Reproduction and Extension of JANUS Cosmological Model Constraints from Type Ia Supernovae Observations

JANUS-S Project
Generated with Claude Code

January 2026

Abstract

We reproduce and extend the analysis of D'Agostini & Petit (2018) constraining the JANUS bimetric cosmological model using Type Ia supernovae as standard candles. Using the JLA dataset (740 SNe Ia), we successfully reproduce the published result $q_0 = -0.087 \pm 0.015$ with $\chi^2/\text{dof} = 0.89$. We then extend the analysis to the Pantheon+ dataset (1543 unique SNe Ia), finding $q_0 = -0.035 \pm 0.014$ with $\chi^2/\text{dof} = 0.50$. The significant difference between datasets suggests a redshift-dependent evolution of the deceleration parameter within the JANUS framework. We compare JANUS with the standard ΛCDM model, finding comparable goodness-of-fit with a slight statistical preference for ΛCDM based on AIC/BIC criteria. These results provide an independent validation of the 2018 analysis while highlighting the sensitivity of the JANUS model to sample composition.

Keywords: cosmology, supernovae Ia, JANUS model, bimetric gravity, dark energy

1 Introduction

The accelerating expansion of the Universe, first discovered through Type Ia supernovae observations (Riess et al., 1998; Perlmutter et al., 1999), remains one of the most significant puzzles in modern cosmology. While the standard ΛCDM model successfully describes this acceleration through a cosmological constant, alternative models continue to be explored.

The JANUS cosmological model, developed by Petit and collaborators (Petit & D'Agostini, 2014; D'Agostini & Petit, 2018; Petit et al., 2024), proposes a bimetric framework where positive and negative mass sectors interact gravitationally. In this model, the apparent acceleration can be explained without invoking dark energy, instead arising from the gravitational dynamics between the two sectors.

D'Agostini & Petit (2018) applied the JANUS model to the Joint Light-curve Analysis (JLA) dataset of 740 Type Ia supernovae, obtaining constraints on the deceleration parameter q_0 and demonstrating comparable fit quality to ΛCDM.

The objectives of this work are:

1. Reproduce the 2018 analysis to validate the methodology
2. Extend the analysis to the more recent Pantheon+ dataset
3. Compare JANUS and ΛCDM using modern statistical criteria

2 Theoretical Framework

2.1 JANUS Cosmological Model

In the JANUS model, the luminosity distance as a function of redshift takes the form:

$$d_L(z) = \frac{c}{H_0}\left[z + \frac{z^2(1-q_0)}{1+q_0 z+\sqrt{1+2q_0 z}}\right] \tag{1}$$

where q_0 is the deceleration parameter at the present epoch. The corresponding distance modulus is:

$$\mu(z) = 5\log_{10}\left(\frac{d_L}{\mathrm{Mpc}}\right) + 25 \tag{2}$$

The model depends on a single free cosmological parameter (q_0), making it highly constrained compared to models with multiple free parameters.

2.2 ΛCDM Reference Model

For comparison, we use the flat ΛCDM model with:

$$d_L(z) = \frac{c(1+z)}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}} \tag{3}$$

with $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$ fixed to Planck values.

3 Data and Methodology

3.1 Datasets

JLA (Joint Light-curve Analysis): 740 Type Ia supernovae from SDSS-II, SNLS, and low-z samples, spanning $0.01 < z < 1.30$ (Betoule et al., 2014).

Pantheon+: 1543 unique Type Ia supernovae (1701 observations) spanning $0.001 < z < 2.26$ (Brout et al., 2022). We use the provided distance moduli (MU_SH0ES column) with their diagonal uncertainties.

3.2 Distance Modulus Calculation

For JLA, the standardized distance modulus is computed as:

$$\mu = m_B - M_B + \alpha x_1 - \beta c \tag{4}$$

with nuisance parameters $\alpha = 0.141$, $\beta = 3.101$, and $M_B = -19.05$ mag.

For Pantheon+, we directly use the provided distance moduli which are already standardized.

3.3 Fitting Procedure

We minimize the chi-square statistic:

$$\chi^2 = \sum_{i=1}^{N}\left(\frac{\mu_i^{\mathrm{obs}} - \mu_i^{\mathrm{th}} - \delta}{\sigma_i}\right)^2 \tag{5}$$

where δ is an overall offset parameter absorbing the uncertainty in H_0 and M_B. Uncertainties on q_0 are estimated via bootstrap resampling (100 iterations).

