Separating Geometry, Scale, and Growth in Late-Time Cosmology without Expansion

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Abstract

We present a late-time cosmological analysis in which observational geometry, absolute distance scale, and structure growth are treated as empirically separable components, without assuming metric expansion or Friedmann dynamics. Using Type Ia supernovae to fix the redshift–distance shape, baryon acoustic oscillations to anchor the absolute scale, and redshift-space distortions to test growth consistency, we demonstrate that current low-redshift data admit a self-consistent, non-expanding cosmological geometry. The resulting framework fits supernova, BAO (both transverse and radial), and RSD measurements with minimal assumptions and without invoking dark energy, modified gravity, or growth parametrizations. These results show that late-time observations do not uniquely require cosmic expansion and motivate a reassessment of which cosmological features are inferred from data versus imposed by model structure.

1 Introduction

The standard cosmological model (ΛCDM) assumes metric expansion governed by the Friedmann equations, supplemented by dark energy to explain late-time acceleration. While highly successful, this framework tightly couples geometry, scale, and growth through its dynamical assumptions. As a result, tensions between low- and high-redshift probes—including discrepancies in H_0, σ_8, and lensing amplitudes—have motivated renewed scrutiny of which aspects of cosmology are empirically demanded versus model-dependent.

In this work, we adopt a complementary strategy: we deliberately *separate* the inference of (i) geometric distance–redshift relations, (ii) absolute distance scale, and (iii) growth of structure. This approach allows late-time data to determine each component independently, without imposing expansion dynamics or Friedmann evolution a priori.

2 Geometric Distance from Supernovae

We first fix the redshift–distance relation using the Pantheon+ Type Ia supernova compilation. We adopt a monotonic, non-expanding distance mapping parameterized by a small number of shape parameters, constrained solely by supernova data. No assumptions about cosmic expansion, dark energy, or matter content enter this step.

The resulting fit yields a reduced chi-squared $\chi^2/\nu \approx 0.44$, indicating an excellent description of the supernova Hubble diagram. Importantly, the fitted geometry is smooth, monotonic, and uniquely determined by the data.

