Exploring dark energy evolution

Dr. Víctor H. Cárdenas
Instituto de Física y Astronomía
Facultad de Ciencias
Universidad de Valparaíso

Contents

Context

- Dark Energy (**DE**) is the name of the cause of the cosmic acceleration in expansion detected in 1998.
- So far, the best model that fits observational data, is *still* the LCDM; a cosmological **constant.**
- We do not know what this contribution comes from, neither why it has that value
- The model generates a “cosmic” coincidence, which makes it unnatural

Context

Type Ia supernova measurements give $$m_B(z) = M + 5\log_{10}\left[\frac{d_L(z)}{10\ \mathrm{pc}}\right],$$

Connected to $$d_L(z) = \frac{c}{H_0}(1+z)\int_0^z \frac{dz'}{E(z')},$$

where
$$E(z)^2 = \Omega_m(1+z)^3+\Omega_r(1+z)^4+(1-\Omega_m-\Omega_r)X(z),$$

with
$$X(z) = \exp\left[3\int_0^z \frac{1+w(z')}{1+z'}dz'\right].$$

Context

- We look for hints of DE evolution (with redshift):
  - A variable equation of state (EoS) parameter, w(z).
  - A variable DE density, X(z).

- LCDM is by definition a model where X(z) and w(z) are constants.

RC Bernardo, D Grandón, Jackson S Levi, VHC Parametric and nonpara-metric methods hint dark energy evolution. Phys. Dark Univ., 36:101017, 2022.

Reconstruction program

- A variable equation of state (EoS) parameter, w(z).
- A variable DE density, X(z).
- Cosmology

$$E^2(z) = \Omega_m (1+z)^3 + \Omega_r (1+z)^4 + (1-\Omega_m-\Omega_r) X(z)$$

$$X(z) = \exp[\ 3\int_0^z \frac{1+w(x)}{1+x} dx]$$

CosmoVerse netwok Collab. Phys. Dark Univ. 49 (2025) 101965

Reconstruction program

- There is a problem in trying to extract information from the EoS parameter w(z) (Maor et al. 2000)

- We are interested in test to what extend the data suggest departures from the LCDM model

$$E^2(z) = \Omega_m (1+z)^3 + \Omega_r (1+z)^4 + (1-\Omega_m - \Omega_r) X(z)$$

$$X(z) = \exp[\ 3\int_0^z \frac{1+w(x)}{1+x} dx]$$

Reconstruction program

- The Chevalier-Polarski-Linder (CPL) parametrization

$$w(z) = w_0 + w_a \frac{z}{1+z},$$

- The dark energy density function

$$X_{\mathrm{CPL}}(z) = (1+z)^{3(1+w_0+w_a)} \exp\left(-3\frac{w_a z}{1+z}\right).$$

Reconstruction program

- We assume a quadratic parameterization for *X(z)*

$$X(z) = \frac{(z-z_1)(z-z_2)}{(z_0-z_1)(z_0-z_2)} X_0 + \frac{(z-z_0)(z-z_2)}{(z_1-z_0)(z_1-z_2)} X_1 + \frac{(z-z_0)(z-z_1)}{(z_2-z_0)(z_2-z_1)} X_2$$

where

$$z_0 = 0,\ z_1 = z_2/2,\ z_2 = z_m,\ \text{and}\ X_0 = 1,\ X_1 = f_1,\ X_2 = f_2$$

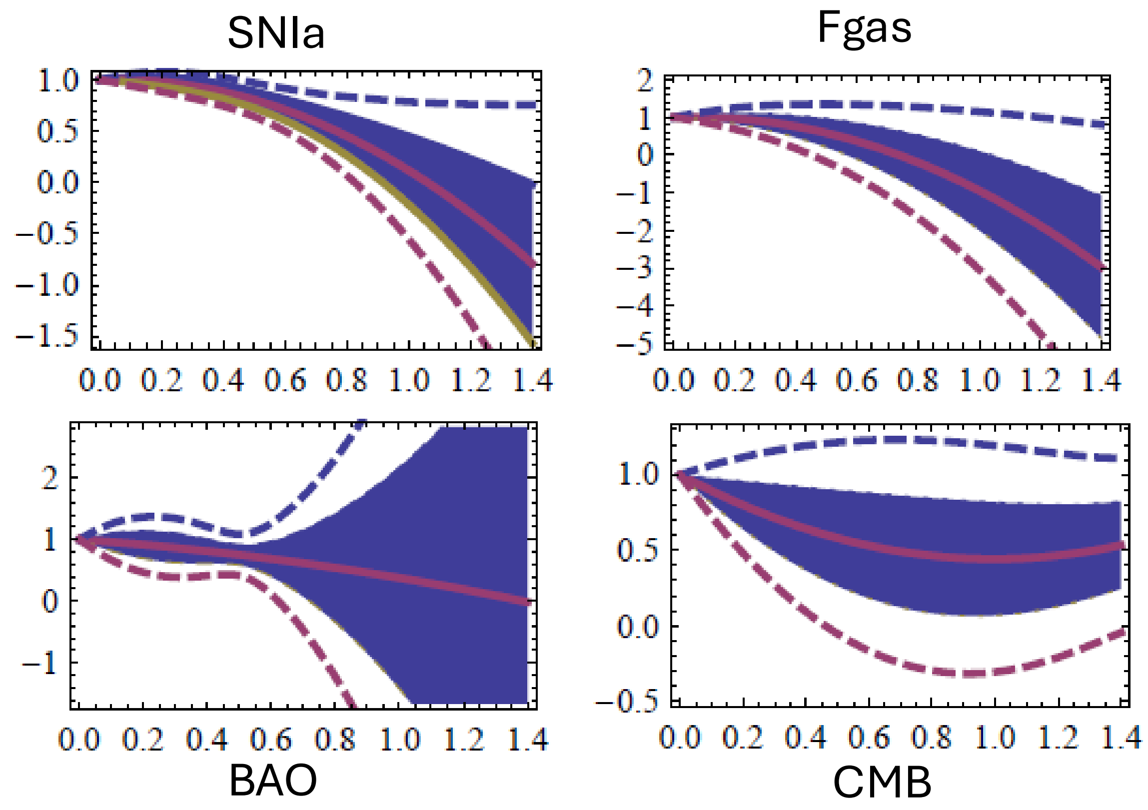
$$\boxed{X(z) = 1 + \frac{z(4f_1 - f_2 - 3)}{z_m} - \frac{2z^2(2f_1 - f_2 - 1)}{z_m^2},}$$

V.H.C. Physics Letter B 750, 128 (2015)

On dark energy evolution

Using each one of the data separately:

