Monthly Notices of the Royal Astronomical Society

MNRAS **549**, 1–6 (2026) https://doi.org/10.1093/mnras/stag844

Pantheon + supernovae corrected for progenitor age indicate the universe is decelerating

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Accepted 2026 April 30. Received 2026 April 30; in original form 2026 March 16

ABSTRACT

We examine the impact of progenitor age-dependent luminosity evolution of Type Ia supernovae on a cosmographic measurement of the deceleration parameter q_0. Our recent redshift tomographic analysis showed that locally q_0 has a strong dipole anisotropy aligned approximately with the bulk flow, and only a small monopole component remains at distances exceeding a few hundred Mpc. Applying redshift-dependent corrections for progenitor age to the Pantheon + catalogue, we find that this shifts the monopole component of q_0 to *positive* values (i.e. deceleration) while leaving the local dipole component essentially unchanged.

Key words: supernovae: general – cosmological parameters – dark energy – cosmology: observations.

1 INTRODUCTION

It has been suggested that the cosmic acceleration inferred from Type Ia supernovae (SNe Ia) could be illusory, due to our being 'tilted' observers embedded in a bulk flow (C. G. Tsagas 2022). The inferred acceleration should then be directed mainly along the local bulk flow, and die out over a few hundred Mpc. J. Colin et al. (2019) analysed the Joint Lightcurve Analysis compilation of 740 SNe Ia in the heliocentric frame (after removing erroneous corrections for peculiar velocities) and found that the deceleration parameter q_0 is indeed mainly a dipole aligned approximately with the local bulk flow direction. This was criticized by D. Rubin & J. Heitlauf (2020) on the grounds that J. Colin et al. (2019) ought to have first boosted to the cosmic microwave background (CMB) frame and applied corrections for peculiar velocities of the SNe Ia host galaxies ('Hubble diagram' analysis). It has been demonstrated however that the distribution of matter as traced by quasars and radio galaxies is *not* isotropic in the CMB frame (N. J. Secrest et al. 2021, 2022; J. D. Wagenveld, H.-R. Klöckner & D. J. Schwarz 2023; L. Böhme et al. 2025) – for a review see N. Secrest et al. (2025). This invalidates the criticism of D. Rubin & J. Heitlauf (2020) which rests on this assumption. Subsequently it was shown that for the Pantheon + compilation (D. Scolnic et al. 2022) too, q_0 is mainly a dipole which dies out by $z \sim 0.1$ and is particularly pronounced in the frame of the Local Group (A. Sah et al. 2025). Cosmic acceleration is thus likely a general relativistic effect due to the anomalous bulk flow in our local Universe, and not due to a Cosmological Constant Λ – as it must then be *isotropic*.

The use of SNe Ia as standard candles relies on the assumption that their properties do not evolve with redshift. However Y. Kang et al. (2020) reported a $\sim 3\sigma$ correlation between standardized SNe Ia luminosity and the stellar-population age, based on spectroscopic observations of early-type host galaxies. The significance of the correlation was challenged by B. M. Rose et al. (2020) but countered by Y.-W. Lee et al. (2020). Y.-W. Lee et al. (2022) then clarified that it arises from a more fundamental dependence of the width–luminosity and colour–luminosity relations on the progenitor age, i.e. at a fixed stretch/colour parameter, SNe Ia with younger progenitors are fainter.

