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# MODEL INDEPENDENT TEST OF THE FLRW METRIC AND THE CURVATURE IN LIGHT OF DESI DR2.

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**Abstract.** We perform a data-driven test of the FLRW metric and the flatness of the Universe, independently of any Dark Energy model, and in light of the latest DESI results. We use Pantheon+ and DESY5 SNIa data to reconstruct the distance modulus, dimensionless comoving distance and Hubble parameter, using an iterative smoothing algorithm. Then, combining the reconstructions with the recent BAO measurements from DESI DR2, we perform the $\mathcal{O}_k$ diagnostic, a litmus test of the FLRW metric and the flatness of the Universe. We obtain robust results that do not depend on Dark Energy models and test some of the underlying hypotheses of the concordance model. The reconstructed $\mathcal{O}_k$ diagnostic is consistent with $\Omega_{k0} = 0$ at $1\sigma$.

Keywords: Methods: statistical, (Cosmology:) cosmological parameters, Cosmology: observations, Cosmology: theory, (Cosmology:) dark energy, (Cosmology:) distance scale, (Cosmology:) large-scale structure of Universe

## 1 Introduction

The current concordance model of cosmology, flat ΛCDM, describes a flat Universe with an energy budget dominated by Dark Energy (Λ) and Cold Dark Matter (CDM). It also relies on the Cosmological Principle (the Universe is homogeneous and isotropic) encoded into the FLRW metric. Despite its success in describing various features of the Universe (accelerated expansion, CMB, etc.), some tensions have arisen in the ΛCDM model, especially in determining the value of the Hubble constant $H_0$. Moreover, the recent second data release of DESI hinted significantly for the first time at a dynamical Dark Energy equation of state, shaking the cosmological constant model from ΛCDM. In this work, our goal is to combine SNIa (Pantheon+, DES Y5) and BAO (DESI DR2) data to obtain a litmus test of the FLRW metric and the flatness, without assuming any Dark Energy model. This method allows to directly test the consistency of the data with the underlying assumptions of the ΛCDM model.

## 2 Iterative Smoothing on SNIa data

Following the methodology of Shafieloo et al. (2006); Shafieloo (2007); L'Huillier & Shafieloo (2017); Shafieloo et al. (2018); L'Huillier et al. (2025), we first perform an iterative smoothing of the distance modulus $\mu$ of Type Ia supernova (see eq. 2.1 and 2.2). This method allows to directly reconstruct the data in a model-independent way. Independently of the initial guess $\hat{\mu}_0$, the reconstructed $\hat{\mu}_n$ will converge to the solution preferred by the data (see Shafieloo et al. 2006; Shafieloo 2007; L'Huillier & Shafieloo 2017; Shafieloo et al. 2018). The final selection of reconstructed $\hat{\mu}(z)$ and the derived dimensionless comoving distances $\mathcal{D}(z)$ and expansion histories $h(z)$ form a non-exhaustive set of plausible expansion histories, all with a better $\chi^2$ to the data than the best-fit flat ΛCDM model. We apply this iterative smoothing to the Pantheon+ and DES Y5 SNIa datasets.

$$\hat{\mu}_{n+1}(z) = \hat{\mu}_n(z) + \frac{\delta\boldsymbol{\mu}_n^T \cdot {\mathbf{C_{SN}}}^{-1} \cdot \mathbf{W}(z)}{\mathbb{1}^T \cdot {\mathbf{C_{SN}}}^{-1} \cdot \mathbf{W}(z)} \tag{2.1}$$

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the weights $\mathbf{W}$ and residuals $\delta\boldsymbol{\mu}_n$ are defined as:

$$W_i(z) = \exp\left(-\frac{\ln^2\left(\frac{1+z}{1+z_i}\right)}{2\Delta^2}\right), \quad \delta\mu_{n|i} = \mu_i - \hat{\mu}_n(z_i). \tag{2.2}$$

## 3 Combining with BAO data

From each previously selected reconstruction, we extract $\mathcal{D}(z)$ and $\mathcal{D}'(z)$ at the redshift of the BAO signal from the latest DESI DR2 data, and combine them with the BAO modes $\frac{\mathcal{D}_M(z)}{r_d}$ and $\frac{\mathcal{D}_H(z)}{r_d}$, to estimate the $\mathcal{O}_k$ and $\Theta$ diagnostics (see eq. 3.1, Clarkson et al. (2008); Shafieloo & Clarkson (2010)).