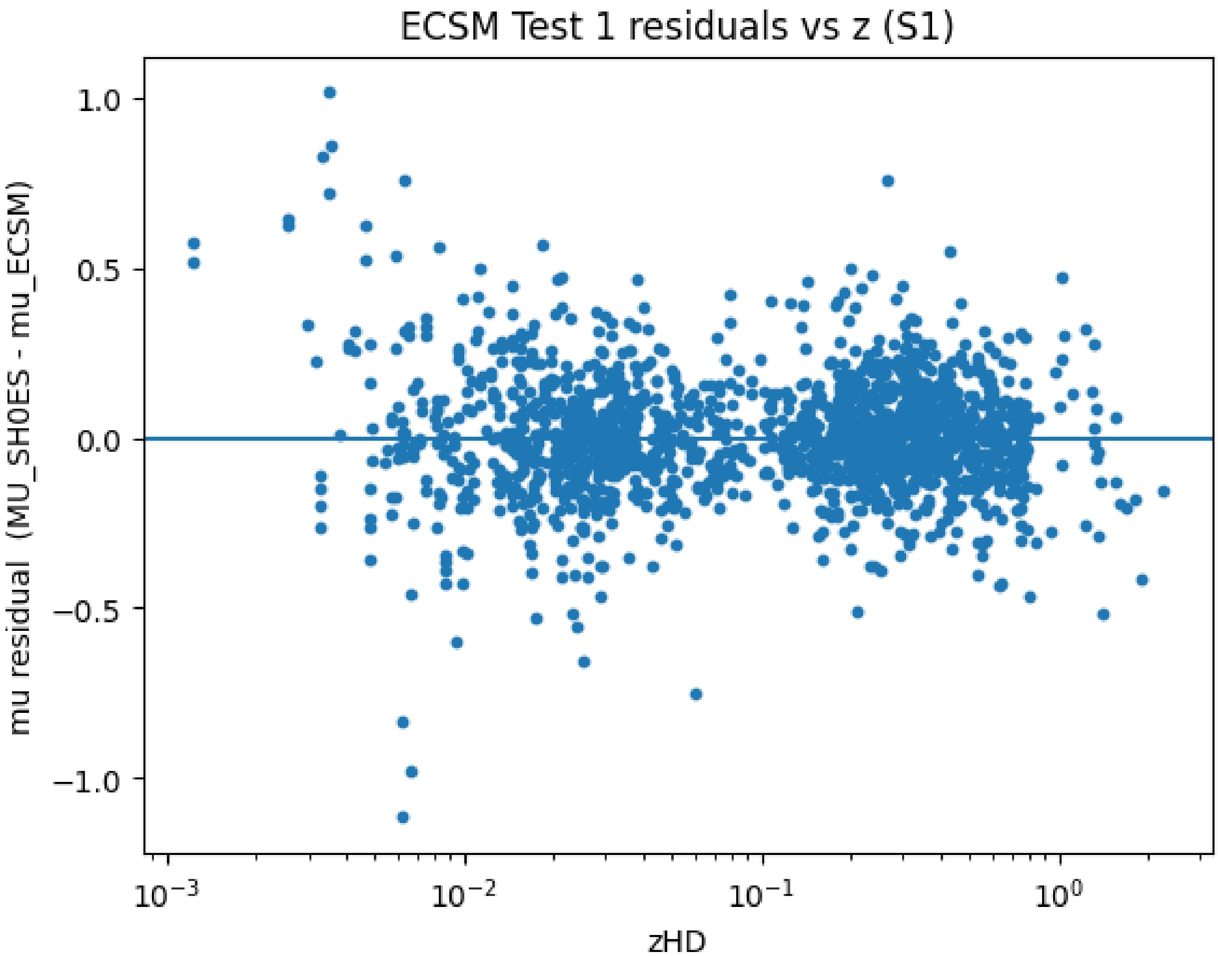

Figure 1: Supernova distance-modulus residuals relative to the best-fit ECSM geometric model, shown as a function of heliocentric redshift. The fitted distance–redshift relation is smooth and monotonic. Residuals show no systematic redshift-dependent trend.