Recently, C. Chung et al. (2025) used an extended sample of 300 galaxies at redshift $z < 0.45$ to estimate the host galaxy ages, finding a more significant correlation of up to 5.5σ with the Hubble residuals. Building on this, J. Son et al. (2025) proposed a correction $\Delta m(z)$ for this redshift-dependent bias to the Phillips–Tripp formula for the SNe Ia distance modulus (in e.g. the SALT2 light-curve template):

$$\mu_{\rm SN} = m_{\rm B} - M + \alpha x_1 - \beta c - \Delta m(z), \quad (1)$$

where $m_{\rm B}$ is the apparent magnitude (in the rest frame 'B' band), M is the absolute magnitude, x_1 and c are the 'stretch' and 'colour' corrections, and

$$\Delta m(z) = \Delta {\rm age}(z) \times 0.030\,{\rm mag\,Gyr^{-1}}, \quad (2)$$

where Δage is the change in mean progenitor age of the SNe Ia population (relative to $z = 0$) derived from the supernova progenitor-age distribution (SPAD). This is obtained by convolving the SNe Ia delay-time distribution with the cosmic star formation history. Individual SNe Ia typically lack direct progenitor-age measurements, so the population-averaged Δage(z) provides an estimate of the average age evolution – see figs 6 and 7 of Y.-W. Lee et al. (2020). While the SPAD, and hence Δage(z), depend on the assumed cosmological model, Y.-W. Lee et al. (2022) showed that this dependence is weak and does not significantly affect their

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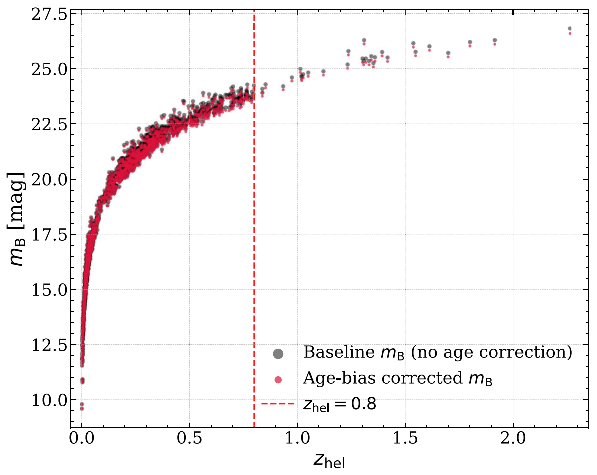

Figure 1. Apparent *B*-band magnitude as a function of heliocentric redshift for the Pantheon + SNe Ia catalogue. The black points show the baseline magnitudes (m_B) without progenitor age correction, while the red points (m_B^*) are corrected for progenitor age following J. Son et al. (2025).

main conclusions. The value of the slope (0.03 mag Gyr^{-1}) was taken as an average of measurements made by C. Chung et al. (2025) from the samples of R. R. Gupta et al. (2011) and B. M. Rose, P. M. Garnavich & M. A. Berg (2019).[1] In this Letter, we test the impact of the progenitor-age-dependent luminosity evolution on the inferred cosmic acceleration and its direction dependence, in the statistically principled SNe Ia analysis framework developed by us (A. Sah et al. 2025).

2 METHOD

We briefly describe our methodology, referring to A. Sah et al. (2025) for a detailed description. The SNe Ia luminosity distance, related to the distance modulus (1) as $\mu_{SN} \equiv 25 + 5\log_{10}(d_L/\text{Mpc})$, is Taylor expanded to third order in redshift, in terms of the Hubble rate $H_0 \equiv (\dot{a}/a)|_{z=0}$, deceleration parameter $q_0 \equiv -(a\ddot{a}/\dot{a}^2)|_{z=0}$, and jerk $j_0 \equiv (a^2\dddot{a}/\dot{a}^3)|_{z=0}$:

$$d_L(z) = \frac{cz}{H_0}\left[1 + \frac{1}{2}(1-q_0)z - \frac{1}{6}\left(1 - q_0 - 3q_0^2 + j_0 + \frac{kc^2}{H_0^2 a_0^2}\right)z^2\right] \times \frac{1+z_{hel}}{1+z}. \quad (3)$$

