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Testing dark energy evolution with optimized SNe constraints

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Abstract

Experimental evidence pointing to the late accelerated expansion of the Universe is often interpreted while assuming a particular dark energy model. We discuss a model-independent approach which relies on optimized estimates of the equation of state parameter at different redshift regions. In this context, recent supernova data favour the cosmological constant scenario over evolving dark energy. Furthermore, the apparent rapid variation in the equation of state parameter w appears to be a feature of certain datasets.

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Observations of high-redshift type Ia supernovae (SNe) are powerful probes of the evolution of the Universe at recent cosmological times. At the end of the last decade, evidence of this kind suggested the existence of a mysterious dark energy (DE) [1]. The most simple theoretical explanation, a cosmological constant, has proved to be consistent with more recent SNe surveys [2, 3] as well as with additional observational tests [4]. However, this conclusion depends strongly on the model chosen to describe the DE equation of state parameter, $w(z)$, and the *a priori* information about w one may consider [5]. To address the problem of parametrizing $w(z)$ in a model-independent way, a method relying on principal component (PC) analysis was proposed by Huterer and Starkman [6], more recent examples being [7–10].

In addition to the problem of finding a model-independent parametrization of $w(z)$, Nesseris and Perivolaropoulos [11, 12] have shown that features of the reconstructed w-model, such as whether it crosses the 'phantom divide' line $w = -1$, depend on the SNe dataset under consideration. To exemplify this, they compared two types of Ia SNe datasets: the *Gold* dataset of Riess *et al* [2] and the more recent dataset of Astier *et al* (SNLS, [3]).

Stephan-Otto [13] (hereafter Paper I) introduced a model-independent optimization scheme to construct a piecewise constant function to describe $w(z)$ according to the constraining capabilities of the data. A variety of the principal component analysis was employed, allowing a straight-forward interpretation of constraints on $w(z)$.

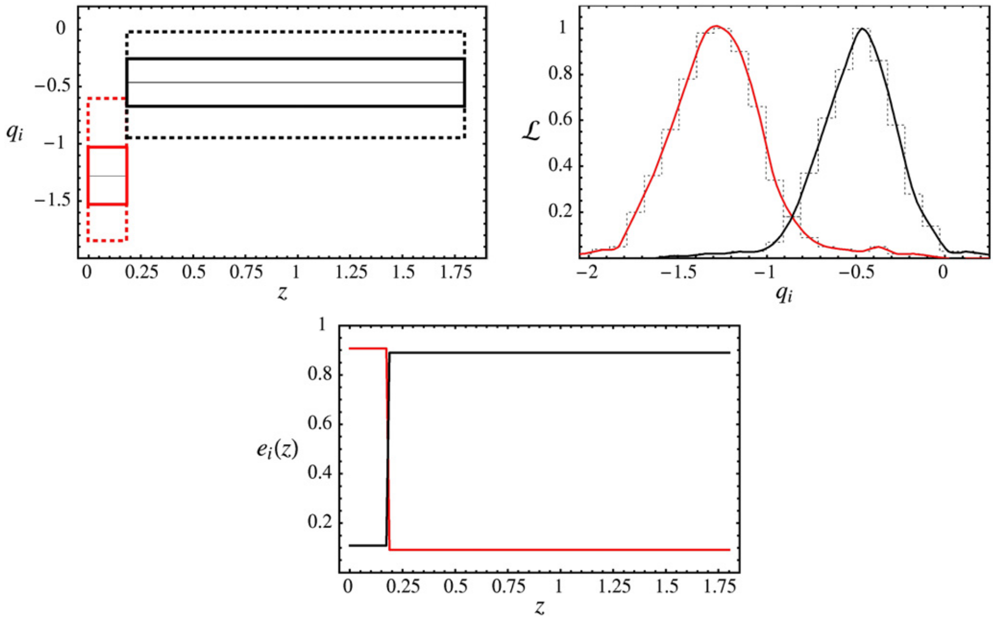

Figure 1. Optimized two-parameter model for $w(z)$ from [13]. This particular model was obtained by requiring both parameter errors to be of a comparable size, in addition to the other optimization and model selection criteria. Top left: thin horizontal lines account for the uncorrelated principal component estimates q_1 (red/grey) and q_2 (black) with corresponding 1-σ (solid) and 2-σ (dotted) rectangles showing 1- and 2-σ constraints (horizontal edges) and redshift span (vertical edges). Top right: likelihoods for the optimized two-parameter model (colour coding is the same for all three plots). Bottom: window functions $e_1(z)$ and $e_2(z)$ that relate the original piecewise estimates of $w(z)$ to the new, uncorrelated ones. The window functions, obtained following [7], are highly localized and mostly positive.

