



## Evidence for Dynamical Dark Energy from BAO Data: Testing Double-Crossing Parameterization

**Saddam Hussain, Simran Arora, Anzhong Wang, Benjamin Rose**

Institute for Theoretical Physics and Cosmology, Zhejiang University of Technology, Hangzhou 310023, China

Center for Gravitational Physics and Quantum Information, Yukawa Institute for Theoretical Physics, Kyoto University, 606-8502, Kyoto, Japan.

GCAP-CASPER, Department of Physics and Astronomy, Baylor University, Waco, TX 76798-7316, USA.

### INTRODUCTION & AIM

- The recent release of DESI BAO DR11 data from Dark Energy Spectroscopic Instrument provides strong hints for a dynamical dark energy component, potentially deviating from  $\Lambda$ CDM.
- At intermediate redshifts ( $z \gtrsim 0.5$ ), the dark energy equation of state  $w = p/\rho$ , appears to cross the phantom divide ( $w \leq -1$ ).
- However, at higher redshifts, dark energy is strongly suppressed relative to dark matter, raising an important conceptual question: If DE becomes dynamically subdominant at high  $z$ , does it truly remain phantom at all epochs?

#### Key Question

##### 1. Does dark energy:

- Remain phantom at all redshifts?
- Or undergo multiple transitions, becoming non-phantom at both high redshift ( $z \gtrsim 4$ ) and low redshift ( $z \lesssim 0.5$ )?

##### 2. Standard parametrizations such as $w_0w_a$ CDM allow only a single transition, often resulting in:

- Inflated error bars at higher  $z$ ,
- Limited theoretical flexibility.

#### Our Approach

We investigate multiple-transition behavior in the dark energy equation of state. We demonstrate that:

- Allowing multiple transitions can provide a better description of near-redshift dynamics.
- The large uncertainties seen in single-transition models may signal model incompleteness rather than data inconsistency.
- Modified gravity scenarios may generate effective phantom behavior at late times, while restoring non-phantom behavior at earlier epochs.

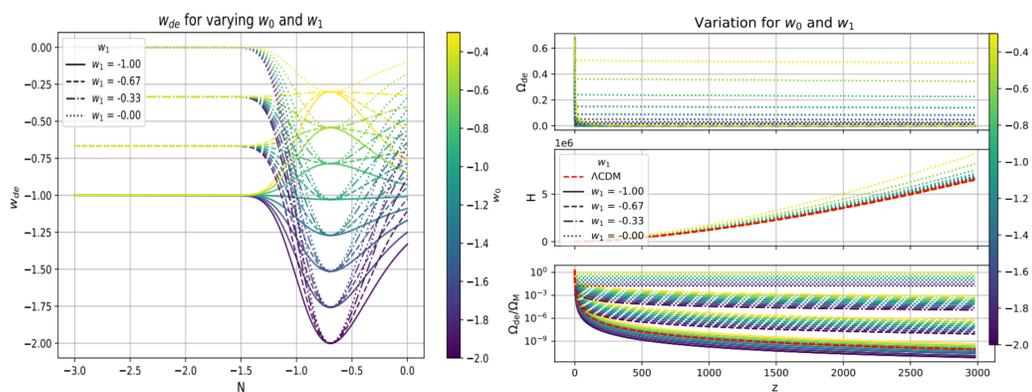
### MODELS

1. CPL Parameterization:  $w(a) = w_0 + w_a(1 - a)$ ,

2. Bell Parameterization:

$w(z) = w_1 + (w_0 - w_1) \exp\left(-\left(\frac{z-z_t}{\Delta}\right)^2\right)$ , where  $z_t$  is a transitional redshift, and  $\Delta$  captures the spread. These parameters can be directly constrained from observation.

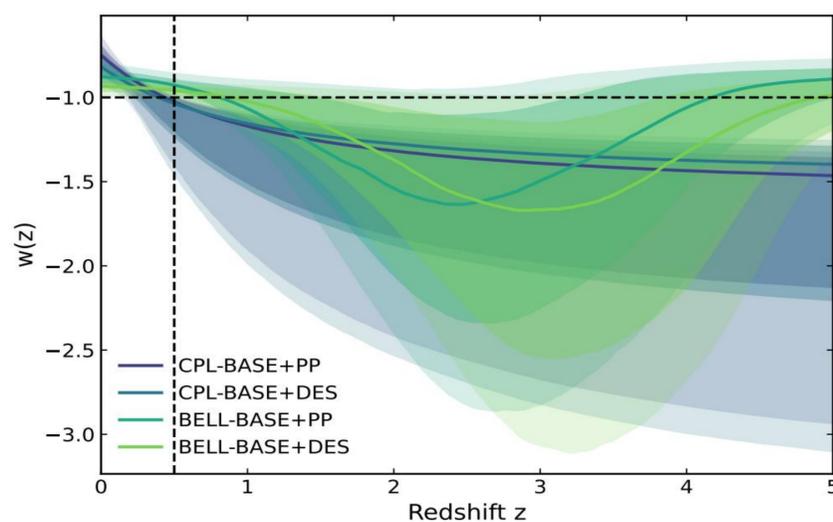
### RESULTS & DISCUSSION



The EoS variation of Bell model is shown as a function of  $N = \log\left(a = \frac{1}{1+z}\right)$ . The behaviour indicates that in the asymptotic past,  $w_{de} \propto w_1$ . However, as  $z \rightarrow z_t$  at lower redshift, the value of  $w_0$  can take values either  $> -1$  or  $< -1$ , indicating the near-redshift sensitivity of the model.

The evolution for density parameter and the Hubble parameter is shown for Bell model. For  $w_1 > -0.3$ , dark energy becomes comparable to dark matter. The ratio of DE density to DM density becomes significantly smaller in the past only when  $w_1 < -0.6$  and  $w_0 < -1$ .

Data sets: [1] Planck+DESI BAO + BBN + Pantheon+ : (BASE+PP)  
[2] Planck+DESI BAO + BBN + DES-SN-5Yr : (BASE+DES)



### CONCLUSION (BELL Model vs CPL)

- Both models yield similar values of  $H_0 = 68.0$  km/s/Mpc
  - Current data are therefore insufficient to clearly distinguish between the two models.
  - Although the Bell model exhibits phantom behavior, it remains in significant tension with the SH0ES measurement.
- Bayesian evidence for both models is comparable and moderately favored over  $\Lambda$ CDM.
- The Bell model provides tighter parameter constraints compared to the CPL parametrization.
- Phantom behavior appears only at low redshift, suggesting that:
  - An effective modified gravity theory or non-minimal coupling could trigger phantomness only at late times.
  - And can potentially avoid ghost instabilities while reproducing the observed late-time dynamics.

### REFERENCES

- S. Hussain, S. Arora, A. Wang and B. Rose, "Probing the Dynamics of Gaussian Dark Energy Equation of State Using DESI BAO," doi:10.1093/mnras/staf1924, [arXiv:2505.09913 [astro-ph.CO]]