Here, z_{hel} is the measured redshift in the heliocentric frame and z is the cosmological redshift in the Cosmic Rest Frame – usually identified with the CMB frame together with source peculiar velocity corrections – which we denote as z_{HD} (for ‘Hubble diagram’). We also show comparisons when it is just boosted to the CMB frame (z_{CMB}), as well as to the frame of the Local Group (z_{LG}). The multiplicative term accounts for our local peculiar velocity, ensuring that $d_L = (1 + z_{hel}) \times$ comoving distance (D. Rubin & J. Heitlauf 2020). To ensure good convergence of the cosmographic expansion (3), we impose a cut in redshift $z_{hel} \leq 0.8$ on the Pantheon + catalogue, thereby excluding just 31 out of 1701 SNe Ia (see Fig. 1). We then adopt the maximum likelihood estimator (J. T. Nielsen, A. Guffanti & S. Sarkar 2016):

$$\mathcal{L}(\theta) = p[(\hat{m}_B, \hat{x}_1, \hat{c}) \mid \theta] = \int p[(\hat{m}_B, \hat{x}_1, \hat{c}) \mid (M, x_1, c)]\ p[(M, x_1, c) \mid \theta]\ dM\,dx_1\,dc, \quad (4)$$

and the covariance matrix of Z. G. Lane et al. (2025) – as in analysis **C2** of A. Sah et al. (2025). Here, the ˆ refers to the observed quantity and p to the underlying probability distribution of the true data. To reflect the expectation that an observer embedded in a bulk flow will infer a dipolar modulation of the deceleration parameter (C. G. Tsagas & M. I. Kadiltzoglou 2015), we model it as

$$q_0 = q_m + \boldsymbol{q}_d \cdot \hat{n}e^{-z/S}, \quad (5)$$

where $\hat{n}$ is the direction towards individual SNe Ia, and the direction of the dipole ($\boldsymbol{q}_d$) is initially fixed to the CMB dipole direction.

2.1 Correcting for progenitor age bias

Following J. Son et al. (2025), we apply the correction (2) to the apparent magnitudes of the Pantheon + SNe Ia (see Fig. 1):

$$m_B^* = m_B - \Delta\text{age}(z) \times 0.030 \text{ mag Gyr}^{-1}. \quad (6)$$

Using the data for the redshift evolution of the median relative age in fig. 2 of J. Son et al. (2025), we use a cubic spline to interpolate the corresponding values of Δage(z) at the desired redshift. In J. Son et al. (2025), the redshift evolution of the stellar population age was derived using the $w_0 - w_a$ cold dark matter (CDM) model fitted to Dark Energy Spectroscopic Instrument (DESI) and CMB data. Since progenitor age estimates are mildly cosmology dependent, we test later the sensitivity of our results to alternative assumptions.

3 RESULTS

We employ the age-bias-corrected magnitudes (6) in the likelihood (4) with a cut $z_{hel} > 0.00937$ and show the results in Table 1, both with and without progenitor age bias corrections. While the statistical significance of the dipole remains unchanged, the monopole component shifts towards more positive values. The dipole direction was fixed to the CMB dipole direction but allowing this to vary does not change our conclusions – the best-fit dipole direction remains consistent within uncertainties, Note that $\boldsymbol{q}_d$ reverses sign in going from the heliocentric (or Local Group) to the CMB (or Hubble diagram) frames.[2] Also, as found

[1] A new study by P. Wiseman et al. (2026) criticizes C. Chung et al. (2025) and J. Son et al. (2025) for not having done host-mass standardization and argues that correcting for these removes any correlation between the Hubble residuals and the progenitor age. They also state that the progenitor age difference between nearby and distant supernovae was overestimated due to assumptions about the SNe Ia delay time distribution. The debate continues.

