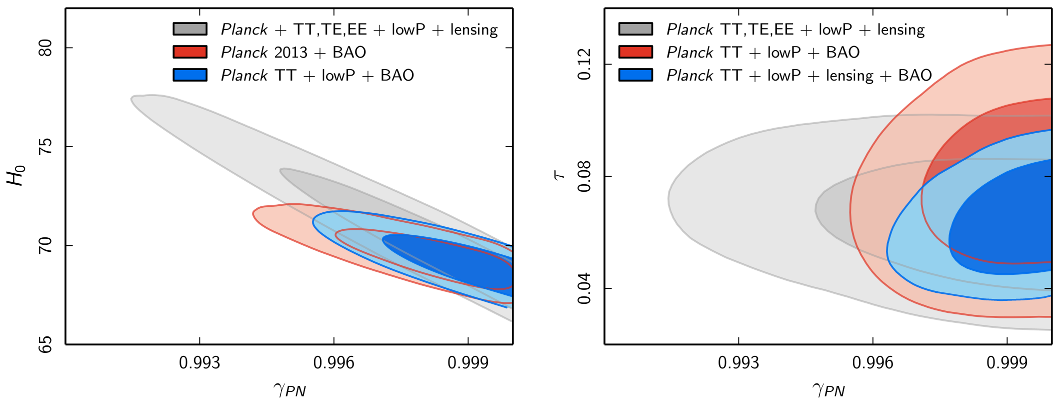

Figure 2: 2D marginalized confidence levels at 68 % and 95 % for ($\gamma_{\rm PN}$, H_0) on the left and ($\gamma_{\rm PN}$, τ) on the right, figures from [3].

In order to constrain the parameters of the models we perform a MCMC analysis by using the publicly available code MONTEPYTHON [7] connected to our modified version of the public Einstein-Boltzmann code CLASS [8, 5].

By combining the full mission temperature information from *Planck* and a compilation of BAO data, we obtain:

$$10^3\ \gamma < 0.89\ (95\ \%\ \text{CL},\ \textit{Planck}\ \text{TT} + \text{lowP} + \text{BAO}) \tag{6}$$

which improves by ~ 30 % the limit found with the *Planck* 2013 temperature data, obtained with the same compilation of BAO data, and updates previous constraints on Brans-Dicke-like models [9]. When we include CMB lensing, a tighter cosmological constraint is found:

$$10^3\ \gamma < 0.75\ (95\ \%\ \text{CL},\ \textit{Planck}\ \text{TT} + \text{lowP} + \text{lensing} + \text{BAO}) \tag{7}$$

which is compatible with the inclusion of high-ℓ polarization data, as shown in [3]. It's important to stress that thanks to all the information available from the CMB angular power spectra, including high-ℓ polarization and CMB lensing, it's possible to obtain a constraint based on PLANCK data alone:

$$10^3\ \gamma < 1.7\ (95\ \%\ \text{CL},\ \textit{Planck}\ \text{TT},\text{TE},\text{EE} + \text{lowP} + \text{lensing})\,. \tag{8}$$

We also derive limits on the variation of the gravitational constant using the same combination of data sets. The change of the Newton constant between the radiation era and the present time $\delta G_{\rm N}/G_{\rm N} = (\sigma_{\rm i}^2 - \sigma_0^2)/\sigma_0^2$:

$$\frac{\delta G_{\rm N}}{G_{\rm N}} = -0.011^{+0.010}_{-0.004}\ (68\ \%\ \text{CL},\ \textit{Planck}\ \text{TT} + \text{lowP} + \text{BAO}) \tag{9}$$

and the constraint on its derivative ($\dot{G}_{\rm N}/G_{\rm N} \equiv -2\dot{\sigma}_0/\sigma_0$) at present time:

$$\frac{\dot{G}_{\rm N}}{G_{\rm N}}(z=0) = -0.45^{+0.43}_{-0.16}\ (68\ \%\ \text{CL},\ \textit{Planck}\ \text{TT} + \text{lowP} + \text{BAO})\,. \tag{10}$$

The constraint obtained on the variation of the gravitational constant by combining CMB and BAO data results to be stronger than the ones obtained from BBN. In fact, as shown in [3], the inclusion of a modified version of the BBN consistency condition, in order to take into account the effects of the effective gravitational constant due to IG, does not change the constraints on γ.

We analyse also the cases with different potentials, i.e. $n = 0, 2, 4, 6, 8$. The dependence on the exponent of the potential in Eq. 2 is weak both on the six standard cosmological parameters and on γ, and does not affect their constraints, see Fig. 10 of [3]. On the other hand, the posterior distributions of $\dot{G}/G$ and $\ddot{G}/G$ are strongly dependent from the potential choice [3].

Acknowledgements

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