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

arXiv:2601.20293

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# THE STANDARD ΛCDM MODEL

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**FLRW METRIC**

Encodes the Cosmological Principle : Universe homogeneous and isotropic

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## COSMOLOGICAL CONSTANT & FLATNESS

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$$h(z) = \sqrt{\Omega_{m0}(1+z)^3 + \Omega_{k0}(1+z)^2 + \Omega_{\Lambda 0} \exp\left(3\int_0^z \frac{1+w(z)}{1+z}\right)}$$

Dimensionless Hubble parameter

Matter density

Curvature

Dark Energy density

Equation of State of Dark Energy

Dimensionless comoving distance :

$$\mathcal{D}(z) = \frac{1}{\sqrt{-\Omega_{k,0}}} \sin\left[\sqrt{-\Omega_{k,0}} \int_0^z \frac{\mathrm{d}x}{h(x)}\right]$$

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## COSMOLOGICAL CONSTANT & FLATNESS

$$\begin{cases} \Omega_{k0} = 0 \\ w(z) = -1 \end{cases}$$

$$\mathcal{D}(z) = \int_0^z \frac{\mathrm{d}x}{h(x)}$$

# TEST OF FLRW METRIC AND FLATNESS

The Ok diagnostic :

$$\mathcal{O}_k(z) = \frac{\Theta^2(z) - 1}{\mathcal{D}^2(z)}$$

Chris Clarkson, Bruce Bassett, and Teresa Hui-Ching Lu 2008 "A general test of the Copernician Principle" arXiv:0712.3457v2

$$\Theta(z) = h(z)\mathcal{D}'(z)$$

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**Goal** : to combine type Ia supernovae (SNIa) and and Baryonic Acoustic Oscillations (BAO) data to obtain a model independent test of FLRW and the curvature, using the Ok diagnostic.

# DATA COMBINATION

B. L'Huillier, A. Mitra et al. 2025
"Litmus tests of the flat ΛCDM model and model-independent measurement of H0rd with LSST and DESI"
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$$\Theta(z) = \frac{d_M(z)/r_d}{d_H(z)/r_d} \frac{\mathcal{D}'(z)}{\mathcal{D}(z)}$$

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**BAO**

From DESI DR2, transverse and radial mode of the BAO give :

$$\begin{cases} \dfrac{d_M(z)}{r_d} = \dfrac{c}{H_0 r_d}\mathcal{D}(z) \\ \dfrac{d_H(z)}{r_d} = \dfrac{c}{H(z) r_d} \end{cases}$$

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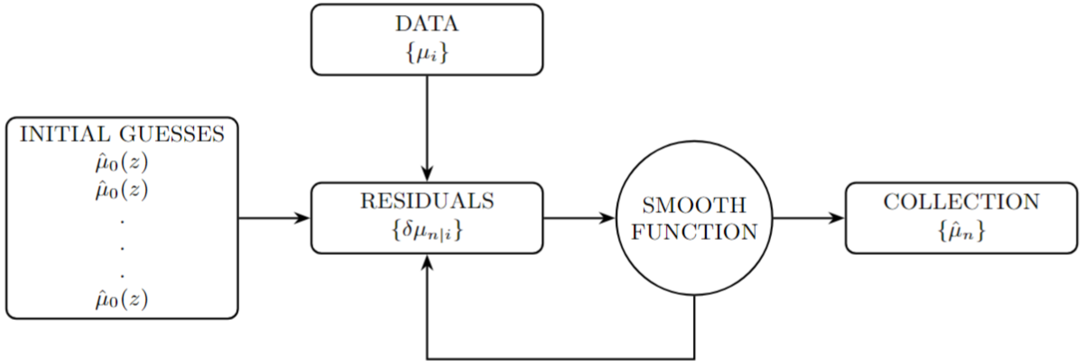
## SNIa

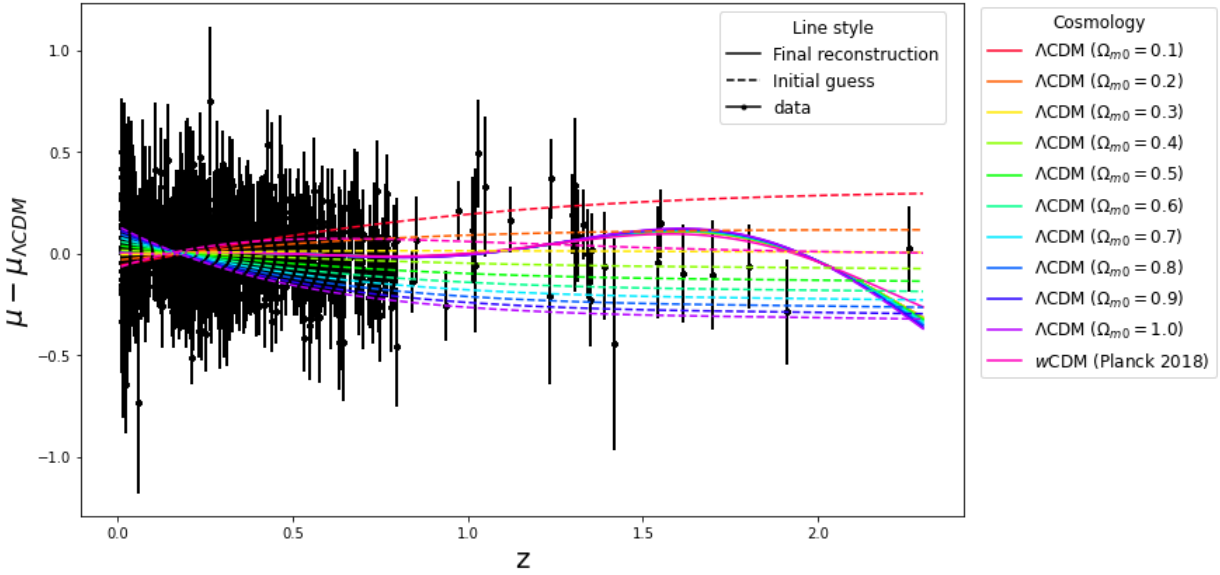
Pantheon+ and DES Dovekie
$\{z_i, \mu_i(z_i)\}$

Using an Iterative Smoothing Algorithm, we reconstruct

$$\mathcal{D}(z) = \frac{c}{H_0}\frac{10^{\frac{\mu(z)}{5}-5}}{1+z}$$

# ITERATIVE SMOOTHING ON SNIA DATA




- Smooth data over redshift without assumption on Dark Energy model

A. Shafieloo, U. Alam, V. Sahni and A.A. Starobinsky, 2007
Smoothing Supernova Data to Reconstruct the Expansion History of the Universe and its Age
arXiv:astro-ph/0505329v4

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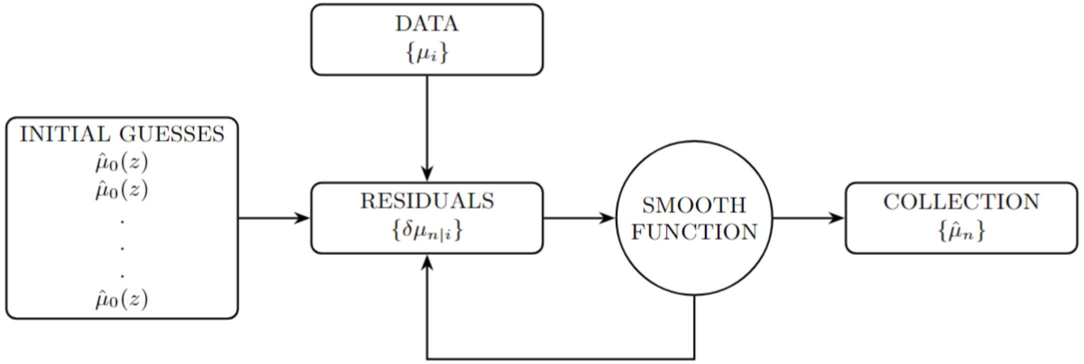