[2] The redshift boosted to the Local Group (LG) frame is obtained from $(1 + z_{LG}) = (1 + z_{hel}) \times (1 + z_{LG\text{-}hel})$, where $z_{LG\text{-}hel} = \sqrt{(1 - \vec{v}_{LG\text{-}Sun} \cdot \hat{n}/c)/(1 + \vec{v}_{LG\text{-}Sun} \cdot \hat{n}/c)} - 1$ and $\vec{v}_{LG\text{-}Sun}$ is the velocity of the LG frame relative to the heliocentric frame. The Sun's motion around the Galaxy is nearly in the *opposite* direction to the CMB dipole hotspot, so while the heliocentric frame moves wrt the CMB at 369.82 ± 0.11 km s^{-1} towards $l = 264.021° \pm 0.011°$, $b = 48.243° \pm 0.005°$ (which yields z_{CMB} from z_{hel}), the LG moves wrt the CMB at 620 ± 15 km s^{-1} towards $l = 271.9° \pm 2.0°$, $b = 29.6° \pm 1.4°$ (N. Aghanim et al. 2020).

Table 1. Best-fit dipole amplitude $\boldsymbol{q}_{\rm d}$, monopole $q_{\rm m}$, likelihood ratio $\Delta \ln \mathcal{L}(q_{\rm d} = 0)$, and statistical significance α (in σ), before and after applying the progenitor age-bias correction. Results are shown in the heliocentric, Local Group, CMB, and Hubble diagram (CMB frame with peculiar velocity corrections) frames. The dipole amplitude (and the scale on which it decays) is unchanged by the correction, while the monopole shifts to positive values.

	Baseline (no age corrections)					With age bias corrections				
Frame	$\boldsymbol{q}_{\rm d}$	$q_{\rm m}$	S	$\Delta \ln \mathcal{L}$	α	$\boldsymbol{q}_{\rm d}$	$q_{\rm m}$	S	$\Delta \ln \mathcal{L}$	α
Hel	−31.8	0.01	0.0094	36.9	5.7	−32.1	0.35	0.0094	36.9	5.7
LG	−61.4	−0.04	0.0099	135.5	> 7	−62.0	0.31	0.0099	135.1	> 7
CMB	21.1	−0.03	0.011	31.8	5.3	21.3	0.32	0.011	31.4	5.3
HD	11.4	−0.14	0.01	7.3	2.2	11.4	0.21	0.01	7.1	2.2

