Model-agnostic assessment of dark energy after DESI DR1 BAO

Bikash R. Dinda[1] and Roy Maartens[1,2,3]

[1]Department of Physics & Astronomy, University of the Western Cape, Cape Town 7535, South Africa
[2]Institute of Cosmology & Gravitation, University of Portsmouth, Portsmouth PO1 3FX, United Kingdom
[3]National Institute for Theoretical & Computational Science, Cape Town 7535, South Africa

Abstract

Baryon acoustic oscillation measurements by the Dark Energy Spectroscopic Instrument (Data Release 1) have revealed exciting results that show evidence for dynamical dark energy at $\sim 3\sigma$ when combined with cosmic microwave background and type Ia supernova observations. These measurements are based on the w_0w_aCDM model of dark energy. The evidence is less in other dark energy models such as the wCDM model. In order to avoid imposing a dark energy model, we reconstruct the distance measures and the equation of the state of dark energy independent of any dark energy model and driven only by observational data. To this end, we use both single-task and multi-task Gaussian Process regression. Our results show that the model-agnostic evidence for dynamical dark energy from DESI is much less than the evidence when imposing the w_0w_aCDM model. Our analysis also provides model-independent constraints on cosmological parameters such as the Hubble constant and the matter-energy density parameter at present. We find that the reconstructed values of these parameters are not consistent with the results reported in DESI with the w_0w_aCDM model. However, they are almost consistent with DESI for the wCDM model.

Introduction

- **DESI DR1 BAO (April 2024)** $\Longrightarrow$ Evidence for dynamical dark energy with w_0w_aCDM model at $\sim 3\sigma$ [1] .
- **E.o.S of DE:** $w(a) = w_0 + w_a(1-a)$; **ΛCDM:** $w_0 = -1$, $w_a = 0$; **wCDM:** $w_0 = w$, $w_a = 0$
- **DESI+CMB:** $w_0 = -0.45^{+0.34}_{-0.21}$, $w_a = -1.79^{+0.48}_{-1.0}$ $\sim 2.6\sigma$ tension
- **DESI+CMB+PP:** $w_0 = -0.827 \pm 0.063$, $w_a = -0.75^{+0.29}_{-0.25}$ $\sim 2.5\sigma$ tension
- **Is this evidence similar for other models?** Not really.
  - **DESI+CMB:** wCDM: $w = -1.122^{+0.062}_{-0.054}$ $\sim 2\sigma$ tension
  - **DESI+CMB+PP:** wCDM: $w = -0.997 \pm 0.025$ $\sim 0.1\sigma$ tension
- **Evidence for dynamical dark energy (deviation from ΛCDM) may depend on specific model choice.**

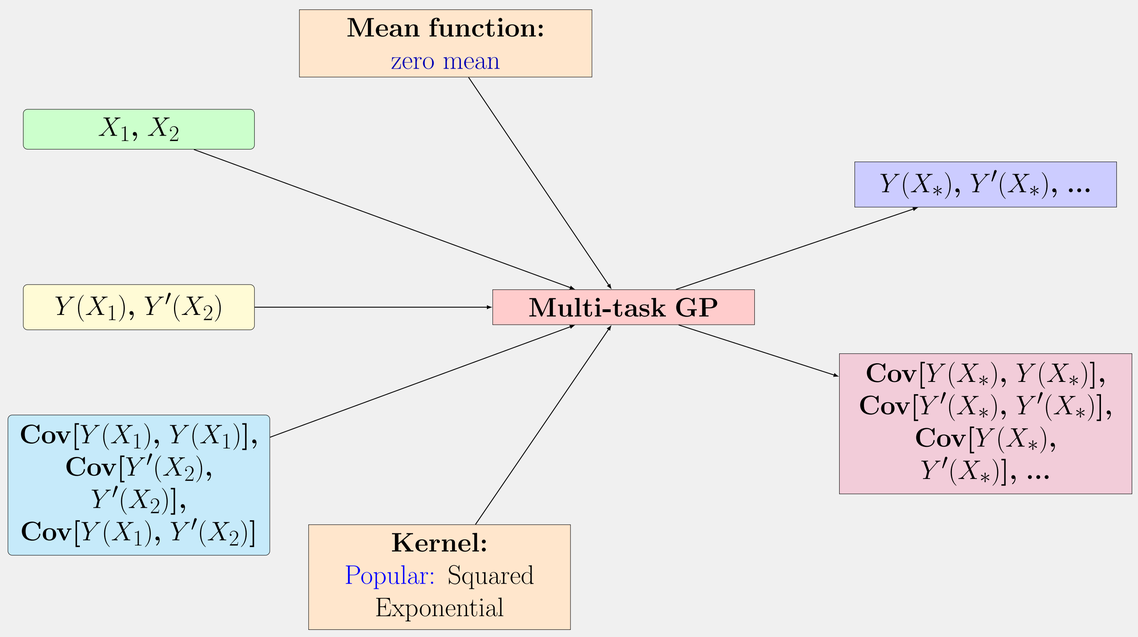
Main Objectives: Model-Independent Approach: Why It Matters?