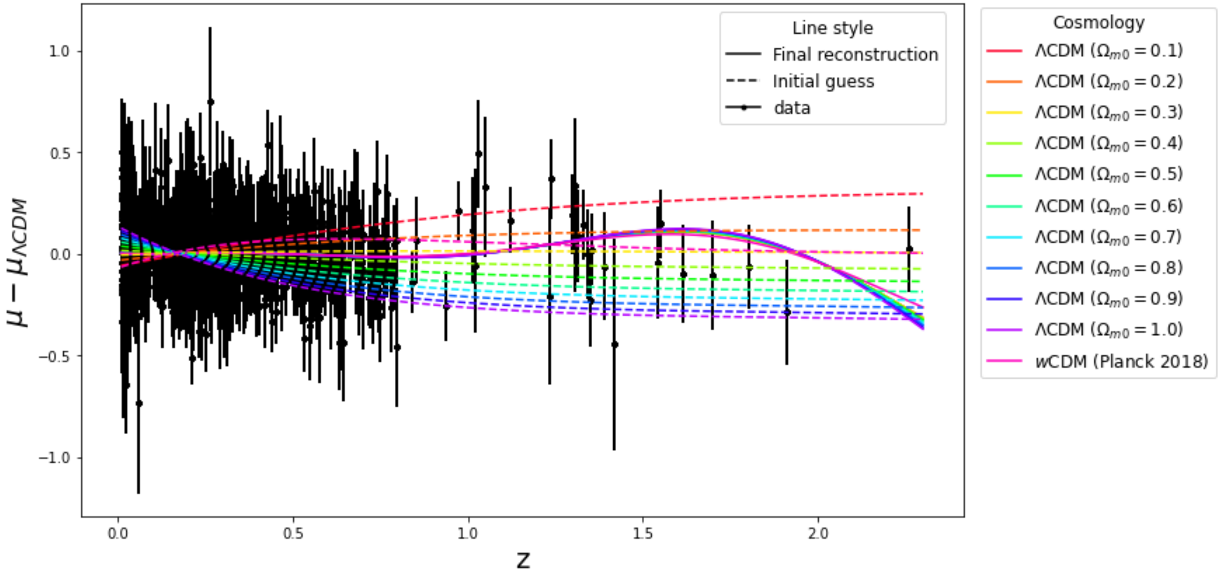


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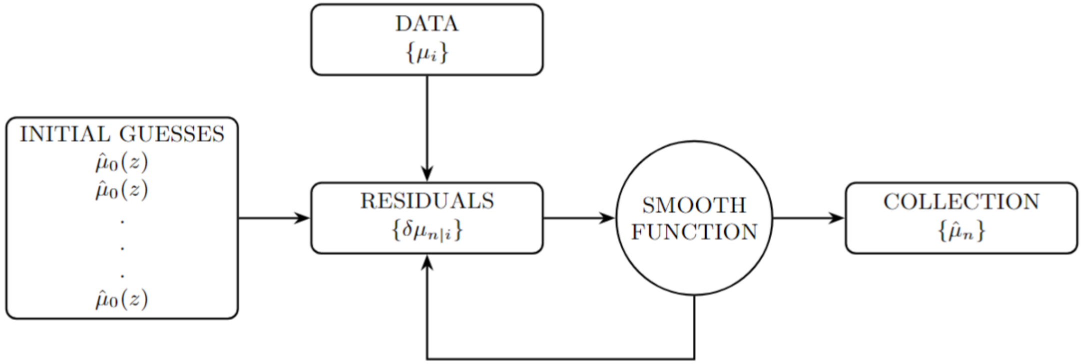


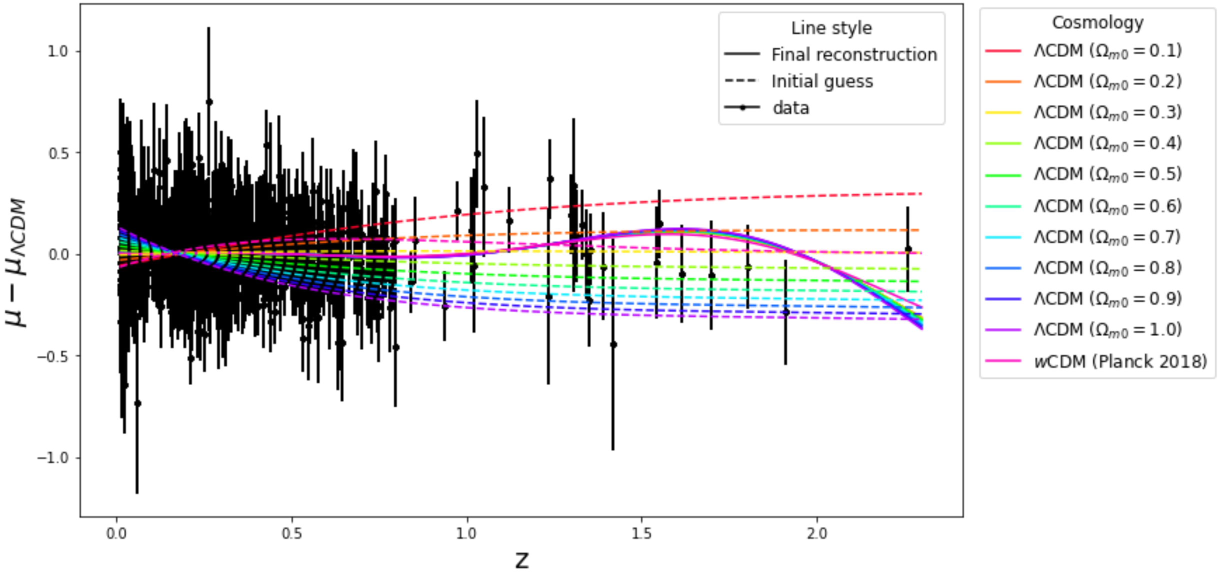


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- The smoothing converge toward the solution preferred by the data, independently of the initial guess.


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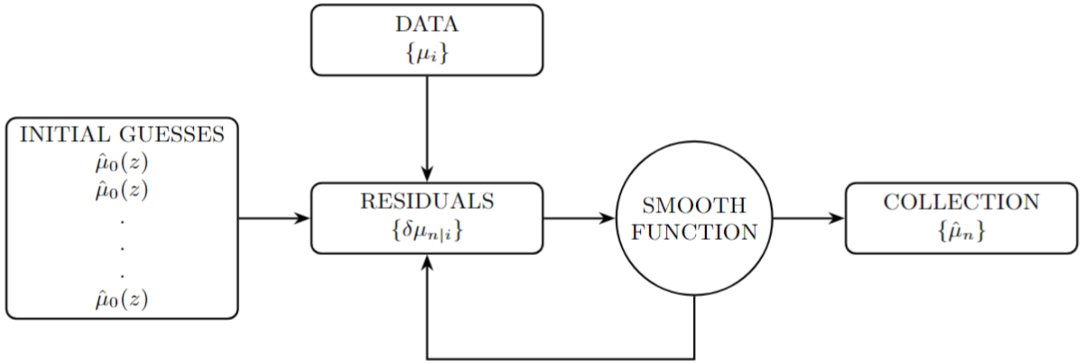


