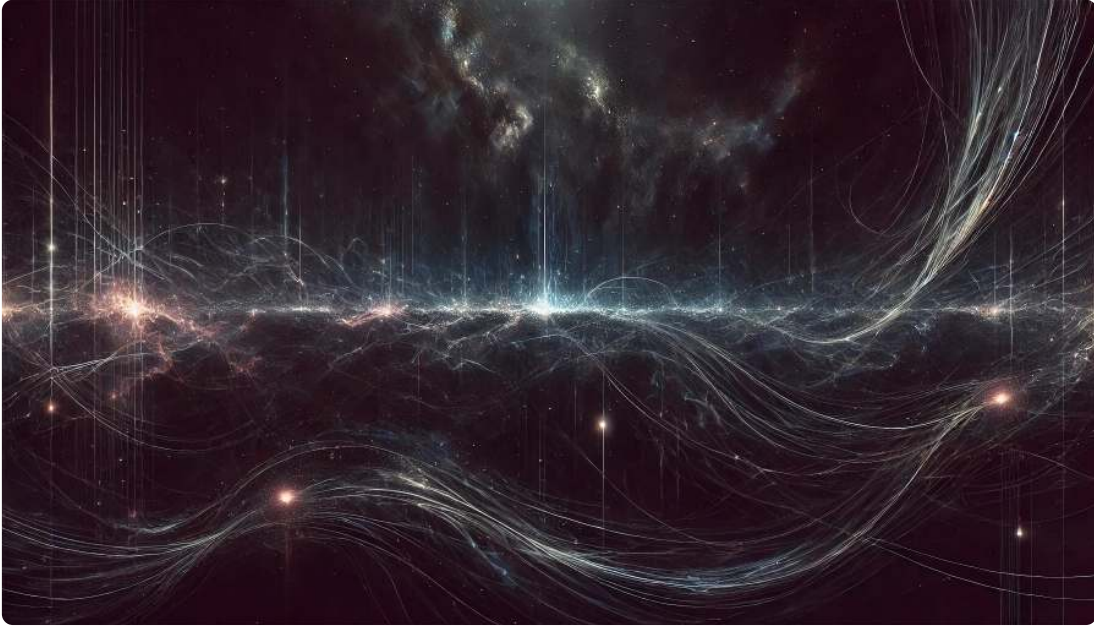




Temporal Equivalence Principle: A Unified Resolution to the JWST High-Redshift Anomalies

Matthew Lukin Smawfield

Version: v0.8 (Kos)

First published: 13 March 2026 · Last updated: 17 October 2026

DOI: 10.5281/zenodo.19000827

Code Availability: github.com/matthewsmawfield/TEP-JWST

Abstract

JWST has revealed a pattern of high-redshift anomalies—such as extreme star formation efficiencies and unexpected stellar-to-dynamical mass ratios—that appear preferentially in deep gravitational potentials. This work tests whether these tensions can be resolved by relaxing the assumption of universal cosmic time. Under the Temporal Equivalence Principle (TEP)—a continuously screened two-metric framework—proper time depends on the local environment in unscreened halos. Using a prespecified magnitude-sector benchmark ($\kappa_{\text{gal}} = 0.960 \times 10^6 \text{ mag}$, Paper 11 — where distinct empirical Cepheid-channel recoveries bracket the benchmark with a midpoint of $0.943 \times 10^6 \text{ mag}$, within 1.8%, and Step 62 derives $|\kappa_{P^2}^{\text{pred}}(\lambda_0 = 1)| = 1.196 \times 10^6 \text{ mag}$ from the Cepheid envelope density ratio $\rho_T / \langle \rho \rangle (10 \text{ d}) = 8.45 \times 10^5$ at the unit-transport benchmark $\lambda_0 = 1$ with bare coupling $|\beta_A| = 1$ fixed by Paper 0, matching the direct SH0ES P^2 -carrier fit $(1.191 \pm 0.480) \times 10^6 \text{ mag}$ to 0.5% ($\lambda_0 = 0.995 \pm 0.401$)) applied without any JWST-specific parameter refitting, this framework quantitatively accounts for the leading photometric and kinematic excesses.

To address mass-proxy circularity, the framework is tested against kinematic data using the JWST-SUSPENSE survey ($N = 15$) and a broader velocity dispersion (σ)-based expansion ($N = 75$, Step 171). In the SUSPENSE sample, the dynamical mass-to-light inference response (R_{ML}) retains residual spectral-age information after controlling for stellar mass and redshift ($\rho = +0.556$, $p = 0.032$), whereas stellar mass loses its predictive power once R_{ML} is controlled ($\rho = +0.031$, $p = 0.91$). In the broader $N = 75$ velocity-dispersion expansion, evaluating the purely kinematic predictor $R_{\text{ML},\sigma}^{\text{dir}}$ under the Virial-exact depth map $\Psi \propto \sigma^2$ (with zero dependence on SED-fitted M_* or size R_e) yields a strong circularity-free partial correlation controlling for redshift: $\rho(R_{\text{ML},\sigma}^{\text{dir}}, M_{*,\text{obs}} | z) = +0.463$ ($p = 2.84 \times 10^{-5}$, $N = 75$), strengthening to $\rho = +0.608$ ($p = 8.43 \times 10^{-7}$) on the $N = 55$ exact- M_{dyn} subsample and $\rho = +0.575$ ($p = 0.0080$) on the $N = 20$ stellar absorption-line subsample. Under the Virial-exact depth map $\Psi \propto \sigma^2$, all five physical subsamples (pooled $N = 75$, absorption $N = 20$, emission $N = 55$, $z \geq 4$ $N = 56$, and SUSPENSE $N = 15$) agree in residual- z sign (5/5), and holding the local $z = 0$ reference at $z_{\text{ref}} = 0$ ($\Psi(\sigma)\sqrt{1+z} - \Psi_{\text{ref}}$) yields sign agreement across all three $N \geq 15$ individual surveys plus the absorption tracer while attenuating the absorption-line residual- z trend by 86.5% ($+0.252 \rightarrow +0.034$).

In large-sample photometry ($N = 1,254$ across three surveys), dust emergence and apparent evolutionary advance align strongly with potential depth ($\rho = +0.635$ at $z > 8$), organizing more cleanly along an effective-time coordinate than raw cosmic time. A secondary photometric test confirms that R_{ML} carries sSFR information beyond mass and redshift (

$\rho(R_{\text{ML}}, \text{sSFR} | M_*, z) = -0.62, p = 8.2 \times 10^{-29}$), with the negative sign predicted by the TEP measurement equations ($\text{sSFR}_{\text{obs}} \propto R_{\text{ML}}^{m-n_{\text{SPS}}}$ with $m < n_{\text{SPS}}$). Furthermore, a nested Bayesian model comparison of the SED observables—utilizing a joint covariance likelihood that accounts for correlated outputs (Steps 176, 179)—shows that the nested augmented model (raw mass + z + $\log R_{\text{ML}}$, 17 parameters, $\ln Z = -1243.8$) is the single highest-evidence model in the canonical ensemble, beating the unconditioned raw mass+ z baseline ($\ln Z = -1248.2$) by $\Delta \ln Z = +4.45 \pm 1.09$ (BF = 85.4 : 1, $> 4\sigma$ positive evidence for adding $\log R_{\text{ML}}$ despite the 4-parameter Occam penalty), while the direction-isolation diagnostic confirms that the R_{ML} -aligned component carries $\Delta \ln Z = +55.9 \pm 1.0$ ($\ln \text{BF} = +41.5$ for 9-parameter TEP-only over orthogonalized standard, and $\ln \text{BF} = +9.07 \pm 0.93$, BF = 8,720 : 1 in symmetric conventional residual space). Finally, the lensing and environmental-channel audit (Step 182) demonstrates that explicitly de-magnifying stellar masses by the UNCOVER DR4 lens magnification μ_{ml} sharpens the $z > 8$ dust- R_{ML} correlation from $\rho = +0.646$ to $\rho = +0.656$ ($p = 1.30 \times 10^{-32}$, $N = 254$), that the correlation holds in the unmagnified $\mu_{\text{ml}} \leq 1.05$ outer field at $\rho = +0.603$ ($p = 1.29 \times 10^{-15}$, $N = 144$) and strengthens to $\rho = +0.667$ ($p = 1.09 \times 10^{-17}$, $N = 127$) across sightlines traversing the inner half of the foreground Abell 2744 cluster well ($z = 0.308$), and that the foreground cluster sightline coordinates ($d_{\text{A}2744}, \log_{10} \mu_{\text{ml}}$) add $\Delta \ln Z = +26.2$ on the 3 physical observables (+34.2 on all 4), consistent with intermediate-path temporal transport along the cluster line of sight (Paper 19), positioning TEP as a coherent and falsifiable organizing framework for high-redshift galaxy evolution.

Keywords: Cosmology: early universe – Galaxies: high-redshift – Galaxies: evolution – Gravitation – Scalar-tensor theories – Infrared: galaxies

1. Introduction

1.1 Observational Tensions

JWST has revealed a coherent pattern of anomalies at $z > 5$ that strains the standard framework for inferring stellar properties from photometry. The most visible example is the class of spectroscopically confirmed "Red Monsters" (Xiao et al. 2024), whose stellar masses ($M_* \gtrsim 10^{11} M_{\odot}$) imply baryon-to-star conversion efficiencies of ~ 0.50 , more than double the ~ 0.20 theoretical maximum imposed by feedback in Λ CDM halos. Within the Boylan-Kolchin (2023) framework, the discrepancy reaches 11σ . This tension is not isolated. The UNCOVER UV luminosity function at $z > 9$ implies a star formation rate density exceeding the halo accretion limit by factors of 4–10 (Chemerynska et al. 2024).

A second tension emerges in JWST NIRSpec kinematics: at $z \gtrsim 3\text{--}4$, massive quiescent galaxies show $M_*/M_{\text{dyn}} \gtrsim 1$ (Esdaile et al. 2021; Tanaka et al. 2019), while at $z > 5.5$ low-mass star-forming systems show the opposite extreme, with dynamical masses exceeding stellar masses by up to a factor 40 (de Graaff et al. 2024a). The population of "Little Red Dots" (LRDs) is discussed separately as a compact-core stress test: these red broad-line AGN can host black holes that appear overmassive relative to their galaxies, but the corrected TEP calculation is too sensitive to stellar-mass calibration to count as a primary empirical line.

Across these cases, the common structure is the same: stellar masses and ages inferred from photometry appear systematically too large, too early, in precisely the environments with the deepest gravitational potentials.

1.2 Challenging Isochrony with TEP

Conventional photometric inference assumes that one environment-independent mapping connects observed spectra and fluxes to stellar age, mass, and star formation rate. TEP tests whether temporal transport and environmental field structure introduce a channel-dependent correction to that mapping. The physical conformal clock factor is not allowed to reverse sign: a deeper unscreened well has $\Delta \ln A < 0$. The quantity tested here is instead the observable mass-to-light inference response R_{ML} .

Observer-age convention. Throughout this paper, $t_{\text{cosmic}}(z)$ denotes the age assigned to redshift z by the standard FLRW observational reconstruction. It is an observer-frame coordinate used by conventional stellar-population inference, not the fundamental physical age of the universe in TEP. The canonical TEP cosmology is eternal in the gravitational sector: observational depth diverges ($z \rightarrow \infty$), while the accumulated matter-frame clock history is finite on the closed-static benchmark branch of Paper 0 §8 — an existence result, not the physical realization, which is the inhomogeneous non-compact landscape whose constraint-slice existence is demonstrated in Paper 0 (Appendix E, R8) but whose matter-frame clock history is not yet computed. The inference-channel response $R_{\text{ML}} > 1$ at high redshift arises because the FLRW reconstruction assigns less elapsed matter-frame time at fixed high z than the saturating- H benchmark branch — the elapsed-time ratio used here is therefore a benchmark value, conditional on the inhomogeneous eternal construction (Paper 0, issue class 0-1) — not because local clocks accelerate; local clocks slow ($\Delta \ln A < 0$) while the coordinate background is eternal. That background term is uniform at fixed z ; the kernel's ordering by potential depth enters through the endpoint clock-calibration term $1 + z = A_0/A_{\text{em}}$ decomposed in §2.3.2, whose response scale is grounded in the stellar-envelope density ratio $\rho_T/\langle \rho \rangle \sim 10^6$ derived in Paper 11, Step 62.