Set	d_σ	Ω_m	f_1	f_2
SNIa	2.46	0.299	0.627	-0.635
f_{gas}	1.896	0.293	0.196	-2.622
CMB	1.107	0.256	0.503	0.509
BAO	0.976	0.262	0.637	0.049



V.H.C. Physics Letter B 750, 128 (2015)

Reconstruction program

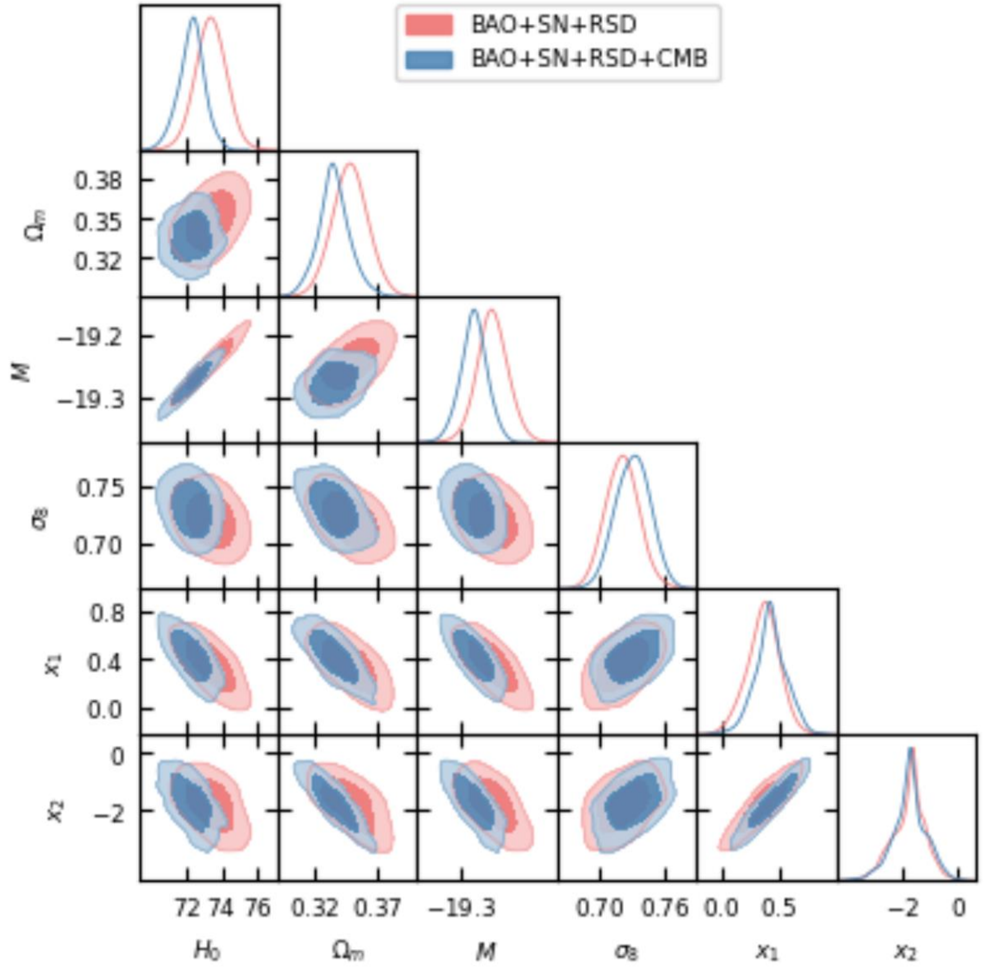
- Data:
  - Type Ia supernova: Pantheon+
  - DESI first year data release
  - Redshift space distorsión (RSD) data

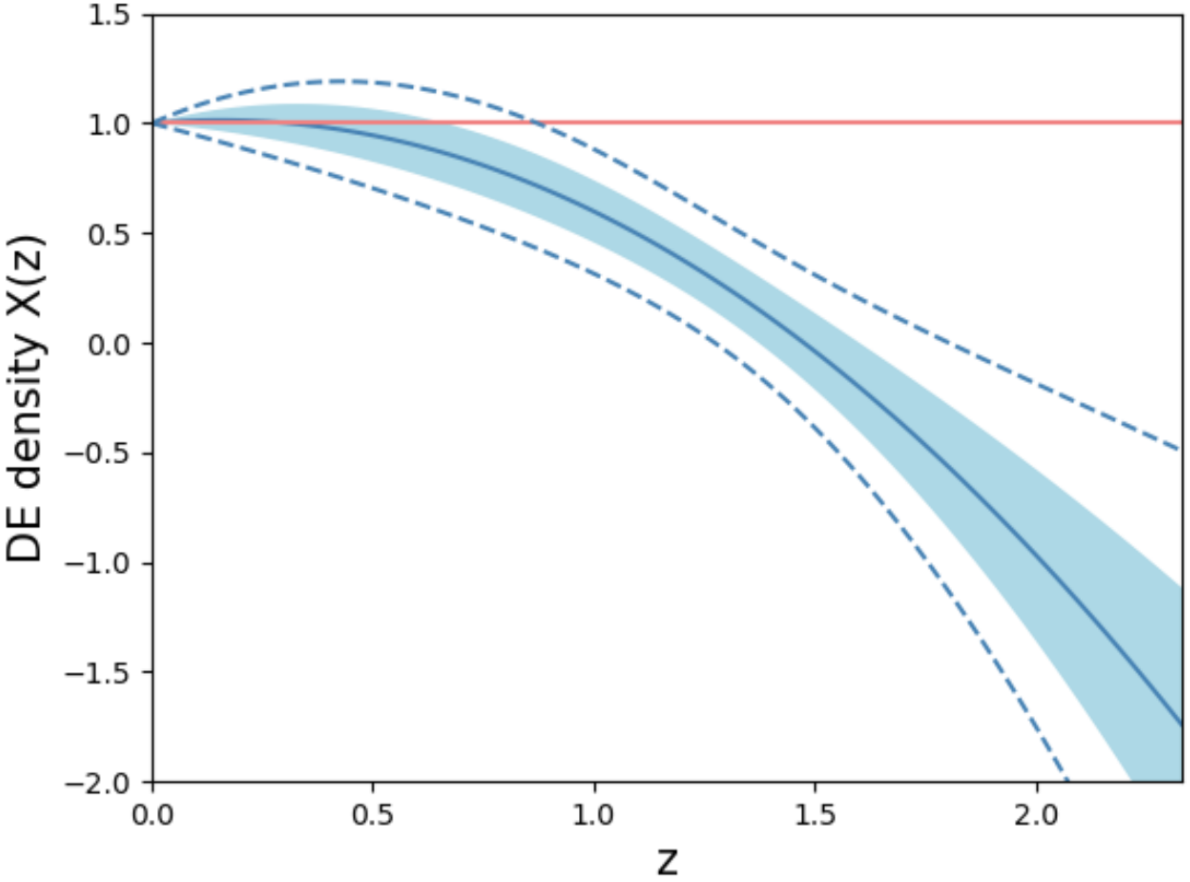
$$E^2(z) = \Omega_m(1+z)^3 + \Omega_r(1+z)^4 + (1-\Omega_m-\Omega_r)X(z)$$

$$\boxed{X(z) = 1 + \frac{z(4f_1 - f_2 - 3)}{z_m} - \frac{2z^2(2f_1 - f_2 - 1)}{z_m^2},}$$