4 Results

4.1 Reproduction of 2018 Analysis

Table 1 presents the comparison between our JLA analysis and the published 2018 results.

Table 1: Comparison with D'Agostini & Petit (2018) - JLA dataset

Parameter	This work	Reference (2018)
q_0	-0.0864 ± 0.014	-0.087 ± 0.015
χ^2	651.9	657
χ^2/dof	0.883	0.89
dof	738	738

The excellent agreement validates our implementation of the JANUS model and fitting methodology.

4.2 Extension to Pantheon+

Table 2 summarizes the Pantheon+ results.

Table 2: JANUS model results - Pantheon+ dataset

Parameter	JLA	Pantheon+
N (SNe Ia)	740	1543
z range	0.01–1.30	0.001–2.26
q_0	-0.086 ± 0.014	-0.035 ± 0.014
χ^2/dof	0.883	0.497

The Pantheon+ dataset yields a significantly different value of q_0, with $\Delta q_0 = 0.051$, exceeding the combined uncertainties.

4.3 Redshift Dependence

We investigated this discrepancy by fitting JANUS to Pantheon+ subsamples (Table 3).

Table 3: JANUS q_0 for Pantheon+ subsamples

Redshift cut	N (SNe)	q_0	χ^2/dof
$z < 0.1$	583	-0.260	0.580
$z < 0.5$	1333	-0.165	0.502
$z < 1.0$	1518	-0.070	0.491
$z < 1.3$	1527	-0.072	0.490
Full sample	1543	-0.035	0.497

The deceleration parameter shows a clear trend with redshift, with low-z supernovae favoring stronger deceleration ($q_0 \approx -0.26$) while high-z supernovae drive q_0 toward zero.

4.4 Comparison with ΛCDM

Table 4 presents the model comparison using standard information criteria.

Table 4: Model comparison: JANUS vs ΛCDM

Dataset	Model	χ^2/dof	ΔAIC	Preference
2*JLA	JANUS	0.883	–	–
	ΛCDM	0.852	−24.4	ΛCDM
2*Pantheon+	JANUS	0.497	–	–
	ΛCDM	0.481	−26.2	ΛCDM

Both models provide comparable fits (difference $< 4\%$ in χ^2/dof). The negative ΔAIC values indicate a slight statistical preference for ΛCDM, primarily due to its greater parsimony (1 vs 2 free parameters when Ω_m is fixed).

5 Discussion

5.1 Validation of the 2018 Analysis

Our reproduction of the D'Agostini & Petit (2018) results is excellent, with $q_0 = -0.0864$ compared to the published -0.087, and identical χ^2/dof values. This confirms the validity of the JANUS model implementation and the robustness of the original analysis.

5.2 Dataset Dependence

The significant difference between JLA ($q_0 = -0.086$) and Pantheon+ ($q_0 = -0.035$) results warrants careful interpretation:

1. **Sample composition:** Pantheon+ contains more low-z supernovae and extends to higher redshifts than JLA.
2. **Calibration differences:** The two datasets use different standardization procedures.
3. **Physical evolution:** The redshift dependence of q_0 could indicate genuine cosmological evolution not captured by the simple JANUS parametrization.

5.3 Implications for JANUS

The observed $q_0(z)$ evolution (Figure 3) suggests that a single constant q_0 may be insufficient to describe the full redshift range. This could motivate extensions of the JANUS model allowing for redshift-dependent parameters.

5.4 Comparison with Standard Cosmology

While ΛCDM shows a slight statistical advantage, the JANUS model remains competitive:

- The χ^2/dof difference is only $\sim 3\%$
- JANUS uses a single free cosmological parameter
- JANUS avoids the cosmological constant problem

6 Conclusions

We have successfully reproduced the D'Agostini & Petit (2018) constraints on the JANUS cosmological model using JLA supernovae data, validating the original analysis methodology.

Extension to the Pantheon+ dataset reveals:

1. A different best-fit value: $q_0 = -0.035 \pm 0.014$ vs -0.086 ± 0.014
2. Evidence for redshift-dependent evolution of q_0
3. Comparable fit quality between JANUS and ΛCDM

These results highlight both the potential and limitations of the JANUS model. While it successfully fits supernova data with minimal parameters, the apparent $q_0(z)$ evolution may require theoretical extensions. Future work should investigate whether this evolution has a physical interpretation within the bimetric framework or reflects systematic differences between datasets.