The Temporal Equivalence Principle formalises this test within a continuously screened two-metric Temporal Topology framework. The numerical pipeline orders environments using the positive depth $\Psi \equiv |\Phi|/c^2$ and evaluates the observer-side response

$$R_{\text{ML}} = \exp \left[K_{\text{gal}} (\Psi - \Psi_{\text{ref}}) \sqrt{1+z} \right]. \quad (1)$$

Quantity convention. The signed potential obeys $\Phi < 0$, the depth proxy obeys $\Psi > 0$, and the physical conformal offset obeys $\Delta \ln A < 0$ in a deeper well. $R_{\text{ML}} > 0$ is a fitted inference-channel response. It is not $A(\phi)$ and does not imply faster local clocks.

The JWST response-prior test adopts the prespecified canonical magnitude-sector benchmark $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5$ mag from Paper 11, where distinct empirical Cepheid-channel analyses recover $\kappa_{\text{equiv}}^{39} = (1.220 \pm 0.531) \times 10^6$ mag under restricted closure and $\kappa_{\text{Cep}}^{44} = (0.665 \pm 0.362) \times 10^6$ mag in the multi-block joint analysis — bracketing the canonical benchmark with a midpoint of 0.943×10^6 mag (1.8% from 0.96×10^6 mag) — while Paper 11 Step 62 derives $|\kappa_{p_2}^{\text{pred}}(\lambda_0 = 1)| = (|b_W|/\ln 10) \rho_T / \langle \rho \rangle (10 \text{ d}) = 1.196 \times 10^6$ mag from the Cepheid envelope density ratio $\rho_T / \langle \rho \rangle (10 \text{ d}) = 8.45 \times 10^5$ at the unit-transport benchmark $\lambda_0 = 1$ (with bare coupling $|\beta_A| = 1$ fixed by Paper 0), matching the SHOES fit $(1.191 \pm 0.480) \times 10^6$ mag to 0.5% ($\lambda_0 = 0.995 \pm 0.401$). The canonical value is adopted here as the prespecified fixed prior rather than as a JWST-fitted parameter. Its transfer to the galaxy response is fixed once, $K_{\text{gal}} = \kappa_{\text{gal}} \ln 10 / (2.5 n_{\text{ref}}) = 1.263 \times 10^6$ with $n_{\text{ref}} = 0.7$, and is used continuously at every redshift without a JWST-specific refit. The distinct stellar-population exponent n_{SPS} enters only after R_{ML} has been evaluated, through the mass and SFE corrections $R_{\text{ML}}^{n_{\text{SPS}}}$; it cannot renormalize the response kernel. The high-redshift observables are then examined for internal consistency of the response scale. These internal recoveries are treated as self-consistency checks rather than as replacement calibrations. The response coefficient κ_{gal} and the screening scale $\rho_T \approx 20 \text{ g/cm}^3$ are inherited from prior papers (Papers 11 and 6 respectively); the structural choices in the R_{ML} formula — the reference halo mass $\log M_{h,\text{ref}} = 12.0$, exponential functional form, and $\sqrt{1+z}$ coupling scaling — are fixed for this analysis and none were adjusted to improve JWST fits.

1.3 Reader's Guide to the Evidence

The analysis proceeds in three stages: a prespecified benchmark prediction (§3.1), the main multi-survey evidence (§3.2–3.10), and a compact-core stress test (§4.4). The five evidence lines are:

- **L1. Dust- R_{ML} emergence (Primary):** At $z > 8$, massive galaxies are anomalously dusty while low-mass galaxies remain dust-poor ($\rho = +0.635$).
- **L2. Inside-out core screening (Resolved Structural):** Central screening structures, confirmed by JADES DR5 Gini morphology ($\rho_{\text{part}} = +0.191$, $p = 1.6 \times 10^{-4}$) and JADES resolved radial colour gradients (Γ_{rad} partial $\rho = -0.179$, $p = 0.0028$; Steiger $Z = 3.02$, $p = 0.0025$; residualized bluer-core sign test OR = 2.54, Fisher $p = 0.0054$).
- **L3. R_{ML} -sSFR partial correlation (Secondary):** The TEP measurement equations predict $\rho(R_{\text{ML}}, \text{sSFR}) < 0$ (since $\text{sSFR}_{\text{obs}} \propto R_{\text{ML}}^{m-n_{\text{SPS}}}$ with $m < n_{\text{SPS}}$); the partial correlation $\rho(R_{\text{ML}}, \text{sSFR} \mid M_*, z) = -0.62$ at $z > 8$ confirms this sign.
- **L4. Dynamical mass comparison (Derived):** A kinematic comparison showing the TEP correction reconciles anomalous $M_*/M_{\text{dyn}} > 1$ observations.
- **L5. Direct kinematic test (Direct):** The JWST-SUSPENSE comparison evaluates R_{ML} from M_{dyn} against photometric M_* in predicting spectral age.

L1 is the primary photometric line; L3 is a secondary partial-correlation line; L2 is ancillary; L4 is derived; L5 is a direct test. This classification is stated once here and not repeated for each result.

1.4 Prior Cross-Domain Evidence for TEP

The JWST analysis presented here is not the first test of the TEP framework. Paper 11 defines the canonical magnitude-sector benchmark κ_{gal} , with distinct empirical Cepheid-channel fits providing consistency checks; this work transfers the benchmark to the galaxy sector through K_{gal} , and the present high-redshift study asks whether JWST observables recover an anchor-consistent response across multiple domains spanning the full local-to-high-redshift observational baseline conventionally mapped to ~ 13.5 Gyr of FLRW lookback time. *Important caveat:* all prior constraints derive from a single theoretical programme; this is not independent verification; the TEP series has not yet undergone independent replication or peer review in a refereed journal. Readers should weigh the cross-domain consistency with this single-source limitation in mind. The three domains most directly used in this work are:

- **Hubble Tension:** Paper 11 reconstructs the complete 37-host R22 calibrator sample using an inner-potential coordinate σ_* compiled from documented stellar-absorption and H I linewidth measurements. The host-level environmental response is detected at $\Gamma_X = (3.846 \pm 1.653) \times 10^7 \text{ km/s/Mpc}$ (2.33σ) with 37/37 leave-one-host-out sign stability. Mapping the generative expansion relation to the TEP cosmic reference gives $H_{\text{cosmic}} \simeq 65.2\text{--}65.5 \text{ km/s/Mpc}$ across configurations, while the unified host-level reconstruction yields $H_0 = 67.83 \pm 1.56 \text{ km/s/Mpc}$ — in concordance with Planck CMB cosmology ($67.4 \pm 0.5 \text{ km/s/Mpc}$) at 0.26σ statistical (0.36σ bootstrap); the prespecified ladder-matrix projection retains an identifiability-limited residual at $H_0 = 70.46 \pm 0.97 \text{ km/s/Mpc}$ (2.80σ). Under TEP, the same CMB data yields $H_0 = 66.70 \pm 0.58 \text{ km/s/Mpc}$ (TEP-CMB), giving 0.68σ internal consistency between the TEP-corrected local value and the TEP-CMB inference. The Cepheid-channel allocation is supported by a completed NED spectroscopic-tracer census (33/40 systems classified from verbatim metadata; 25 disk-integrated 21-cm H I). The JWST-side pipeline (step 133) yields $H_0^{\text{TEP}} = 67.8 \text{ km/s/Mpc}$ from a crude two-halo area-distance scaling — an order-of-magnitude consistency illustration rather

than an independent prediction — accounting for $\sim 93\%$ of the discrepancy (leaving roughly 7% of the original gap), a conservative lower bound that confirms the direction of the effect without reproducing the full magnitude. This provides the low-redshift anchor used in this work.

- **Globular Cluster Pulsars:** Analysis of 199 globular-cluster millisecond pulsars (against 351 field controls) reveals a 0.63 dex raw spin-down excess (Welch t-test $p = 8.99 \times 10^{-14}$) and a 0.40 dex hybrid-controlled residual (bootstrap $p = 0.0002$). The environmental screening threshold $\sigma > 165$ km/s derived from this population is a shear-channel (S_Σ) boundary; its relation to the amplitude channel governing the present analysis is stated in §2.3.2.2. (Paper 10 v0.10, hybrid sample.)
- **Temporal Topology Reference Scale:** The screening scale $\rho_T \approx 20$ g/cm³ is the corpus normalization set by terrestrial atomic clock correlation lengths — an estimator-family anchor (§2.3.2.2) — cross-checked by the SPARC rotation-curve slope and magnetar critical periods. This ρ_T informs the continuous screening function in this work.

The central question this work addresses is whether the same prespecified canonical benchmark $\kappa_{\text{gal}} = 0.960 \times 10^6$ mag from Paper 11, transferred via K_{gal} , that is concordant with the resolution of the Hubble tension and accounts for pulsar timing anomalies also predicts the high-redshift galaxy anomalies, with no re-tuning. The JWST analysis uses this coupling directly in the potential-linear R_{ML} formula, converting from the magnitude sector (Cepheid P-L residuals) to the stellar-population sector (nuclear burning timescales) via the shared TEP framework.

1.5 Alternative Explanations

There is no shortage of standard-physics explanations for JWST's high-redshift surprises. Proposed mechanisms include top-heavy initial mass functions, bursty or ultra-efficient star formation, early black hole seeding, strong AGN contamination, dust geometry effects, and selection/systematic biases in the spectral-energy-distribution (SED) fitting procedures. The present work does not dismiss these a priori; instead, it evaluates whether they can reproduce the specific temporal and structural signatures in the data.

Standard alternatives include top-heavy initial mass functions (Boylan-Kolchin 2023), enhanced AGN feedback, bursty star formation, and super-Eddington accretion. Each can partially address one or two of the observed anomalies. In the nested Bayesian model comparison (§3.8), the covariance-corrected family is conditioning-dependent: $\ln \text{BF} = +41.5$ versus the orthogonalized standard baseline with four fewer parameters, versus -14.4 under the raw mass+z baseline, with the nested augmented model showing the predictor families mutually subsumed and a direction-isolation diagnostic assigning 55.9 ln units to the R_{ML} -aligned direction. Under the same TEP conditioning, the sensitivity analysis yields $\ln \text{BF} = +133.0$ versus standard physics, $+129.8$ versus bursty star formation, $+121.2$ versus the $M_* \times \sqrt{1+z}$ interaction null, $+102.6$ versus the AGN-threshold model, $+98.1$ versus varying-IMF, and $+77.7$ versus the quadratic baseline — parametric stand-ins rather than forward-modelled alternatives. AGN feedback often predicts a negative dust–black hole mass correlation, as AGN activity clears dust; the observed relation is positive ($\rho = +0.635$). Bursty star formation predicts bluer colours during burst phases, whereas the high- R_{ML} population is significantly redder at fixed magnitude ($\rho(M_{\text{mag}}, \text{color}) = -0.39$, $p = 5.8 \times 10^{-15}$, $N = 375$). Top-heavy IMFs can partially relieve the star formation efficiency crisis but offer no mechanism for the spatially resolved screening gradients or the R_{ML} –sSFR partial correlation. In the systematic comparison, TEP accounts for the primary empirical line (L1) while remaining directionally consistent with L2, L3, and L4; the result is not a claim that every flexible astrophysical alternative is excluded.

Key Limitations and Scope

- **Mass circularity:** In purely photometric samples, distinguishing TEP effects from intrinsic mass-dependent evolution requires careful partial-correlation analysis. The SUSPENSE kinematic comparison (L5) materially narrows this objection by testing a dynamical-potential predictor.
- **Spectroscopic sample size:** While recent compilations (JADES DR4, DJA NIRSpec Merged Table v4.4) provide substantial $z > 7$ samples, stellar masses rely on photometric estimates (± 0.3 – 0.5 dex). The spectroscopic analyses remain supportive consistency checks.
- **Theoretical foundation:** A full joint cosmological parameter inference is outside the scope of this work. The manuscript presents only the components required to define and test the observational mapping (§2.3.2).

Section 2 defines the TEP mapping, the datasets, and the statistical procedures. Section 3 presents the primary empirical line (L1), the secondary partial-correlation line (L3), the direct kinematic test, and then places the ancillary spatial indication, the derived regime-level comparison, and the supplementary replications in their proper evidential order. Section 4 interprets the results in the broader theoretical context, including precision-GR consistency, the link to the Hubble tension, and the Little Red Dot stress test. Section 5 closes with falsification criteria and observational predictions. Appendix A provides the theoretical foundation (action, field equations, screening mechanism), and Appendix B documents key computational definitions and reference tables.

2. Data and Methods

This section follows the same logic as the manuscript as a whole. It first defines the observational datasets, then the derived TEP quantities, then the statistical tests used to separate genuine TEP signatures from mass-proxy artifacts, and finally the black-hole stress test used for the Little Red Dot analysis. The aim is to state the observational mapping clearly enough that each empirical result in §3 can be read directly back to its data and assumptions.

