ON THE DARK CONTENTS OF THE UNIVERSE: A EUCLID SURVEY APPROACH

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In this work we study the consequences of allowing non pressureless dark matter when determining dark energy constraints. We show that present-day dark energy constraints from low-redshift probes are extremely degraded when allowing this dark matter variation. However, adding the CMB we can recover the $w_{DM} = 0$ case constraints. We also show that with the future Euclid redshift survey we expect to largely improve these constraints; but, without the complementary information of the CMB, there is still a strong degeneracy between dark energy and dark matter equation of state parameters.

1 Introduction

The ΛCDM cosmological model is the current standard model in cosmology thanks to its good phenomenological fit to cosmological data like SNIa[1], BAO[2] or CMB[3]. However, neither a dark matter, nor a dark energy candidate have been experimentally detected, so there is still room to study models differing from this ideal case. There has been a great effort in studying models accounting for different dark energy components than a cosmological constant[3] and there has also appeared some studies of models accounting for variations on the dark matter sector[4]. We propose here to study which are the consequences on the dark energy constraints when considering non pressureless dark matter. For this, we use present-day data and we forecast the precision of the Euclid redshift survey.

2 Dark content(s) of the Universe

In this section we use present-day data from type Ia supernovae (SNIa), the baryonic acoustic oscillations (BAO) and the cosmic microwave background (CMB) to constraint cosmological models with perturbations in both the dark matter and the dark energy sector. In all this work a flat Universe is assumed and we consider a Robertson-Walker metric with Friedmann-Lemaître dynamics.

2.1 Method and data samples

In the following we use compressed versions of the different probes likelihood, since they have been shown to be faster and easier to evaluate and still remain accurate for the most common cases.

In order to determine the constraints on the parameters under study we use the common χ^2 minimization procedure and, since we are combining essentially independent probes, we compute the total χ^2 function as the sum of the χ^2 for each probe.

For the SNIa data we use the compressed likelihood of the JLA sample from Betoule *et al.*[1]. Corresponding the BAO data, we use the measurements of the ratio of the comoving sound horizon at the redshift of baryon drag to the BAO distance scale at three different redshifts: $z = 0.106$[6], 0.35[7], 0.57[8], following Planck Collaboration XVI[9]. For the CMB probe we use the values of the so-called reduced parameters (the scaled distance to recombination R, the angular scale of the sound horizon at recombination ℓ_a and the reduced density parameter of the baryons ω_b) provided by the Planck 2015 data release[3], where temperature-temperature fluctuations and the low-ℓ Planck temperature-polarization likelihoods have been used.

2.2 Models

In the standard ΛCDM model there exist a dark matter component with equation of state $P = w_{DM}\rho$, $w_{DM} = 0$, and a dark energy component with equation of state $P = w_{DE}\rho$, $w_{DE} = -1$. In this work we consider that the dark equation of state parameters w_{DM} and w_{DE} are constant but may differ from their standard value. This leads to the Friedmann-Lemaître equation:

$$\frac{H^2(z)}{H_0^2} = \Omega_r(1+z)^4 + \Omega_b(1+z)^3 + (\Omega_m - \Omega_b)(1+z)^{3(1+w_{DM})} + (1-\Omega_r-\Omega_m)(1+z)^{3(1+w_{DE})}\,. \quad (1)$$

We consider three different models: the wCDM model, consisting of standard cold dark matter ($w_{DM} = 0$) and dark energy with constant equation of state parameter($w_{DE} = w$); the ϵCDM model, with constant dark matter equation of state parameter ($w_{DM} = \epsilon$) and a cosmological constant ($w_{DE} = -1$); and the ϵwCDM model, with both dark matter and dark energy constant equation of state parameters ($w_{DM} = \epsilon$ and $w_{DE} = w$). Since in the ϵCDM and ϵwCDM models we are modifying the matter component at the CMB era, we must adapt the computation of the reduced parameters by changing the dark matter density parameter to an effective dark matter density parameter: $\Omega_{DM}^{eff} = \Omega_{DM}(1 + z_{CMB})^{3\epsilon}$.