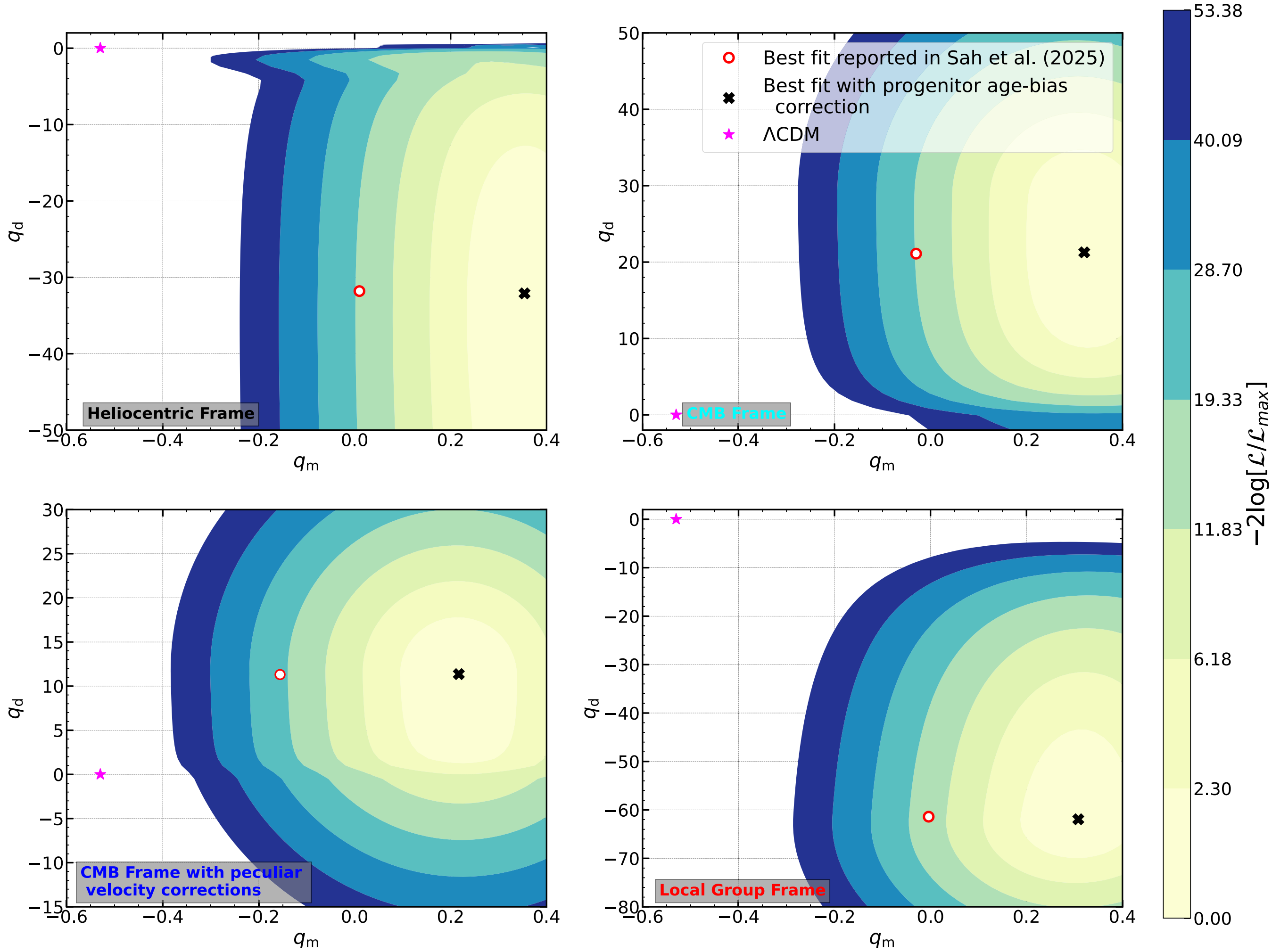

Figure 2. Contours at 1, 2, 3, 4, 5, 6, and 7σ for $q_{\rm m}$ and $\boldsymbol{q}_{\rm d}$ in the heliocentric, CMB, Hubble diagram (CMB frame with peculiar velocity corrections), and Local Group frames, for Pantheon + SNe Ia with a redshift cut: $0.00937 < z < 0.8$. The black cross is the best fit with the progenitor age correction, while the red circle is the best fit without such correction reported earlier (A. Sah et al. 2025). The magenta star denotes the expectation in the ΛCDM model (S. Navas et al. 2024).

earlier (A. Sah et al. 2025), the scale S on which it decays (5) corresponds to a redshift of $z \sim 0.01$ i.e. $30\,h^{-1}$ Mpc, as expected if it indeed arises due to the local bulk flow (C. G. Tsagas 2022). Fig. 2 shows the $(1-7)\sigma$ contours around the best-fit q_m–$\boldsymbol{q}_{\rm d}$ values listed in Table 1, constructed using Wilks' theorem.

In Fig. 3, we plot $q_{\rm m}$ moving the low-redshift supernovae in 50 SNe Ia per step. It is evident that the age bias correction to SNe Ia magnitudes removes any indication of accelerated expansion. This is consistent with the findings of J. Son et al. (2025) who too reported a currently decelerating expansion after accounting for progenitor age-dependent luminosity evolution.