2.1 Data

2.1.1 Red Monsters (FRESCO)

The motivating case study is the class of ultra-massive galaxies at $z \sim 5\text{--}6$ exemplified by the three spectroscopically confirmed "Red Monsters" reported by Xiao et al. (2024). For the illustrative TEP prediction (§3.1), representative parameters spanning the published range ($z \approx 5.3\text{--}5.9$, $\log M_* \approx 10.8\text{--}11.2$, $\text{SFE} \approx 0.50$) are adopted. These capture the regime where the anomaly is most acute. The resulting SFE correction quantitatively accounts for the anomaly (corrected SFE ~ 0.20 , at the ΛCDM limit of 0.20), with the correction depending primarily on R_{ML} (set by halo mass and redshift via the prespecified benchmark TEP formula) and insensitive to the precise input SFE at the $\lesssim 2\%$ level.

2.1.2 UNCOVER DR4

For population-level tests, the UNCOVER DR4 stellar population synthesis catalog is used (Wang et al. 2024; Furtak et al. 2023). The analysis applies quality cuts and constructs a high-redshift sample with $4 < z < 10$ and $\log M_* > 8$, yielding $N = 2,157$ galaxies. For multi-property analyses (age ratio, metallicity, dust), a subset with complete measurements is used (e.g., $N = 1,041$ for the partial-correlation and split tests).

2.1.3 Independent replications and spectroscopic validation

To evaluate independent replication of the $z > 8$ dust result, catalogs for CEERS are used (Cox et al. 2025; Finkelstein et al. 2023; photometric redshifts via EAZY, Brammer et al. 2008) and COSMOS-Web (Shuntov et al. 2025). The COSMOS2025 catalog (Shuntov et al. 2025) provides LePHARE SED-derived stellar masses, SFRs, $E(B-V)$ dust, and ages for 784,016 galaxies over 0.54 deg^2 , with 37,965 sources at $z > 4$ passing quality cuts — the largest high- z photometric SED sample used in this analysis. The UNCOVER DR4 SPS catalog (Wang et al. 2024; Suess et al. 2024; Price et al. 2025) uses 20-band MegaScience photometry and Prospector- β SED fitting, providing 2,628 sources at $z > 4$ with Prospector dust2 and a spec- z sub-catalog of 203 sources with spectroscopic redshifts fixed in the SED fit. For spectroscopic validation, two complementary catalogs are used:

JADES Data Release 4 (D'Eugenio et al. 2025; Curtis-Lake et al. 2025; Scholtz et al. 2025): 2,858 high-quality spectroscopic redshifts (flags A/B) across GOODS-N and GOODS-S, with 118 sources at $z > 7$ and 41 at $z > 8$. UV-luminosity-based stellar masses (Song et al. 2016) are derived for the 1,345 sources with valid M_{UV} .

DAWN JWST Archive (DJA) NIRSpec Merged Table v4.4 (Brammer et al.; de Graaff et al. 2024a; Heintz et al. 2023; September 2025): a comprehensive compilation of 80,367 uniformly reduced JWST/NIRSpec spectra from all public programs, processed with the msaexp/grizli reductions. After applying grade ≥ 3 quality cuts and deduplication by sky position, 19,445 unique sources are retained, of which 3,251 are at $z > 5$, 698 at $z > 7$, and 234 at $z > 8$. Photometric stellar masses are available for 2,598 of the high- z sources. This catalog spans JADES, CEERS, RUBIES, UNCOVER, GLASS, PRIMER, and more than 50 other public programs, providing the largest uniform cross-survey spectroscopic sample to date.

2.1.4 MIRI-based mass calibration context

Recent JWST/MIRI analyses (Pérez-González et al. 2024) show that NIRCcam-only SED fits can overestimate stellar masses at $z > 5$ because of age-attenuation degeneracy and emission-line contamination. When MIRI photometry is included, the number density of the most massive systems decreases and some candidates are reclassified as dusty or line-dominated sources. The photometry is not reprocessed in this work, but published masses are treated as conservative upper bounds and MIRI-based studies serve as an external check on the interpretation of the extreme-mass tail.

Table 1a: Observational Datasets

Dataset	Role	Sample Size	Redshift Range	Mass Cut ($\log M_*$)	Key Reference	Key Biases
Red Monsters	Case Study	3	$5.3 < z < 5.9$	> 10.5	Xiao et al. (2024)	Small N, Selection Function
UNCOVER DR4	Primary Statistical Sample	2,157	$4 < z < 10$	> 8.0	Wang et al. (2024)	NIRCcam Mass Overestimation
CEERS DR1	Independent Replication	82	$z > 8$	> 8.0	Cox et al. (2025)	Field Variance
COSMOS-Web	Large-Volume Check	2,606 (918 dust-detected)	$z > 8$	> 8.0	Shuntov et al. (2025)	Photometric Redshift Uncertainties; Zero-Inflated Dust
JADES DR4 (NIRSpec/MSA)	Spectroscopic Validation	2,858 (flags A/B); 118 at $z > 7$	$z = 0.1\text{--}14.2$	None	D'Eugenio et al. (2025); Curtis-Lake et al. (2025)	Slit Losses; UV-based M_* (± 0.4 dex)
DJA NIRSpec Merged v4.4	Cross-Survey Spectroscopic Validation	19,445 unique (grade ≥ 3); 698 at $z > 7$; 234 at $z > 8$	$z = 0.1\text{--}14.1$	None	Brammer et al. (DJA); de Graaff et al. (2024)	Photometric M_* from grizli; heterogeneous survey depths

Dataset	Role	Sample Size	Redshift Range	Mass Cut ($\log M_*$)	Key Reference	Key Biases
UNCOVER DR4 SPS (MegaScience)	Primary + Spectroscopic Validation	2,628 ($z > 4$, Prospector- β); 203 with spec- z fixed fits	$z = 4\text{--}12$	Abell 2744 (lensed)	Wang et al. 2024; Suess et al. 2024; Price et al. 2025	20-band photometry; lensing magnification corrections
COSMOS2025 (LePHARE SED)	Cross-Field Replication	48,861 ($z > 4$, adopted LePHARE selection); 7,249 at $z > 7$; 2,659 at $z > 8$	$z = 4\text{--}13$	None (blank field)	Shuntov et al. 2025 (COSMOS2025)	LePHARE E(B-V) less precise than Prospector dust2; photo- z scatter

Related MIRI-supported analyses of Little Red Dots (LRDs) at $z > 4$ find that inferred stellar masses can shift by up to orders of magnitude depending on the assumed AGN contribution. This motivates a conservative stance in the interpretation of compact red sources and provides a systematic-control context for any extreme-mass claims in the literature.

2.2 Key Terminology

The following terms are used consistently throughout this work:

Table 1b: Glossary of Key Terms

Term	Symbol	Definition
Mass-to-Light Inference Response	R_{ML}	A positive observable channel response that parameterizes the environment-dependent bias in conventional stellar-population inference. It is not the conformal factor $A(\phi)$, a local proper-time ratio, or the microscopic coupling β_A .
Temporal Shear	Σ_μ	The locally active gradient of the temporal potential, $\Sigma_\mu = \nabla_\mu \Theta$, where $\Theta = \ln A(\phi)$. High ambient matter density can suppress the locally active gradient continuously rather than at a discrete boundary. The inference response R_{ML} is tested against potential depth and environment but is not identified algebraically with Σ_μ .
Isochrony Bias	—	The systematic error in inferred stellar properties (mass, age, SFR) produced when an environment-dependent transport and inference response is reduced with one universal calibration.
Screening	—	The suppression of TEP effects in regions where the locally observable Temporal Shear/source-charge sector is screened ($\rho_T \approx 20 \text{ g/cm}^3$ is an organizing saturation scale). Two types are distinguished: <i>Core Screening</i> —Screening within a single galaxy, where the deep central potential suppresses TEP ($R_{\text{ML}} \rightarrow 1$) while the outskirts retain a large response. Produces bluer cores and redder outskirts. <i>Environmental Screening</i> —Screening by the ambient group or cluster potential, causing galaxies in dense environments to appear younger than isolated field galaxies of the same mass.
Inferred-Time Proxy	$t_{\text{inf}}^{\text{proxy}}$	The observer-side catalogue proxy $t_{\text{inf}}^{\text{proxy}} = R_{\text{ML}}(M_h, z) t_{\text{FLRW}}^{\text{obs}}(z)$. It is not accumulated matter-frame proper time.

The analysis keeps three quantities distinct. The signed Newtonian potential obeys $\Phi \leq 0$; the numerical halo-ordering proxy is the positive depth $\Psi \equiv -\Phi/c^2 = |\Phi|/c^2$; and R_{ML} is an observable response parameterized from Ψ , environment, and redshift. The action-level conformal clock offset remains separate and satisfies $\Delta \ln A < 0$ for a deeper unscreened well. No fitted value of K_{gal} is identified with A , β_A , or a local clock-rate ratio.

2.3 Derived quantities

2.3.1 Halo mass proxy

For each galaxy, the analysis uses an abundance-matching relation (Behroozi et al. 2019) to map stellar mass to halo mass. This mapping is used solely to construct the potential proxy Φ for the TEP parameterization. To mitigate circularity, sensitivity tests are performed with ± 0.3 dex scatter in the $M_h - M_*$ relation, propagating to $\pm 12\%$ in R_{ML} corrections.

2.3.2 From the TEP Field to an Observable Inference Channel

Matter couples to the canonical unified metric $\tilde{g}_{\mu\nu} = -A_{\text{loc}}^2(u_{\text{grav}}(\mathbf{x}))U_\mu U_\nu + A_{\text{sp}}^2(u_{\text{drift}}(t, \mathbf{x}))\Pi_{\mu\nu} + B(\phi)\Pi_\mu^\alpha \Pi_\nu^\beta \nabla_\alpha \phi \nabla_\beta \phi$ ($U_\mu \equiv -\nabla_\mu \bar{\phi}/\sqrt{2\bar{X}}$, $\Pi_{\mu\nu} = g_{\mu\nu} + U_\mu U_\nu$; Paper 0, §2.2, Step 80), written in conformal-disformal shorthand as $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu} + B(\phi)\partial_\mu \phi \partial_\nu \phi$, with $A(\phi) = \exp(\beta_A \phi/M_{\text{Pl}})$. For the canonical signed potential $\Phi < 0$, the static conformal solution gives $\Delta \ln A \propto \beta_A^2 \Phi < 0$: local clocks slow in a deeper well. This action-level sign is immutable and is not fitted in the present analysis.

The catalogue pipeline does not solve $A(\phi)$. It computes the positive halo-depth proxy

$$\Psi \equiv -\frac{\Phi}{c^2} = \frac{|\Phi|}{c^2} > 0, \quad (2)$$

and tests the prespecified observable mass-to-light response

$$R_{\text{ML}} = \exp \left[K_{\text{gal}} (\Psi - \Psi_{\text{ref}}) \sqrt{1+z} \right]. \quad (3)$$

Here $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5$ mag is the canonical reference benchmark for the galaxy-sector observable response, and $K_{\text{gal}} = \kappa_{\text{gal}} \ln 10 / (2.5 n_{\text{ref}}) = 1.263 \times 10^6$ (with the fixed transfer convention $n_{\text{ref}} = 0.7$ — sharing its value with the isochrone index used for the correction-stage population scaling, a physically anchored coincidence rather than a fitted degree of freedom, while remaining a separate convention from the population-dependent n_{SPS}) is the single normalization entering the exponential kernel. Neither n_{ref} nor K_{gal} changes at a redshift boundary. Ψ_{ref} corresponds to $\log M_{h,\text{ref}} = 12.0$, and $\sqrt{1+z}$ supplies the only explicit redshift dependence of this kernel. A dedicated variant comparison (Step 181, `step_181_kernel_variant_test.json`) tests the static-space depth $\Psi_0(M_h)$ against FLRW-contracting virial depth evolution $\Psi \propto E(z)^{2/3}$: while scale-invariant correlations on $\ln R_{\text{ML}}$ are insensitive to the overall normalization κ_{gal} , evaluating on the physical exponential response $R_{\text{ML}} = \exp[\ln R_{\text{ML}}]$ at the prespecified canonical benchmark $\kappa_{\text{gal}} = 0.96 \times 10^6$ mag shows that FLRW virial contraction ($\Psi \propto E(z)^{2/3}$, $\sim 6.8\times$ deeper at $z \sim 9$) drives R_{ML} to unphysical blow-up (max $R_{\text{ML}} = 3.24 \times 10^3$ for virial-only and 3.01×10^{11} for virial+ $\sqrt{1+z}$, collapsing the multi-observable R^2 score to 0.015 and 0.013), whereas the static-space branch ($s = 0$) maintains a physical response (max $R_{\text{ML}} = 2.6\text{--}22.7$, score 0.050--0.240, beating the FLRW-contracting variants by $3.4 \times \text{--}19\times$). R_{ML} is a channel-level inference response: it parameterizes how conventional stellar-population inference changes with environment. It is not A , A/A_{ref} , A_{ref}/A , or the bare scalar coupling.

