

Model-independent constraints on Type Ia supernova light-curve hyper-parameters and reconstructions of the expansion history of the Universe

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Introduction

- Type Ia supernovae (SNe Ia) are commonly used as standardizable candles for distance measurement and have become one of the important portion of modern cosmology
- To use SNe Ia as standardizable candles, SN Ia light-curve parameters should be constrained
- The light-curve parameters are usually constrained based on assumption of cosmological model

Joint Light-curve Analysis

- Joint Light-curve Analysis (JLA) have SNe Ia light curve parameters information based on SALT2 model
Betoule et al. 2014
Guy et al. 2007; Moshir et al. 2014
- Provides observed B-band peak magnitude, stretching of the light curve, supernovae color at maximum brightness

Light-curve parameters

- $\mu = m_B^\star - (M_B - \alpha X_1 + \beta C)$
- m_B^\star : Observed B-band peak magnitude
- X_1 : Stretching of the light curve
- C : Supernovae color at maximum brightness
- Included in JLA

Tripp.1998
Betoule et al. 2014

Light-curve hyper-parameters

- $\mu = m_B^\star - (M_B - \alpha X_1 + \beta C)$
- α, β : Proportional factors of X_1 and C
- M_B^1, Δ_M : Absolute B-band peak magnitude
 $M_B = M_B^1$ if $M_{\text{stellar}} < 10^{10} M_{\text{sun}}$
 $M_B = M_B^1 + \Delta_M$ otherwise
- Need to be constrained

Tripp.1998
Betoule et al. 2014

Iterative smoothing method

- The non-parametric method to reconstruct the distance modulus and expansion history of the Universe
Shafieloo et al. 2006; Shafieloo. 2007; Shafieloo et al. 2018
- Starts from initial guess of distance modulus, but generates model-independent reconstruction of distance modulus with lower χ^2 value after numerous iterations

$$\hat{\mu}_{n+1}(z) = \hat{\mu}_n(z) + \frac{\delta\mu_n^T \cdot \mathbf{C}^{-1} \cdot \mathbf{W}(z)}{\mathbf{1}^T \cdot \mathbf{C}^{-1} \cdot \mathbf{W}(z)} \quad (\mathbf{C}^{-1}: \text{inverse of the covariance matrix from JLA})$$
$$\mathbf{1}^T = (1, \dots, 1), \quad W_i(z) = \exp\left(-\frac{\ln^2\left(\frac{1+z}{1+z_i}\right)}{2\Delta^2}\right), \quad \delta\mu_n|_i = \mu_i - \hat{\mu}_n(z_i)$$