L. Orchard, VHC, Physics of the Dark Universe, 46 (2024) 101678

Reconstruction program





L. Orchard, VHC, Physics of the Dark Universe, 46 (2024) 101678

New approach

- We invert the apparent magnitude at z equation to get X(z)

$$m_B(z) = M + 5\log_{10}\left[\frac{d_L(z)}{10\ \mathrm{pc}}\right], \qquad d_L(z) = \frac{c}{H_0}(1+z)\int_0^z \frac{dz'}{E(z')},$$

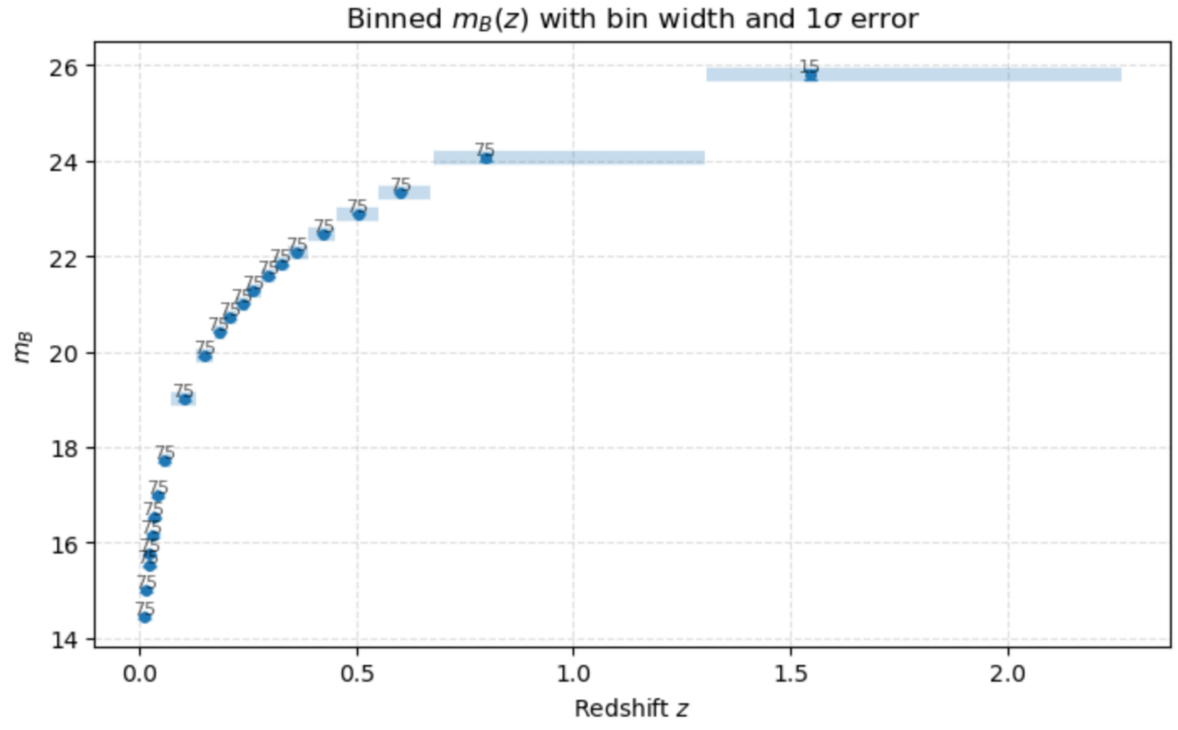
$$\boxed{X(z) = \frac{1}{1-\Omega_m}\left[-\Omega_m(1+z)^3 + B^{-2}(z)\right],}$$

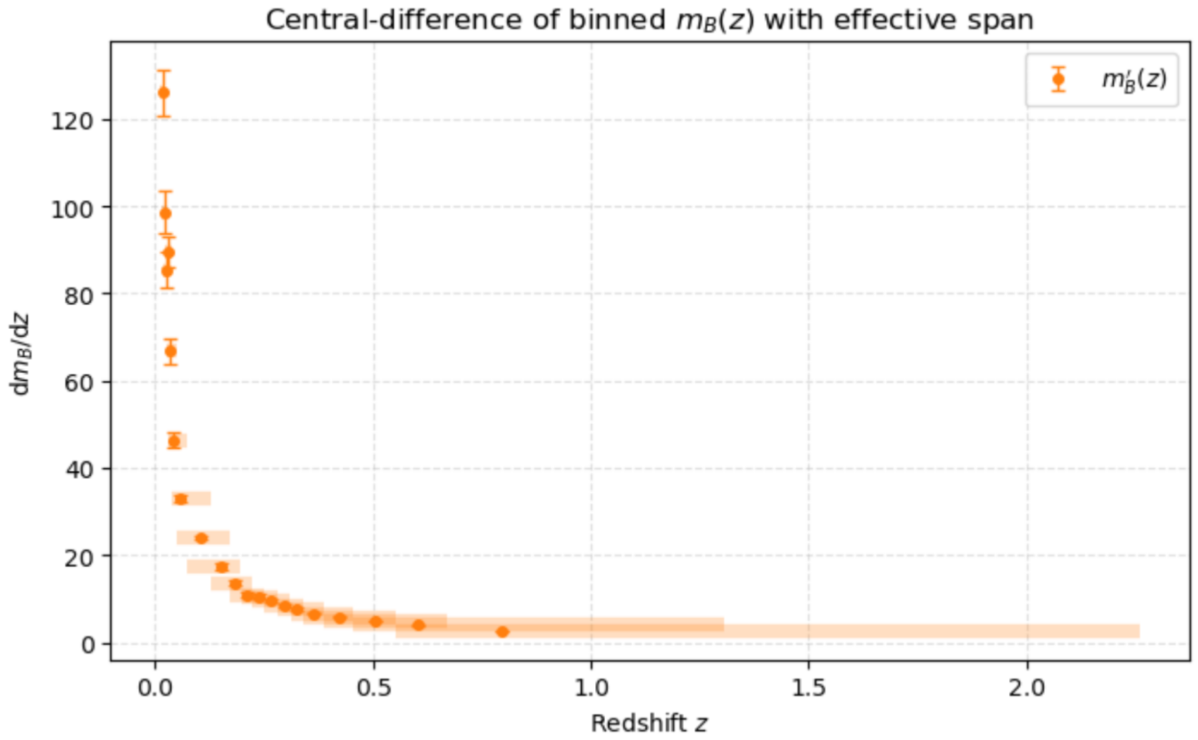
$$B(z) = 10^{(m_B-25-M)/5}\left\{\frac{\ln(10)m'_B(z)}{5(1+z)} - \frac{1}{(1+z)^2}\right\}.$$