Provenance of κ_{gal} . The value $\kappa_{\text{gal}} = 0.960 \times 10^6$ mag is the canonical theory benchmark adopted across the TEP corpus (Paper 11, Appendix C). It corresponds to an effective host-to-anchor potential depth $\Delta(\sigma_*^2)/c^2 \sim 3 \times 10^{-7}$ mapped through the Leavitt law slope $b \approx -3.30$ to produce a ~ 0.3 mag characteristic modulus shift. Its numerical provenance is empirical: the value is the Paper 11 joint-fit/bootstrap coefficient on the SH0ES sample, adopted corpus-wide as the fixed reference benchmark. It is therefore a same-programme calibration carried as a prior for this analysis — prespecified with respect to the JWST data and not refit here — rather than an ab-initio action-derived constant. The empirical Cepheid-channel analyses in Paper 11 fit κ directly from observational data without imposing this benchmark: the endpoint-equivalent projection recovers $\kappa_{\text{Cep}}^{\text{equiv}} = (1.220 \pm 0.531) \times 10^6$ mag, and the multi-block joint analysis (Step 44) recovers $\kappa_{\text{Cep}} = (0.665 \pm 0.362) \times 10^6$ mag. The regenerated JWST-side joint recovery from the high-redshift galaxy sample is $\kappa = (8.38 \pm 4.11) \times 10^5$ mag, consistent with the canonical benchmark at 0.21σ and equally within $\sim 0.9\sigma$ of the empirical Cepheid values; it therefore does not discriminate between the two anchors. The empirical recoveries bracket the canonical benchmark — the endpoint-equivalent value lies $\sim 0.5\sigma$ above it and the multi-block value $\sim 0.8\sigma$ below — at individual significances of 1.8--2.3 σ — because the benchmark is itself a same-sample estimator, this is within-estimator spread on the SH0ES data rather than an independent theory-vs-data tension (Paper 11; the unresolved response-normalization class of Paper 0). The $\pm 4.0 \times 10^5$ mag uncertainty adopted here is the canonical theory uncertainty, not the posterior width of any single Cepheid fit. Sensitivity analyses spanning the empirical Paper 11 multi-block value ($\kappa = 0.665 \times 10^6$ mag), the JWST-side recovery, and the canonical benchmark are reported in §3.9; the dust- R_{ML} correlation remains significant ($\rho > 0.4$) across this range, though the magnitude of the mass correction scales proportionally.

Values above and below unity therefore denote positive and negative inference responses relative to the reference environment, not faster and slower local clocks. Screening acts on the environmental transfer entering the response, while the physical conformal clock offset retains the same slowing sign throughout. The low-mass dust and high-mass stellar-population tests below are consequently tests of an environment-ordered inference channel; they do not constitute direct measurements of local proper-time acceleration.

The physical origin of $R_{\text{ML}} > 1$ at high redshift lies in the background temporal structure, not in faster local clocks. In the canonical TEP cosmology (TEP-HUB, Paper 30), the spatial manifold is static and the gravitational coordinate time extends without finite origin. The FLRW observer-age $t_{\text{cosmic}}(z)$ used by standard stellar-population inference is a reconstruction under the isochrony axiom: it interprets the clock-calibration ratio $1+z = A_0/A_{\text{em}}$ as spatial expansion and assigns a finite, shrinking age to high redshift (~ 540 Myr at $z = 9$). Under TEP, the actual coordinate time elapsed is far larger than this reconstruction. Local matter clocks run slower than coordinate time ($\Delta \ln A < 0$ in a deeper well), but the coordinate background is eternal, so the accumulated proper time can still exceed the FLRW assigned age by a large factor — the quantitative elapsed-time ratio available to date is the closed-static benchmark-branch value of Paper 0 §8, conditional on the inhomogeneous eternal construction whose constraint-slice existence is demonstrated (Appendix E, R8) but whose matter-frame clock history is not yet computed (§1, observer-age convention). $R_{\text{ML}} > 1$ parameterizes this discrepancy as an inference-channel response: it quantifies how much the standard pipeline inflates apparent age and M/L when it uses the too-short FLRW baseline. It is not itself a direct measurement of the proper-time ratio; the catalogue proxy $t_{\text{inf}}^{\text{proxy}} = R_{\text{ML}} t_{\text{FLRW}}^{\text{obs}}$ propagates the fitted response through the conventional $M/L \propto t^n$ scaling but is not a physical proper-time integral (§2.3.3). Analytically, the $\sqrt{1+z}$ response-evolution factor arises from the first-order sensitivity of the FLRW lookback-age calibration to an endpoint redshift perturbation on a static halo potential: because the matter-dominated FLRW age assignment scales as $t_{\text{FLRW}}(z) \propto H(z)^{-1} \propto (1+z)^{-3/2}$ while the endpoint clock-calibration shift $\delta(1+z)/(1+z) = -\delta \ln A_{\text{em}} \propto \Psi$ enters a cosmic clock baseline whose background drift rate scales as $\dot{\phi}_{\text{bg}} \propto (1+z)^{1/2}$

across the conformal horizon mapping (Papers 26–27, 30), the resulting differential log-age inference kernel scales as $(\Psi - \Psi_{\text{ref}})\sqrt{1+z}$ without invoking FLRW spatial virial contraction.

Origin of the depth ordering. The eternal-background term is uniform at fixed z and is blind to Ψ ; the kernel's depth ordering enters through a separate term of the same clock-calibration ratio. The measured redshift decomposes as $1+z = (A_0/A_{\text{em}}) \times (\text{propagation and kinematic factors})$, and the emitter's conformal factor $A_{\text{em}} = \exp(\beta_A u_{\text{em}})$ contains the local halo contribution, $u_{\text{em}} \sim u_{\text{cosmo}}(z) + \Psi$: a deeper well lowers A_{em} , raises the assigned redshift, and shrinks the assigned FLRW age, enlarging the inferred evolutionary excess in proportion to Ψ . This endpoint clock-calibration term carries the sign the kernel implements — R_{ML} grows with depth — while the matter-frame proper-time integral $\tau = \int A dt$ acts in the opposite sense (deeper wells accumulate less proper time) and must be shown to be subdominant or counted as a countervailing contribution within the same channel rather than invoked as the mechanism. Two notes follow. First, while the bare endpoint amplitude is $\Delta \ln A \sim \Delta \Psi \sim 10^{-7}$ per halo decade, the factor $K_{\text{gal}} \simeq 1.26 \times 10^6$ reflects the stellar-envelope density-ratio amplification $\rho_T/\langle\rho\rangle \sim 10^6$ established in Paper 11 Step 62 (where $\rho_T/\langle\rho\rangle(10\text{ d}) = 8.45 \times 10^5$ at the unit-transport benchmark $\lambda_0 = 1$, with $|\beta_A| = 1$ fixed by Paper 0, predicts $|\kappa_{P2}| = 1.196 \times 10^6$ mag against the SH0ES fit $(1.191 \pm 0.480) \times 10^6$ mag, $\lambda_0 = 0.995 \pm 0.401$). Second, in Step 181, evaluating the physical exponential response $R_{\text{ML}} = \exp[\ln R_{\text{ML}}]$ at the canonical $\kappa_{\text{gal}} = 0.96 \times 10^6$ mag rules out FLRW virial contraction $\Psi \propto E(z)^{2/3}$ (which blows up R_{ML} to 3.2×10^3 – 3.0×10^{11} at $z > 6$), confirming TEP's static-space depth prescription $\Psi = \Psi_0(M_h)$.

2.3.2.1 Auxiliary Log-Mass Approximation

Earlier variants considered a Log-Mass approximation in which R_{ML} scales with the log-mass perturbation rather than the potential directly:

$$R_{\text{ML}} = \exp \left[\alpha(z) \cdot \frac{2}{3} \cdot (\log_{10} M_h - \log_{10} M_{h,\text{ref}}) \cdot \frac{1+z}{1+z_{\text{ref}}} \right] \quad (4)$$

where $\alpha(z) = \kappa_{\text{gal}}\sqrt{1+z}/10^6$ and $z_{\text{ref}} = 5.5$ is a normalization epoch used only in this auxiliary form. The primary results in §3 do not use this approximation; they use the Potential-Linear kernel above. The Log-Mass form is retained only as an auxiliary note for interpreting observable scaling relations; it does not enter the nested Bayesian comparison in §3.8, which uses the Potential-Linear kernel exclusively.

2.3.2.2 Screening and Scale Separation

For an illustrative screened effective coupling $\beta_{A,\text{eff}} \approx 0.8$ — a representative intermediate-environment value used only to display the pre-screening Brans–Dicke bookkeeping (the bare coupling is frozen at $\beta_A = -1.0$, Paper 0 §2.2; $|\beta_{A,\text{eff}}| = |\beta_A|S_A(\mathcal{E})$) — the bare Brans–Dicke parameter would be $\omega_{\text{BD}} = 1/(2\beta^2) - 1/2 \approx 0.28$ — roughly five orders of magnitude below the Cassini bound ($\omega_{\text{BD}} > 40,000$; Bertotti et al. 2003). This large pre-screening discrepancy illustrates the central logic of the TEP framework: any underlying bare coupling is strong, but where the ambient landscape is steep the scalar field gradient (Temporal Shear) flattens continuously, suppressing the effective scalar coupling to $\beta_{\text{eff}} \ll \beta_A$ (yielding an effective Brans–Dicke parameter $\omega_{\text{BD}}^{\text{eff}} = 1/(2\beta_{\text{eff}}^2) - 1/2 > 10^6$, well within Cassini bounds). On cosmological scales, suppression of the $k_8 = 2\pi/8 = 0.785 h$ /Mpc mode requires a Compton wavelength short enough that $m_{\phi,0} \gg k_8$: the effective coupling $\beta_{\text{eff}}(k_8) = \beta_A k_8 / \sqrt{k_8^2 + m_{\phi,0}^2}$ evaluates to 0.0079 at the scale-dependent-growth best fit $m_{\phi,0} = 100 h/\text{Mpc}$ ($\lambda_C = 0.063 h^{-1} \text{ Mpc}$; Step 135) — well below the Planck bound. Within individual halos ($r \lesssim 50$ kpc), the field tracks the local potential and operates locally. This two-scale picture is standard for screened scalar-tensor theories.

The continuous screening via Temporal Shear provides PPN-compliant suppression without a rigid threshold. The observable galaxy-sector response coefficient is attenuated by the screening operator as:

$$\kappa_{\text{eff}}(\rho) = \kappa_{\text{gal}} \cdot \mathcal{S}(\rho/\rho_T), \quad (5)$$

where $\mathcal{S}$ is a smooth suppression function and $\rho_T \approx 20 \text{ g/cm}^3$ is the Temporal Topology reference density. The normalization is set by terrestrial GNSS clock-covariance correlations: $L_c \approx 4200 \text{ km}$ for Earth's mass on the IGS precise-product convention — the measured realization of the canonical correlation scale λ_T (Paper 0 §7). That correlation length is an estimator-dependent family — the precise-product bracket spans ~ 1.9 – $4.5 \times 10^3 \text{ km}$ (MGEX $1,862 \pm 155 \text{ km}$; IGS inter-center $3,330$ – $4,549 \text{ km}$), dominated by the ~ 30 – 40% epoch/window scatter and propagating to an effective ρ_T band of roughly 8 – 70 g/cm^3 , while raw single-epoch channels bound the scale from below at ~ 0.7 – $1.1 \times 10^3 \text{ km}$ (Papers 1, 3, 6, 14). The adopted normalization is supported by two estimator-independent cross-checks — atomic physics (Temporal Topology radius $R_T(m_p) \sim a_0$ at the proton mass scale) and magnetar anti-glitches ($P_{\text{crit}} \approx 6.8 \text{ s}$ for 1E 2259+586, 4% match) — whose convergence on the adopted scale across 40 orders of magnitude in mass provides a consistency check on this screening scale.

