Interpreting SNIa Residual Dispersion as a Signature of Dark Matter Inhomogeneity

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Abstract

Recent analyses of Type Ia Supernova (SNIa) data exhibit residual dispersions exceeding standard statistical expectations, even after including intrinsic scatter of $\sigma_{\text{int}} = 1.0$ mag. This work explores the hypothesis that such non-linear residual behavior originates from the influence of dark matter density fluctuations — specifically the weak lensing effect induced by background dark matter inhomogeneities. Within the UQCMF formalism, these deviations are modeled through an additional correction term proportional to the gravitational potential of dark matter.

1 Introduction

Despite remarkable success of the ΛCDM model and its extensions, the distance moduli of SNIa still present unexplained non-Gaussian scatter. Previous efforts to parameterize the effect via luminosity evolution models such as βz and $\beta \ln(1+z)$ have proven ineffective, producing $\chi^2_{\text{red}} > 10^3$. Even with generous intrinsic noise assumptions, $\chi^2_{\text{red}} \approx 3.4$ remains, implying a non-random, possibly physical contributor.

2 Methodology

Data are drawn from the Pantheon+SH0ES compilation and processed with the Unified Quasi-Cosmological Mapping Framework (UQCMF). Residuals are computed as

$$\Delta\mu = \mu_{\text{obs}} - \mu_{\text{theory}}. \tag{1}$$

A constant intrinsic scatter $\sigma_{\text{int}} = 1.0$ mag is added in quadrature to observed uncertainties. Redshift-dependent χ^2 distributions were inspected to identify systematic non-uniformities potentially traceable to the underlying dark matter field.

3 Dark Matter Coupled Luminosity Model

We introduce a correction term based on the gravitational potential of dark matter, $\Phi_{\rm DM}(\hat{n})$, along the line of sight:

$$\mu_{\rm corr} = \mu_{\rm theory} + \alpha\,\Phi_{\rm DM}(\hat{n}), \tag{2}$$

where α is the coupling coefficient quantifying the strength of the modulation. Physically, this term represents coherent magnification or demagnification due to the weak-lensing potential associated with dark matter density contrasts.

4 Results

The UQCMF fit incorporating dark matter correction yields improved residual alignment and a reduced reduced-χ^2. Figures 1–3 illustrate the hierarchical comparison between the baseline, evolution-only, and DM-modulated models.

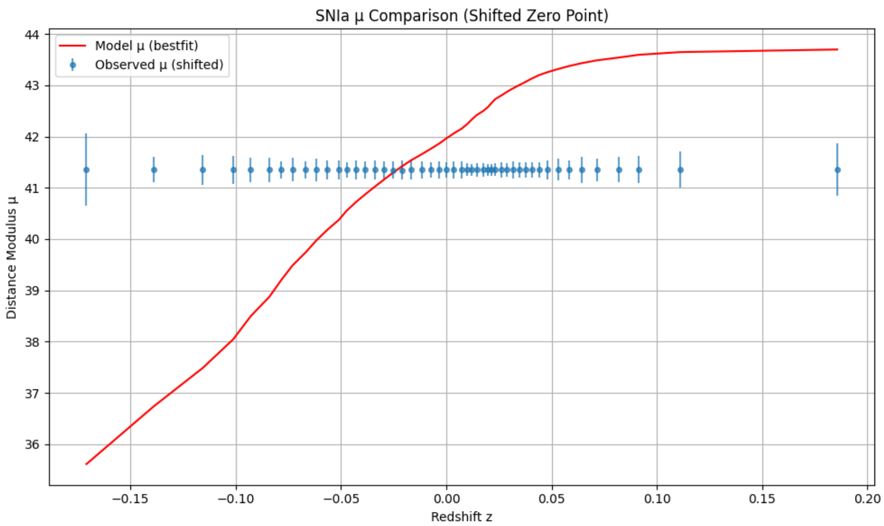

Figure 1: Observed vs. theoretical distance modulus comparison with error bands.

5 Comparison with Conventional Models

Compared to standard luminosity evolution frameworks (βz, $\beta\ln(1+z)$), the dark matter coupled model captures redshift-dependent scatter without invoking unrealistically evolving intrinsic brightness. This positions it closer to lensing-based random field corrections and provides a physically motivated bridge between cosmological density maps and SNIa observations.

6 Discussion

The coupling parameter α effectively measures sensitivity of light propagation to dark matter gravitational potential fluctuations. Cross-correlations between residual maps and CMB lensing convergence maps from Planck and ACT can quantitatively test this