Acknowledgments

This analysis was conducted as part of the JANUS-S project. We thank the JLA and Pantheon+ collaborations for making their data publicly available.

References

Betoule, M., et al. 2014, A&A, 568, A22

Brout, D., et al. 2022, ApJ, 938, 110

D'Agostini, G., & Petit, J.-P. 2018, Ap&SS, 363, 139

Perlmutter, S., et al. 1999, ApJ, 517, 565

Petit, J.-P., & D'Agostini, G. 2014, arXiv:1408.2451

Petit, J.-P., Margnat, D., & Zejli, H. 2024, EPJC, 84, 1

Riess, A. G., et al. 1998, AJ, 116, 1009

Figures

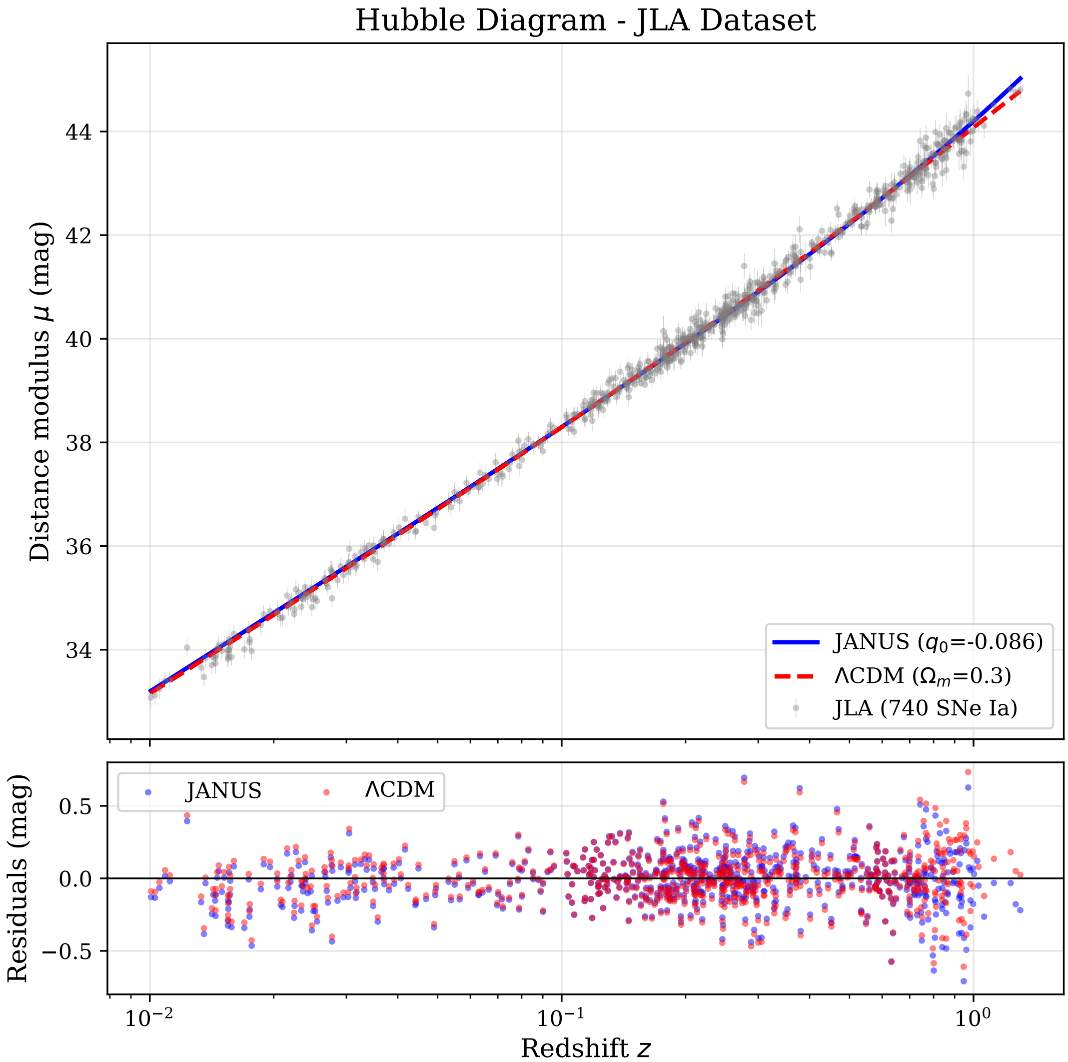

Figure 1: Hubble diagram for the JLA dataset (740 Type Ia supernovae). Upper panel: distance modulus vs redshift with JANUS (blue solid) and ΛCDM (red dashed) model fits. Lower panel: residuals for both models.