(This figure is in colour only in the electronic version)

Such a scheme was illustrated using the *Gold* dataset from [2]. A Bayesian information criterion (BIC, [14]) model selection technique was used to explore the optimized models in order to find the one in better agreement with the observational situation. According to the analysis of Paper I, some of the most favoured optimized models agree with $w < -1$ at low redshift and $w \sim -0.5$ elsewhere, which is reminiscent of the results of [7, 15, 16], among others. Nevertheless, the results are inconclusive on whether w is rapidly varying or constant. Figure 1 shows a two-parameter optimized model which, additionally, is chosen so that errors in both parameters are similar in size[1]. The window functions, obtained following [7], are highly localized and mostly positive. Such a model appears to be as favoured as the single-parameter one, which results in an estimate $w = -0.90 \pm 0.12$ (68% c.l.). Nevertheless, both of the latter are disfavoured with respect to the 'zero parameters' model: a cosmological constant with $w \equiv -1$.

For these proceedings we take up the optimized reconstruction scheme proposed in Paper I and apply it to the SNLS dataset. Table 1 lists a few of the simplest piecewise constant w

[1] Note that in order to retrieve $w(z)$, we must write it in terms of $w(z) = \sum q_i e_i(z)$, where $e_i(z)$ are the window functions relating the original piecewise components of $w(z)$ to the new, uncorrelated ones and q_i are their best-fit values.

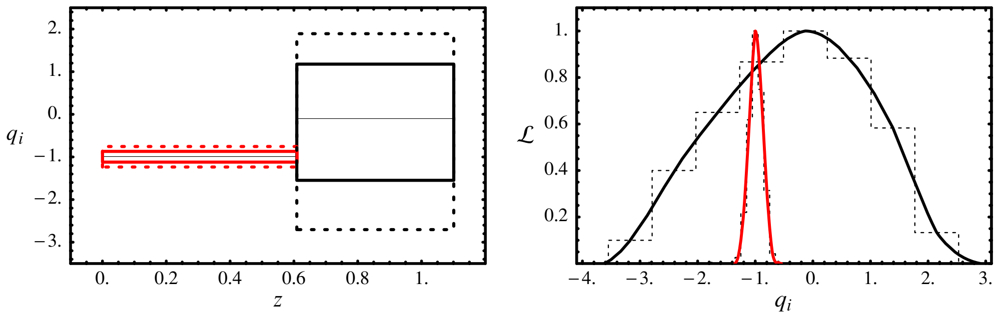

Figure 2. Two-parameter estimates of the second-to-best model of our optimization scheme. The model is definitely disfavoured by BIC when considering SNLS, but is nevertheless shown here in order to compare its constraints with respect to those of *Gold* (figure 1). We note how poorly constrained the second parameter of the model is.

Table 1. Parameter estimates together with the BIC values employed in model selection. $z_{\rm div}$ values are the optimized divisions between redshift bins and q_i the uncorrelated w-estimates in every bin.

Model	$z_{\rm div}$	$q_1[\sigma_1, \sigma_2]$	$q_2\ [\sigma_1, \sigma_2]$	$\chi^2_{\rm min}$	BIC
ΛCDM		$\equiv -1$		111.97	111.97
$N_{\rm p} = 1$		$-0.94\ [\,^{+0.09}_{-0.11}, ^{+0.16}_{-0.21}\,]$		111.63	116.37
$N_{\rm p} = 2$	0.61	$-0.99\ [\,^{+0.12}_{-0.13}, ^{+0.22}_{-0.23}\,]$	$-0.10\ [\,^{+1.27}_{-1.44}, ^{+1.98}_{-2.59}\,]$	111.44	121.12

models and their corresponding BIC values[2]. The table illustrates the disadvantage of adding parameters to the analysis of this dataset, since χ^2 is only slightly improved when increasing the number of parameters, resulting in disfavoured models due to BIC penalization. The one-parameter model is only moderately disfavoured ($\lesssim$5 BIC difference) with respect to the preferred model ΛCDM, while the rest are definitely disfavoured (a BIC difference $>$10). Figure 2 shows the two-parameter model obtained from the SNLS data although disfavoured by model selection; we show it here to illustrate the differences with the bounds inferred by *Gold* (figure 1).

Conclusions

As a new application of the model-independent parametrization scheme proposed in Paper I, we have analysed the SNLS dataset. We find that, as previously studied by Nesseris and Perivolaropoulos [11], the crossing of the 'phantom divide' line seems to be a feature of the *Gold* dataset. The approach presented goes one step further: it removes the arbitrariness of choosing the model used to parametrize w 'by hand', letting data guide the reconstruction. According to our simple model selection tool, a cosmological constant stands as the most favoured model for both datasets. Although figures 1 and 2 depict models disfavoured by our model selection scheme, they illustrate the different bounds on two-parameter models obtained when the two different datasets are used.

[2] The Bayesian information criterion value is BIC$= -2\ln\mathcal{L}_{\rm max} + N_{\rm parameters}\ln N_{\rm data}$, where the second term is seen to penalize the addition of model parameters.

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