We also perform a scale-*independent* fit to the dipole in q_0:

$$q_0 = q_{\rm m} + \boldsymbol{q}_{\rm d} \cdot \hat{n}, \tag{7}$$

employing 17 shells, each containing 100 SNe Ia (the highest redshift shell contains just 53), with the direction of the dipole

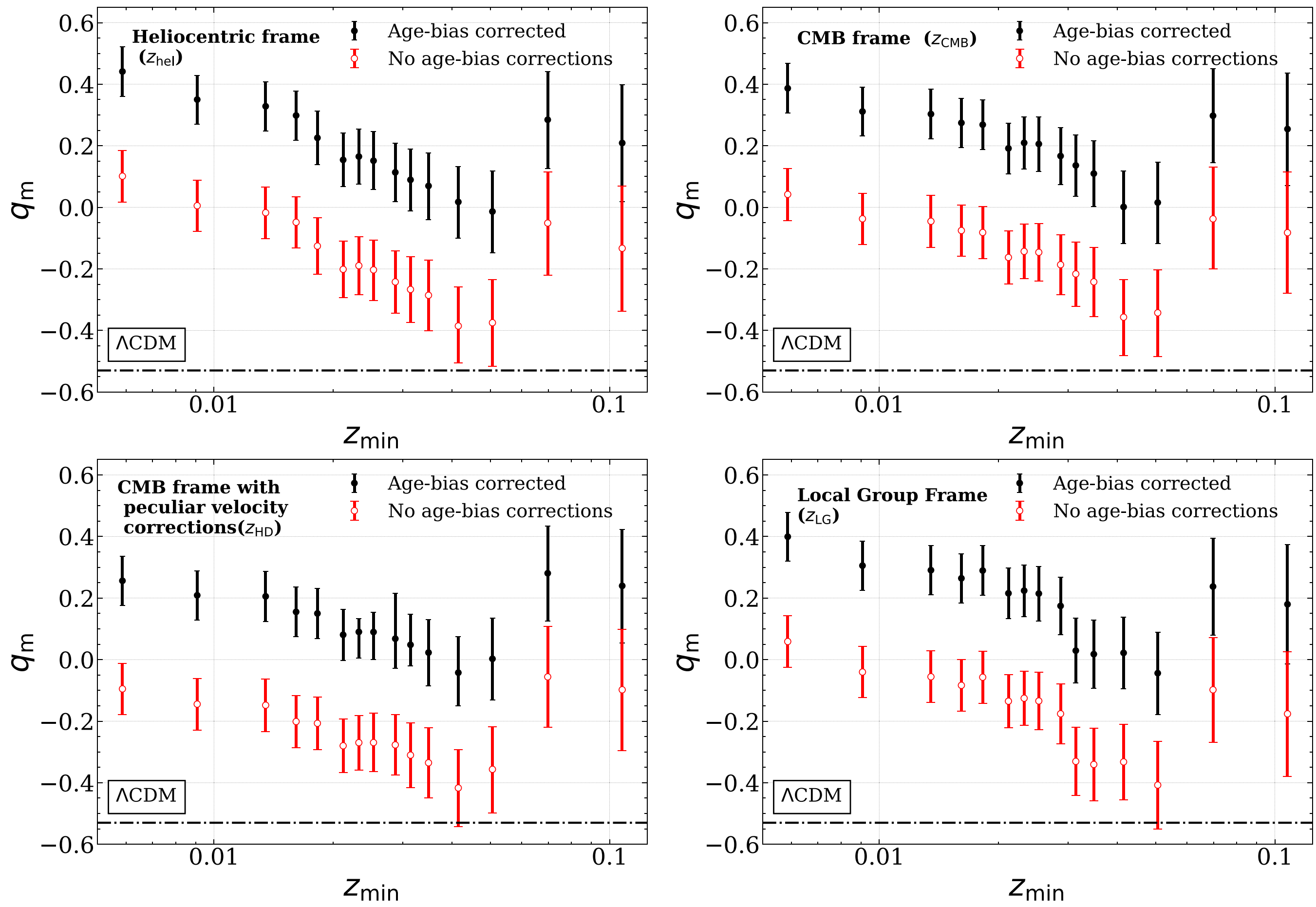

Figure 3. The monopole q_m of the deceleration parameter for Pantheon + SNe Ia with progressively higher cuts in redshift ($z > z_{min}$): in the heliocentric, CMB, Hubble diagram (CMB with peculiar velocity corrections) and Local Group frames. Error bars indicate 1σ uncertainties obtained using Wilk's theorem. Black and red points indicate the measurements with and without age-bias corrections. The dashed horizontal line indicates $q_m = -0.53$, the ΛCDM expectation.

fixed to the CMB dipole direction. In Fig. 4, we show the dipole amplitude versus the median redshift of each shell. It is seen that the dipole amplitude q_d remains unchanged, and its redshift dependence is consistent with that found earlier by A. Sah et al. (2025) without any progenitor age bias corrections.