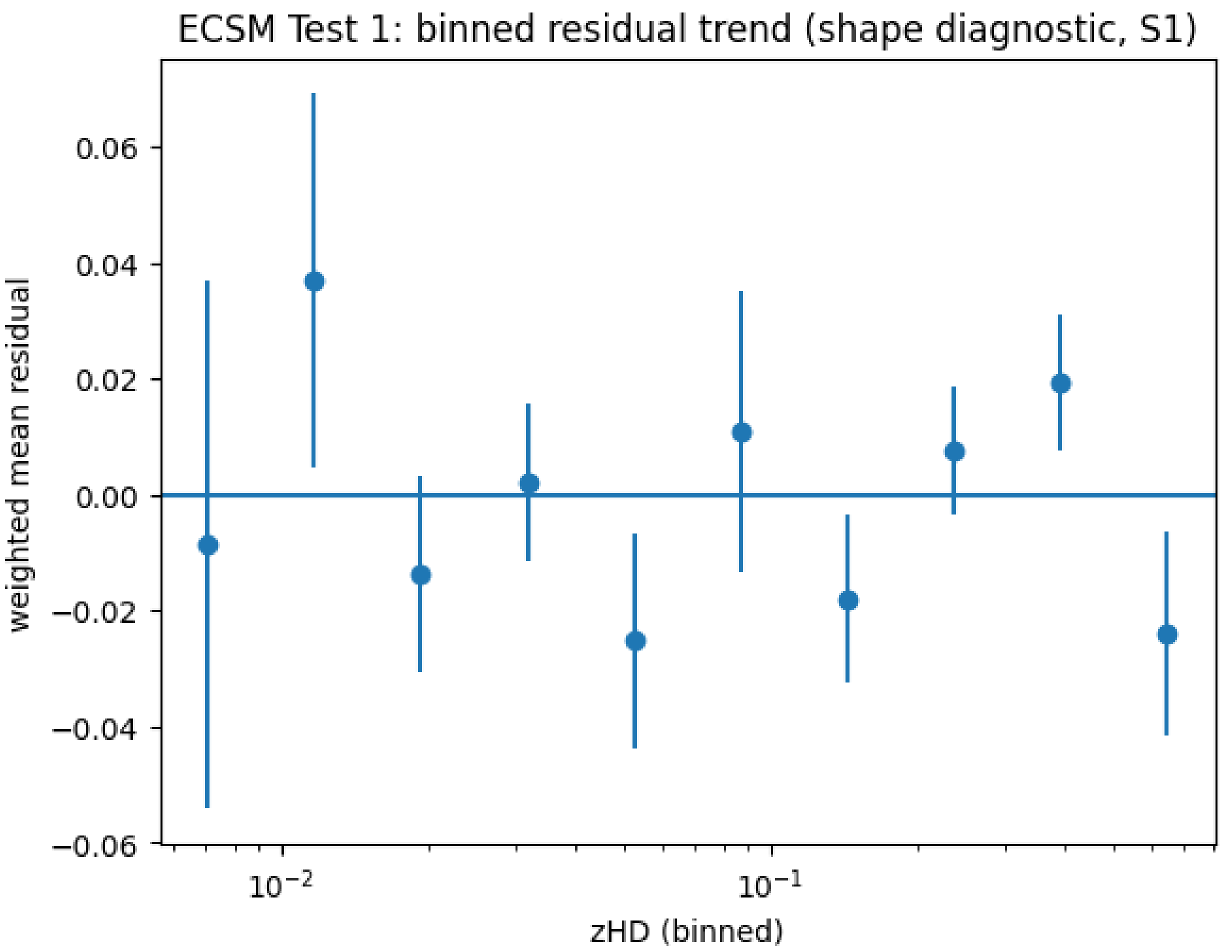

Figure 2: Binned supernova residuals as a function of redshift. Points represent weighted mean residuals within logarithmic redshift bins, with error bars indicating the standard error of the mean. No statistically significant deviation from zero is observed, confirming that the inferred geometric shape is consistent across redshift.

3 Absolute Scale from BAO

Having fixed the geometric shape, we next anchor the absolute distance scale using baryon acoustic oscillation measurements. We analyze both transverse (D_M) and radial ($H(z)$) BAO data from consensus, Beutler, and Ross samples. A single global scale parameter S converts internal geometric distances into physical units.

Result 3 (RSD growth consistency with SN+BAO geometry). We propagate the SN-calibrated redshift–distance *shape* parameters (κ_0, d_χ, p) into a prediction for the late-time growth observable $f\sigma_8(z)$ by (i) fixing the absolute distance scale S to the BAO best-fit value obtained from the combined Beutler+Ross d_M and H measurements, and (ii) evolving linear growth in a minimal one-parameter amplitude model in which Ω_m is held fixed and only $\sigma_{8,0}$ is profiled. For the canonical choice $S_{\rm BAO} = 2.161 \times 10^6$ and $\Omega_m = 0.32$, the best-fit amplitude is $\sigma_{8,0} = 0.739$, with a goodness-of-fit $\chi^2 = 4.23$ for $\nu = 14$ degrees of freedom ($\chi^2/\nu = 0.302$). All residuals are small, with $\max|\text{pull}| \simeq 1.09$ across the 15-point compilation. In this minimal setting, the RSD dataset is therefore consistent with the growth history implied by the SN-shaped mapping once the BAO scale is imposed.