- **Model-independent analysis** is crucial.
- Model-dependent analysis may introduce biases in estimation.
- Model independent means:
  - No specific cosmological model.
  - No parameterization.
- Of course, nothing is completely model-independent. We must consider basic physical theories, e.g., type Ia supernovae are standard candles.
- Approach: "Completely Data Driven"

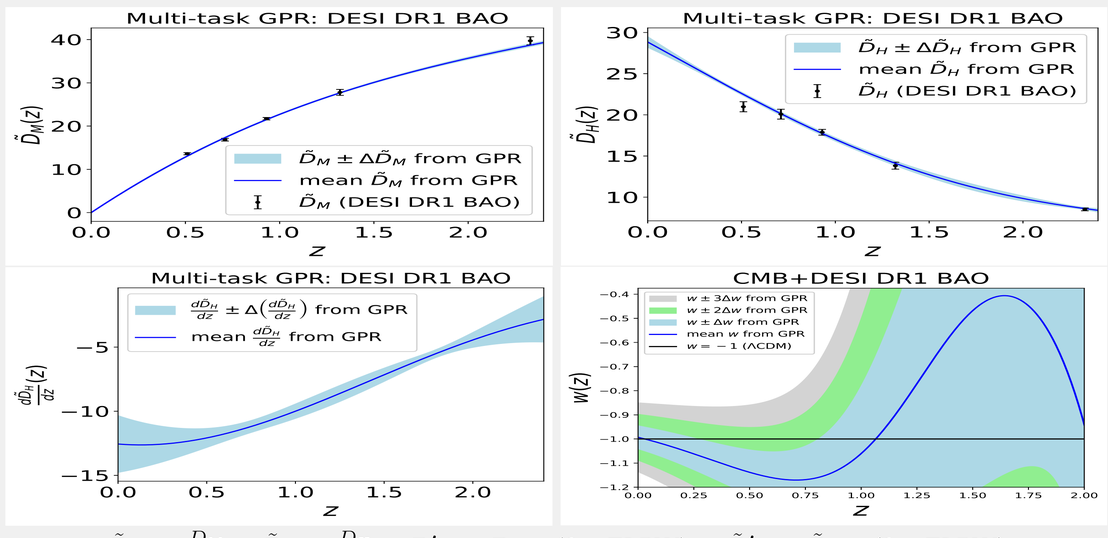
Deriving $w(z)$ from Observational Data

- **1.** $w(z) = -1 - \dfrac{2(1+z)D'_H(z) + 3\beta(1+z)^3 D^3_H(z)}{3\left[D_H(z) - \beta(1+z)^3 D^3_H(z)\right]}$; $\beta = \dfrac{\Omega_{\rm m0}H_0^2}{c^2}$; $D_H(z) = \dfrac{c}{H(z)}$
  (Useful for observations like calibrated BAO)
- **2.** $w(z) = -1 - \dfrac{2(1+z)\tilde{D}'_H(z) + 3\gamma(1+z)^3 \tilde{D}^3_H(z)}{3\left[\tilde{D}_H(z) - \gamma(1+z)^3 \tilde{D}^3_H(z)\right]}$; $\gamma = \beta r_d^2$, $\tilde{D}_H(z) = \dfrac{D_H(z)}{r_d}$
  (Useful for observations like uncalibrated BAO)
- **3.** $w(z) = -1 - \dfrac{2(1+z)d''_M(z) + 3\delta(1+z)^3 d'^3_M(z)}{3\left[d'_M(z) - \delta(1+z)^3 d'^3_M(z)\right]}$; $\delta = \beta\, e^{-2b(20+M_B)}$, $d_M(z) = \dfrac{\exp\left\{b\left[m_B(z) - 5\right]\right\}}{1+z}$ Mpc
  (Useful for observations like SNIa) Used $D'_M = D_H$