As noted in Section 1, the age estimates for SNe Ia progenitors are cosmology dependent. To assess this, we repeat our analysis using the Δage values reported for two models by Y.-W. Lee et al. (2022): $\Omega_\Lambda = 0.73$, $\Omega_m = 0.27$, and $\Omega_\Lambda = 0$, $\Omega_m = 0.27$. The differences are small and do not affect the inferred dipole amplitude or its statistical significance.

We also repeat the analysis with a cut $z_{hel} < 0.5$, finding no qualitative change in our results. As noted earlier (A. Sah et al. 2025), this is also the case when the entire Pantheon + catalogue is included.

4 CONCLUSIONS

Although the evidence for an SNe Ia progenitor-age bias (Y. Kang et al. 2020; Y.-W. Lee et al. 2020, 2022) is still under discussion (P. Wiseman et al. 2026), it is notable that correcting for these leaves the local dipole q_d in the inferred deceleration parameter (A. Sah et al. 2025) unchanged within uncertainties. This correction rather turns the monopole component q_m positive. There is thus no evidence for *isotropic* accelerated expansion of the Universe, which can be ascribed to either a Cosmological Constant Λ or more general dark energy.[3]

[3]We note that in contrast to A. Sah et al. (2025), A. J. Zhou, S. Dodelson & D. Scolnic (2025) report 'no hint of anisotropy' in the Hubble expansion rate in their analysis of the Pantheon + catalogue. They employ the redshifts z_{HD} (CMB frame with source peculiar velocity corrections) using which the anisotropy in H_0 is minimized, as shown in fig. 3 of A. Sah et al. (2025) (and for q_0 in Fig. 2). They also integrate over redshift in each direction, thus diluting the significance of the anisotropy, which is more prominent at low redshift as seen in fig. 3 of A. Sah et al. (2025) (and for q_0 in Fig. 4). We have argued elsewhere (M. Rameez 2025) that such corrections – for our motion, as well as that of the SNe Ia host galaxies, with respect to the CMB frame – constitutes circular reasoning around an *assumed* background FLRW cosmology. Moreover the recently established $> 5\sigma$ mismatch between the dipole in the CMB and that in cosmologically distant quasars and radio sources (see N. Secrest et al. 2025; N. J. Secrest 2025) is a direct challenge to the FLRW assumption. Hence boosting to the CMB frame and applying peculiar velocity corrections to the sources (in order to emulate the Cosmic Rest Frame) is questionable.

