Searching for Evidence of Dark Energy at Small Distance

Rui Zhang (张睿)

In collaboration with Zhen Zhang

2021.10.22

Story of Dark Energy

Come from cosmology constant

$$R^{\mu}_{\nu} - \frac{1}{2} g^{\mu}_{\nu} R = 8\pi G T^{\mu}_{\nu} + g^{\mu}_{\nu} \Lambda = 8\pi G (T^{\mu}_{\nu} + T^{w\,\mu}_{\nu})$$

Ideal Fluid

$$T^{w}_{\mu\nu} = (\rho_{\Lambda} + p_{\Lambda}) u_{\mu} u_{\nu} - p_{\Lambda} g_{\mu\nu}$$

State Parameter

$$w \equiv \frac{T^{w\,r}_{r}}{T^{w\,0}_{0}} = \frac{-\Lambda}{\Lambda} = -1$$

Phenomenological Models

Quintessence

$$\rho = \frac{1}{2}\dot{\varphi}^2 + V(\varphi)$$
$$p = \frac{1}{2}\dot{\varphi}^2 - V(\varphi)$$

Phantom

$$\rho = -\frac{1}{2}\dot{\varphi}^2 + V(\varphi)$$
$$p = -\frac{1}{2}\dot{\varphi}^2 - V(\varphi)$$

Quintom

$$\rho = \frac{1}{2}\dot{\varphi}^2 - \frac{1}{2}\dot{\sigma}^2 + V(\varphi)$$
$$p = \frac{1}{2}\dot{\varphi}^2 - \frac{1}{2}\dot{\sigma}^2 - V(\varphi)$$

Higher Spin

$$\rho = V$$
$$p = \frac{\partial V}{\partial \overline{\psi}\psi}\overline{\psi}\psi - V$$

Chaplygin Gas

$$p = a(\frac{1}{\rho_0} - \frac{1}{\rho})$$

Holographic

$$\rho = 3c^2 M_{\rm pl}^2 R_h^{-2}$$
$$w = -\frac{1}{3} - \frac{2}{3c}$$

Experimental Results

Planck 2018

This value is our "best estimate" of H_0 from *Planck*, assuming the base-ΛCDM cosmology.

Since we are considering a flat universe in this section, a constraint on Ω_m translates directly into a constraint on the dark-energy density parameter, giving

ΛCDM model

$$\Omega_\Lambda = 0.6847 \pm 0.0073 \quad (68\,\%, \text{TT,TE,EE+lowE+lensing}). \quad (15)$$

In terms of a physical density, this corresponds to $\Omega_\Lambda h^2 = 0.3107 \pm 0.0082$, or cosmological constant $\Lambda = (4.24 \pm 0.11) \times 10^{-66}\,\text{eV}^2 = (2.846 \pm 0.076) \times 10^{-122}\, m_{\text{Pl}}^2$ in natural units (where m_{Pl} is the Planck mass).

To test a time-varying equation of state we adopt the functional form

$w(z)$ CDM model

$$w(a) = w_0 + (1-a)w_a\,, \quad (49)$$

where w_0 and w_a are assumed to be constants. In ΛCDM, $w_0 = -1$ and $w_a = 0$. We use the parameterized post-Friedmann (PPF)