$$\chi_n^2 = \delta\mu_n^T \cdot \mathbf{C}^{-1} \cdot \delta\mu_n$$

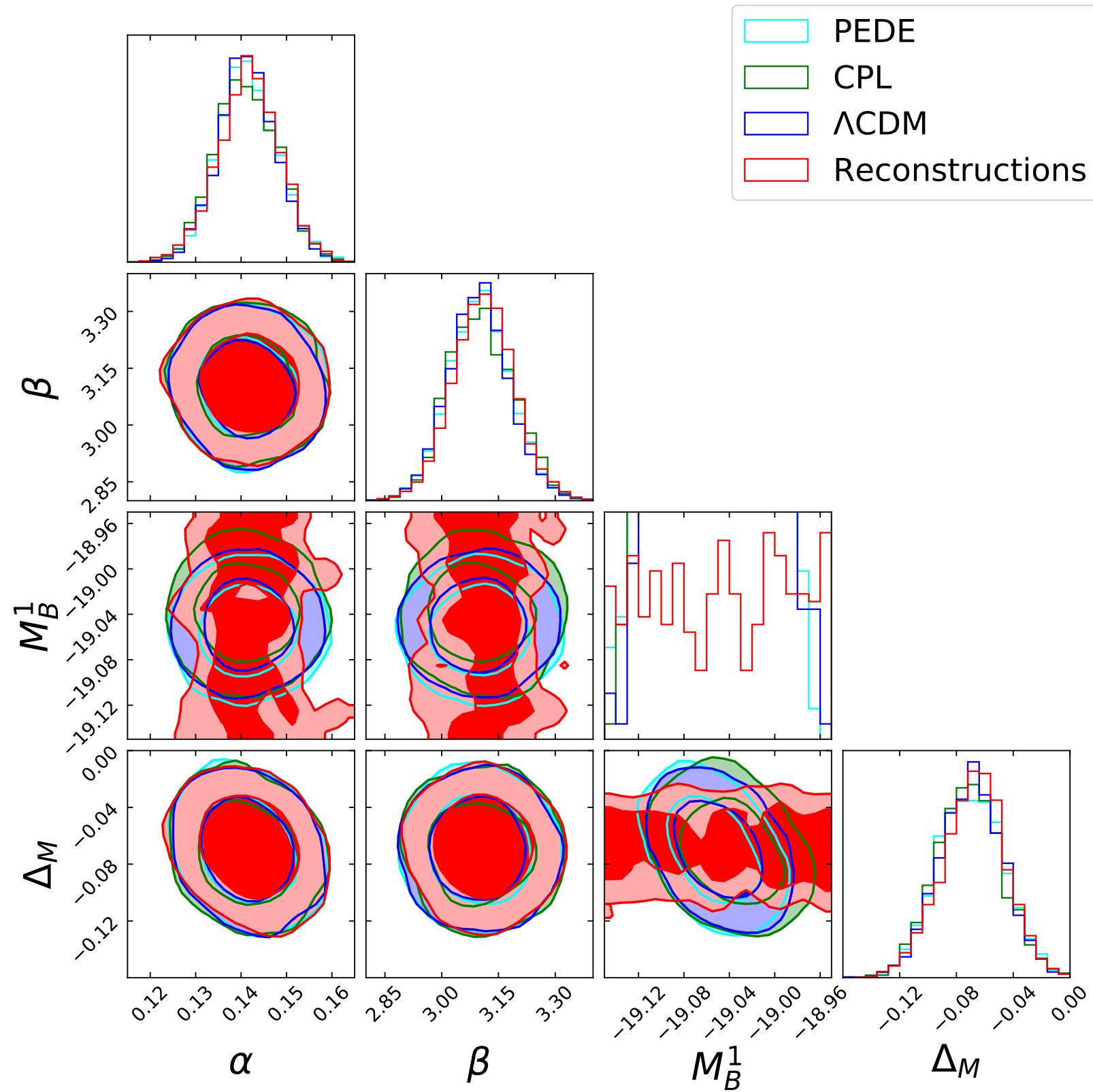
Cosmological models to compare

- Λ CDM: Lambda-cold dark matter model
 $w(z) = -1$ (w : the equation-of-state parameter)
- CPL: Chevallier-Polarski-Linder parametrization of dark energy
$$w(z) = w_0 + w_a \frac{z}{1+z}$$