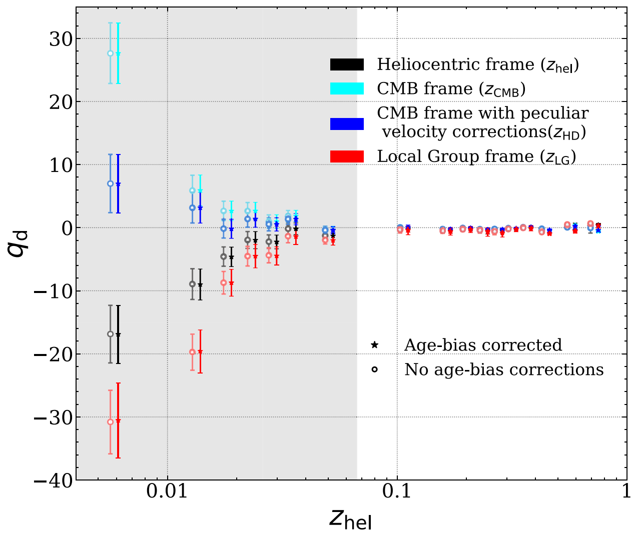

Figure 4. The local dipole $\boldsymbol{q}_{\rm d}$ in the deceleration parameter evaluated in 17 shells containing around 100 SNe Ia each, plotted against their median redshift. The parameterization is scale independent, i.e. $q_0 = q_{\rm m} + \boldsymbol{q}_{\rm d} \cdot \hat{n}$ within each shell. Open circles and stars denote results without and with progenitor age-dependent luminosity evolution corrections. Analyses are performed in the heliocentric, CMB, Hubble diagram (CMB with peculiar velocity corrections), and Local Group frames, with the direction fixed to the CMB dipole. Error bars are 1σ and age-corrected points are offset in z for clarity. The grey shaded region indicates $z < 0.0667$ i.e. distance $< 200h^{-1}$ Mpc.

ACKNOWLEDGEMENTS

We thank Young-Wook Lee for helpful communications. This work was carried out while SS was visiting the Tata Institute of Fundamental Research, supported by a VAIBHAV Fellowship awarded by the Department of Science & Technology, Government of India.

DATA AVAILABILITY

The code for reproducing our results is available at: https://github.com/Shin107/Anisotropy-in-Pantheon-Plus.

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APPENDIX A: ALTERNATIVE ANALYSIS (C1)

To enable fair comparison with D. Rubin & J. Heitlauf (2020), we also employ a second likelihood – called **C1** in A. Sah et al. (2025):

$$\mathcal{L}[\theta] = \int p[\hat{m}_{B\rm corr}|M] \times p[M|\theta]{\rm d}M. \tag{A1}$$

This uses SNe Ia magnitudes that have been corrected with sample- and redshift-*dependent* stretch (x_1) and colour (c) corrections, as advocated by D. Rubin & B. Hayden (2016) and D. Rubin & J. Heitlauf (2020). These make the monopole of the deceleration parameter more negative as noted earlier (D. Rubin & J. Heitlauf 2020; A. Sah et al. 2025).

The age-bias correction is now incorporated as

$$m_{B\rm corr} = m_{B\rm corr} - \Delta{\rm age}(z) \times 0.030 \text{ mag Gyr}^{-1}. \tag{A2}$$

The results with and without age bias corrections are shown in Table A1. The effect of progenitor age bias corrections is to shift $q_{\rm m}$ to more positive values that are consistent with zero, i.e. expansion at a constant rate.

Table A1. Best-fit dipole amplitude $\boldsymbol{q}_{\rm d}$, monopole $q_{\rm m}$, likelihood ratio $\Delta \ln \mathcal{L}(q_{\rm d} = 0)$, and statisticalsignificance α for analysis **C1**, shown before and after applying the progenitor age-bias correction. Results are presented in the heliocentric, CMB, Hubble diagram (CMB frame with peculiar velocity corrections), and Local Group frames. The dipole in q_0 remains unchanged by the correction while its monopole component becomes close to zero.

	Baseline (no age corrections)					With age bias corrections				
Frame	$\boldsymbol{q}_{\rm d}$	$q_{\rm m}$	S	$\Delta \ln \mathcal{L}$	α	$\boldsymbol{q}_{\rm d}$	$q_{\rm m}$	S	$\Delta \ln \mathcal{L}$	α
Hel	−6.27	−0.37	0.024	30.5	5.2	−6.27	−0.01	0.024	30.5	5.2
LG	−39.6	−0.41	0.012	119.7	> 7	−39.7	−0.05	0.012	119.3	> 7
CMB	20.5	−0.39	0.011	28.3	5.0	20.6	−0.03	0.011	27.9	4.9
HD	11.4	−0.49	0.01	6.3	2.0	11.4	−0.12	0.01	6.2	2.0

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