$$\mathcal{O}_k(z) = \frac{\Theta^2(z) - 1}{\mathcal{D}^2(z)}, \quad \Theta(z) = \frac{d_M(z)}{d_H(z)} \cdot \frac{\mathcal{D}'(z)}{\mathcal{D}(z)} \tag{3.1}$$

In an FLRW universe, $\mathcal{O}_k(z) = \Omega_{k0}$. Therefore, a deviation from constancy in $\mathcal{O}_k(z)$ would hint at a departure from the FLRW metric, while a deviation from 0 would hint at a departure from flatness. Then, we calculate the likelihood of each collection and display the normalized results on the top panel of Fig. 1 and 2.

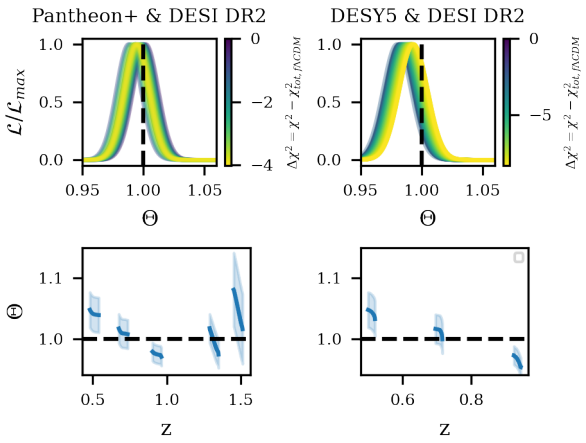


Fig. 1: *Lower panel:* Θ parameter at $z_{BAO}$. *Top panel:* Normalised likelihood.

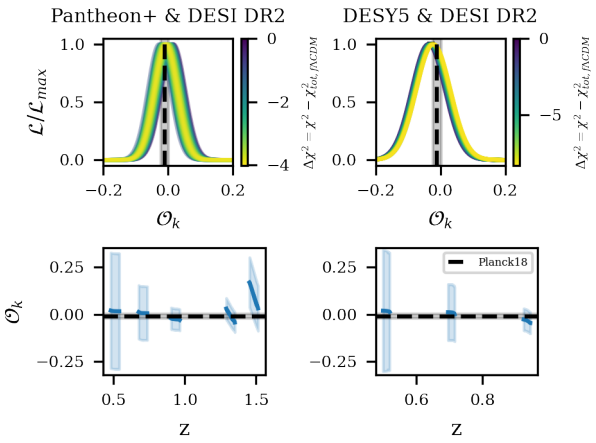


Fig. 2: *Lower panel:* $\mathcal{O}_k(z)$ parameter at $z_{BAO}$. *Top panel:* Normalised likelihood.

## 4 Conclusion

We performed a model-independent litmus test of the FLRW metric and the flatness of the universe. Using an iterative smoothing algorithm on Pantheon+ and DESY5 data, we reconstructed $\mathcal{D}$ and $\mathcal{D}'$. Combining these with DESI DR2 BAO data, we derived the Θ parameter and the subsequent $\mathcal{O}_k$ diagnostic. For the Pantheon+ & DESI DR2 data combination, the median $\mathcal{O}_k$ value is $\mathcal{O}_k = -0.006 \pm 0.035$, and the maximum likelihoods have a spread of $\Delta\mathcal{O}_k = 0.16$. For the DESY5 & DESI DR2 data combination, we obtain $\mathcal{O}_k = -0.027 \pm 0.052$, with a spread of $\Delta\mathcal{O}_k = 0.045$. The standard deviations depend on the BAO data, so they are expected to be similar between the two combinations of data. However, only 3 BAO data points were used with DES Y5 supernovae, resulting in slightly higher standard deviations. $\Delta\mathcal{O}_k$ depends on the uncertainties on supernovae data. The data density at $z < 1.2$ being higher in the DESY5 sample, the spread of DESY5 & DESI DR2 is lower than the spread of Pantheon+ & DESI DR2. For both data sets, the recovered $\mathcal{O}_k$ agree with the $\Omega_k$ values from Planck 2018 within $1\sigma$. Across all redshifts, the $\mathcal{O}_k$ diagnostic remains constantly consistent with zero within $1\sigma$, supporting a flat FLRW Universe.

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