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Exploring late-time physics to explain the Hubble tension

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In this work we analyze Type Ia supernovae (SNe Ia) data from the Pantheon+ compilation (Scolnic et al., 2022) to investigate late-time physics effects that impact the expansion history, $H(z)$, at low redshifts ($z < 2$). Dynamic Dark Energy (DE) models allow for increased acceleration of the expansion at late times while preserving the physics of the early universe, consistent with Cosmic Microwave Background (CMB) results. We focus on a late DE model that introduces a deviation in the DE equation of state, w_0, at a specific redshift, z_a, by means of a Dark Energy Sigmoid model as described by Torres-Arzayus et al. (2024). The fit results are: $H_0 = 73.3^{+0.2}_{-0.6}$ km s^{-1} Mpc^{-1}, $w_0 = -0.95^{+0.15}_{-0.02}$ and $z_a = 0.8 \pm 0.46$.

The Hubble tension refers to the 5σ discrepancy in the values of the Hubble constant, H_0, derived from CMB data and those measured from the magnitude-redshift relation using standard candles (Di Valentino et al., 2021). The late DE mechanism proposed here employs a sigmoid function to describe the dark energy equation of state, $w(z)$, transitioning from $w_a = -1$ for $z > z_a$ to w_0 for $z < z_a$, as follows:

$$w(z) = w_0 + \frac{w_a - w_0}{1 + e^{\left(\frac{z_a - z}{r}\right)}}. \qquad (1)$$

The equation above describes a smooth transition taking place at a redshift centered around z_a with a transition rate r. The value of w_a is set to -1 to ensure that at high redshifts the universe's dynamics adhere to the standard ΛCDM. A Monte Carlo code was developed to generate synthetic SNe compilations at the same redshifts of the Pantheon+ SNe subset used in the main fit, and using a nominal SN magnitude error $\sigma_m = 0.2$ (the average magnitude error). For each realization, the Monte Carlo loop generates randomized magnitudes with σ_m Gaussian width, and using an underlying sigmoid model with true parameters (w_0, z_a) set equal to the best fit values. For each

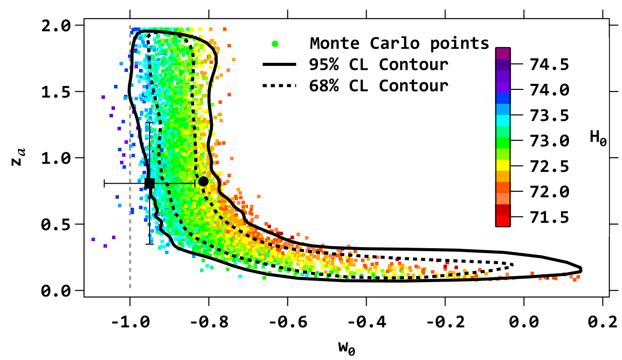

Figure 1. 95% and 68% CL contours for Monte Carlo points. The color coded points on the (w_0, z_a) plane are each one the result of a fit to a randomized realization of SN magnitudes at the same redshifts as the sample used for the main analysis (Torres-Arzayus et al., 2024). The Color scale represents the corresponding H_0 values. The black square with error bars is the best fit sigmoid DE model, the round circle is the Monte Carlo average.

Monte Carlo realization, the fit code was executed and a corresponding set of (w_0, z_a) best fit parameters obtained. The 68% and 95% CL contours of the Monte Carlo points on the (w_0, z_a) plane are shown in Figure 1.

The fit to the sigmoid DE model is slightly better, but not statistically significant, than a fit to the baseline ΛCDM model. The sigmoid model is not rejected by the data and identifies a specific redshift, $z_a = 0.8$, where a potential transition in the equation of state could have occurred. As can be seen in Figure 1, the sigmoid model does not favor a DE in the phantom region ($w_0 < -1$). While the sigmoid DE model does not completely resolve the H_0 tension, it offers a transition mechanism that can still play a role along side other potential solutions.

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