New approach

$$\boxed{X(z) = \frac{1}{1-\Omega_m}\left[-\Omega_m(1+z)^3 + B^{-2}(z)\right],}$$

$$B(z) = 10^{(m_B-25-M)/5}\left\{\frac{\ln(10)m'_B(z)}{5(1+z)} - \frac{1}{(1+z)^2}\right\}.$$

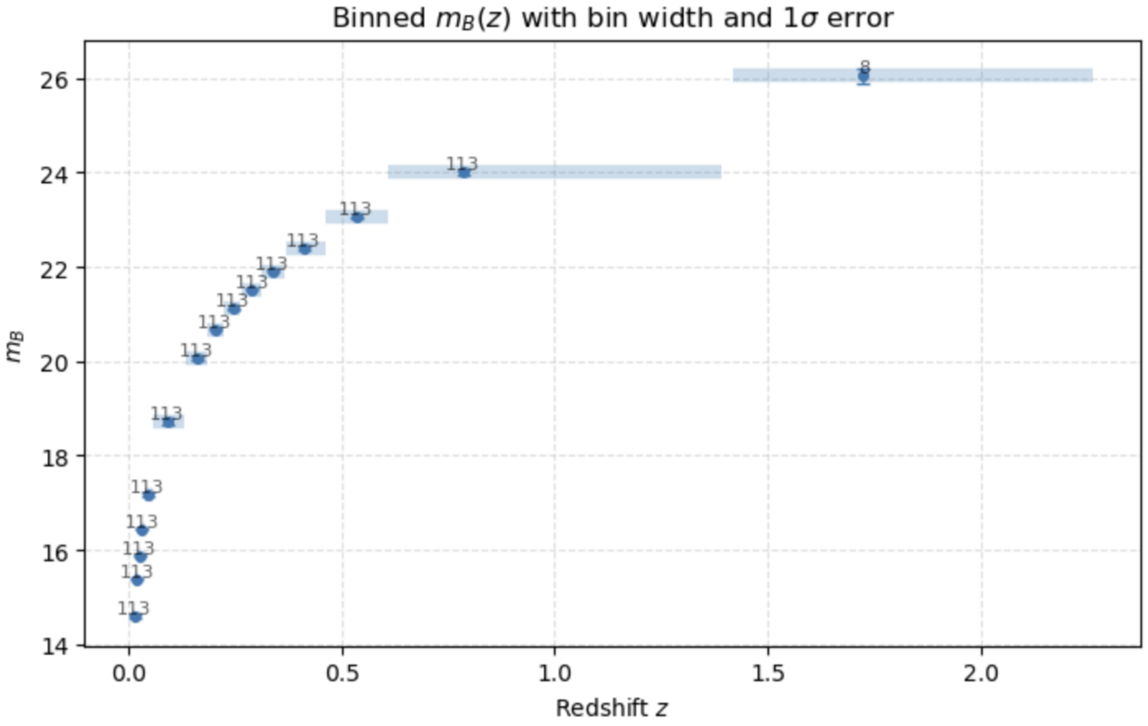


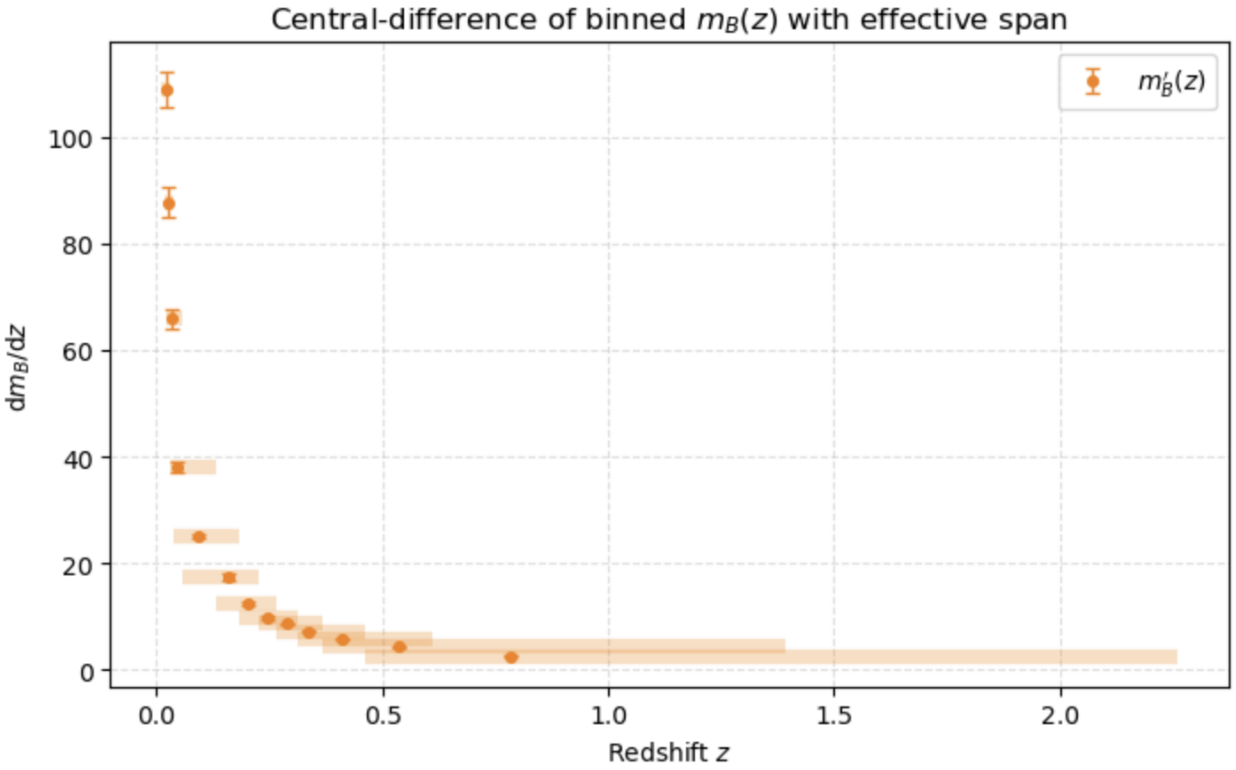


New approach

$$\boxed{X(z) = \frac{1}{1-\Omega_m}\left[-\Omega_m(1+z)^3 + B^{-2}(z)\right],}$$

$$B(z) = 10^{(m_B-25-M)/5}\left\{\frac{\ln(10)m'_B(z)}{5(1+z)} - \frac{1}{(1+z)^2}\right\}.$$