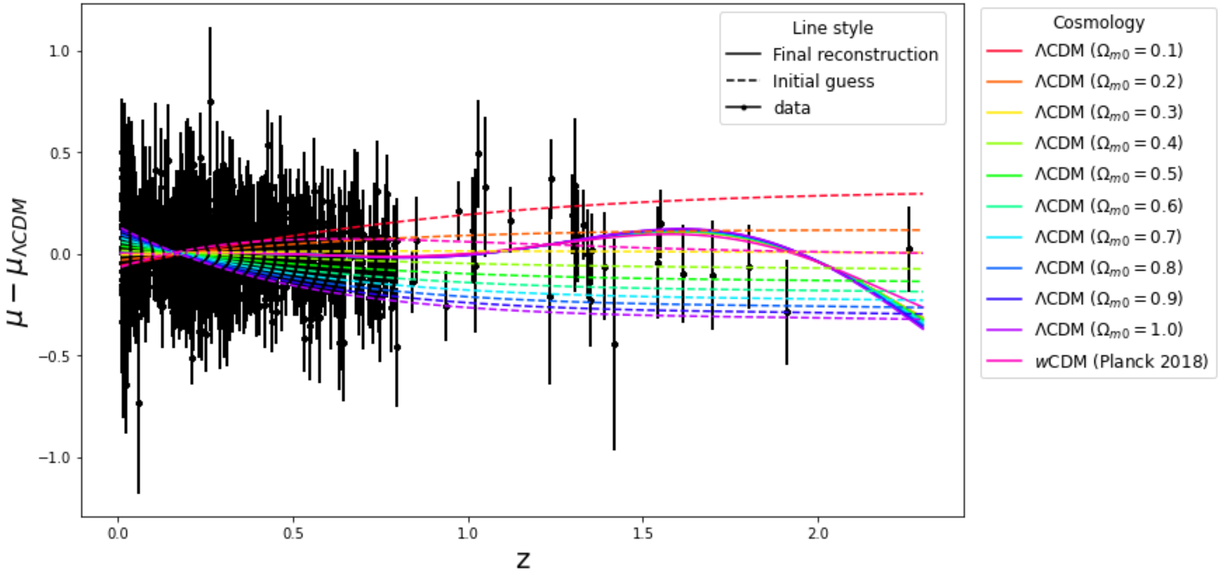


- Smooth data over redshift without assumption on Dark Energy model
- Starting from any initial guess, each iteration minimizes the chi square
- The smoothing converge toward the solution preferred by the data, independently of the initial guess.
- Usually, we only keep the reconstructions with

$$\Delta\chi^2 = \chi^2_{\text{reco}} - \chi^2_{\Lambda\text{CDM}} < 0$$

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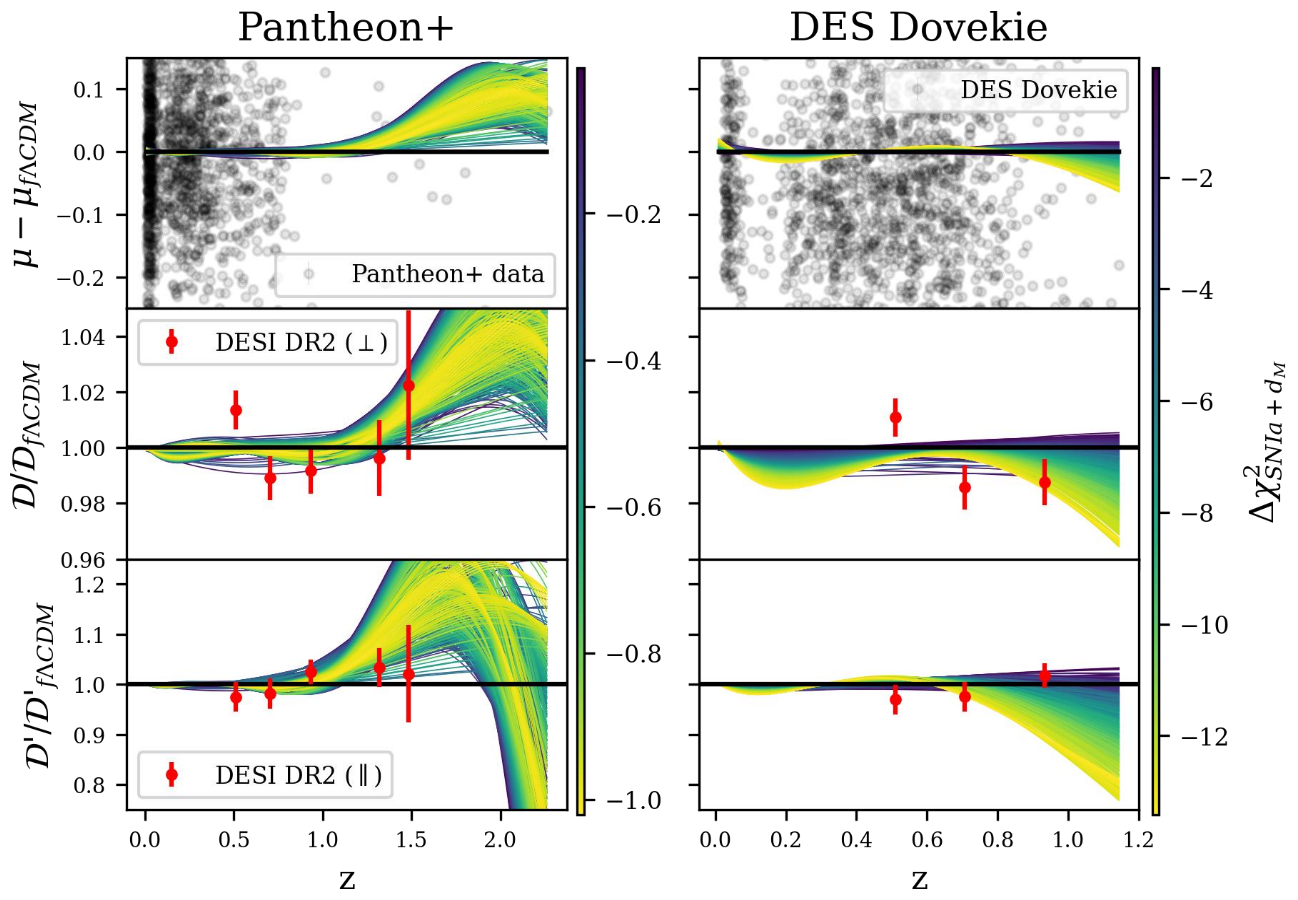
# SMOOTHING RESULTS




Results of the iterative smoothing on Pantheon+ and DES Dovekie data.