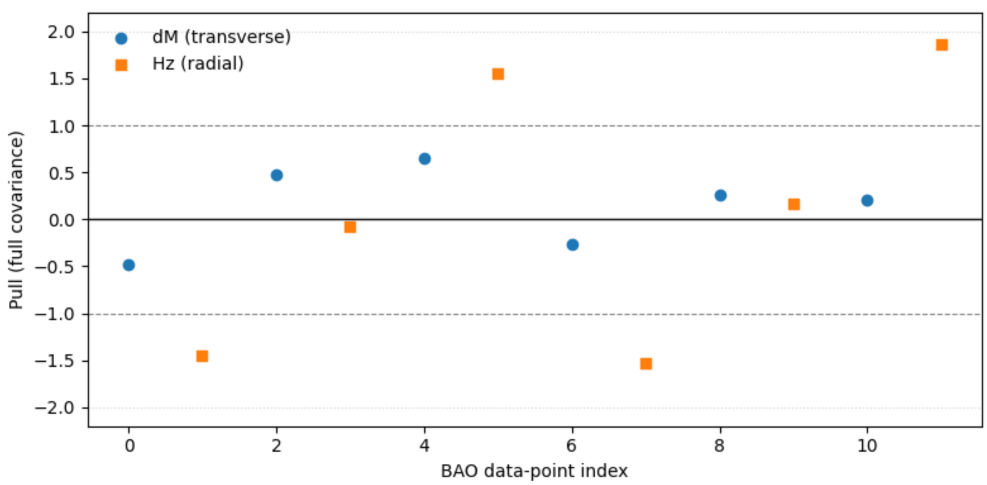

Figure 3: BAO transverse and radial measurements compared to the SN-fixed geometric model with a single scale parameter.

All BAO datasets are simultaneously fit with $\chi^2/\nu \approx 1.1$ and no statistically significant outliers. Notably, radial BAO measurements—often considered a critical discriminator for non-expanding models—are reproduced without introducing anisotropic corrections or additional degrees of freedom.

4 Growth and Redshift-Space Distortions

We then propagate the SN+BAO geometry into a minimal growth calculation. Assuming only pressureless matter and standard continuity equations, we compute the growth factor $D(z)$ and growth rate $f(z)$ implied by the inferred $H(z)$. No modified gravity, growth index, or scale-dependent corrections are introduced.