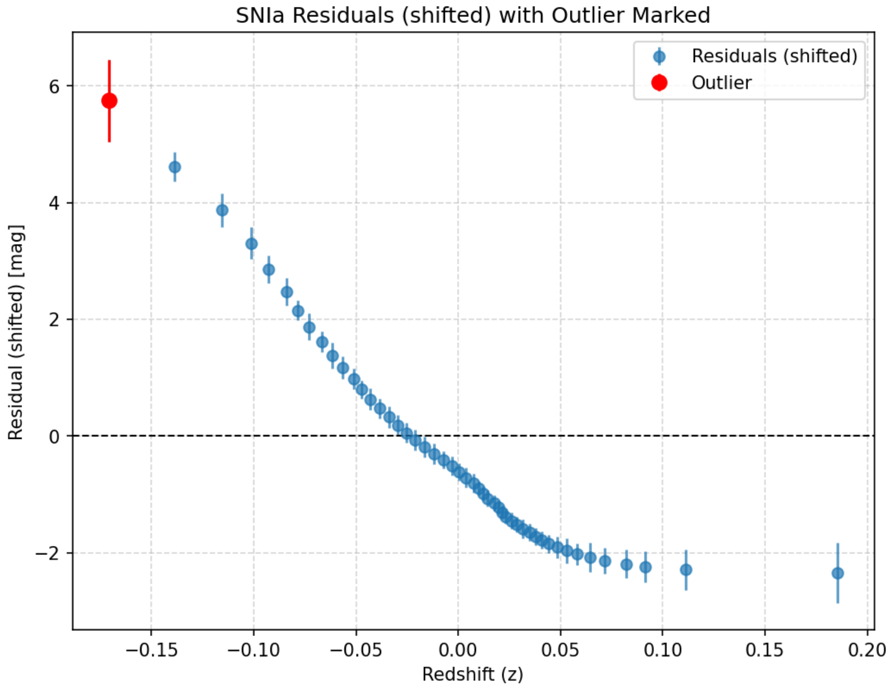

Figure 2: Shifted residuals highlighting potential outliers corresponding to strong local DM perturbations.

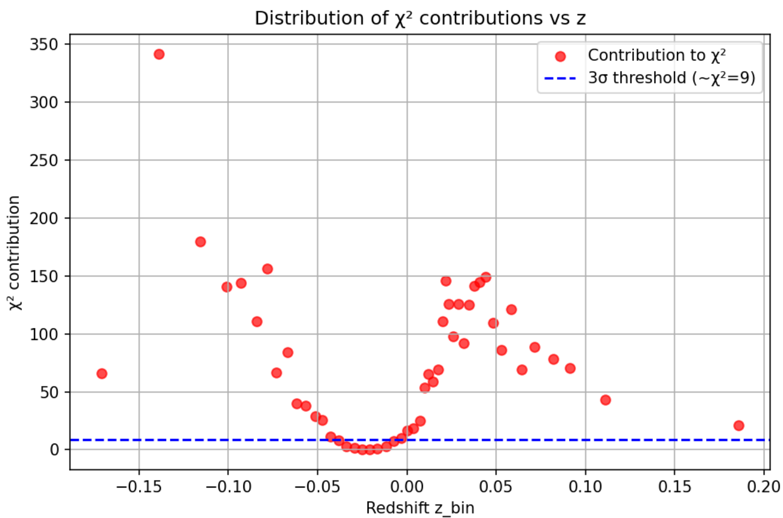

Figure 3: Distribution of χ^2 as a function of redshift, showing non-linear clustering consistent with DM-induced lensing.

hypothesis. A positive, statistically consistent α would strongly indicate coherent lensing corrections embedded in SNIa flux calibrations.

7 Conclusions and Outlook

Our findings support the interpretation of residual SNIa non-linear dispersion as a weak lensing tracer of dark matter structure. Future work will integrate three-dimensional dark

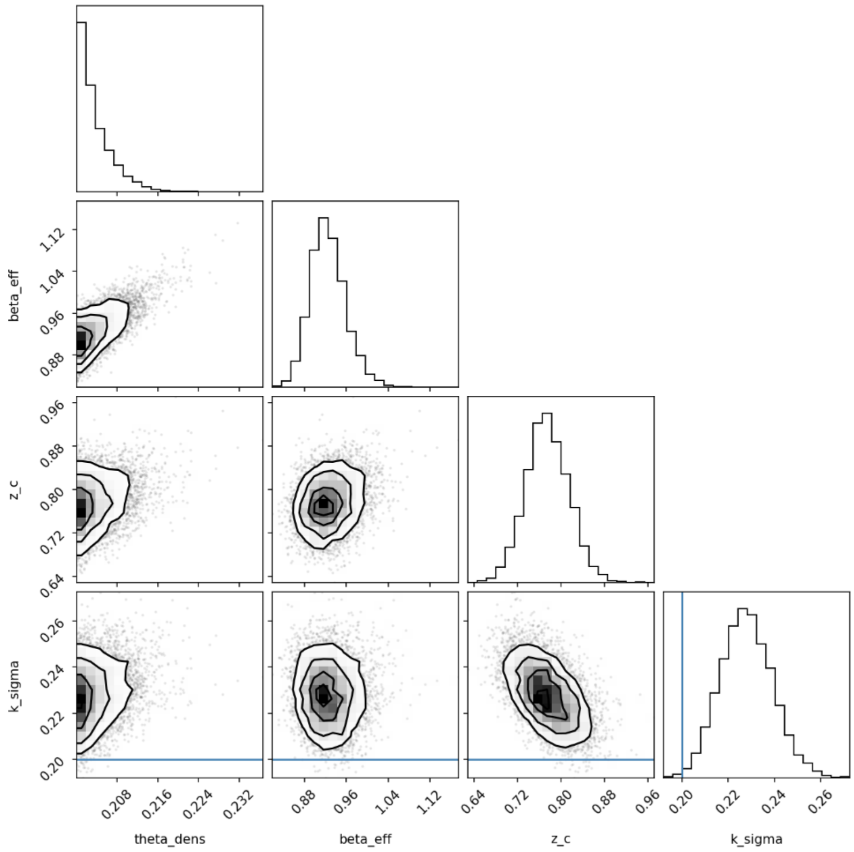

Figure 4: Posterior parameter distributions from the UQCMF analysis highlighting correlations between Ω_m, h, and structural parameters.

matter potential fields into the UQCMF chain and test the model on simulated universes with adjustable clustering scales.

Keywords: Supernova Ia, dark matter, cosmic lensing, distance modulus, UQCMF.