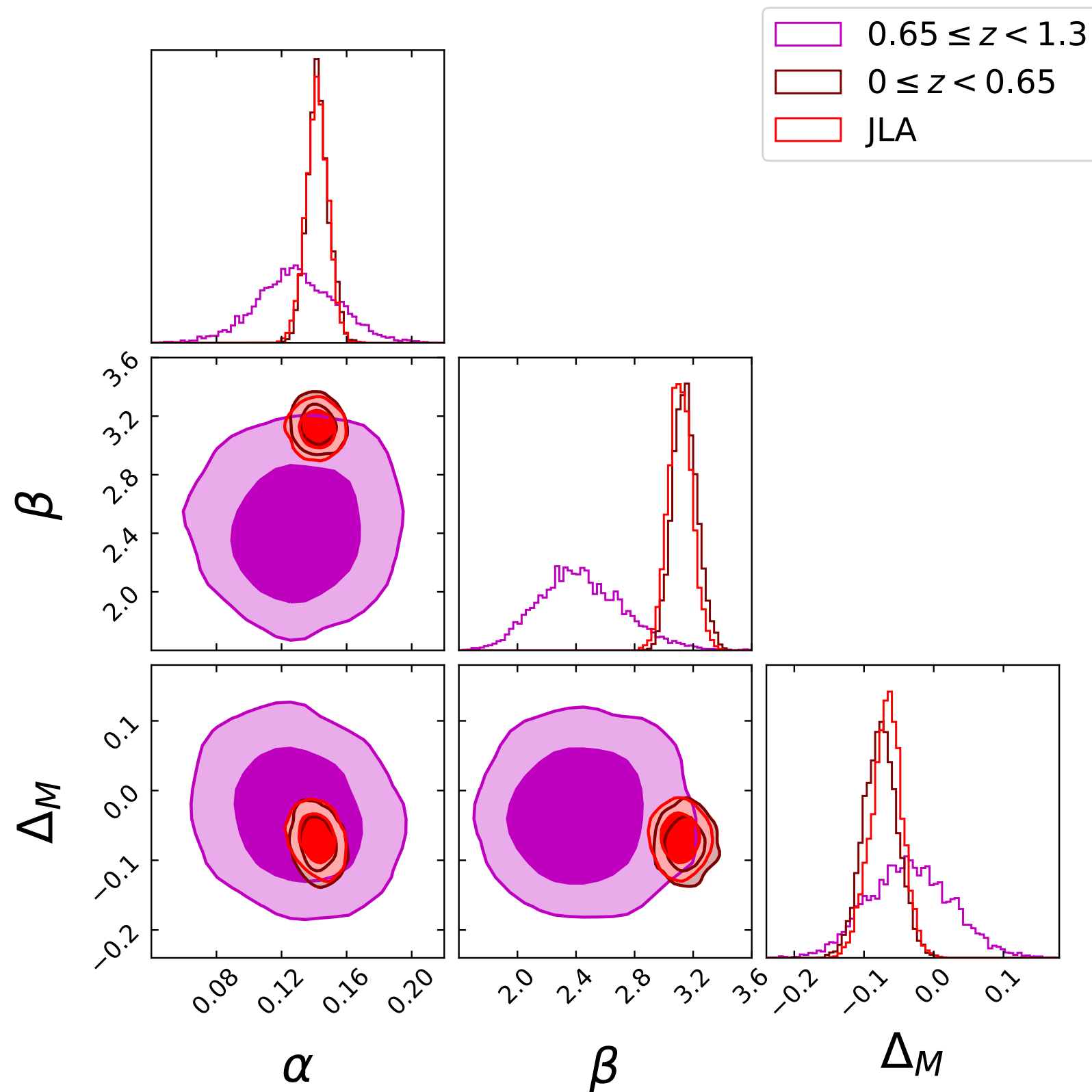
Chevallier. Polarski. 2001; Linder. 2003
- PEDE: Phenomenologically Emergent Dark Energy model
$$w(z) = -\frac{1}{3\ln 10}(1 + \tanh[\log_{10}(1+z)]) - 1$$

Li. Shafieloo. 2019

Constraints



Constraints (Reconstructions)