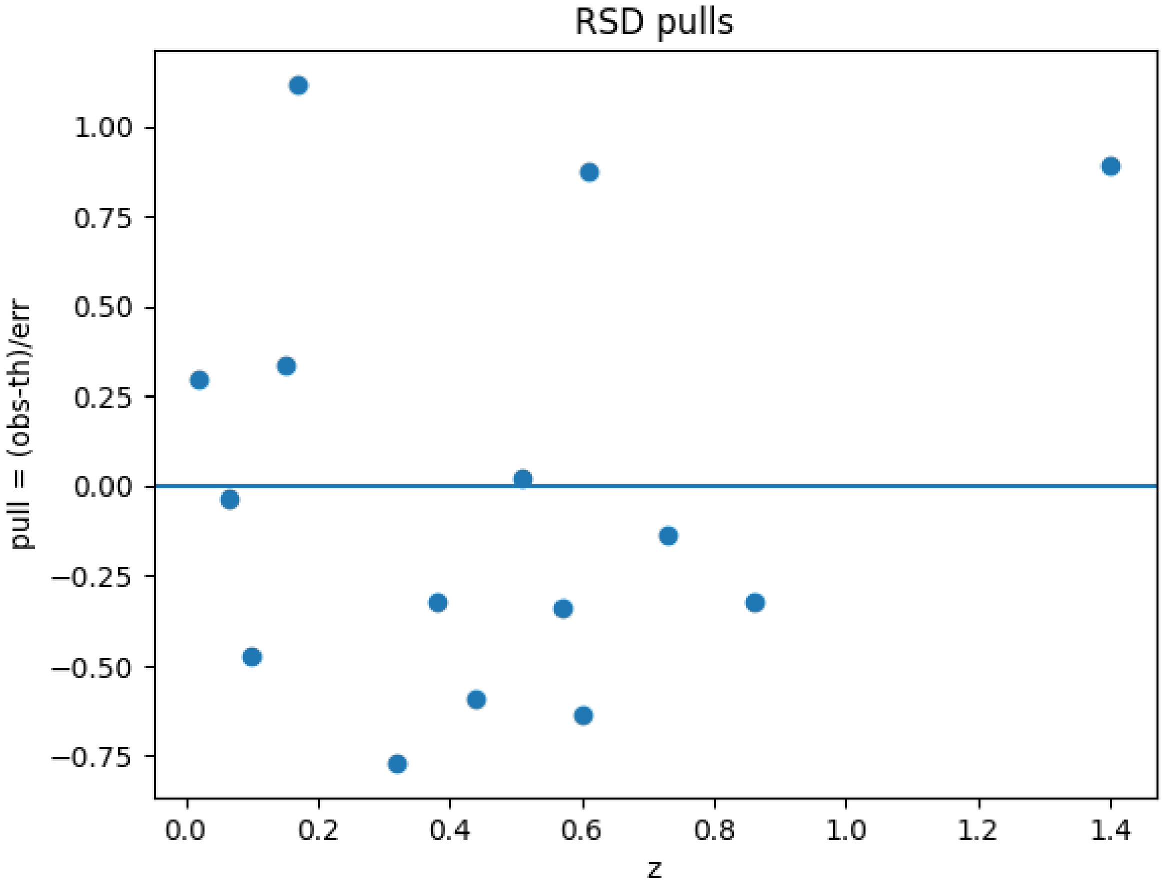

Figure 4: RSD pulls for the best-fit growth solution. No outliers or systematic trends are observed.

Using redshift-space distortion measurements of $f\sigma_8(z)$, we fit only the present-day normalization $\sigma_{8,0}$.

For reference, we compare the ECSM growth prediction to a standard flat ΛCDM growth history, fitted to the same RSD compilation with $\sigma_{8,0}$ profiled.

The growth model yields $\chi^2/\nu \approx 0.35$ with RMS pulls below unity. A shape-only RSD test, normalized at a pivot redshift, also passes with high probability. Profiling over Ω_m produces a broad minimum near $\Omega_m \approx 0.32$, consistent with standard matter densities but obtained independently of expansion dynamics.