2.3 Results

The obtained constraints for the cosmological parameters[a] of the different models are shown in columns 1 and 3 of Table 1.

For the wCDM model our results are very similar to those of Betoule *et al.*[1]. Concerning the ϵCDM model we have obtained compatible results with Thomas *et al.*[4]. The values obtained for the ϵwCDM model are slightly worse than the ones obtained for the wCDM and the ϵCDM models due to the introduction of a new degree of freedom.

All the constraints for the proposed models are compatible with the ΛCDM model. However, two points worth to be mentioned: first of all, the CMB probe plays a crucial role here, since SNIa+BAO data alone cannot constraint ϵ and w at the same time. And secondly, the constraints on dark matter and dark energy are not completely independent (see the left panel of Fig. 1); therefore, all the assumptions done in one of the sectors may influence the constraints obtained in the other one.

3 Dark content(s) of the Universe: a Euclid forecast

In this section we study the models departing from the ΛCDM ideal case presented by looking at the expected precision from a galaxy power spectrum Euclid[b] survey forecast. In this work we restrict ourselves to the spectroscopic Euclid redshift survey. Adding the photometry and

[a] The baryon density parameter is not shown because either it is fixed to the Planck 2015[3] value (column 1) or it is very well constrained close to it (column 3). The radiation contribution is fixed following Komatsu *et al.*[5].

[b] http://www.euclid-ec.org

the weak lensing probe we can expect even better constraints than the ones presented in this work.

3.1 Method

In order to perform the forecast, we use a Fisher matrix formalism in a parameterized cosmological model, considering the Hubble parameter and the angular-diameter distance as observables.

The Fisher matrix in a given redshift interval is given by[10]:

$$F_{ij} = \int_{-1}^{1} \int_{k_{min}}^{k_{max}} \frac{\partial \ln P_{obs}(k,\mu)}{\partial p_i} \frac{\partial \ln P_{obs}(k,\mu)}{\partial p_j} V_{eff}(k,\mu) \frac{2\pi k^2 dk d\mu}{2(2\pi)^3} \,, \tag{2}$$

where V_{eff} is the effective volume of the survey (redshift range: 0.7-2.1, area: 15000 sq. deg., number of galaxies: $50{\times}10^6$), p_i and p_j stand for the observables and P_{obs} is the observed power spectrum, which differ from the matter power spectrum because of the biasing of galaxies and their velocity field[11]. We consider the bias given in Amendola *et al.*[12]: $b(z) = \sqrt{1+z}$. We assume that there is no extra noise in this power spectrum relation. We follow Seo & Eisenstein[11] in cutting the integral of eq. (2) at k_{min} and k_{max} to keep the linear part of the power spectrum. Also, we multiply the integrand of the Fisher matrix by an exponential suppression $\exp(-k^2\mu^2\sigma_r^2)$, with $\sigma_r = c\sigma_z/H(z)$, in order to take into account the redshift error $\sigma_z = 0.001(1+z)$ of the galaxy survey. Once we obtain the Fisher matrix for the observables we propagate it to the parameters under study following Wang *et al.*[13]. The final Fisher matrix is obtained as the sum of the different matrices for the different redshift bins.

3.2 Results

The obtained constraints from the forecast on the cosmological parameters[c] of the different models are shown in column 2 of Table 1. The constraints obtained combining the forecast with the CMB probe are shown in column 4 of Table 1. We have used the values obtained in column 3 (SNIa+BAO+CMB) as fiducial model for the forecast.

For the wCDM and the ϵCDM models, the obtained constraints from the forecast alone are extremely better than present-day low-redshift constraints (SNIa+BAO). When adding the CMB to the forecast we obtain constraints between a factor 2 and 6 more precise than the current ones. Given that these results are only for the galaxy clustering probe restricted to the linear scale we expect even better constraints from the full exploitation of the future Euclid data. Concerning the ϵwCDM model, the results obtained with the forecast alone are extremely better than SNIa+BAO data (which do not lead to significant constraints), but they still show a degradation on the dark energy constraints due to the dark matter freedom. When adding the CMB we recover constraints similar to the ones obtained for the wCDM and the ϵCDM models (see right panel of Fig. 1).