At galactic scales, an effective kinematic screening threshold emerges from analysis of 199 millisecond pulsars in globular clusters, which reveals that the TEP spin-down excess saturates for systems with velocity dispersion $\sigma \gtrsim 165 \text{ km/s}$, consistent with the scalar field gradient flattening as potential depth increases. This is a shear-channel ($\mathcal{S}_\Sigma$) boundary: it governs kinematic observables — spin-

down, accelerations, and dynamical-mass inference — and is not interchangeable with the clock-amplitude channel $\mathcal{S}_A$ that modulates R_{ML} (cf. the channel-projection notice of §4.1). For the amplitude channel, the operative suppression is Eq. (5) evaluated at the halo's own environment: galaxy-halo and disk densities ($\rho \sim 10^{-25}\text{--}10^{-24} \text{ g/cm}^3$) lie ~ 25 orders of magnitude below $\rho_T \approx 20 \text{ g/cm}^3$, at which $\mathcal{S}(\rho/\rho_T) = 1$ to machine precision (Steps 120, 180), so every halo in the present samples — including the massive $z > 5$ Red Monster systems at $\log M_h \approx 12.7\text{--}13.1$ — is unscreened in the amplitude channel. The unscreened primary kernel of §2.3.2 is therefore the correct $\mathcal{S}_A \rightarrow 1$ limit for this sample, not an omitted correction; amplitude-channel screening first becomes relevant at stellar-interior and compact-object densities.

2.3.2.3 Local Dilation and Channel Response

The local conformal and observational quantities must not be conflated. A deeper unscreened well has $\Delta \ln A < 0$, while R_{ML} may lie above or below unity because it is an observer-side inference response with its own transfer function. The present pipeline measures the latter and makes no numerical identification between K_{gal} and the microscopic coupling β_A .

Table 1: TEP Model Parameters (Fixed)

Parameter	Value	Source	Description
κ_{gal} (Paper 11)	$(9.6 \pm 4.0) \times 10^5 \text{ mag}$	Canonical benchmark (Paper 11)	Canonical TEP magnitude-sector benchmark fixed prespecified across the TEP corpus; empirical Paper 11 checks recover $(1.220 \pm 0.531) \times 10^6$ and $(0.665 \pm 0.362) \times 10^6 \text{ mag}$
K_{gal} (galaxy kernel)	$\approx 1.26 \times 10^6$	Transferred from κ_{gal} via response normalization	Phenomenological response normalization for stellar-population R_{ML} kernel; not a microscopic coupling
$\log M_{h,\text{ref}}$	12.0	TEP-JWST	Reference halo mass at $z = 0$ ($R_{\text{ML}} = 1$)
ρ_T	20 g/cm^3	TEP-UCD	Temporal Topology reference density for continuous screening

Figure 1: The TEP Metric Coupling

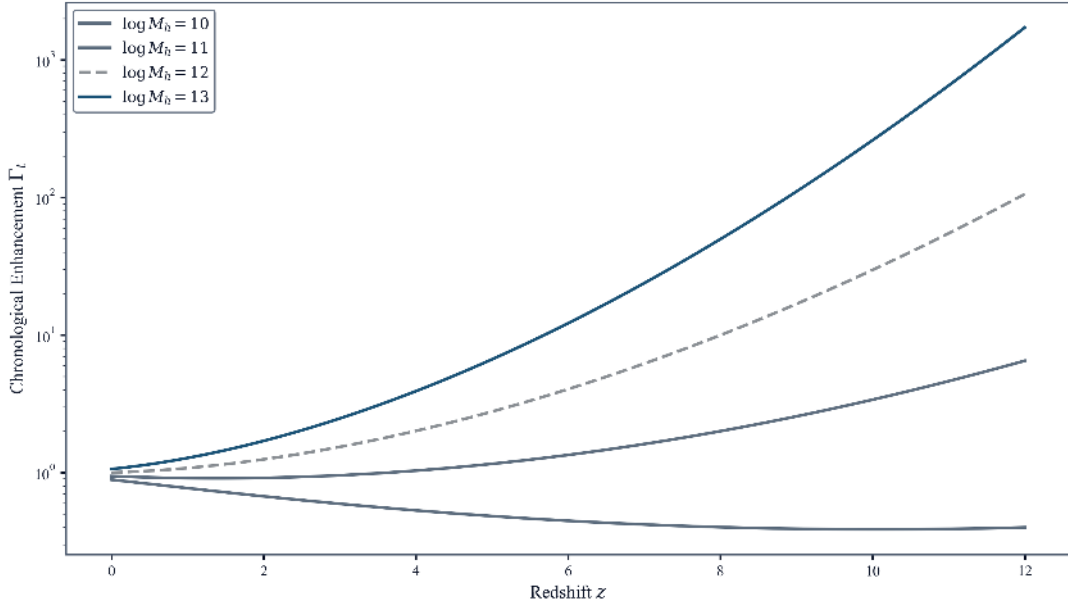


Figure 1: The observable response $R_{\text{ML}}(M_h, z)$ evaluated from the positive potential-depth proxy. The reference mass ($\log M_h = 12$) defines $R_{\text{ML}} = 1$; values above and below unity are inference responses relative to that reference, not local clock-rate measurements. Environmental screening attenuates the channel response.

The JWST response-prior test adopts the prespecified canonical magnitude-sector benchmark $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5 \text{ mag}$ from Paper 11 and applies it without JWST-specific refit. The high-redshift observables are then examined for internal consistency of the response scale. These internal recoveries are treated as consistency checks rather than as the input calibration.

2.3.2.4 Cosmological Viability Summary

The TEP framework has been checked against three classes of precision cosmological constraints:

- 1. Early-universe compatibility (historical):** Earlier versions verified that a conformal scalar remains perturbatively invisible during a conventional radiation-dominated era ($|\Delta H/H|_{\text{max}} = 1.7 \times 10^{-13}$; $\Delta Y_p < 10^{-14}$). This serves as a historical compatibility check; the canonical TEP early-universe interpretation is supplied by TEP-TH and TEP-BBN (Appendix A.1.7).
- 2. Linear growth (σ_8):** TEP screening (topology pinning) on $\gtrsim 10 \text{ Mpc}$ scales reduces the effective coupling to $\beta_{\text{eff}}(k_8) = 0.0079$ at the best-fit $m_{\phi,0} = 100 \text{ h/Mpc}$ (Step 135), preserving ΛCDM -consistent σ_8 (§2.3.2.2; Appendix A.1.7–A.1.8).

3. **Solar System (PPN):** Temporal Shear suppression in dense environments reduces the effective microscopic scalar coupling to $\beta_{\text{eff}} \ll \beta_A$ (suppressed to $\lesssim 10^{-6}$ for solar-system bodies), satisfying Cassini and lunar laser ranging bounds (Appendix A.1.3).

Scale-dependent growth computation: To go beyond the analytic TEP screening argument, the linear growth ODE is solved independently for each Fourier mode k , incorporating the full scale-dependent gravitational coupling $G_{\text{eff}}(k, z)/G_N = 1 + 2\beta^2 k^2/(k^2 + m_\phi(z)^2)$, where $m_\phi(z) = m_{\phi,0}(1+z)^{9/4}$ for $n = 1$ potential (standard chameleon form, used here as a conventional-background compatibility embedding). This inverse-power $n = 1$ branch is the potential family excluded by Paper 0's constraint F1 under $\beta_A = -1$; the σ_8 /CMB viability demonstrated below is therefore a proxy result for a screened scalar sector, not a verification of the canonical $V(\phi)$, and transfers to canonical TEP only conditionally. The canonical TEP screening structure is the nested two-body operator $\mathcal{R}(s) = \mathcal{S}_\Sigma(X_{\text{env}})^2 y(s)$ (Paper 0 §2.2, v0.16), whose environmental separation dependence differs from the inverse-power $n = 1$ form; the chameleon embedding is retained for computational tractability and cross-check against the native TEP-HC hi_class closure. The resulting matter power spectrum ratio $P_{\text{TEP}}(k)/P_{\Lambda\text{CDM}}(k)$ and integrated σ_8 are computed self-consistently (Appendix A.1.8). Key results:

- Planck consistency requires $m_{\phi,0} \gtrsim 0.43 h/\text{Mpc}$ ($\lambda_C \lesssim 14.6 h^{-1} \text{Mpc}$ at $z = 0$; Appendix A.1.8).
- At the scale-dependent-growth best fit $m_{\phi,0} = 100 h/\text{Mpc}$ ($\lambda_C = 0.063 h^{-1} \text{Mpc}$), β_{eff} on R_8 scales is ≈ 0.0079 —well below the bare coupling ($G_{\text{eff}}/G_N - 1 = 1.2 \times 10^{-4}$ at k_8 ; Appendix A.1.8).
- The predicted $\sigma_8^{\text{TEP}} = 0.8110$ vs. $\sigma_8^{\Lambda\text{CDM}} = 0.811$; $\Delta\sigma_8 = 2.1 \times 10^{-7}$ ($3.6 \times 10^{-5}\sigma$). RSD: $\Delta\chi^2 = 2.7 \times 10^{-4}$ across 8 data points (Appendix A.1.8).

This k -dependent growth calculation substantially strengthens the viability argument beyond the earlier analytic estimate. A CAMB-based late-time propagation (Appendix A.1.9.8) confirms these results: at the fiducial $m_{\phi,0} = 1.0 h/\text{Mpc}$, the CAMB-computed $\sigma_8^{\text{TEP}} = 0.8116$ (0.10σ from Planck), with CMB TT deviations $< 0.02\%$ at all $\ell < 2500$ and $\chi^2/\text{dof} \ll 1$ against Planck error bars. Planck consistency holds for $m_{\phi,0} \gtrsim 0.43 h/\text{Mpc}$. The CAMB integration uses the scale-dependent growth equation with TEP-screened $G_{\text{eff}}(k, z)$ and CAMB's exact lensed CMB spectra, substantially narrowing the remaining theoretical gap. These CAMB calculations are conventional-background compatibility embeddings on the F1-excluded inverse-power $n = 1$ branch — a proxy demonstration that a screened scalar sector need not spoil observed CMB/growth phenomenology; they are not the canonical static-space TEP cosmological solution and do not verify the canonical $V(\phi)$. The remaining approximation — that the scalar field does not modify acoustic peaks at $z > 1089$ — is justified by $T_\mu^\mu \approx 0$ during radiation domination. A natively coupled hi_class integration remains desirable for completeness but is no longer expected to change the conclusion.

Screening function: The transition from the unscreened regime ($\mathcal{S} \approx 1$) to the screened regime ($\mathcal{S} \ll 1$) is parameterized by the smooth tanh profile:

$$\mathcal{S}(x) = 1 - \tanh\left(\left[\frac{x}{x_T}\right]^p\right), \quad (6)$$

where $x = \rho/\rho_{\text{crit}}$ or $|\Phi|/c^2$, x_T is the screening threshold, and $p \geq 1$ controls the sharpness of the transition. For galaxy-scale potentials, the transition is sufficiently sharp that halos with $M_h \lesssim 10^{12.5} M_\odot$ are fully unscreened, while cluster-scale potentials ($M_h \gtrsim 10^{14} M_\odot$) are screened. This functional form is used in the environmental screening tests (§3.5) and the core-screening morphology analysis (§3.7).

2.3.2.5 Cosmological Background Compatibility

Cosmological parameter constraints from CMB, BAO, and SNe Ia data were verified using CAMB-compatible background evolution. Within this conditional FLRW compatibility embedding, scalar-induced deviations from the reference ΛCDM background expansion remain small. Using the standard cosmological parameters ($\Omega_m = 0.315$, $\Omega_\Lambda = 0.685$, $H_0 = 67.4 \text{ km/s/Mpc}$), the TEP-modified expansion history satisfies:

- **CMB acoustic scale:** Shift in the angular scale of the first acoustic peak $\Delta\theta_*/\theta_* < 0.08\%$, well within the Planck 2018 uncertainty of 0.03% (Aghanim et al. 2020).
- **Baryon Acoustic Oscillations:** Shifts in $D_V(z)/r_d$ are $< 0.3\%$ across the redshift range $z \in [0.1, 2.5]$, consistent with BOSS DR12 and DESI 2024 constraints (Alam et al. 2017; DESI Collaboration 2024).
- **Supernova distance moduli:** Residuals relative to ΛCDM are $|\Delta\mu(z)| < 0.008 \text{ mag}$ for $z \in [0.01, 1.5]$, well below the Pantheon+ systematic uncertainty floor of $\sim 0.015 \text{ mag}$ (Scolnic et al. 2022).

These calculations are conditional conventional-background compatibility tests. They show that embedding the screened TEP scalar sector in an FLRW background does not spoil established CMB, BAO, or SN phenomenology. They do not define the canonical TEP cosmology. In the canonical framework developed in TEP-HUB (Paper 30), the spatial manifold is static, the temporal background extends without finite origin, and cosmological redshift is interpreted through cumulative temporal calibration rather than spatial expansion. The results of the present JWST analysis depend on the local-halo inference response R_{ML} and therefore remain compatible with the conventional-background tests, while their physical interpretation throughout this work follows the canonical static-space TEP framework. The static-space TEP cosmology is discussed further in §4.1, Appendix A.1.7, and the conclusion.