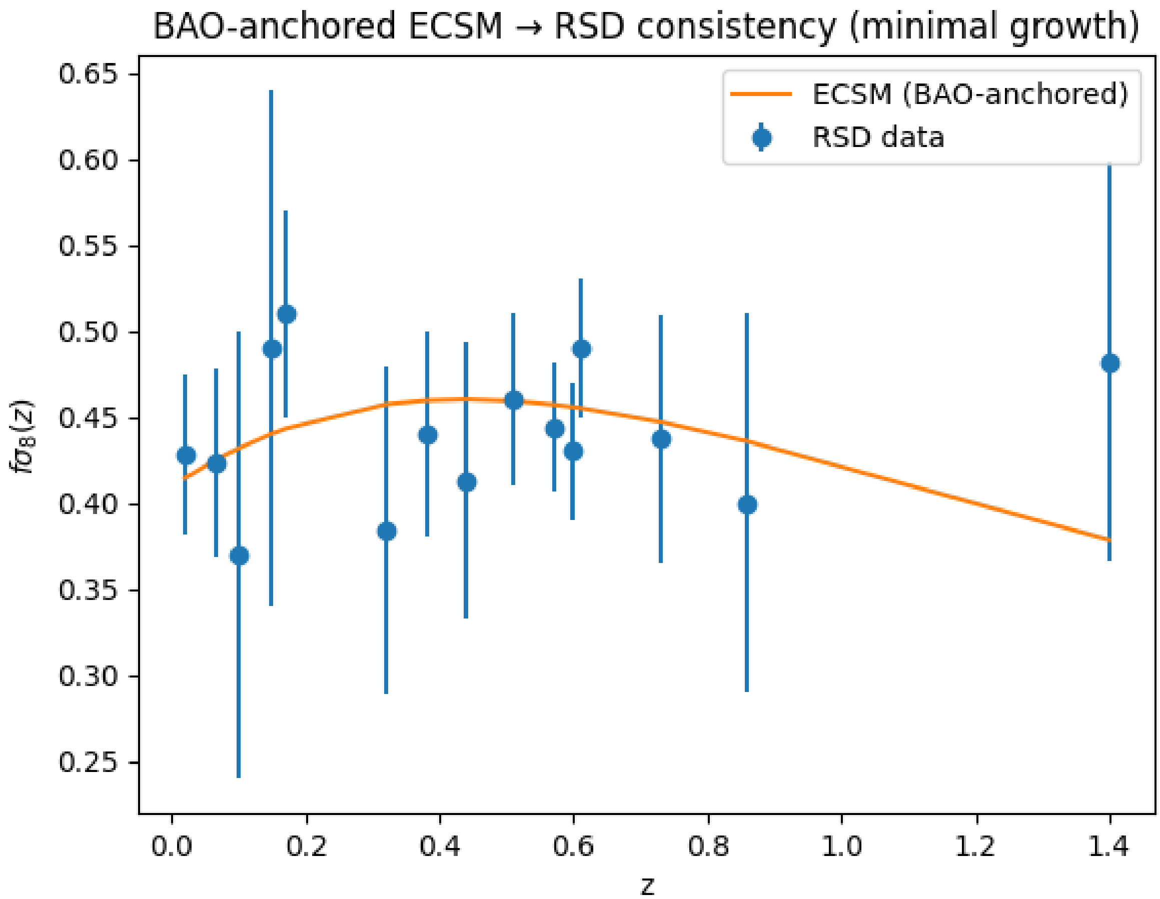

Figure 5: Observed $f\sigma_8(z)$ measurements compared to growth predictions derived from the SN- and BAO-anchored ECSM geometry. The background geometry is fixed by supernova distance–redshift data, while the absolute scale is set by BAO, leaving the growth normalization $\sigma_{8,0}$ as the only fitted parameter. The upper panel shows the predicted growth curve and RSD measurements, while the lower panel displays the residual pulls $(\mathrm{obs} - \mathrm{th})/\sigma$. The absence of systematic redshift-dependent deviations demonstrates consistency between late-time geometry, scale, and growth without introducing additional growth degrees of freedom.