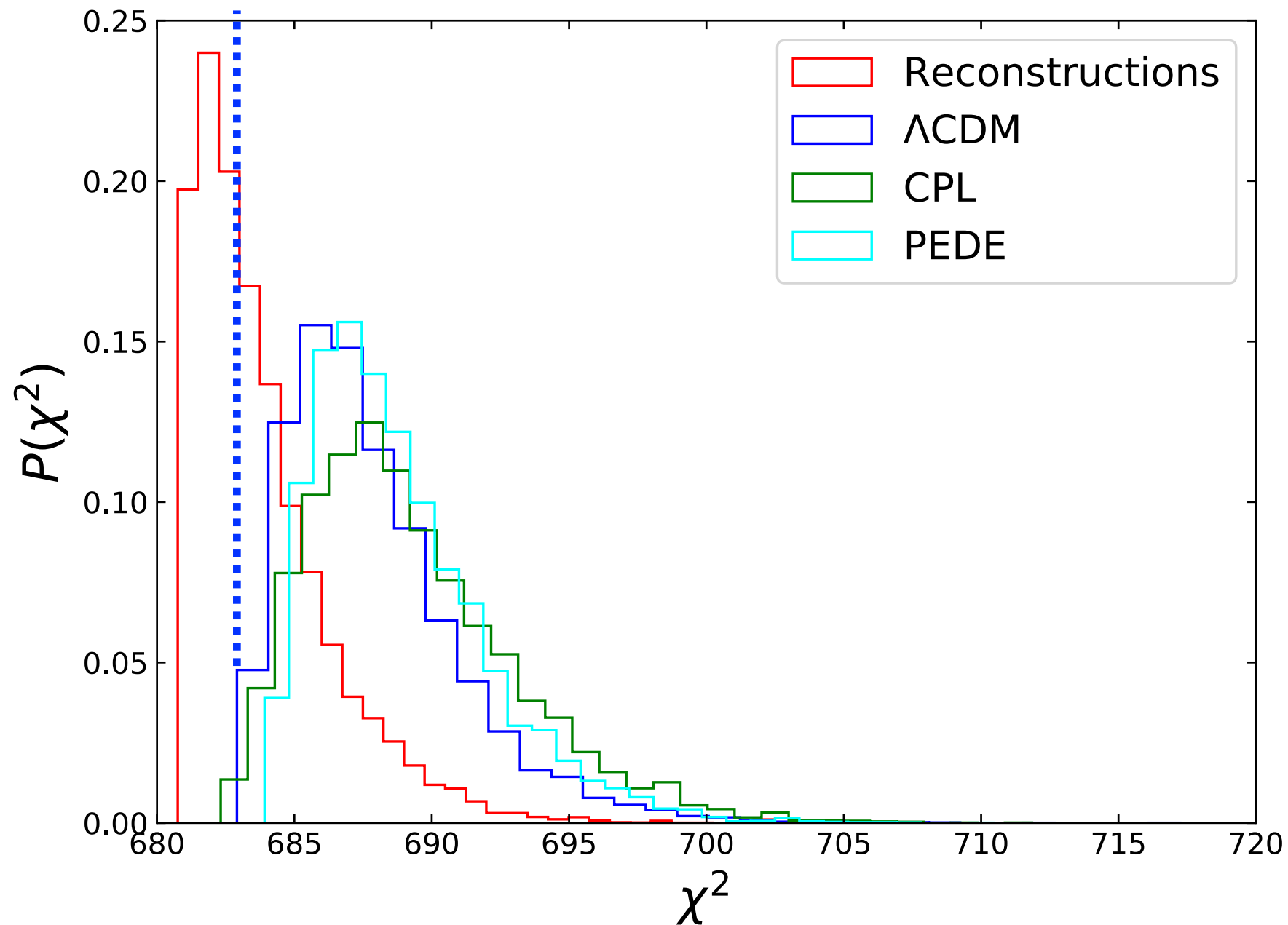
Constraints

- Constraints from reconstructions and predictions of 3 different models are consistent with each other
- The distance moduli constructed from the JLA data are mostly independent of the cosmological model
- The light-curve parameters are constrained mainly by the data included in the low redshift bin

Reconstructions

- Explore possibilities of the expansion history of the Universe with higher likelihood than that of Λ CDM
- Reconstruct the expansion history of the Universe on parametric space of light-curve hyper-parameters explored by using MCMC samples
- Also reconstruct the parameters which describe the dark energy properties and compare them with the predictions of Λ CDM, CPL, PEDE