4 Conclusions

We have examined the consequences on the obtained constraints of dark energy properties when the pressureless dark matter assumption is relaxed (assuming constant equation of state parameter for both dark matter and the dark energy). We have found that for low redshift present-day data this freedom in the dark matter equation of state parameter completely degrades the constraints on the dark energy sector. When adding the CMB we almost recover the pressureless dark matter case constraints thanks to the tight constraint on the dark matter equation of state parameter from the CMB. We have also seen that the galaxy clustering probe of the Euclid survey will perform extremely better than low redshift present-day data, but in order to reach

[c]The baryon density parameter is not shown because either it is fixed to the Planck 2015[3] value (column 2) or it is very well constrained close to it (column 4). The radiation contribution is fixed following Komatsu *et al.*[5].

the same precision as in the pressureless dark matter case we need to add the CMB. This strong role from the CMB probably comes from assuming a constant equation of state parameter up to the CMB redshift, but focusing in low redshift data or general variations of the dark matter sector we will have to deal with the observed dark matter and dark energy equation of state parameter degeneracy.

Table 1: Cosmological parameter constraints for the different models and the different probes considered. The errors are given at the 1-σ confidence level on 1 parameter ($\Delta\chi^2 = 1$). The dash in the ϵwCDM model using SNIa+BAO data stands for the extreme degeneracies which do not allow to obtain significant constraints on the cosmological parameters.

		SNIa+BAO	Euclid GC	SNIa+BAO+CMB	Euclid GC + CMB
wCDM	Ω_m	≤ 0.28	0.299 ± 0.022	0.299 ± 0.012	0.2990 ± 0.0021
	w	-0.72 ± 0.25	-0.995 ± 0.026	-0.995 ± 0.054	-0.994 ± 0.022
	H_0	53.0 ± 13.3	68.70 ± 0.45	68.7 ± 1.3	68.68 ± 0.40
ϵCDM	Ω_m	≥ 0.31	0.301 ± 0.010	0.301 ± 0.014	0.3001 ± 0.0030
	ϵ	-0.49 ± 0.44	-0.0003 ± 0.0092	-0.0003 ± 0.0011	-0.00024 ± 0.00066
	H_0	50.00 ± 3.83	68.60 ± 0.27	68.6 ± 1.2	68.62 ± 0.12
ϵwCDM	Ω_m		0.301 ± 0.041	0.301 ± 0.014	0.3011 ± 0.0038
	w		-1.01 ± 0.13	-1.010 ± 0.077	-1.010 ± 0.023
	ϵ	–	0.000 ± 0.046	-0.0004 ± 0.0016	-0.00045 ± 0.00066
	H_0		68.6 ± 1.0	68.6 ± 1.3	68.60 ± 0.44

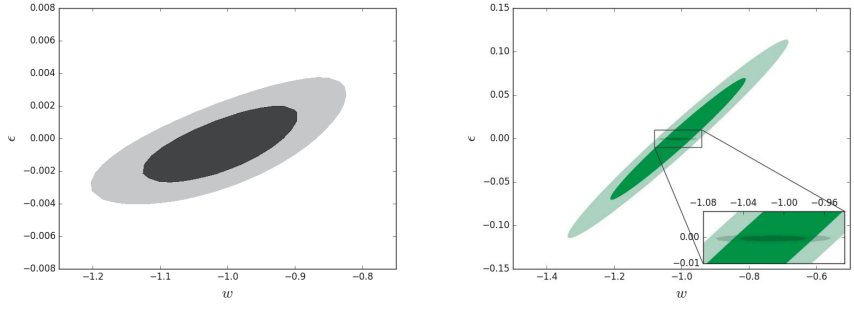

Figure 1 – Confidence contours at 68% and 95% confidence level for the w and ϵ parameters of the ϵwCDM model. Left panel: SNIa+BAO+CMB present-day data. Right panel: Euclid galaxy clustering forecast (green) and Euclid galaxy clustering+CMB (black).

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