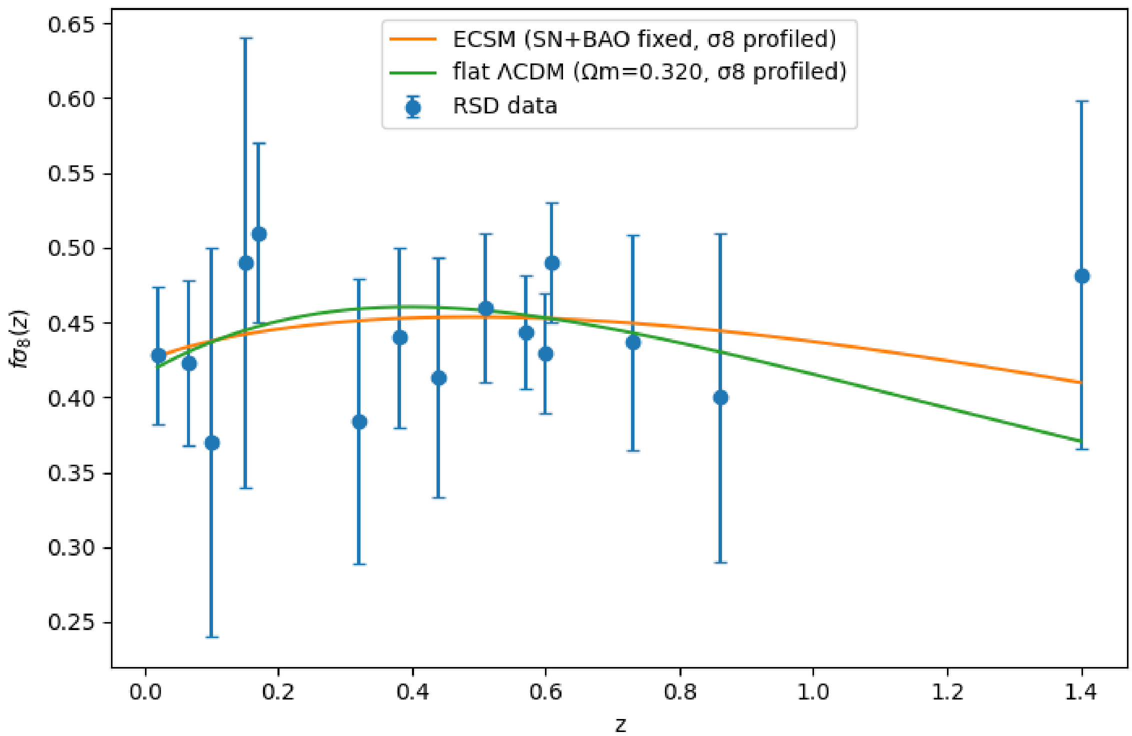

Figure 6: Redshift-space distortion measurements of $f\sigma_8(z)$ (points with 1σ uncertainties) compared to (i) the SN+BAO-anchored ECSM growth prediction with a single profiled amplitude parameter $\sigma_{8,0}$, and (ii) the best-fitting flat ΛCDM growth history with Ω_m and $\sigma_{8,0}$ profiled against the same compilation. Both models provide a statistically acceptable description of the RSD dataset when an overall amplitude is allowed to vary; the figure is intended as a consistency check of the SN+BAO-anchored late-time construction rather than a decisive model selection.