Methodology: Multi-task Gaussian Process (GP) Regression

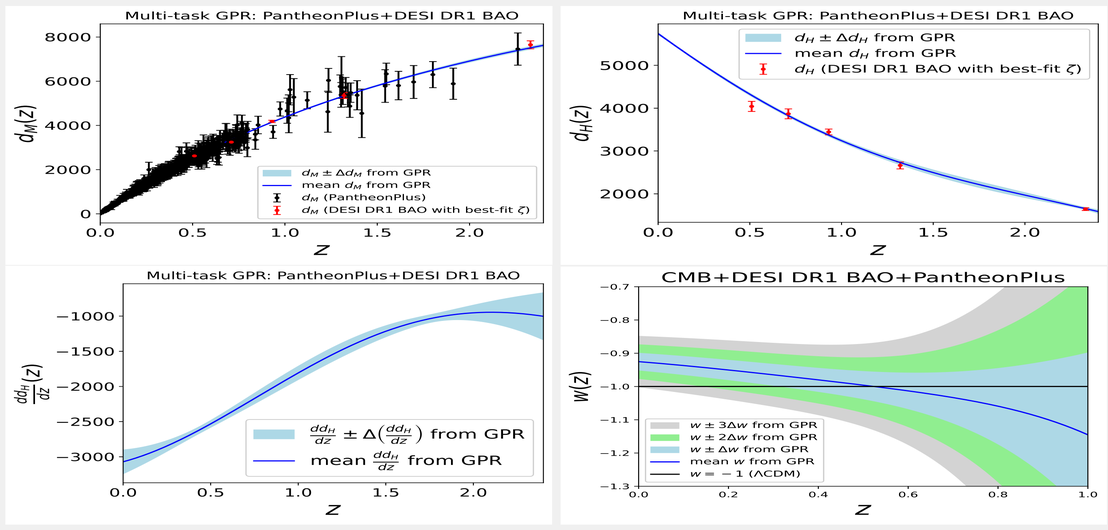


Results: I. DESI DR1 BAO+CMB



$\tilde{D}_M = \dfrac{D_M}{r_d}$; $\tilde{D}_H = \dfrac{D_H}{r_d}$; $D'_M = D_H$ (flat FLRW); $\tilde{D}'_M = \tilde{D}_H$ (flat FLRW)

II. DESI DR1 BAO+PantheonPlus(PP)+CMB



III. Reconstructed Constant Parameters

Data Combination	$\frac{H_0 r_d}{100}$ [km/s]	H_0 [$\frac{\rm km}{\rm s\ Mpc}$]	$\Omega_{\rm m0}$	M_B [mag]
CMB+DESI	104.02 ± 2.34	70.74 ± 1.60	0.286 ± 0.013	-
CMB+DESI+PP	100.65 ± 1.03	68.45 ± 0.71	0.305 ± 0.007	-19.414 ± 0.021

Conclusions

1. DESI DR1 BAO+CMB: ΛCDM within 1σ in most redshift ranges, slightly more than 1σ away at $0.3 \lesssim z \lesssim 0.8$.
2. DESI DR1 BAO+PantheonPlus+CMB: No significant tension, ΛCDM $\lesssim 2\sigma$ to 1σ away in $z \lesssim 0.35$.
3. Derived H_0 and $\Omega_{\rm m0}$ values consistent with wCDM, not ΛCDM.
4. Hubble and M_B tensions with local measurements like SHOES

References

[1] **DESI** Collaboration, A. G. Adame et al., *DESI 2024 VI: Cosmological Constraints from the Measurements of Baryon Acoustic Oscillations*, arXiv:2404.03002.

For more information! Scan the QR Code:

Contact Information: Bikash R. Dinda — Email: bikashd18@gmail.com