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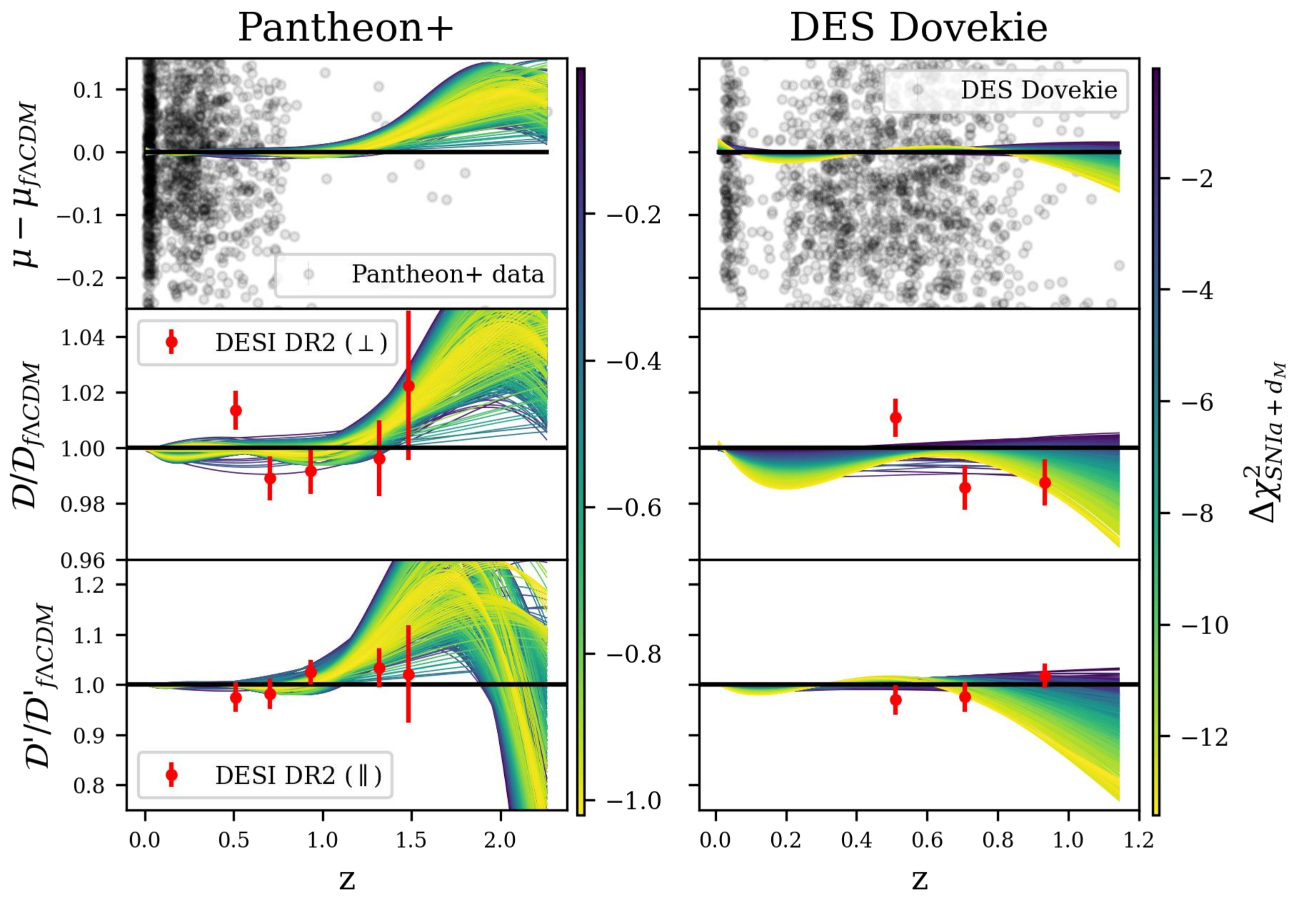


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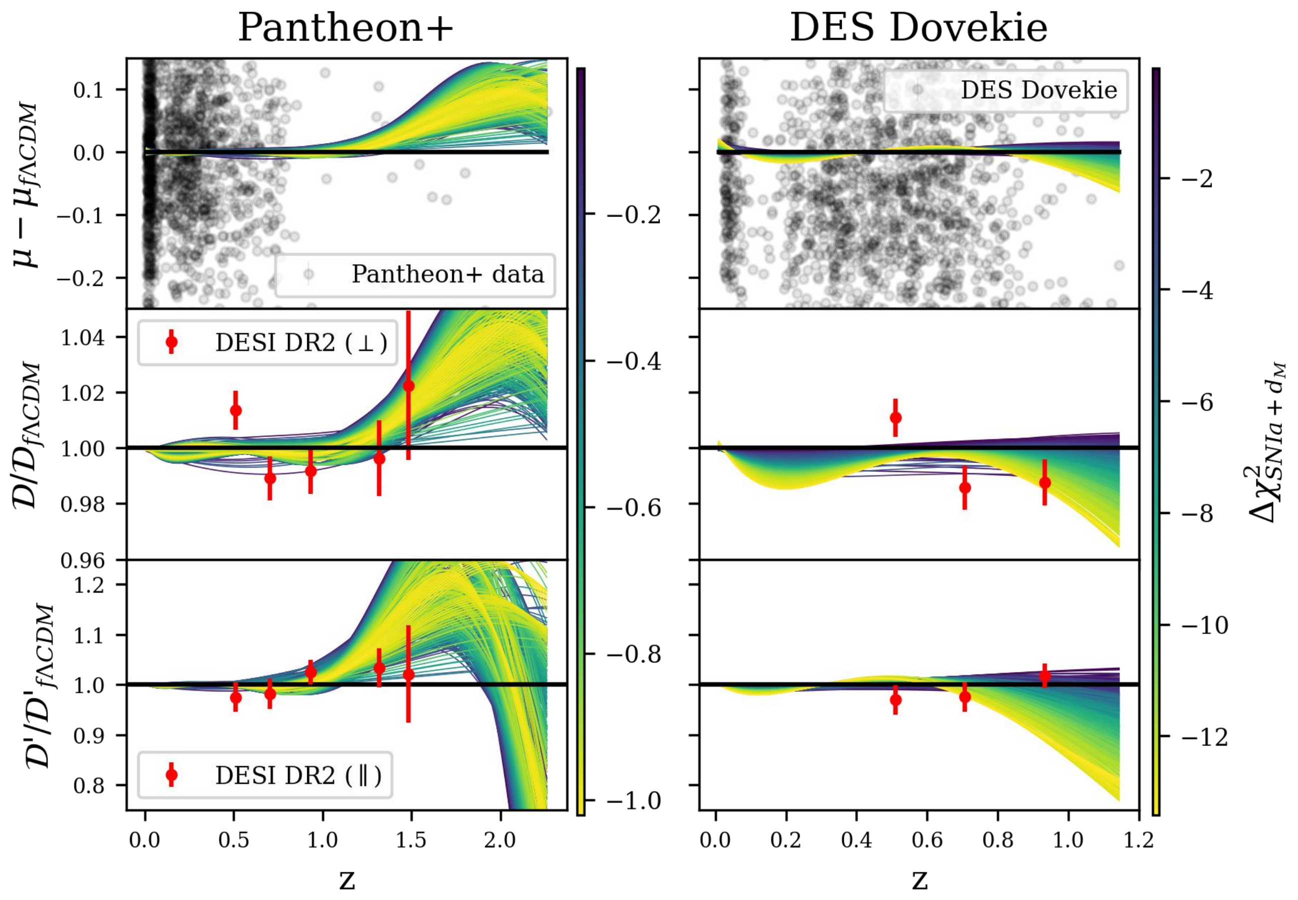