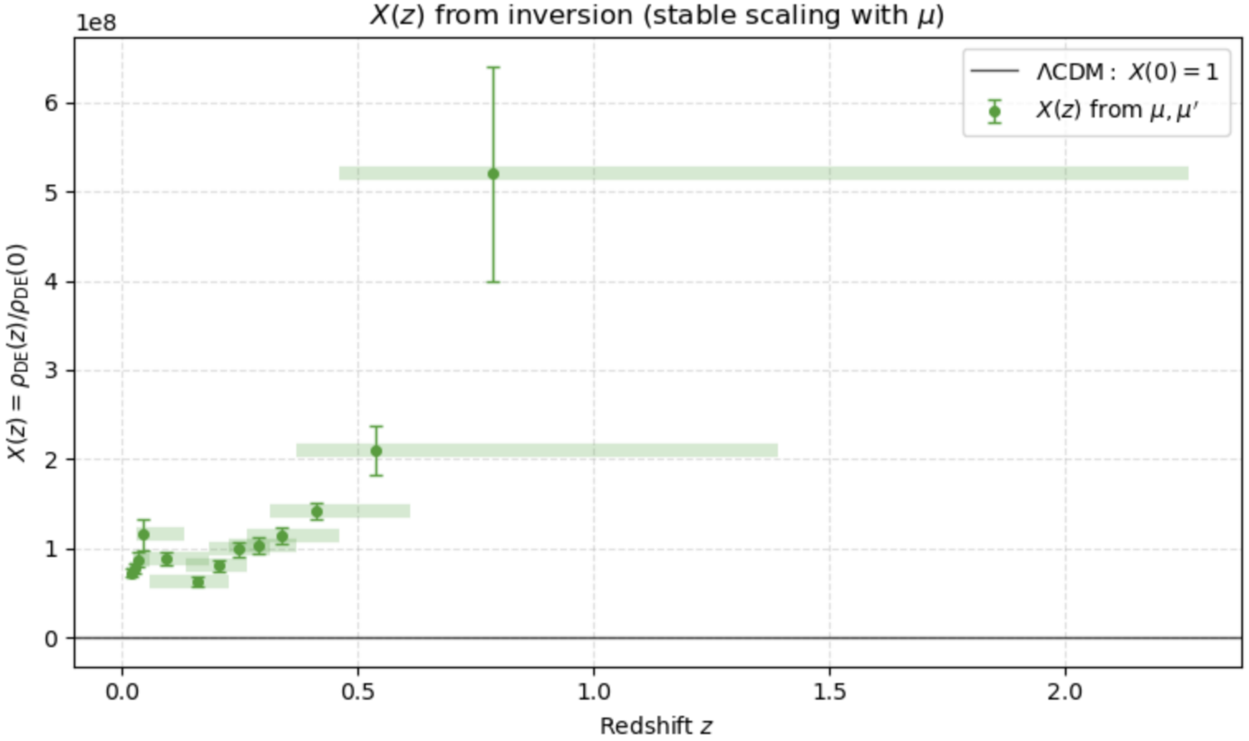


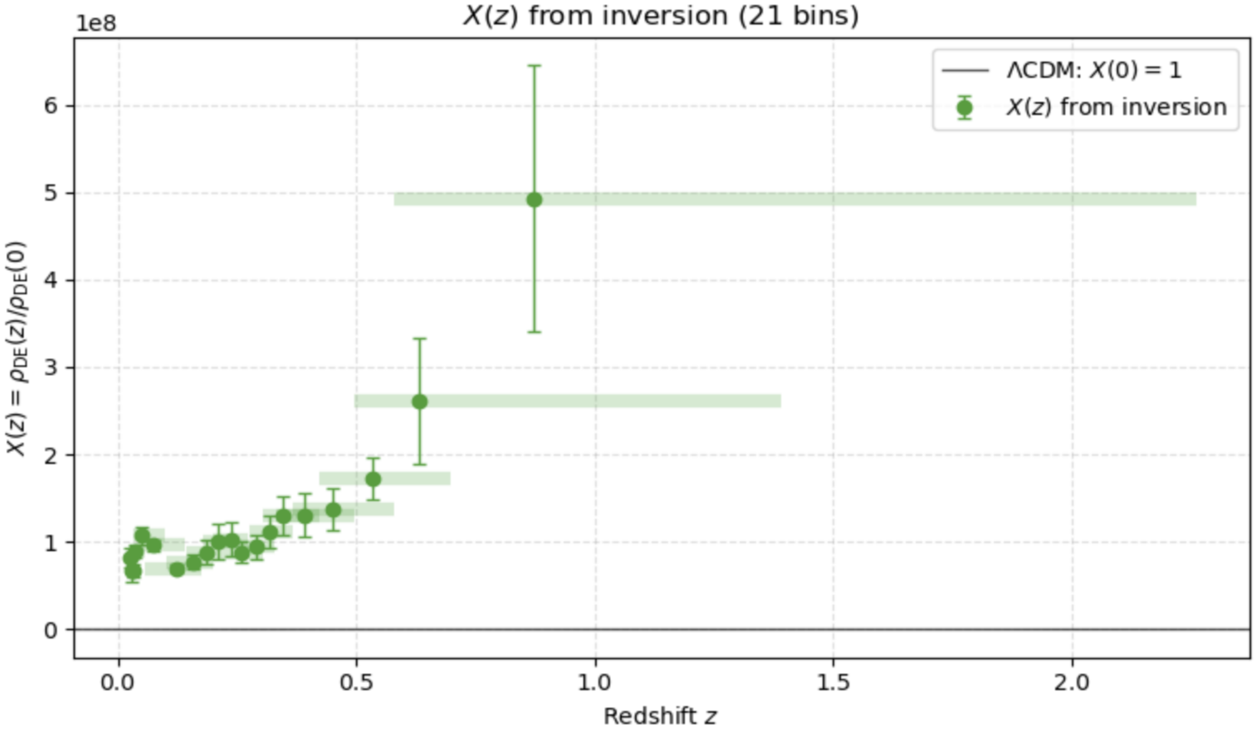


New approach

$$\boxed{X(z) = \frac{1}{1-\Omega_m}\left[-\Omega_m(1+z)^3 + B^{-2}(z)\right],}$$

$$B(z) = 10^{(m_B - 25 - M)/5}\left\{\frac{\ln(10)m'_B(z)}{5(1+z)} - \frac{1}{(1+z)^2}\right\}.$$