Reconstructions

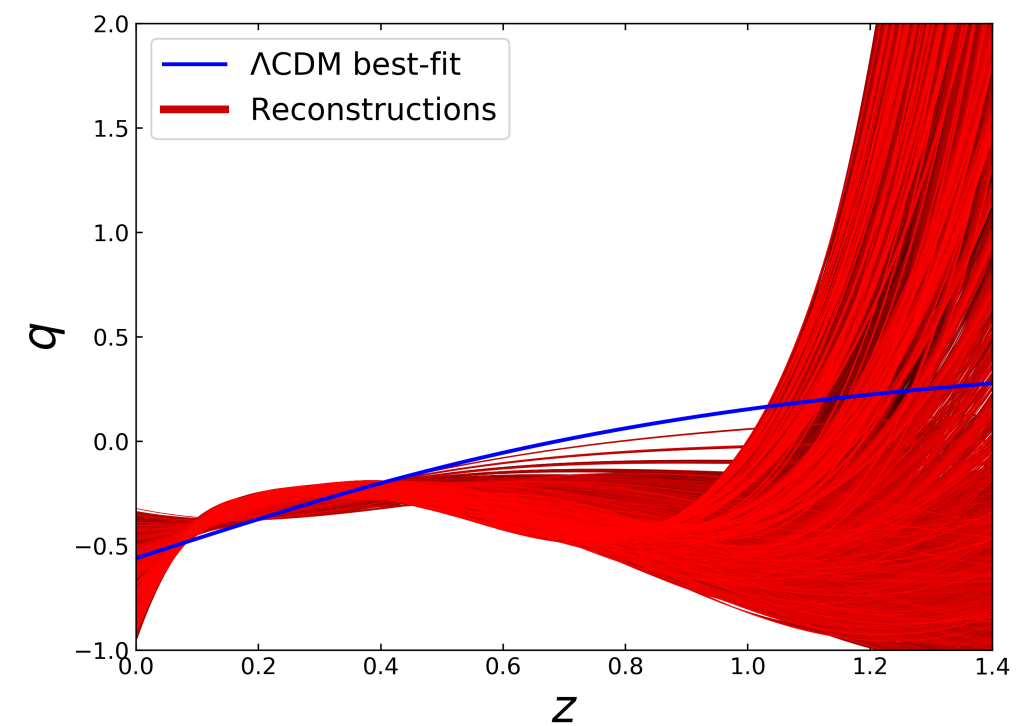
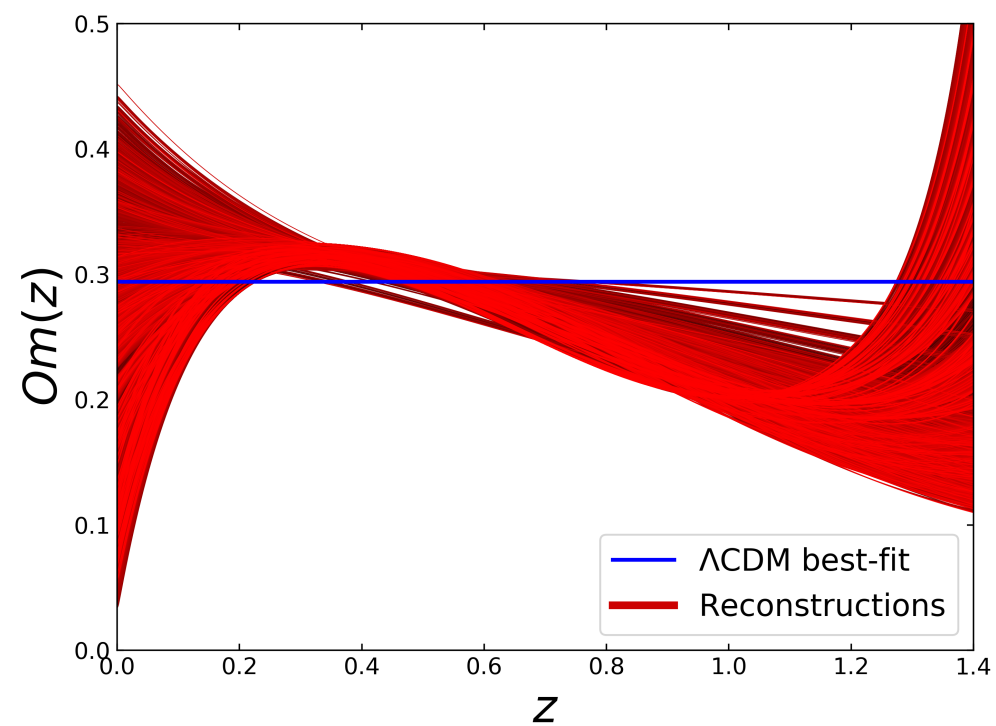
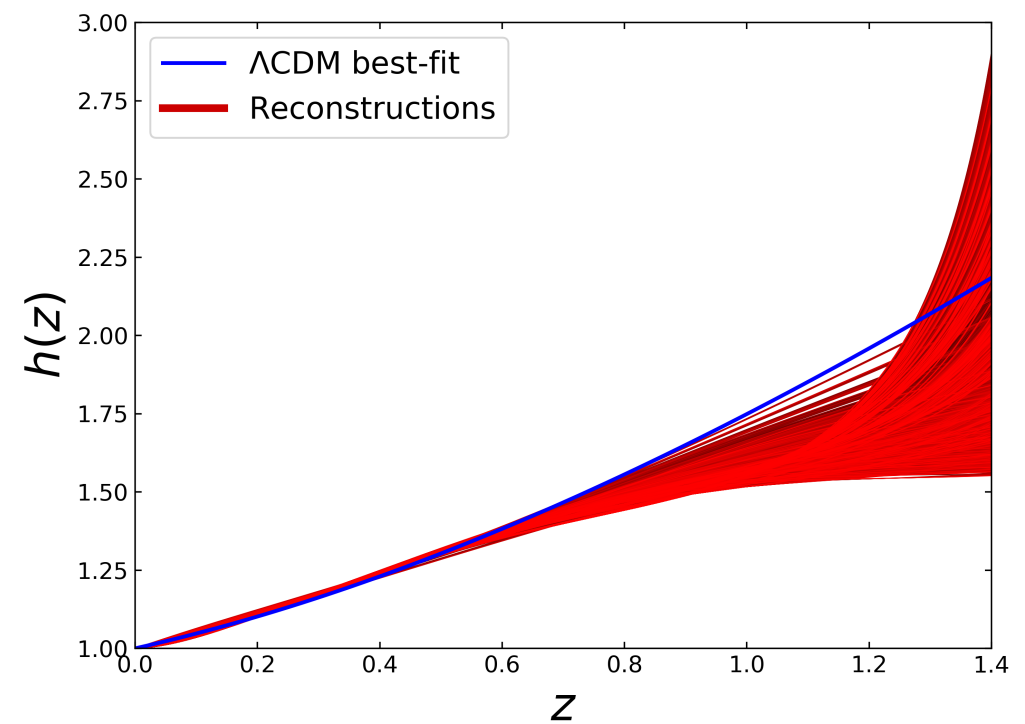
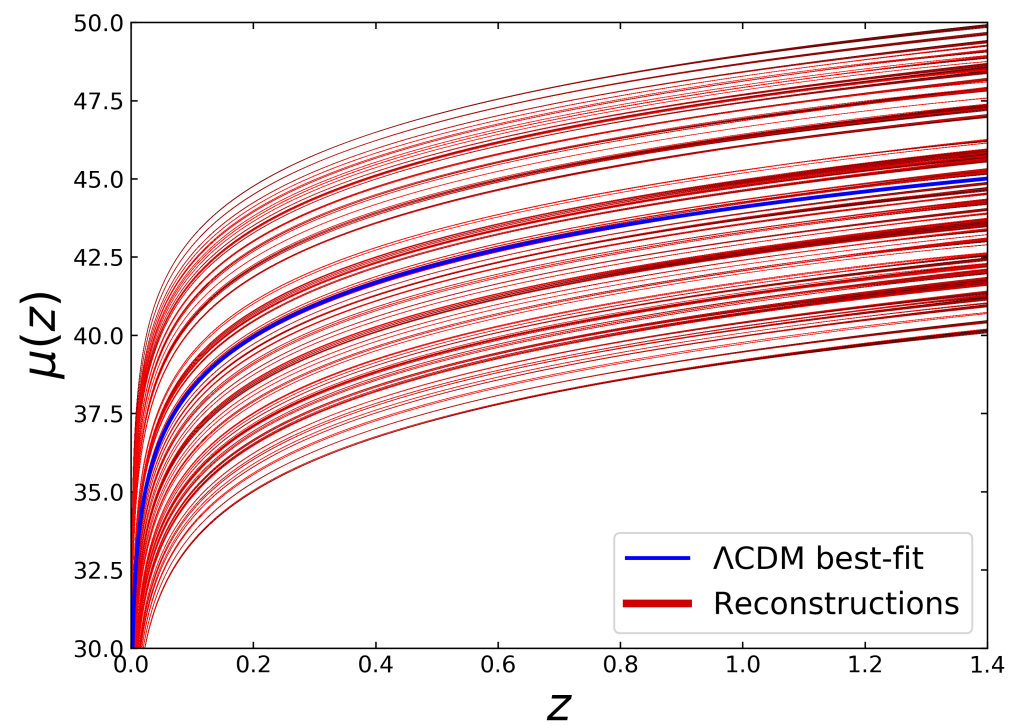


- Reconstructions with $\chi^2 < \chi^2_{\Lambda\text{CDM best-fit}}$ were selected

Reconstructions

- Luminosity distance: $d_L(z) = 10^{\hat{\mu}_n/5-5}$
- Expansion history: $h(z) = \frac{c}{H_0} \left[\frac{d}{dz} \frac{d_L(z)}{(1+z)} \right]^{-1}$
- Om parameter: $Om(z) = \frac{h(z)^2 - 1}{(1+z)^3 - 1}$
Sahni. Shafieloo. Starobinsky. 2008
- Deceleration parameter: $q(z) = (1+z) \frac{\frac{dh}{dz}}{h} - 1$

Reconstructions



Reconstructions

- The reconstructed expansion history of the Universe and parameters which describe properties of dark energy seems to be in good agreement with the prediction from the standard Λ CDM model
- There are considerable flexibility for expansion history of the Universe and other parameters

Summary

- Constraints from model-independent reconstructions are in good agreement with predictions of 3 different models
- The distance moduli constructed from the JLA data are mostly independent of the cosmological model
- The reconstructed expansion history of the Universe seems to be consistent with the prediction of the standard Λ CDM model with considerable flexibility