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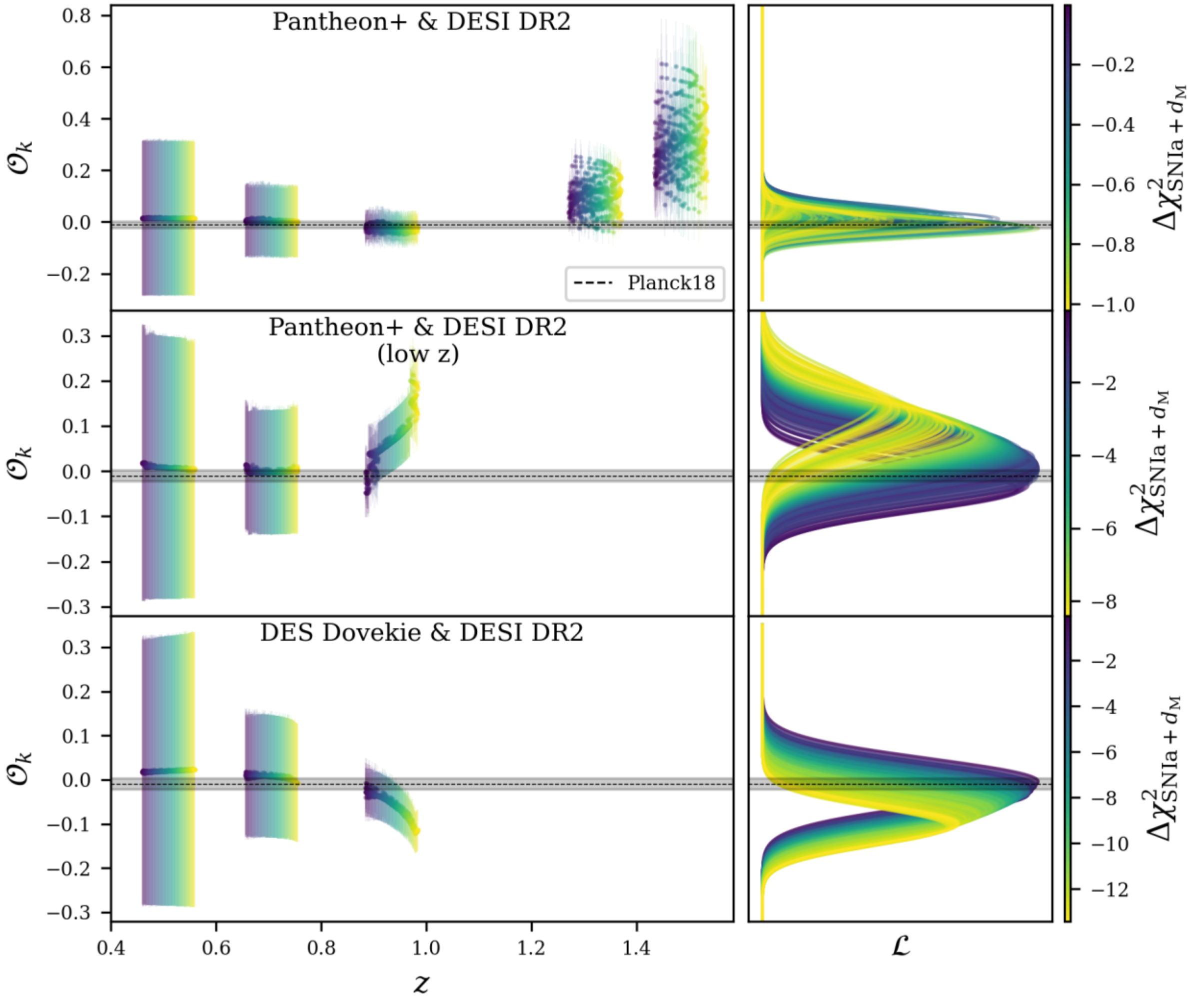
BAO transverse and radial mode have been overplotted but were not involved in smoothing.

# RESULTS




| $\Delta\chi^2$ criterion | Data combination | $\Omega_{k,0}^{\mathrm{med}}$ |
|---|---|---|
| | P+ & DESI DR2 | $0.045^{+0.045}_{-0.081} \pm 0.038$ |
| $\Delta\chi^2_{\mathrm{SNIa}+d_\mathrm{M}} < 0$ | P+ & DESI DR2 (low-$z$) | $0.095^{+0.063}_{-0.136} \pm 0.063$ |
| | DES Dov. & DESI DR2 | $-0.102^{+0.099}_{-0.005} \pm 0.043$ |

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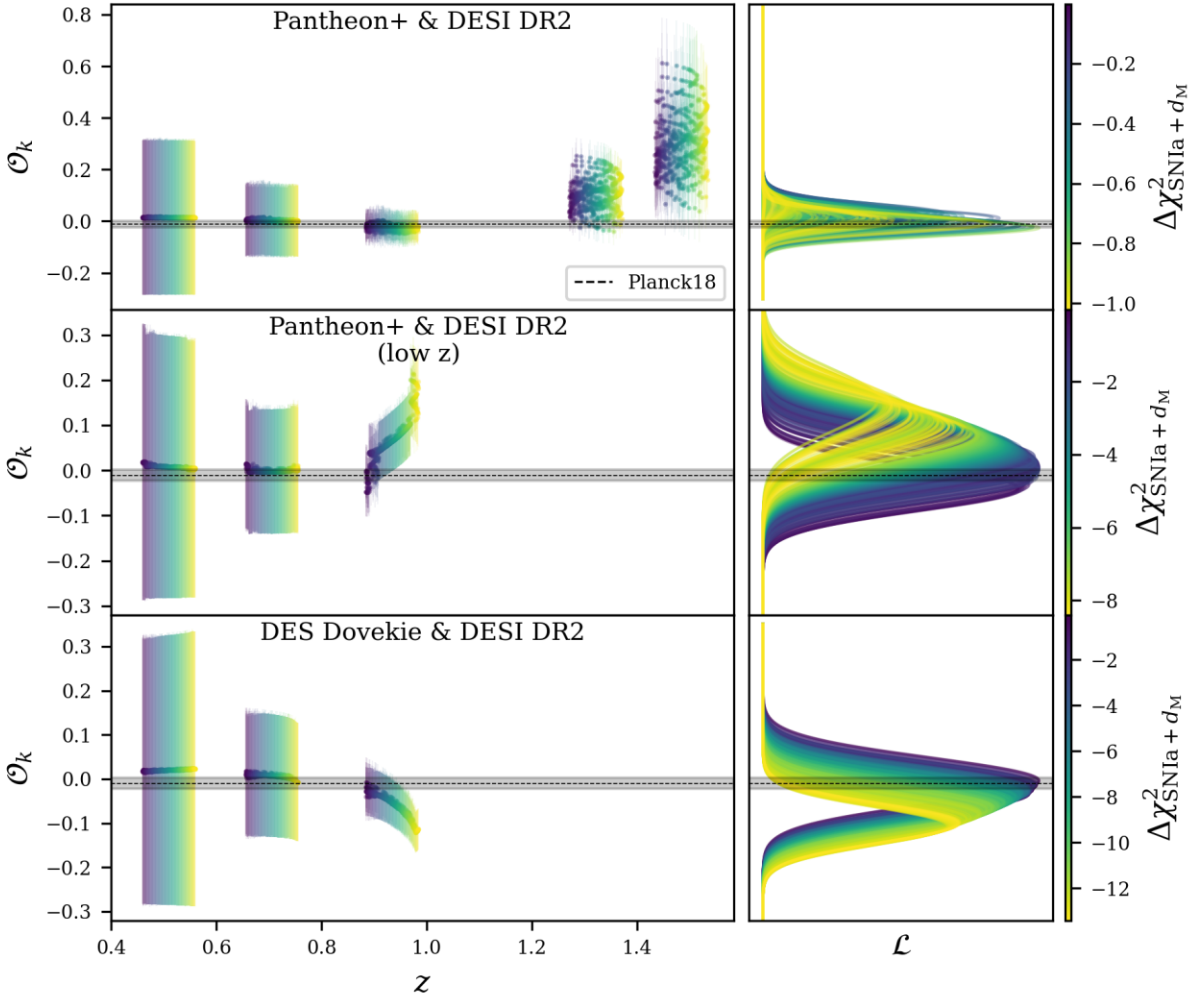


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For all data combination, 100% of reconstructions are compatible with FLRW.