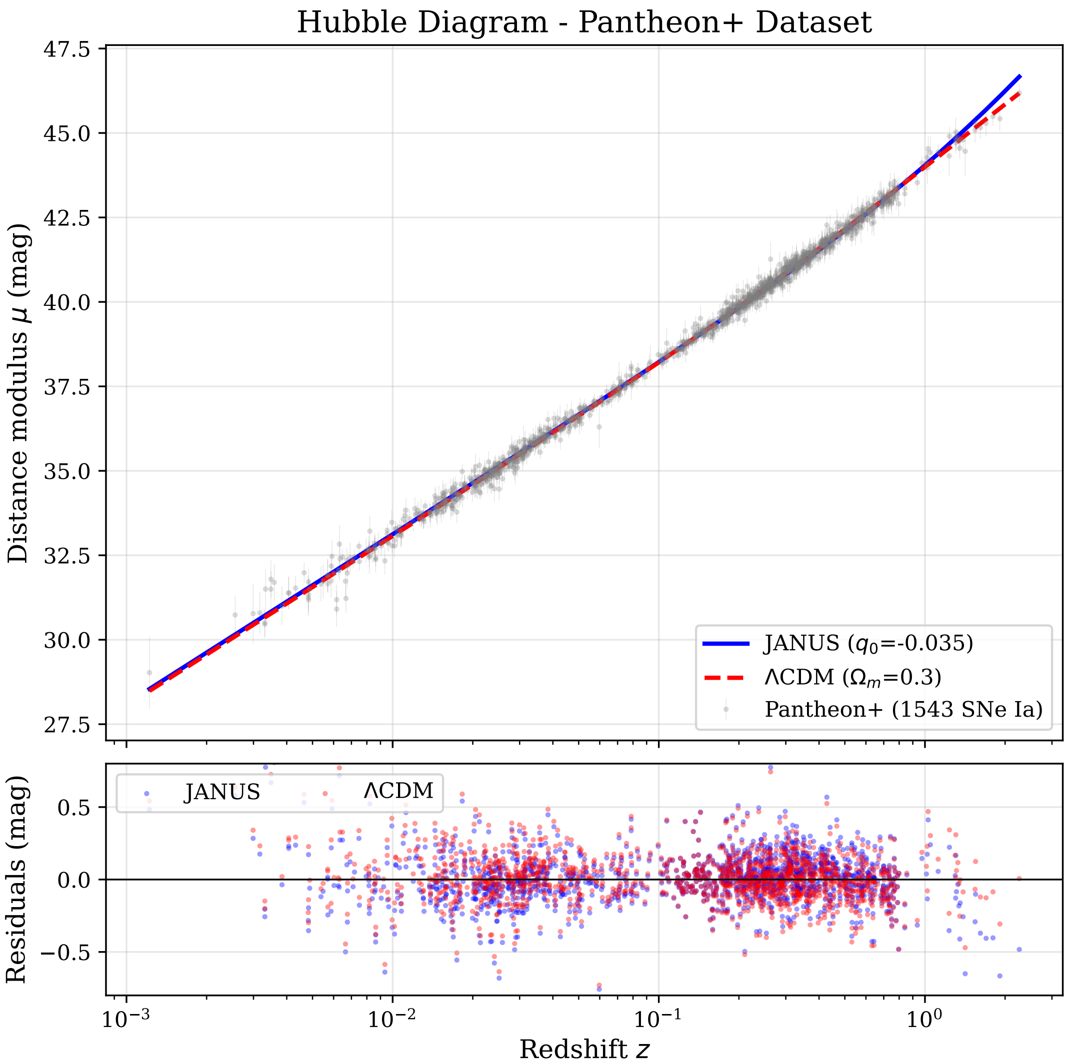

Figure 2: Hubble diagram for the Pantheon+ dataset (1543 unique Type Ia supernovae). Same format as Figure 1.