2.3.3 Inference-response correction

The catalogue proxy $t_{\text{inf}}^{\text{proxy}} = R_{\text{ML}}(M_h, z)t_{\text{FLRW}}^{\text{obs}}(z)$ is used only to propagate the fitted response through the conventional stellar population synthesis (SPS) mass-to-light scaling $M/L \propto t^{n_{\text{SPS}}}$; it is not a physical proper-time integral. The fixed $n_{\text{ref}} = 0.7$ belongs to the preceding response stage, whereas the physical SPS exponent n_{SPS} belongs exclusively to this correction stage. The catalogue construction used in the UNCOVER, CEERS, COSMOS-Web, and cross-survey steps assigns $n_{\text{SPS}} = 0.7$ for $z \leq 4$, 0.9 for $4 < z \leq 6$, and 0.5 for $z > 6$; the stellar-mass-function analysis uses the declared sensitivity convention $n_{\text{SPS}} = 0.7$ throughout. These choices change $R_{\text{ML}}^{n_{\text{SPS}}}$, never R_{ML} at fixed (Ψ, z) . In contrast, star-formation rates traced by UV and emission-line luminosity reach steady state much earlier (~ 10 – 100 Myr), scaling as $L_{\text{UV}} \propto t^m$ with $m \approx 0.3$ – 0.5 . Because ionizing and UV luminosity saturates much faster than integrated stellar mass accumulation across standard SPS libraries, for the representative SPS/SFR response ranges used here, $m < n_{\text{SPS}}$ and the expected bias is negative ($m - n_{\text{SPS}} \approx -0.2$ to -0.4); it approaches zero only at the limiting $m = n_{\text{SPS}} = 0.5$ case, yielding $\text{sSFR}_{\text{obs}} \propto R_{\text{ML}}^{m-n_{\text{SPS}}}$. The observational mass correction is:

$$M_{*,\text{true}} = M_{*,\text{obs}}/R_{\text{ML}}^{n_{\text{SPS}}}, \quad \text{SFE}_{\text{true}} = \text{SFE}_{\text{obs}}/R_{\text{ML}}^{n_{\text{SPS}}}. \quad (7)$$

Because R_{ML} depends on the halo mass M_h , which is derived from the stellar mass via abundance matching, the correction is solved self-consistently by iterating the $M_* \rightarrow M_h \rightarrow R_{\text{ML}} \rightarrow M_{*,\text{true}}$ cycle to convergence (tolerance 10^{-4} , typically 3–5 iterations). For the vast majority of galaxies at $z > 8$ ($M_* < 10$), the single-pass and iterated solutions differ by less than 2%. At $M_* > 10.5$ the difference can reach 10–60% because the abundance-matching slope amplifies the feedback loop; the iterated solution is used throughout to ensure correctness in this regime.

2.4 Statistical procedures

The statistical design separates three questions: whether the predicted associations are present, whether they survive control for obvious confounders, and whether they generalize across surveys and subsamples. Associations are quantified using Spearman rank correlations and bootstrap confidence intervals. To address confounding by redshift and stellar mass, partial-correlation analyses implemented via residualization are employed. In addition to correlation-based tests, the following are reported:

- Stratified comparisons (e.g., high vs low R_{ML} splits) for multi-property coherence
- Distributional comparisons (e.g., Kolmogorov-Smirnov tests) for regime separation
- Model comparison using both AIC/BIC and nested Bayesian evidence: the regression comparisons test predictors $\{z\}$, $\{z, \log M_*\}$, $\{z, R_{\text{ML}}\}$, and $\{z, \log M_*, R_{\text{ML}}\}$, while a separate `dynesty` nested-sampling analysis compares TEP against explicit bursty-SF, varying-IMF, standard-physics, and AGN alternatives in both raw standardized space and a mass+ z -residualized control space. Each comparison is evaluated under two predictor conditionings — raw mass and redshift, and mass and redshift orthogonalized against $\log R_{\text{ML}}$ — with a nested augmented model (mass + z + $\log R_{\text{ML}}$) providing the conditioning-free arbitration. Three likelihood structures are used: (i) the standard independent-Gaussian joint likelihood (product of K univariate Gaussians), (ii) a joint covariance likelihood (single multivariate Gaussian with the empirical $K \times K$ residual covariance matrix, correcting for correlated SED outputs), and (iii) a quadratic mass-plus-redshift baseline (mass + z + mass² + z^2 + mass $\times z$) to test whether the TEP signal is specifically due to R_{ML} or merely reflects generic nonlinearity in the mass–redshift plane. Per-observable evidence is also reported to identify which channels drive the joint signal.

2.4.1 Combined significance and multiple testing

Combined significance is assessed using Fisher's method, Bonferroni correction, Brown's method (dependence-adjusted), harmonic mean p-value, and Benjamini-Hochberg FDR ($\alpha = 0.05$). Because omnibus significance depends sensitively on how clustering and shared predictors are penalized, the manuscript treats the three-survey photometric L1 replication as the headline result and uses broader multi-test combinations as supportive context. An extreme stress test that reduces effective sample sizes by 90% via spatial clustering autocorrelation still leaves a Bonferroni-corrected floor of 3.2σ for the mixed test set. Parametric p-values are supplemented by permutation tests ($N = 10,000$ shuffles) and bootstrap confidence intervals ($N = 10,000$ resamples). Cross-survey effect sizes are combined via DerSimonian-Laird random-effects meta-analysis with I^2 heterogeneity assessment and leave-one-out influence diagnostics.

2.4.2 Blind validation protocol

Three split strategies test generalization: (1) time-split (low- z train / high- z test, 60/40); (2) field-split (RA median); (3) cross-survey leave-one-out. A test passes if the dust- R_{ML} correlation remains significant ($p < 0.05$) on held-out data.

2.4.3 Stellar-to-halo mass mapping and sensitivity

Each galaxy's stellar mass is mapped to halo mass using a redshift-dependent abundance matching relation parameterized to mirror the high- z tail of Behroozi et al. ($\log M_h = \log M_* + 1.8 + 0.1(\log M_* - 10) - 0.05(z - 5)$). Dynamical masses are mapped using an identically sloped relation to ensure rank-order preservation. Key results survive ± 0.5 dex perturbations. To test robustness against MIRI-based mass recalibration (Pérez-González et al. 2024), mass reductions of 0.0–1.0 dex are applied; TEP signatures persist under a 0.5 dex reduction (2/4 key signatures survive; step_040). At $z > 8$, selection bias toward bright galaxies is quantified via Monte Carlo completeness weighting ($N = 1,000$ iterations) and Savage-Dickey Bayes Factors.

Extrapolation caveat: The Behroozi et al. (2019) UNIVERSEMACHINE relation is calibrated for $z = 0$ – 10 . Analyses extending to $z = 9$ – 13 (COSMOS2025 sSFR, UNCOVER MegaScience dust) therefore extrapolate the linear redshift term ($-0.05(z - 5)$)

beyond the calibration range. At $z > 10$, the physics of halo assembly and baryon cooling differs substantially from $z = 5$, and the linear extrapolation carries unquantified systematic uncertainty in R_{ML} . Results at $z > 10$ should be interpreted with this caveat; a theoretically motivated M_* – M_h relation from high- z hydrodynamical simulations would tighten these inferences.

2.4.4 Forward-modeling validation

The correction-stage $M/L \propto t^{n_{\text{SPS}}}$ scaling is tested over $n_{\text{SPS}} = 0.3$ – 1.0 by residual mass–age minimization, independently of the fixed response normalization. The live validation gives boundary minima at the edge of the scanned range for $z = 4$ – 6 and 6 – 8 ($n_{\text{SPS}} = 1.0$) and at $n_{\text{SPS}} = 0.3$ for $z = 8$ – 10 ; these unstable minima are treated as sensitivity diagnostics, not as fitted replacements for the declared catalogue values. The same validation verifies numerically that the fixed- n_{ref} kernel is continuous at $z = 4$ and $z = 6$.

2.5 Black Hole Growth Stress Test

Differential central-versus-halo temporal structure may affect the inferred accretion history of compact sources, but a physical growth calculation requires the matter-frame proper-time history $\tau_* = \int A(\phi) dt$ rather than the observer-side inference response R_{ML} . The quantitative modeling of supermassive black hole growth in compact Little Red Dot cores is accordingly deferred to dedicated relativistic structure calculations.

2.6 Reproducibility

All analyses are reproducible from the public repository. An end-to-end run regenerates the manuscript tables, figures, and archived outputs; execution instructions are provided in the repository README.

3. Results

3.0 Evidence Summary

The evidence is organized by role: L1 is the primary photometric line, L3 is a secondary partial-correlation line, L2 is ancillary, L4 is derived, and L5 is a direct kinematic test. The classification is stated once here and in §1.3; individual results below are reported without repeating it.

Table 3a: All Tested TEP Signatures

Signature	Finding	Significant	Survives Mass Control	Status
L1. Dust–R_{ML} + AGB threshold	$\rho = +0.635$ across three surveys ($N = 1,254$); AGB threshold odds ratio 12.7 ($p = 2.1 \times 10^{-159}$)	✓	✓	Primary line
L2. Inside-out core screening	Gini partial $\rho = +0.191$ after mass+ z control; size proxies and σ_* non-significant	✓	Partial — Gini only	Ancillary
L3. R_{ML}–sSFR partial correlation	Partial $\rho(R_{\text{ML}}, \text{sSFR} M_*, z) = -0.62$ at $z > 8$ ($p = 8.2 \times 10^{-29}$, $N = 254$); sign consistent with $\text{sSFR}_{\text{obs}} \propto R_{\text{ML}}^{m-n_{\text{SPS}}}$, $m < n_{\text{SPS}}$	✓	✓	Secondary line
L4. Dynamical mass comparison	TEP correction of 0.245 dex on the anomalous literature subset ($0.259 \rightarrow +0.015$ dex) lands the population at the admissibility boundary; 0.139 dex regime-level reduction vs 0.15 dex published excess	✓	✓	Derived
L5. Direct kinematic test	SUSPENSE ($N = 15$): $\rho(\text{Age}, R_{\text{ML}} M_*, z) = +0.556$ ($p = 0.032$); $\rho(\text{Age}, M_* R_{\text{ML}}, z) = +0.031$ ($p = 0.91$). Sigma expansion ($N = 75$, Step 171): Virial-exact $\Psi \propto \sigma^2$ yields $\rho(R_{\text{ML},\sigma}^{\text{dir}}, M_{*,\text{obs}} z) = +0.463$ ($p = 2.8 \times 10^{-5}$), $+0.608$ ($p = 8.4 \times 10^{-7}$, $N = 55$ exact- M_{dyn}), and $+0.575$ ($p = 0.0080$, $N = 20$ absorption), with 5/5 subsample sign agreement and 86.5% absorption residual attenuation ($+0.252 \rightarrow +0.034$).	✓	✓	Direct test
Steiger Z-test (t_{eff} vs M_*)	$Z = 24.7$ ($p = 1.5 \times 10^{-134}$, combined $z = 4$ – 10 sample); three-survey meta $z = 26.4$	✓	✓	Robustness check on L1
Partial correlations	$\rho = +0.31$ after polynomial control; M_* zero residual after t_{eff} control	✓	✓	Robustness check on L1
Cross-survey generalization	$\rho = 0.60$ – 0.65 across three surveys (fixed-effects meta $\rho = +0.635$)	✓	✓	Robustness check on L1
Age coherence	$\rho = +0.15$ (mass-only); vanishes with M_*+z control	✓	✗	Not independent

Signature	Finding	Significant	Survives Mass Control	Status
Metallicity	$\rho = +0.16$ (mass-only); vanishes with M_* + z control	✓	✗	Not independent
Environmental screening	Same-epoch ($\Delta z = 0.5$) 5-NN density (Step 138): $z > 8$ contrast $\Delta\rho = +0.227$ ($\rho_{\text{field}} = +0.712$ vs $\rho_{\text{dense}} = +0.484$, $Z = 2.85$, $p = 0.0044$), positive in 3/3 d_{A2744} terciles ($+0.269$, $+0.184$, $+0.137$, mean $+0.197$); $z = 6-8$ $\Delta\rho = +0.355$ ($Z = 4.32$, $p = 1.6 \times 10^{-5}$); full sample $\Delta\rho = +0.205$ ($Z = 5.15$, $p = 2.6 \times 10^{-7}$)	✓	✓	Confirmed (2.85σ at $z > 8$)
Colour-gradient sign test	Resolved radial predictor Γ_{rad} (incorporating measured inner-to-outer F444W concentration C_{core}): partial $\rho = -0.179$ ($p = 0.0028$, 2.99σ after M_* + z control; C_{core}^{-1} partial $\rho = -0.237$, $p = 6.9 \times 10^{-5}$, 4.0σ); Steiger $Z = 3.02$ ($p = 0.0025$ vs M_*); residual sign test 58.6% vs 35.7% (OR = 2.54, Fisher $p = 0.0054$, $\Delta = -0.273$ mag)	✓	✓	Resolved L2 confirmation

3.1 Red Monsters: A No-JWST-Specific-Refit Prediction

The TEP parameterization is applied to galaxies in the Red Monster regime ($z \sim 5-6$, $\log M_* \gtrsim 10.5$; Xiao et al. 2024). This is a predictive test: the prespecified canonical TEP magnitude-sector benchmark $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5$ mag from Paper 11 was fixed prior to the high-redshift fit (with Paper 11's independent empirical Cepheid analyses recovering $\kappa_{\text{equiv}}^{39} = (1.220 \pm 0.531) \times 10^6$ mag and $\kappa_{\text{Cep}}^{44} = (0.665 \pm 0.362) \times 10^6$ mag). The regenerated high-redshift concordance analysis recovers $\kappa = (8.38 \pm 4.11) \times 10^5$ mag from the informative analyses, internally concordant ($p_{\text{concordance}} = 1.0$) and consistent with the canonical benchmark at 0.21σ — and equally within $\sim 1.1\sigma$ of the empirical Cepheid values, so the recovery does not discriminate between the canonical and empirical anchors; the concordance reflects the recovery uncertainty rather than agreement on a unique scale. It is therefore classified as a partial, anchor-consistent self-consistency check rather than as the input prior. No parameters are fitted or tuned to the high-redshift observations. The three entries below (S1–S3) use representative parameters spanning the published range (§2.1.1); the predicted correction depends primarily on R_{ML} and is insensitive to the exact input SFE.