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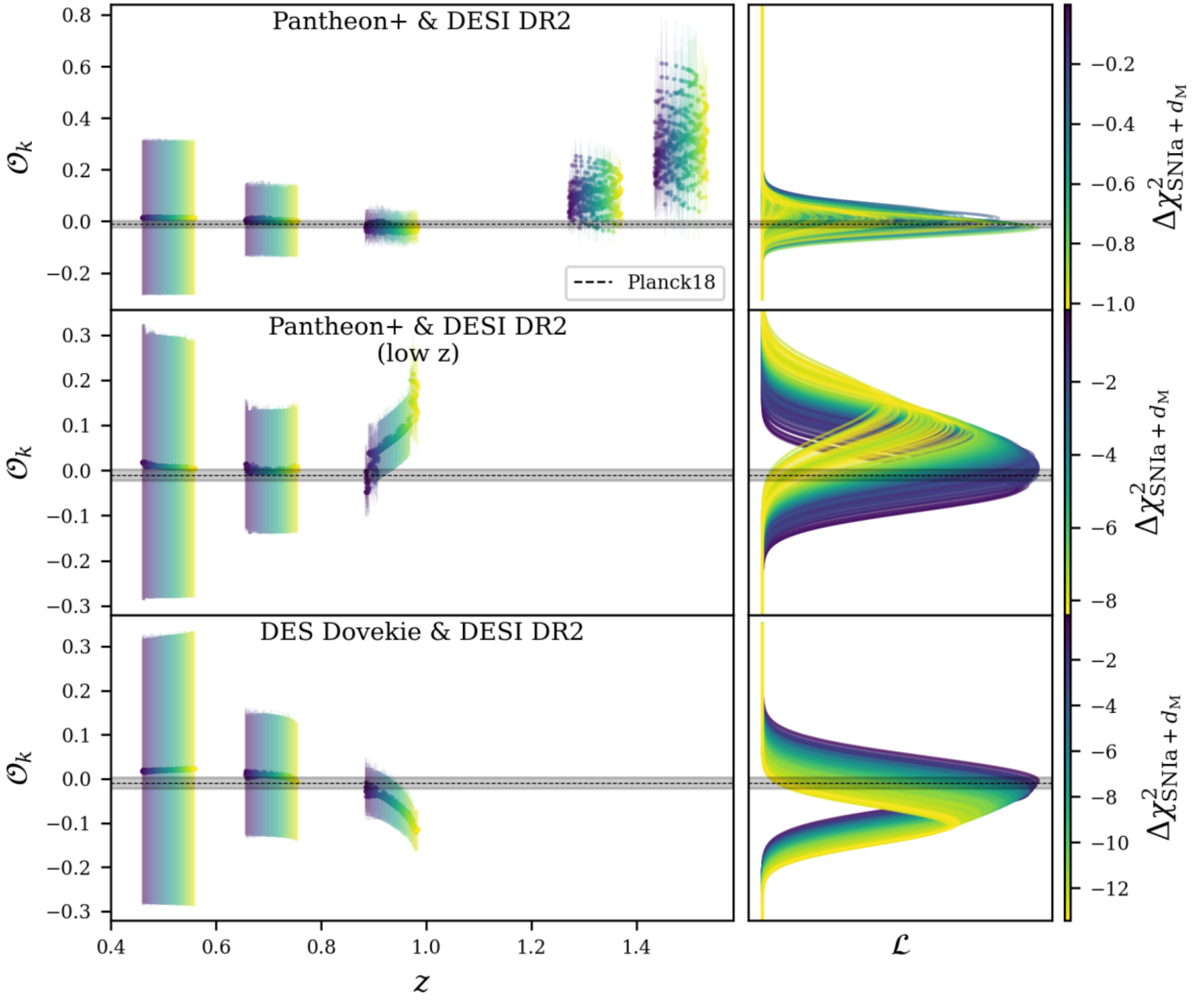


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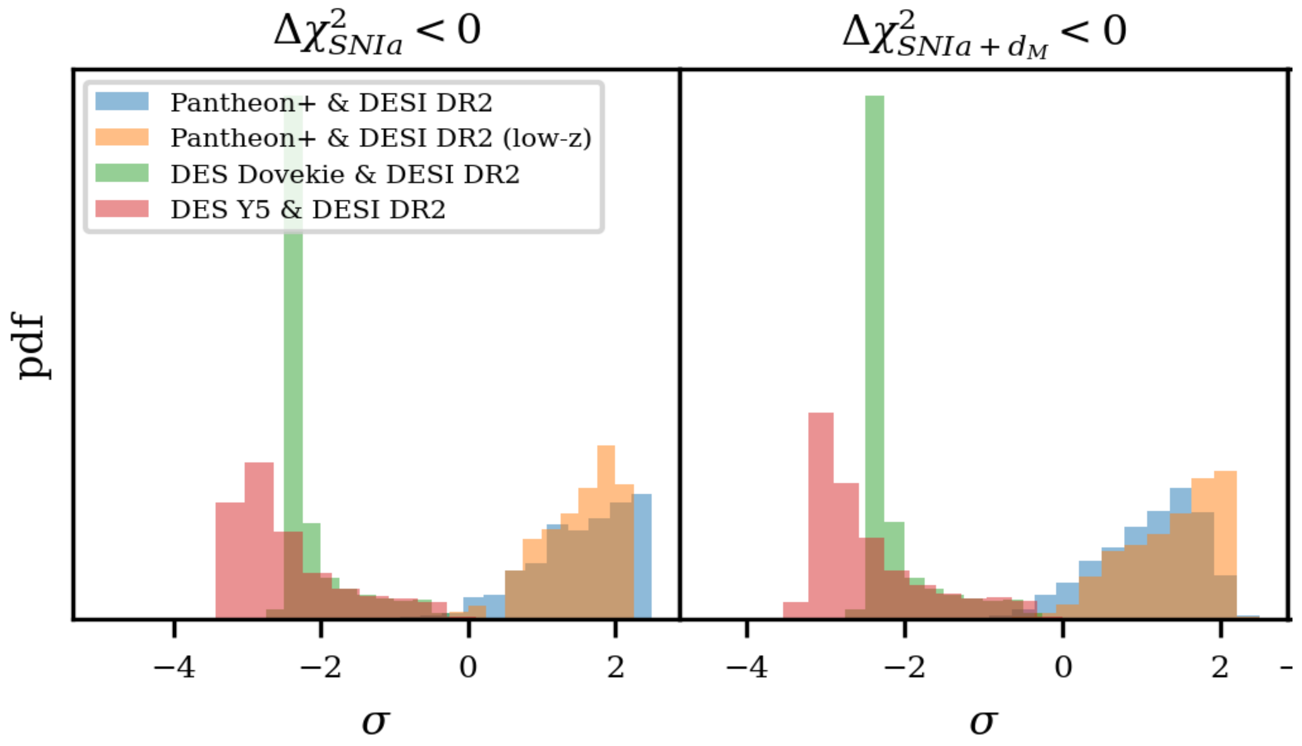
Preferences for positive curvature in Pantheon+ & DESI DR2, and for negative curvature in DESY5 & DESI DR2 appear, both are consistent with flatness within 3σ.

# CONCLUSION




**Pantheon+ & DESI DR2** :

Tension between SNIa and BAO

High redshift data drives the Ok diagnostic away from FLRW

When considering $\Delta\chi^2_{SNIA+dm}$, the deviation from FLRW strongly decreases, and the results are consistent with flatness, with a preference for negative curvature.

**DES Dovekie & DESI DR2** :

Better agreement between SNIa and BAO

All reconstructions are consistent with the FLRW metric, and flatness within 3σ, with a preference for positive curvature.