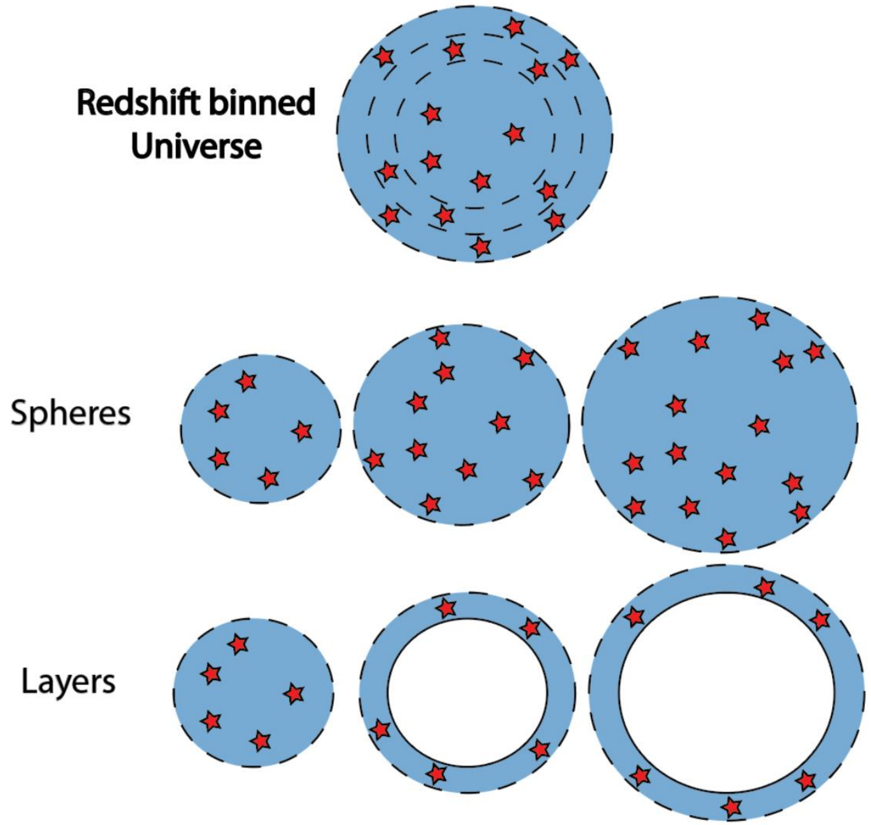
Discussion

- Clearer Evidence of Dark Energy Evolution
    - Recent findings provide stronger indications of dark energy's evolution across cosmic history.
- Uncertainty in the Type of Evolution
    - The specific nature of this evolution remains unclear, requiring more comprehensive and precise datasets.
- Leveraging the Inversion Method
    - The inversion technique offers promising opportunities to further refine our understanding of dark energy dynamics.

Binning LCDM

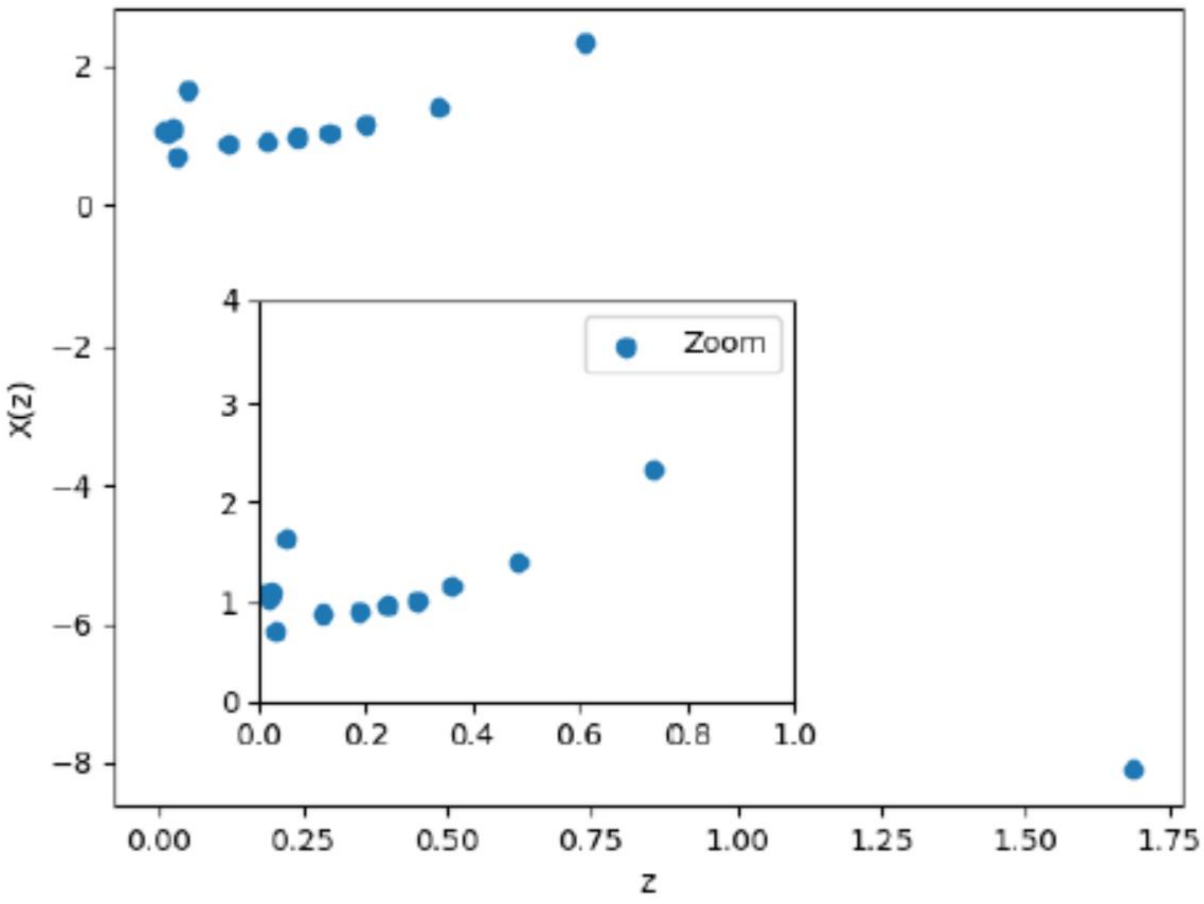
- Results using Pantheon+, for cosmography

$$D_L(z) = \frac{z}{H_0} + \frac{(1-q_0)}{2H_0}z^2 - \frac{(1-q_0-3q_0^2+p_0)}{6H_0}z^3,$$