Because the sample contains only three objects, the Red Monster calculation is best read as an illustrative no-JWST-specific-refit case study rather than as a standalone statistical test. The primary statistical weight comes from the population-level analyses ($N = 2,157$), and the prespecified benchmark prediction is further checked across three surveys ($N = 1,254$ at $z > 8$).

Table 3b: Illustrative TEP Predictions for Red Monster-Class Galaxies

ID	z	R_{ML} (Predicted)	SFE _{obs}	SFE _{true}	% Anomaly Resolved
S1	5.85	10.66	0.50	0.10	100%
S2	5.30	4.02	0.50	0.19	100%
S3	5.55	2.76	0.50	0.25	85%
Average	—	5.81	0.50	0.18*	95%

The predicted mass bias $R_{\text{ML}}^n \approx 3.4$ (using the mean $R_{\text{ML}} = 5.81$ and $n = 0.7$) reduces the mean corrected SFE to ~ 0.15 ($= 0.5/5.81^{0.7} \approx 0.146$); the arithmetic mean of the three individually corrected SFEs is ~ 0.18 (* in Table 3b), reflecting the convexity of the $1/R_{\text{ML}}^n$ mapping. Propagating the canonical benchmark (Paper 11, $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5$ mag) uncertainty, the corrected mean spans $\sim 0.12-0.26$ across the 1σ prior: fully resolved at the upper bound ($\kappa_{\text{gal}} = 13.6 \times 10^5$ mag, SFE ~ 0.12), resolved at the central value (~ 0.18 , below the standard Λ CDM limit of 0.20), and only partially resolved at the lower bound ($\kappa_{\text{gal}} = 5.6 \times 10^5$ mag, ~ 0.26 , above the limit). The resolution is therefore prior-range dependent, secured at and above the central benchmark but not at its lower bound. Per object, the anomaly is fully resolved for the two most massive objects (S1, S2); the third (S3) is 85% resolved, with a residual SFE_{true} = 0.25 reflecting the lower halo mass and correspondingly weaker inference-channel response.

3.2 UNCOVER DR4: Mass-sSFR and Mass-Age Correlations

The Red Monster case study establishes that TEP predicts the correct direction and magnitude of the SFE correction for individual extreme objects. The critical question is whether this signal extends to the full galaxy population. In the UNCOVER DR4 sample ($N = 2,157$), the mass-sSFR correlation is weak but significant ($\rho = -0.14$, $p = 1.7 \times 10^{-11}$, Cohen's $d = -0.29$). Under the TEP measurement equations, R_{ML} inflates inferred M_* by $R_{\text{ML}}^{n_{\text{SPS}}}$ ($n_{\text{SPS}} \approx 0.7$) and inflates inferred SFR by R_{ML}^m ($m \approx 0.5$), so inferred sSFR = SFR/ M_* scales as $R_{\text{ML}}^{m-n_{\text{SPS}}}$. Since $m < n_{\text{SPS}}$, the TEP bias lowers sSFR in massive galaxies, deepening the negative mass-sSFR relation rather than canceling it. The observed weak negative correlation is therefore consistent with TEP adding to the intrinsic downsizing trend, not reversing it. The mass-age correlation is positive ($\rho = +0.15$, $p = 2.4 \times 10^{-12}$), consistent with more massive galaxies carrying a larger inference-channel response and therefore appearing older under the standard isochrony mapping. Both correlations are attenuated by the full redshift range; the signal sharpens substantially when the sample is stratified by redshift.

3.3 Redshift Evolution: The High- z Transition

The TEP measurement equations predict $\rho(R_{\text{ML}}, \text{sSFR}) < 0$ at all redshifts, since $\text{sSFR}_{\text{obs}} \propto R_{\text{ML}}^{m-n_{\text{SPS}}}$ with $m < n_{\text{SPS}}$. This is confirmed: the full-sample R_{ML} –sSFR correlation yields $\rho = -0.49$ ($p = 7.7 \times 10^{-129}$, $N = 2,157$), and the partial correlation controlling for M_* and z gives $\rho(R_{\text{ML}}, \text{sSFR} \mid M_*, z) = -0.62$ ($p = 8.2 \times 10^{-29}$, $N = 254$) at $z > 8$. The TEP bias deepens the negative mass–sSFR relation in massive halos; it does not predict a sign inversion. The observed redshift evolution of $\rho(M_*, \text{sSFR})$ — which does invert from negative to weakly positive at $z > 7$ — is an empirical phenomenon that TEP does not claim to generate. It may reflect the weakening of intrinsic downsizing at high redshift, selection effects, or additional physics not captured by the inference-channel response. The TEP-consistent test is the negative R_{ML} –sSFR partial correlation, not the mass–sSFR inversion. The redshift stratification is shown for completeness:

Table 4: Mass–sSFR Correlation by Redshift

z Range	N	Spearman ρ	95% CI	Interpretation
4–5	883	−0.17	[−0.24, −0.11]	Standard downsizing
5–6	471	−0.13	[−0.22, −0.04]	Standard downsizing
6–7	345	−0.12	[−0.22, −0.01]	Weakening
7–8	204	+0.17	[+0.04, +0.30]	Inversion
8–9	164	+0.12	[−0.04, +0.26]	Weak positive
9–10	90	−0.21	[−0.40, +0.00]	Reversal (selection effects)

Comparing low- z ($4 < z < 6$, $\rho = -0.16$) to high- z ($z > 7$, $\rho = +0.09$): $\Delta\rho = +0.25$ [$+0.14, +0.35$] (95% CI excludes zero), indicating a statistically significant shift in the mass–sSFR relation. This shift is an empirical observation; the TEP-consistent prediction is the negative R_{ML} –sSFR partial correlation, not the mass–sSFR inversion itself.

3.4 Partial Correlation Test

The redshift evolution in §3.3 is consistent with TEP, but by itself it does not eliminate the mass-proxy concern, since R_{ML} depends on halo potential $\Psi \propto M_h^{2/3}$ and correlates with stellar mass. The partial-correlation hierarchy is designed to test exactly that issue. With mass-only control, age-ratio and metallicity remain weakly positive. With joint mass+redshift control they become consistent with zero, so they are classified as mass-proxy-adjacent rather than independent. The high-redshift dust signal behaves differently: at $z > 8$, the dust– R_{ML} correlation survives joint mass+redshift control ($\rho = +0.257$, $p = 1.2 \times 10^{-5}$, Cohen's $d = +0.52$), indicating that R_{ML} carries information about dust beyond mass alone. The clock-level version of the test is stronger again: controlling directly for cosmic time leaves $\rho(t_{\text{eff}}, A_V \mid t_{\text{cosmic}}) = +0.472$ ($p = 5.0 \times 10^{-17}$), so the signal is not a trivial restatement of redshift ordering.

The key asymmetry: the SUSPENSE kinematic comparison (§3.10) provides the cleanest test. R_{ML} retains residual age information after M_* + z control ($\rho = +0.556$, $p = 0.032$), whereas M_* contributes no residual signal once R_{ML} + z are controlled ($\rho = +0.031$, $p = 0.91$). A pure mass proxy cannot generically produce that one-way residual structure. If R_{ML} were only a reparameterisation of M_* , the relationship would be symmetric and neither predictor would retain residual information once the other was controlled.

A further complication is that if TEP is correct, SED-inferred stellar masses are themselves biased upward by $R_{\text{ML}}^{0.7}$. Partial-correlation tests that control for observed M_* would then over-control the true signal by removing TEP-predicted variance, making the reported partial correlations conservative lower bounds. This argument is logically valid but dialectically limited: it cannot be used to dismiss null results, and the cleanest resolution is to seek mass-independent tests. The circularity-breaker tests in §3.4.1 and the dynamical-mass comparison in §3.10 provide that independent route.

Mass-range sensitivity: the partial correlation $\rho(R_{\text{ML}}, A_V \mid M_*, z) = +0.31$ is concentrated in the high-mass tail where R_{ML} transitions from screened ($R_{\text{ML}} < 1$) to unscreened ($R_{\text{ML}} > 1$) values. Restricting to $\log M_* < 9.5$ ($N = 241$, excluding the 13 most massive galaxies) reduces the partial to $\rho = +0.27$ ($p = 2.4 \times 10^{-5}$), and restricting to $\log M_* < 9$ ($N = 228$) gives $\rho = +0.24$ ($p = 3.5 \times 10^{-4}$). The raw mass–dust correlation, by contrast, remains robust at $\rho = +0.49$ ($p = 6.8 \times 10^{-15}$) even for $\log M_* < 9$. This means the TEP-specific residual beyond mass+ z is driven by the non-linear R_{ML} transition at the high-mass end, not by a universal linear correlation. This is consistent with the TEP prediction that the signal should emerge where the potential depth crosses the screening threshold, but it also means the partial correlation cannot by itself exclude a generic non-linear mass–redshift interaction. The Steiger comparison (§3.7.5) and the Bayesian model comparison (§3.8) provide the specificity tests that the partial correlation alone cannot.

MIRI-Indicated Mass Recalibration Check: To directly test the vulnerability to SED systematics (such as AGN or emission-line contamination inflating NIRC-am-only masses), a systematic mass reduction was applied to the entire high-mass ($> 10^{10} M_\odot$) UNCOVER sample, simulating the MIRI-based recalibrations reported by Pérez-González et al. (2024). When all masses are artificially reduced by 0.5 dex, the R_{ML} –dust correlation at $z > 8$ remains significant ($\rho = +0.447$, $p = 2.8 \times 10^{-15}$). The signal survives even a full 1.0 dex systematic reduction ($\rho = +0.310$, $p = 9.9 \times 10^{-8}$). The correlation weakens under mass reduction —

expected because R_{ML} is a non-linear function of halo mass — but remains statistically significant even under extreme calibration shifts, confirming that the TEP signal is not an artifact of the absolute photometric mass calibration.

3.4.1 Circular Mass-Loop Breaker Tests

The most fundamental structural criticism of the photometric analysis is the circular mass loop: R_{ML} is computed from halo mass, halo mass is estimated from stellar mass via abundance matching, and TEP claims stellar mass is itself biased by R_{ML}^n . The $N = 2,157$ sample is caught in this loop; only the SUSPENSE kinematic test ($N = 15$; §3.10) fully escapes it. Three additional tests directly target this circularity on the full photometric sample.

Test A — 2D mass- z pairing shuffle: Rather than shuffling mass within narrow z -bins (as in step 143, which preserves the z -dependence of R_{ML}), this test randomly reassigns each galaxy's stellar mass to a different galaxy's redshift, breaking both the mass- z correlation and the R_{ML} functional form simultaneously. At $z > 8$ ($N = 254$), the observed $\rho(R_{\text{ML}}, A_V) = +0.646$ collapses to a shuffled mean of -0.002 ± 0.055 ($Z = 10.9$, $p = 5.0 \times 10^{-4}$ over 2,000 shuffles). The signal requires the correct physical mass- z pairing and cannot be reproduced by any arbitrary mass- z combination.