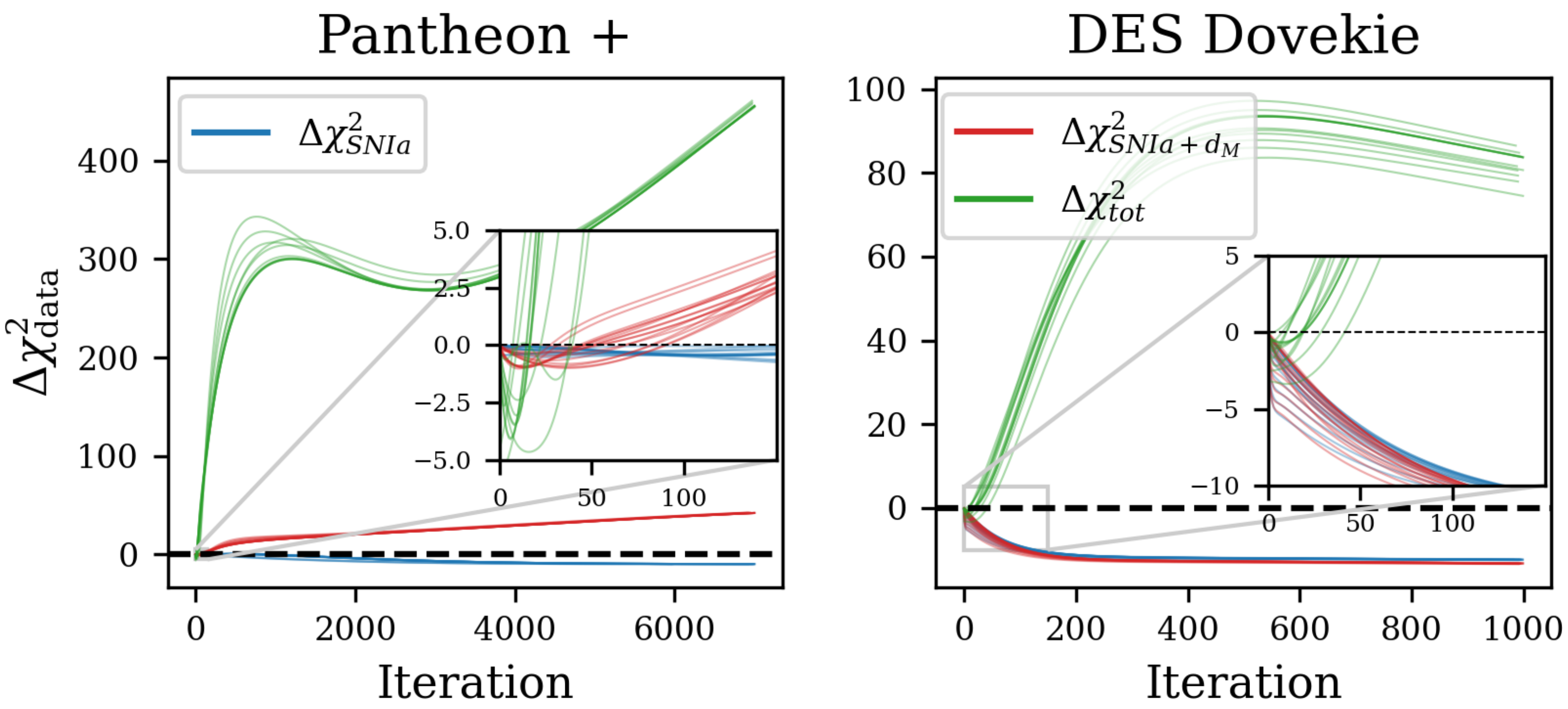
**DES Dovekie & DESY5** :The tension between Pantheon+ and DES on the value of Oko has been alleviated by the update of the DESY5 dataset to DES Dovekie

# BACK UP

# SELECTION

Selection criterions :

| |
|---|
| $\Delta\chi^2_{\mathrm{SNIa}} < 0$ |
| $\Delta\chi^2_{\mathrm{SNIa+d_M}} < 0$ |
| $\Delta\chi^2_{\mathrm{tot}} < 0$ |




- The selection on Pantheon+ reconstructions is heavily impacted by the change in selection criterion.

- The calculation of $\Delta\chi^2_{\mathrm{tot}}$ assumes flatness

# RESULTS

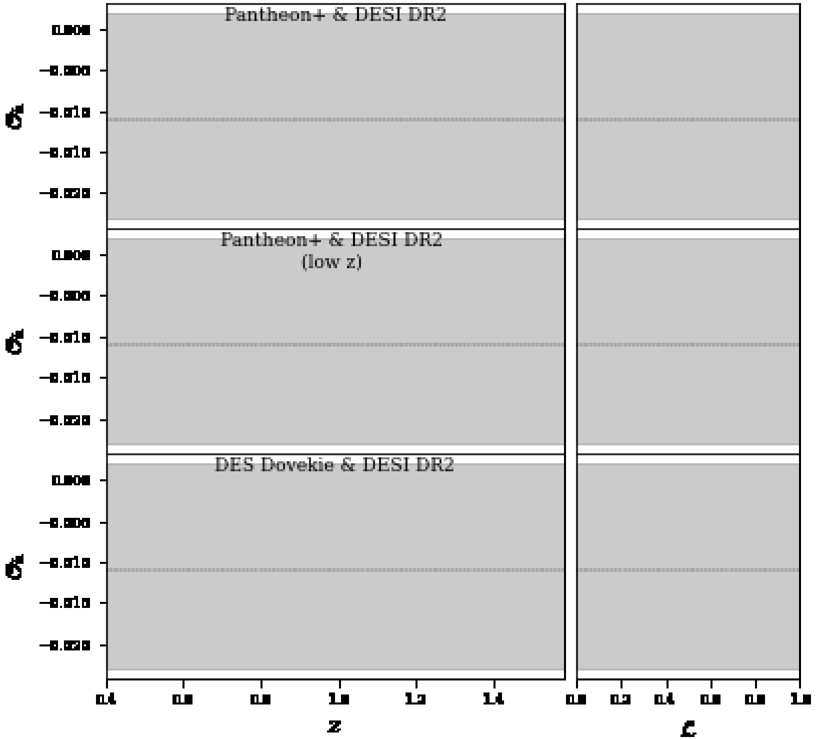
For each previous reconstructions we calculate Ok at the redshift of the BAO (see bottom row) :