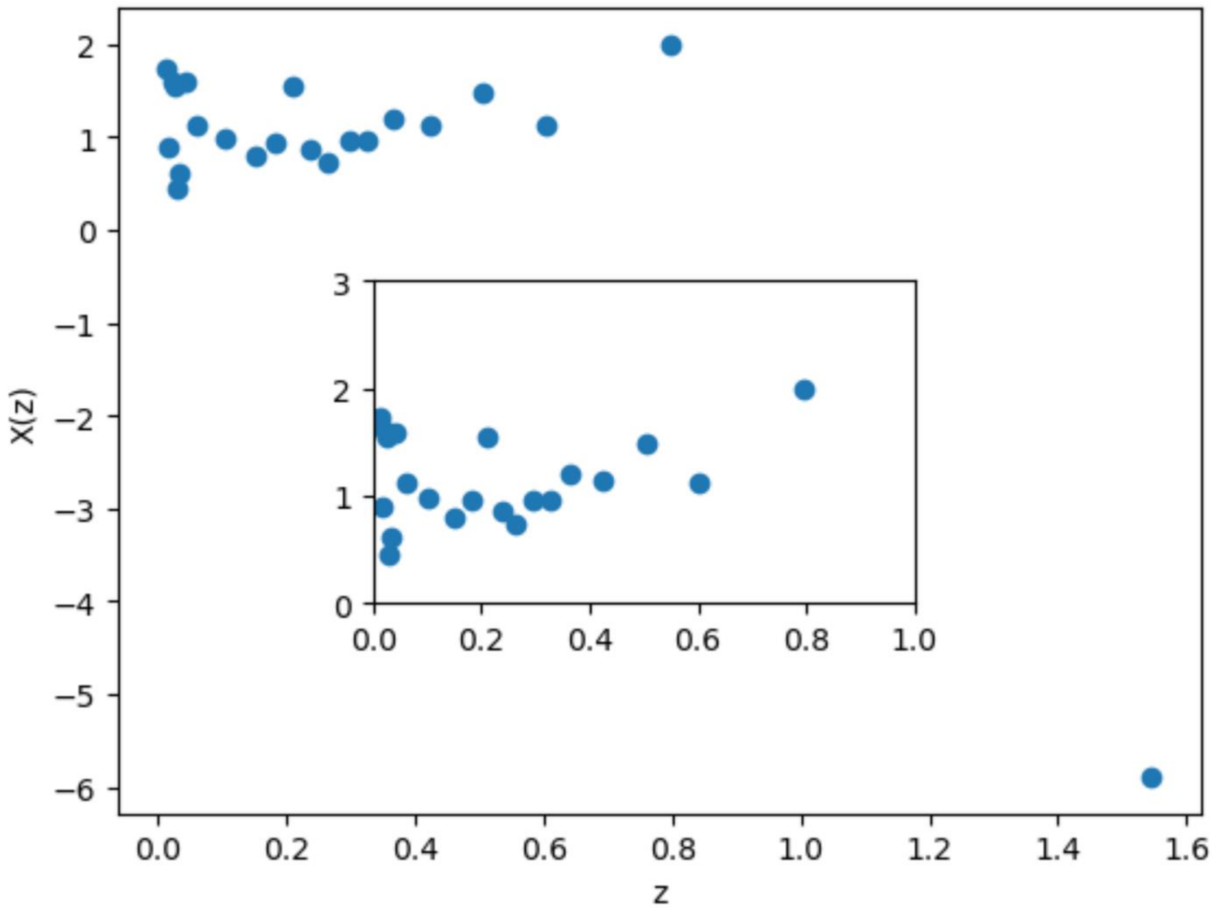


E. Pasten, VHC, Physics of the Dark Universe, 40 (2023) 101224

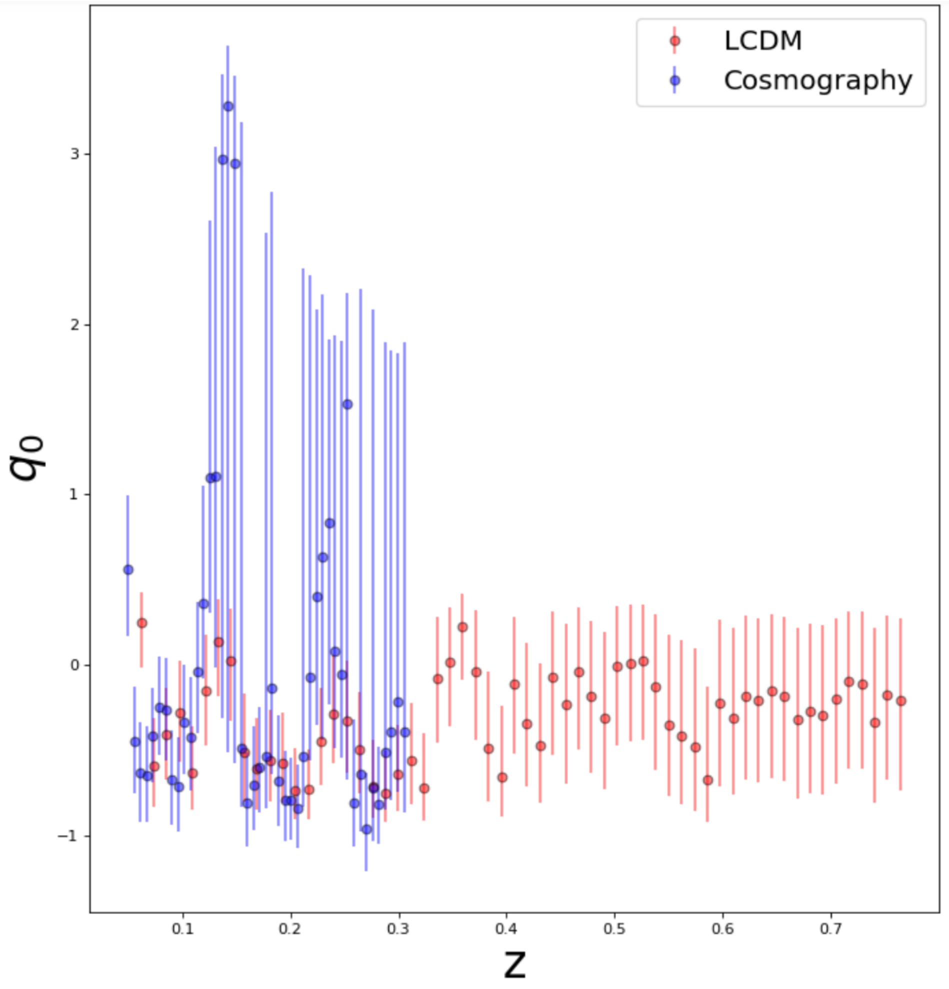
• Results with 13 bins



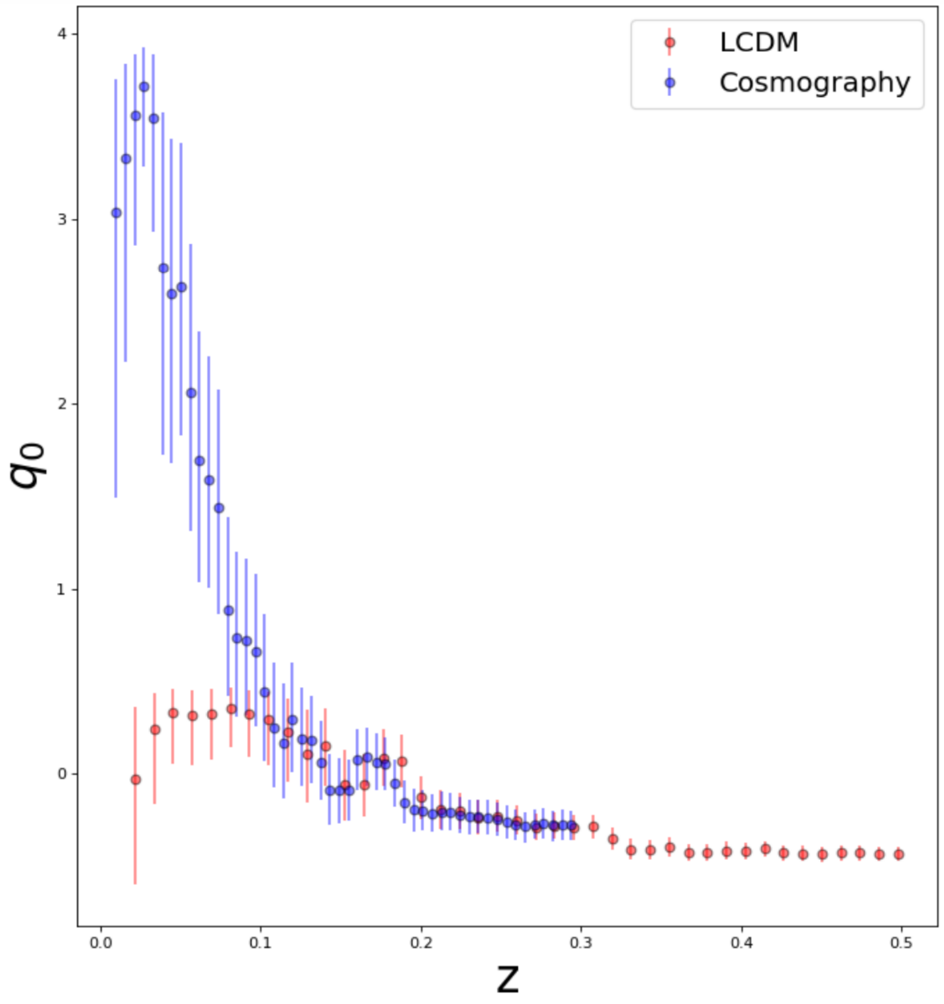
• Result with 22 bins



- Layers