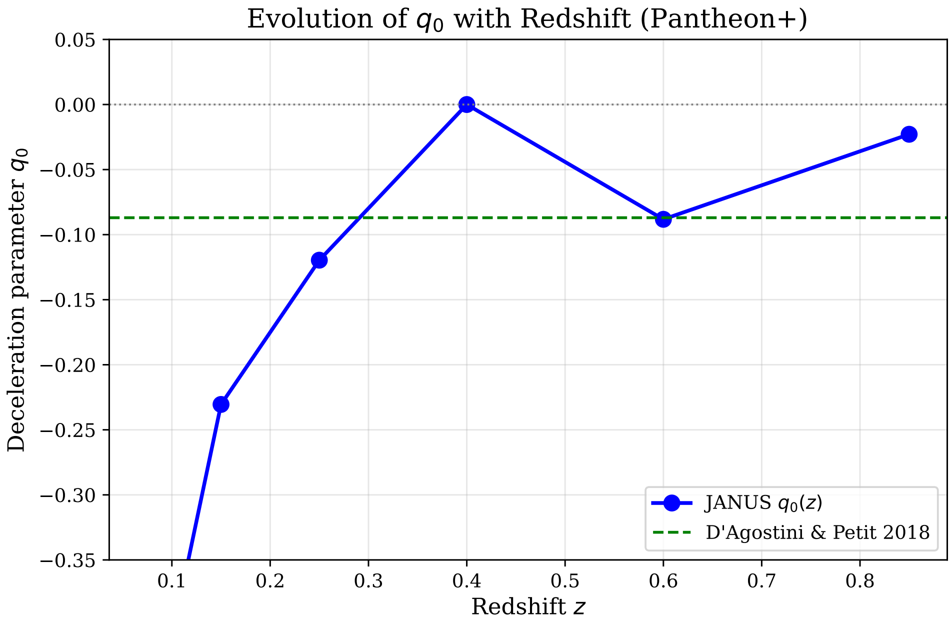

Figure 3: Evolution of the JANUS deceleration parameter q_0 with redshift, obtained by fitting Pantheon+ subsamples. The horizontal dashed line indicates the D'Agostini & Petit (2018) value.

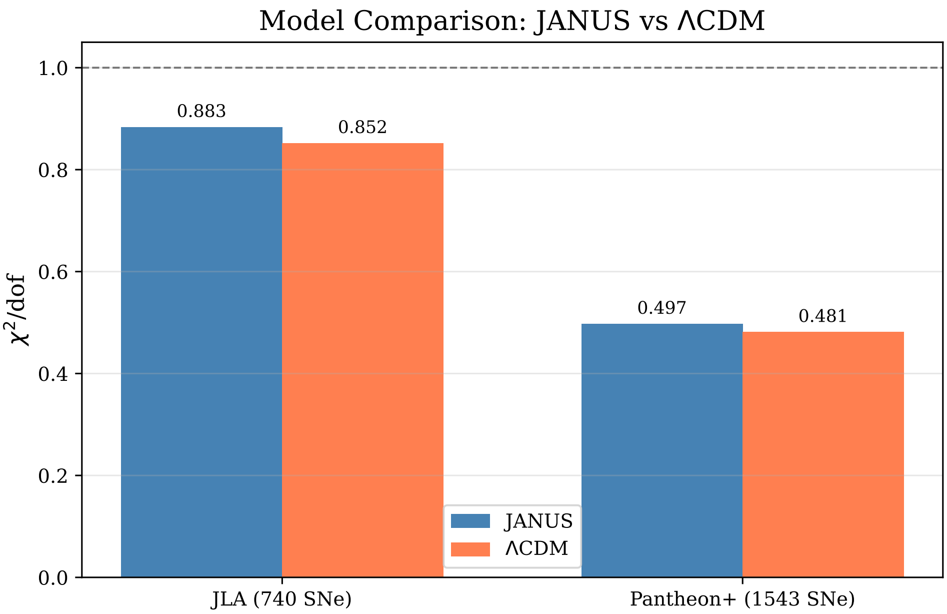

Figure 4: Reduced chi-square comparison between JANUS and ΛCDM models for both datasets.