$$\mathcal{O}_k(z) = \frac{\Theta^2(z) - 1}{\mathcal{D}^2(z)}$$

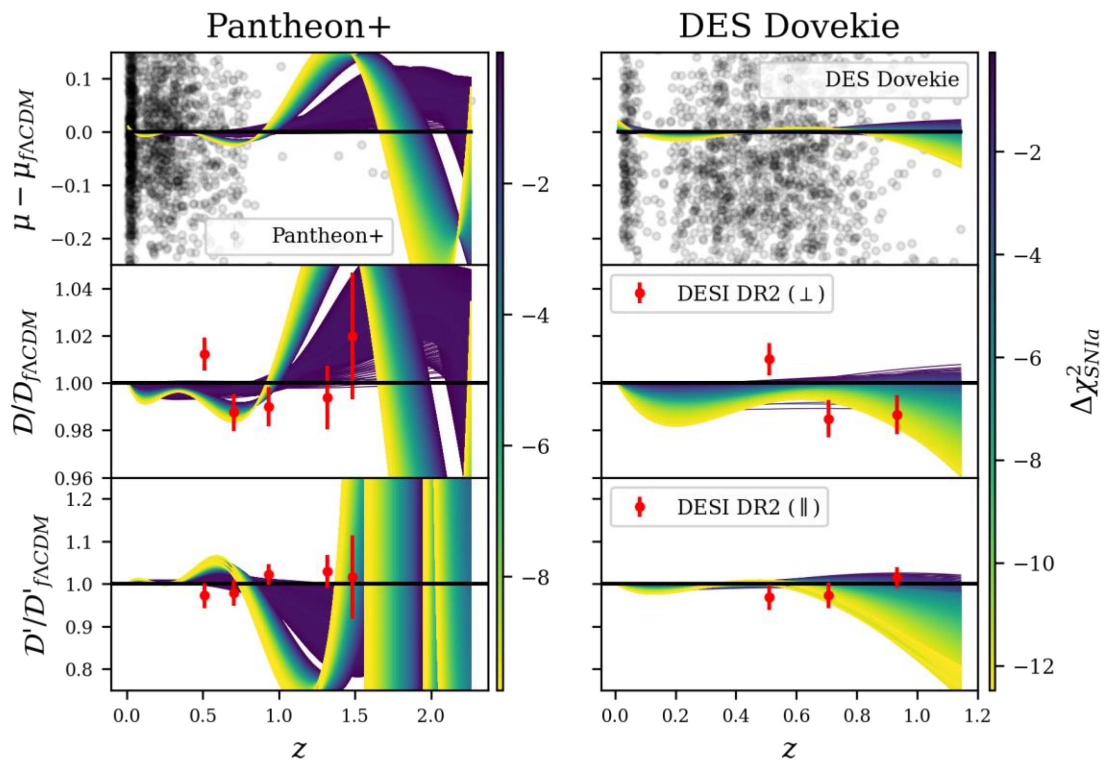
**BAO** **SNIa**

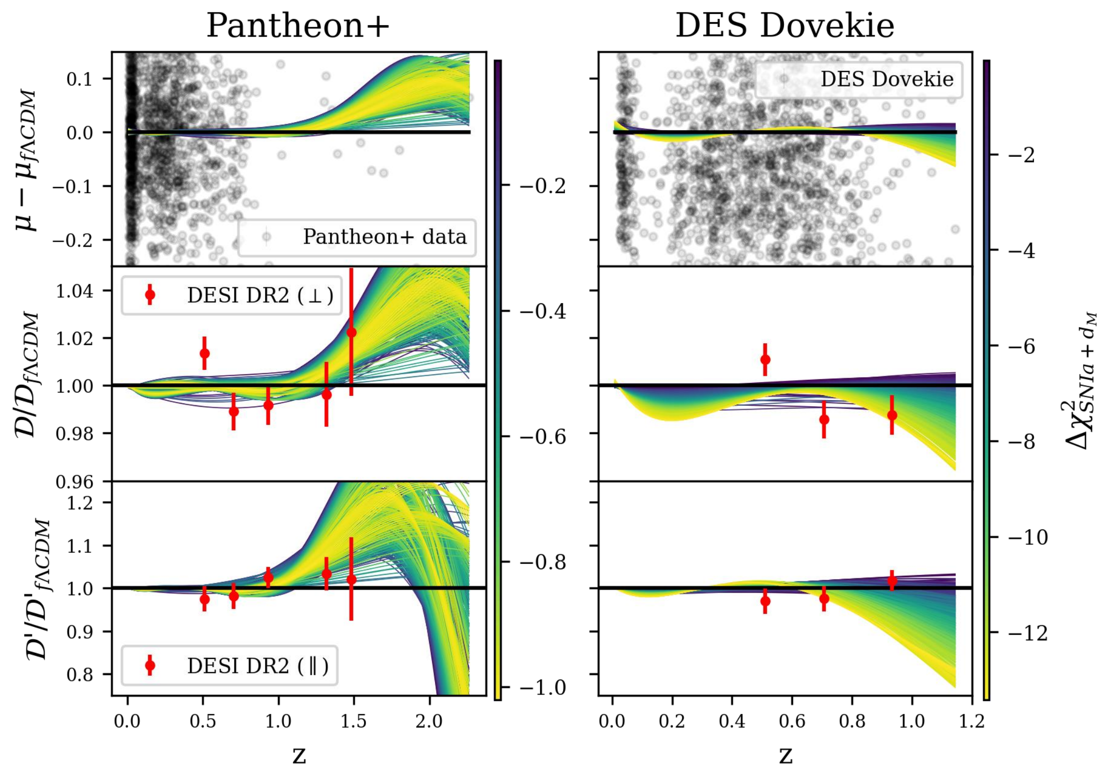
$$\Theta(z) = \frac{d_M(z)/r_d}{d_H(z)/r_d} \frac{\mathcal{D}'(z)}{\mathcal{D}(z)}$$

And display their normalized likelihood in the top row.



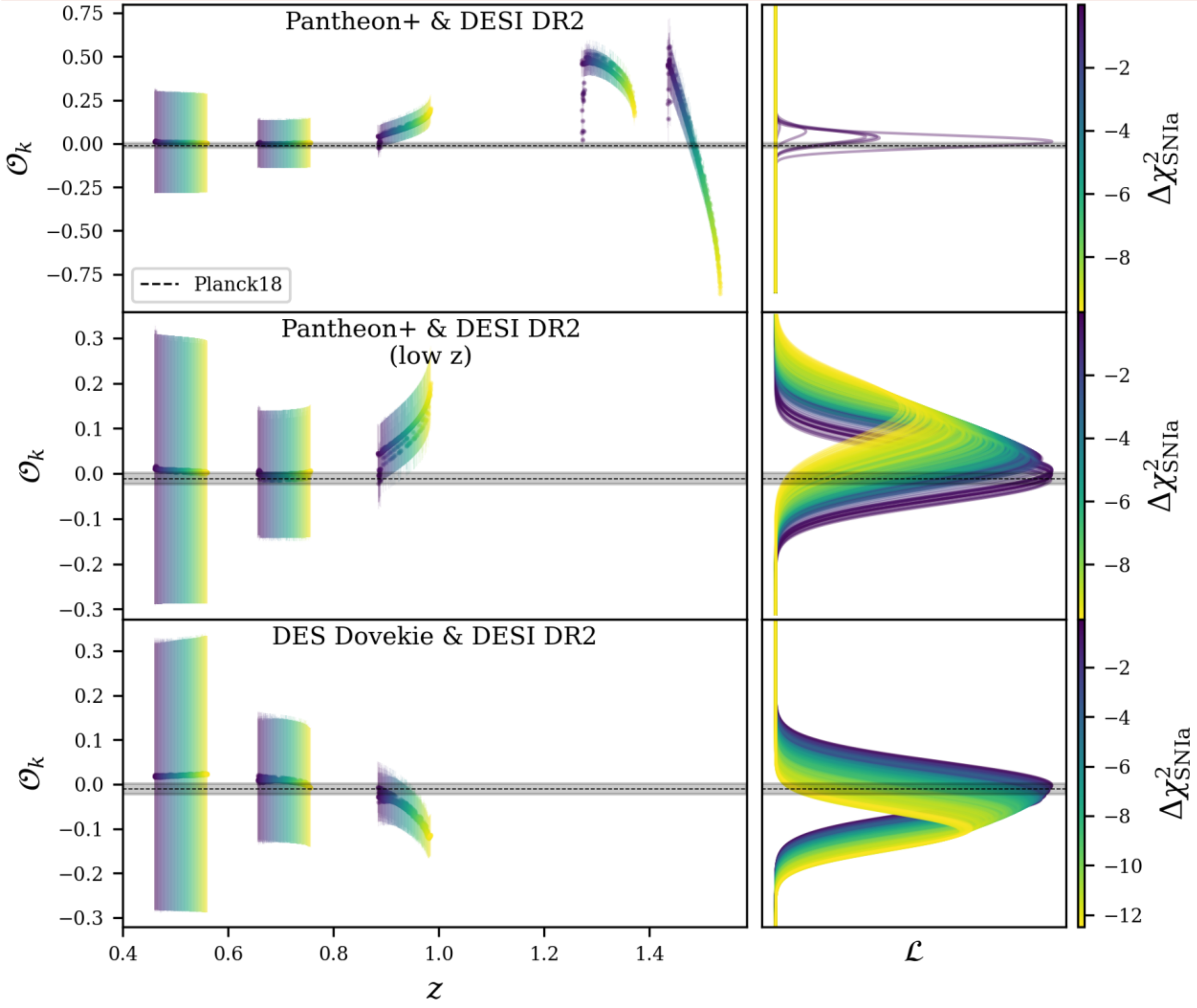
# EFFECT OF SELECTION ON SMOOTHING




A tension between Pantheon and DESI DR2 appears, while the DES collection remains virtually unaffected by the change in selection criterion.

# RESULTS

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| | DES Dov. & DESI DR2 | $-0.102^{+0.100}_{-0.005} \pm 0.043$ |

Pantheon+ & DESI DR2: only 1% of reconstructions are consistent with FRLW.

This inconsistency is driven by high-z data: for Pantheon+ & DESI DR2 (low-z), 100% of reconstructions are consistent with FRLW

DESY5 & DESI DR2: 100 % of reconstructions are consistent with FLRW

Overall, the reconstructions consistent with FLRW are also consistent with flatness within 3σ.