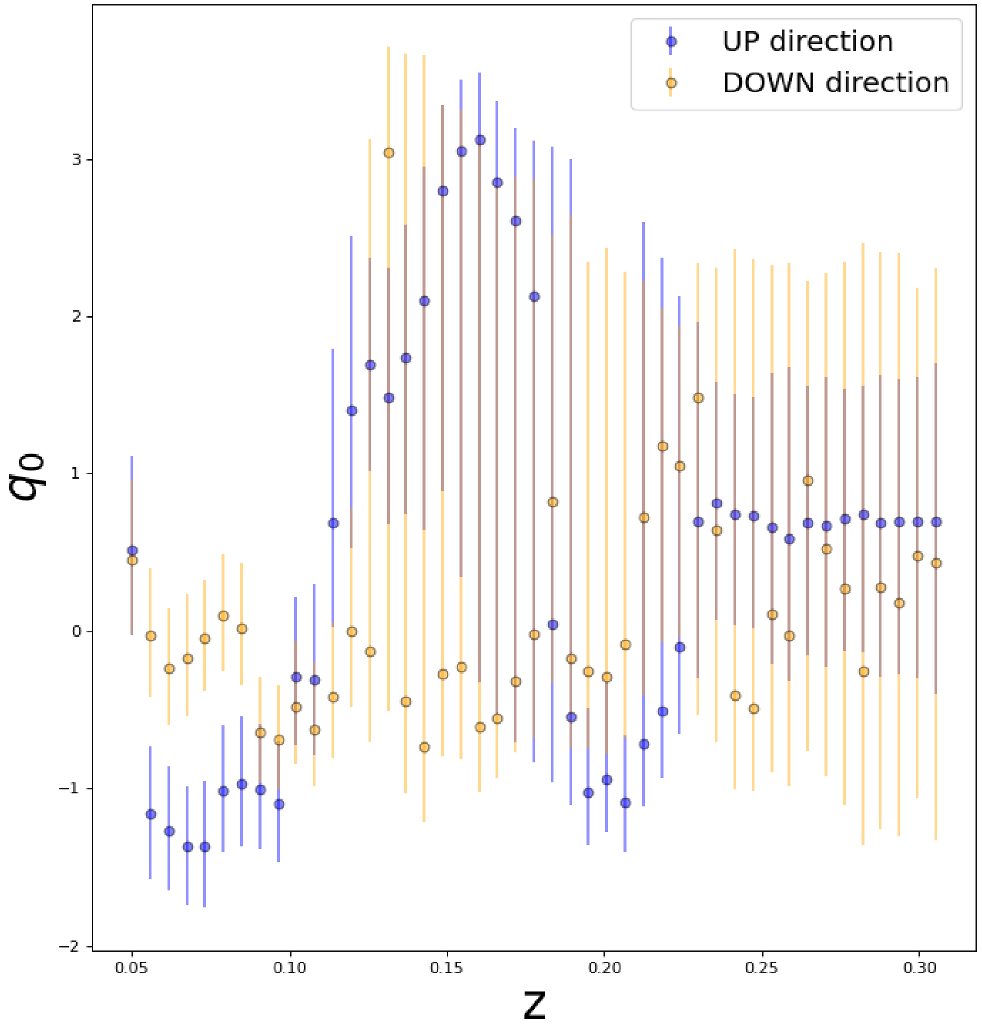


- Spheres



- Hemispheric variation respect CMBR dipole

z bin	Number of SNIA	q_0
0.008 – 0.075(UP)	314	$-0.59^{0.62}_{-0.59}$
0.008 – 0.075(DOWN)	314	$0.19^{0.62}_{-0.57}$



E. Pasten, VHC, Physics of the Dark Universe, 40 (2023) 101224