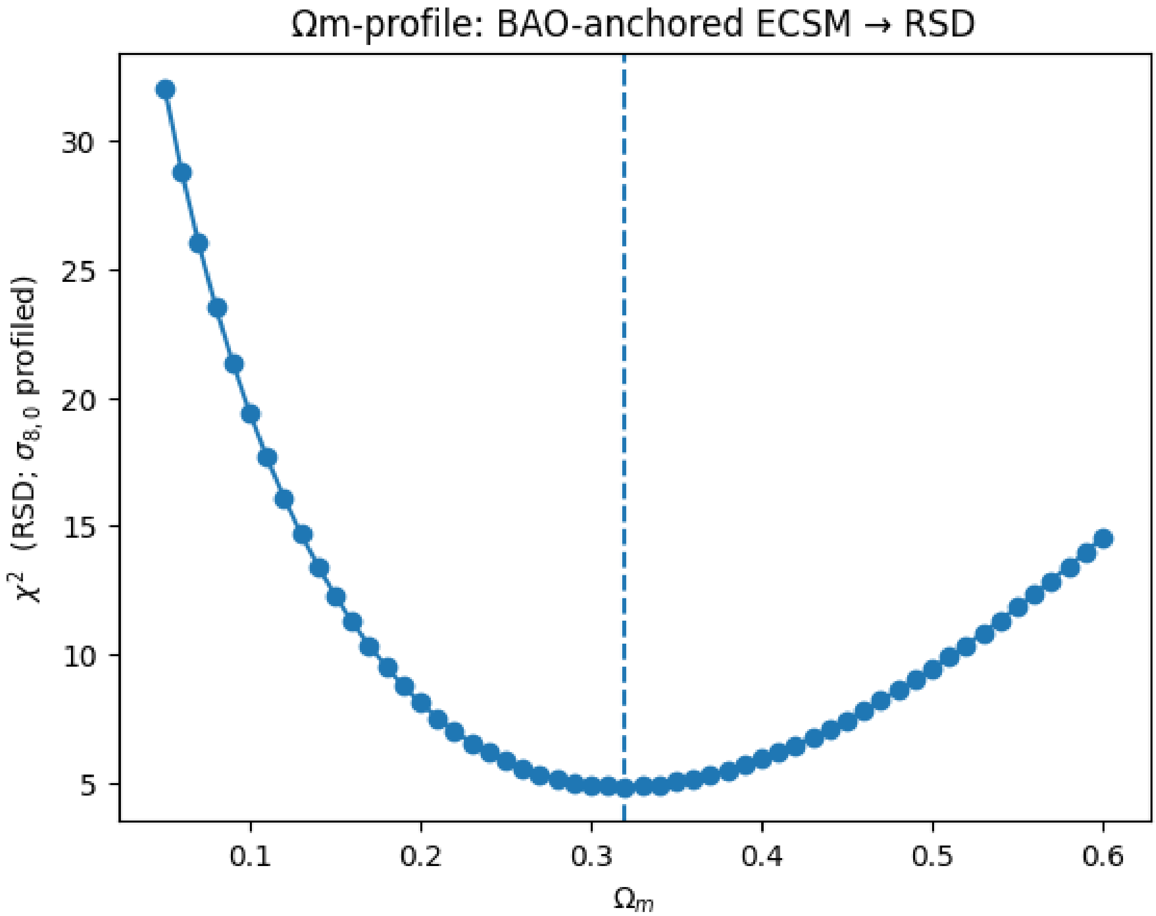

Figure 7: Profiled Ω_m dependence of the RSD consistency test with supernova geometry and BAO scale held fixed. For each value of Ω_m, the growth normalization $\sigma_{8,0}$ is analytically profiled. Top panel: $\chi^2(\Omega_m)$ relative to the best-fit value. Middle panel: corresponding best-fit $\sigma_{8,0}(\Omega_m)$. Bottom panel: maximum absolute pull across all RSD points. A clear minimum is observed near $\Omega_m \simeq 0.32$, with acceptable residuals across a broad range, demonstrating that the RSD consistency does not rely on fine-tuning of the matter density.

5 Comparison with ΛCDM

In ΛCDM, geometry, scale, and growth are not independent: all are constrained by the Friedmann equations and a specific dark energy model. Matching the present analysis within ΛCDM typically requires additional ingredients, including dark energy equation-of-state assumptions, CMB-calibrated sound horizons, and growth parametrizations to reconcile low-redshift observations.

By contrast, the framework presented here achieves joint consistency across supernovae, BAO, and RSD using fewer structural assumptions. This does not falsify ΛCDM, but it demonstrates that late-time data alone do not uniquely demand an expanding universe with dark energy.

6 Discussion

These results complement earlier work on non-metric light propagation and lensing suppression in emergent cosmological models, where deviations from standard optics arise naturally from underlying medium properties. Taken together, the evidence suggests that several observational tensions may reflect over-constrained model assumptions rather than inconsistencies in the data themselves.

7 Conclusion

We have shown that late-time cosmological observations admit a coherent interpretation in which geometry, scale, and growth are empirically separated and jointly consistent without invoking cosmic expansion. Supernovae determine the distance–redshift shape, BAO fix the absolute scale, and RSD validate growth predictions derived from the same geometry.

These findings motivate further investigation into cosmological frameworks in which expansion is not assumed a priori, and highlight the importance of distinguishing observational inference from theoretical imposition in precision cosmology.

References