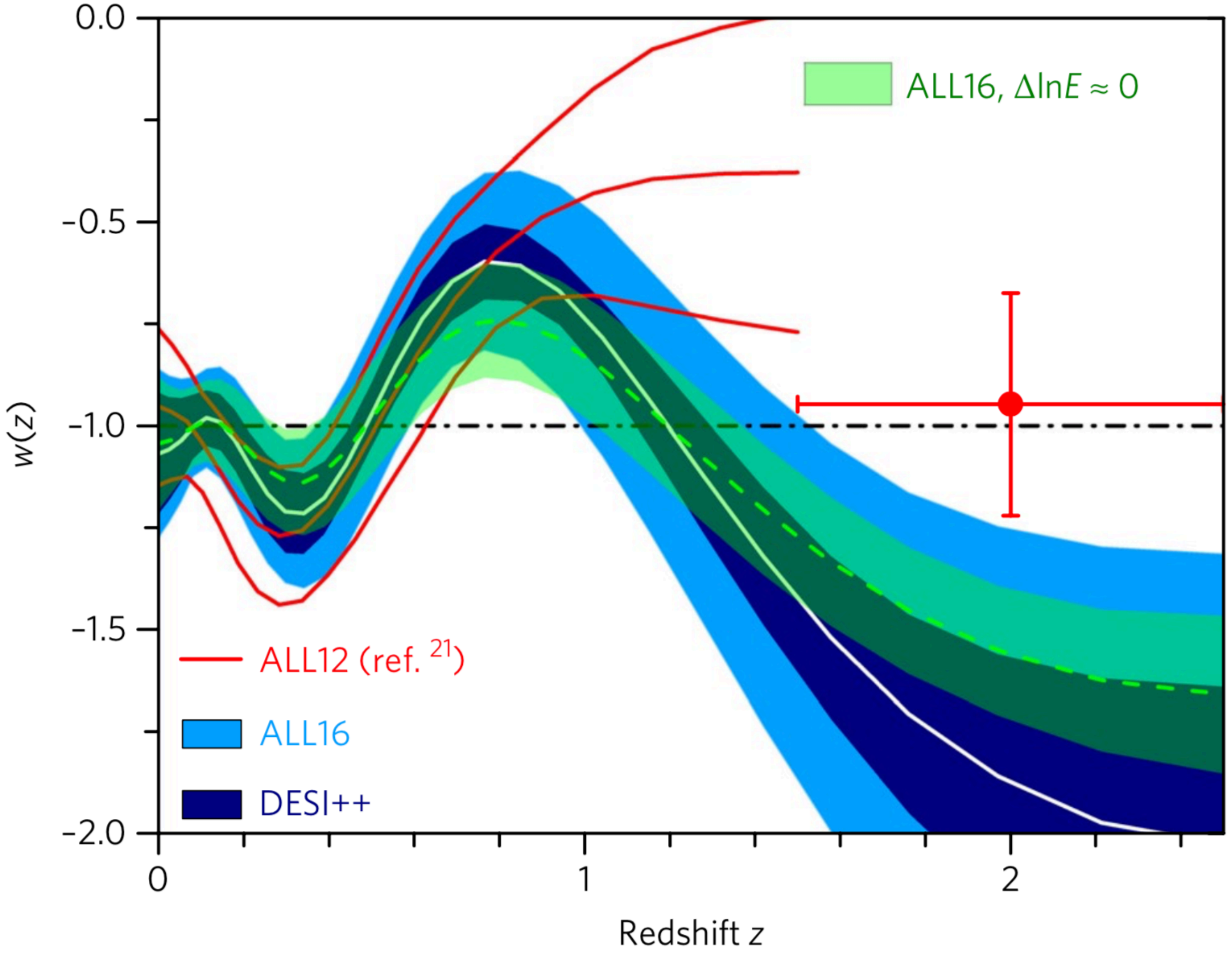
Fixing the evolution parameter $w_a = 0$, we obtain the tight constraint

$$w_0 = -1.028 \pm 0.031 \quad (68\,\%, \textit{Planck}\ \text{TT,TE,EE+lowE+lensing+SNe+BAO}), \quad (50)$$

Table 6. Marginalized values and 68 % confidence limits for cosmological parameters obtained by combining *Planck* TT,TE,EE +lowE+lensing with other data sets, assuming the (w_0, w_a) parameterization of $w(a)$ given by Eq. (49). The $\Delta\chi^2$ values for best fits are computed with respect to the ΛCDM best fits computed from the corresponding data set combination.

Parameter	*Planck*+SNe+BAO	*Planck*+BAO/RSD+WL
w_0	-0.957 ± 0.080	-0.76 ± 0.20
w_a	$-0.29^{+0.32}_{-0.26}$	$-0.72^{+0.62}_{-0.54}$
H_0 [km s^{-1}Mpc^{-1}]	68.31 ± 0.82	66.3 ± 1.8
σ_8	0.820 ± 0.011	$0.800^{+0.015}_{-0.017}$
S_8	0.829 ± 0.011	0.832 ± 0.013
$\Delta\chi^2$	-1.4	-1.4

Experimental Results



CMB data[7]. In this work, we investigate whether these tensions can be interpreted as evidence for a non-constant dynamical dark energy. Using the Kullback-Leibler divergence[13] to quantify the tension between datasets, we find that the tensions are relieved by an evolving dark energy, with the dynamical dark energy model preferred at a 3.5σ significance level based on the improvement in the fit alone. While, at present, the Bayesian evidence for the dynamical dark energy is insufficient to favour it over ΛCDM, we show that, if the current best-fit dark energy happened to be the true model, it would be decisively detected by the upcoming Dark Energy Spectroscopic Instrument survey[14].