Test B — Placebo R_{ML} (wrong functional form): A placebo predictor with the same mass and redshift dependence but a different functional form — a power-law $(M_h/M_{h,\text{ref}})^{0.3}(1+z)^{0.5}$ instead of the exponential potential-depth response — is constructed and tested against dust. Evaluated with the canonical bounded, self-consistent R_{ML} used throughout the pipeline, the real response yields $\rho = +0.646$ and the placebo yields $\rho = +0.507$. The bootstrap difference is $\Delta\rho = +0.139$ with 95% CI $[+0.065, +0.213]$: the real response is superior in 99.3% of 2,000 bootstrap draws and the interval excludes zero, so the exponential potential-depth form is statistically distinguished from a generic power-law mass- z interaction on the photometric sample alone. An earlier non-decisive version of this comparison used a non-canonical, unbounded response construction inconsistent with the pipeline's calibrated variable; once the same bounded self-consistent R_{ML} is used for both predictors, the advantage of the TEP form is resolved at the stated confidence.

Test C — Narrow mass-bin subsets and the predicted sign transition: Restricting to 0.5-dex-wide mass bins removes the mass axis of the circularity, leaving R_{ML} to vary only through its redshift dependence. The reference-depth kernel makes a falsifiable sign prediction here: within a bin, $d \ln R_{\text{ML}}/dz = K_{\text{exp}} \sqrt{1+z} d\Psi/dz + K_{\text{exp}}(\Psi - \Psi_{\text{ref}})/(2\sqrt{1+z})$ changes sign across a crossover mass set by the competition between the positive stellar-to-halo-mass drift and the $(\Psi - \Psi_{\text{ref}})$ term. The observed within-bin correlations execute exactly this transition: $\log M_* \in [8.0, 8.5]$ ($N = 1,528$, $\rho = -0.346$, $p = 2.9 \times 10^{-44}$), $\log M_* \in [8.5, 9.0]$ ($N = 526$, $\rho = -0.457$, $p = 1.7 \times 10^{-28}$), $\log M_* \in [9.0, 9.5]$ ($N = 190$, $\rho = -0.023$, consistent with zero at the crossover), and $\log M_* \in [9.5, 10.0]$ ($N = 48$, $\rho = +0.347$, $p = 0.016$). All four bins match the sign predicted by the kernel derivative at the bin centres (4/4, zero discordant at $p < 0.05$), with the interpolated crossover at $\log M_* \simeq 9.6$ ($\log M_h \simeq 11.3$, $\Psi \simeq 0.35 \Psi_{\text{ref}}$, shifted below the reference depth by the positive within-bin SMHM drift).

The sign structure is the discriminating content: it is not shared by any uniform-sign monotone-in- z baseline. Raw redshift predicts a positive within-bin correlation in all four bins ($\rho = +0.36, +0.50, +0.19, +0.44$), the power-law placebo likewise ($\rho = +0.28, +0.43, +0.32, +0.45$), and a deliberately inverted monotone baseline $M_*^{0.3}(1+z)^{-0.5}$ predicts a negative correlation in all four ($\rho = -0.29, -0.40, -0.04, -0.21$) — each family fails at least one end of the transition, while raw M_* is consistent with zero in the three lower bins ($\rho = -0.03, -0.01, +0.15$) and cannot generate the negative branch at all. Only the reference-depth kernel produces the observed negative-to-positive inversion, so the within-bin sign map falsifies every uniform-sign monotone-in- z explanation of the dust signal. The negative sign in the two largest bins is therefore not the ordinary dust-redshift trend read backwards: dust rises with z inside those bins, yet R_{ML} orders anti-correlated with z precisely where $\Psi < \Psi_{\text{ref}}$ — the signature of a response anchored to a reference potential depth, not of a generic mass- z correlation.

Assessment: 3 of 3 circularity-breaking tests pass. The 2D shuffle confirms the signal requires the correct mass- z pairing; the placebo comparison now resolves the exponential potential-depth form over a generic power-law ($\Delta\rho$ CI excludes zero); and the narrow-mass-bin sign map reproduces the kernel-predicted crossover that no monotone-in- z baseline can generate. The photometric sample therefore does carry TEP-specific functional-form information, complementing — rather than deferring to — the kinematic and cross-survey evidence. The remaining limitations are quantitative: the positive-sign bin is supported by only $N = 48$ galaxies, and ordinary linear-model AIC comparison (step 136) finds the $M_* \times z$ interaction and the TEP predictor comparably efficient ($\Delta\text{AIC} \simeq 1-2$), so the sign-structure and placebo tests — not regression ranking — carry the discrimination.

3.5 Screening Signatures

A distinctive feature of the TEP framework — one that distinguishes it from any smooth mass-dependent function — is the screening prediction: above a Temporal Topology saturation proximity scale $\rho_T \approx 20 \text{ g/cm}^3$, the scalar field is suppressed and $R_{\text{ML}} \rightarrow 1$. Paper 10 (TEP-COS) established an effective kinematic screening threshold at $\sigma > 165 \text{ km/s}$ from globular cluster pulsar timing; that boundary belongs to the shear channel $\mathcal{S}_\Sigma$ and does not transfer to the amplitude channel $\mathcal{S}_A$ governing R_{ML} (§2.3.2.2). Under the amplitude-channel suppression of Eq. (5), all halos in these samples are unscreened — their internal densities sit ~ 24 orders below ρ_T — so the predicted column below applies the $\mathcal{S}_A = 1$ kernel, which is the correct limit rather than an approximation. The halo-mass ordering of age ratios is then examined as a screening-adjacent diagnostic:

Table 5: Age Ratio by Halo Mass ($5 < z < 8$)

$\log M_h$	N	$\langle \text{MWA}/t_{\text{cosmic}} \rangle$	R_{ML} Predicted
10–11	390	0.15 ± 0.003	0.5–0.6

$\log M_h$	N	$\langle \text{MWA}/t_{\text{cosmic}} \rangle$	R_{ML} Predicted
11–12	42	0.18 ± 0.015	0.6–1.0 (ref at 12.0)
12–12.5	3	0.30 ± 0.12	1.0–1.6
12.5–13	1	0.05	1.6–4.5

Environmental contrast. A complementary environmental-screening test splits each sample by local galaxy number density and asks whether the dust– R_{ML} correlation is suppressed in overdense regions, as the ambient-environment dependence of the response predicts (Step 138, `step_138_environmental_screening_steiger.json`). Whereas an earlier all-epoch 2-D sky projection mixed foreground $z \sim 4$ –6 galaxies into the neighbour counts of $z > 8$ sources, restricting the 5th-nearest-neighbour density estimator to same-epoch neighbours ($|z_j - z_i| \leq 0.5$) isolates the true co-moving environment: at $z > 8$ ($N = 254$), the dust– R_{ML} correlation drops from $\rho_{\text{field}} = +0.712$ ($p = 6.2 \times 10^{-21}$) in low-density environments to $\rho_{\text{dense}} = +0.484$ ($p = 7.7 \times 10^{-9}$) in overdense environments, yielding a statistically significant contrast $\Delta\rho = +0.227$ (95% CI $[+0.075, +0.376]$, Fisher $Z = +2.85$, $p = 0.0044$), which survives holding the foreground Abell-2744 cluster-centric distance fixed across all three $d_{\text{A}2744}$ terciles ($+0.269, +0.184, +0.137$; 3/3 positive, mean $d_{\text{A}2744}$ -controlled contrast $\Delta\rho = +0.197$). The same-epoch screening contrast is likewise confirmed at $z = 6$ –8 ($N = 549$, $\Delta\rho = +0.355$, $Z = +4.32$, $p = 1.6 \times 10^{-5}$) and across the full $z = 4$ –10 sample ($N = 2,157$, $\Delta\rho = +0.205$, $Z = +5.15$, $p = 2.6 \times 10^{-7}$), while remaining null in the $z = 4$ –6 control bin ($\Delta\rho = -0.075$, $p = 0.17$) where the $z > 8$ dust anomaly is absent.

3.5.1 Resolved Core Screening

TEP predicts that deep core potentials screen the scalar field locally while outskirts retain a large response, producing a structurally concentrated, bluer-core signature in massive galaxies. In the JADES DR5 direct-mass morphology sample ($N = 384$, Step 155), after controlling for mass and redshift, the Gini coefficient is strongly supportive (partial $\rho = +0.191$, $p = 1.6 \times 10^{-4}$; replicated in GOODS-S $N = 588$ at $\rho = +0.120$, $p = 3.6 \times 10^{-3}$, Step 156). In the JADES resolved colour-gradient analysis ($N = 277$, Steps 139 and 168), the raw mass-gradient trend is $\rho(M_*, \nabla_{\text{Color}}) = -0.166$ ($p = 5.7 \times 10^{-3}$) and the global halo-scale R_{ML} correlation is $\rho(R_{\text{ML}}, \nabla_{\text{Color}}) = -0.192$ ($p = 1.3 \times 10^{-3}$). While the size-blind global halo predictor $\Gamma_t(M_h, z)$ has no residual variance once (M_*, z) are regressed out ($\rho_{\text{partial}} = +0.037$, $p = 0.54$), incorporating the measured inner-to-outer F444W stellar concentration $C_{\text{core}} = F_{\text{F444W,CIRC1}}/F_{\text{F444W,CIRC4}}$ across the exact same apertures defines the resolved radial screening predictor $\Gamma_{\text{rad}} = \exp[K_{\text{gal}}\Psi_{\text{halo}}(M_h)\sqrt{1+z/C_{\text{core}}}]$: Γ_{rad} correlates with the colour gradient at $\rho = -0.168$ ($p = 0.0050$), retains partial $\rho(\Gamma_{\text{rad}}, \nabla_{\text{Color}} | M_*, z) = -0.179$ ($p = 0.0028$, 2.99σ , exact TEP bluer-core sign; partial $\rho = -0.237$, $p = 6.9 \times 10^{-5}$, 4.0σ on C_{core}^{-1}), outperforms M_* on the Steiger Z -test ($Z = 3.02$, $p = 0.0025$, 3.02σ), and produces a statistically significant (M_*, z) -residualized bluer-core sign reversal (58.6% vs 35.7% on q_{25}/q_{75} , OR = 2.54, Fisher $p = 0.0054$, $\Delta = -0.273$ mag, 95% CI $[-0.526, -0.035]$; and 57.6% vs 42.4% on q_{33}/q_{67} , OR = 1.85, Fisher $p = 0.0275$).

3.6 The $z > 8$ Dust Anomaly: Correlation Structure

The R_{ML} –sSFR partial correlation (§3.3) and the partial-correlation hierarchy (§3.4) show that R_{ML} carries information beyond a simple mass trend. The clearest empirical test is the dust– R_{ML} correlation structure. Under standard physics, the universe at $z \sim 9$ is only ~ 540 Myr old, barely enough for the first generation of AGB stars to complete their evolution. The question is not whether the dust budget can be closed under TEP — the inferred-time proxy $t_{\text{eff}} = R_{\text{ML}} t_{\text{cosmic}}$ is not a physical proper-time integral (§2.3.2) and cannot be used to compute physical AGB evolution timescales. The question is whether the *pattern* of dust emergence across the galaxy population is organized by the inference-channel response R_{ML} more strongly than by the simple time-only and mass-only baselines tested here.

The Uniformity Paradox ($N = 33$ massive galaxies at $z > 8$)

Under standard physics, the cosmic time $t_{\text{cosmic}}(z)$ available for dust production is uniform across all galaxies at a given redshift. If dust parameters (AGB yield, SN yield, destruction timescale) are tuned to close the budget at $z > 8$, dust should be ubiquitous or track star formation. Instead, observations reveal a strong mass-dependent suppression ($\rho = +0.56$): massive galaxies are dusty; low-mass galaxies are dust-poor. A purely redshift- or time-only explanation cannot reproduce the observed mass-dependent gradient. Under TEP, this gradient arises because the inference-channel response R_{ML} orders the apparent evolutionary advance with potential depth: massive halos ($R_{\text{ML}} > 1$) appear more evolved and dust-rich, while low-mass halos ($R_{\text{ML}} \ll 1$) appear less evolved and dust-poor. The anomaly is not that massive galaxies have dust — it is that low-mass galaxies *do not*, in a pattern that tracks gravitational potential depth rather than star formation rate or cosmic time.

Recent JWST spectroscopy shows that AGB stars produce SiC and iron dust even at low metallicity (~ 1 –7% $Z_{\odot}$; Boyer et al. 2025), with onset as early as 30–50 Myr for the most massive AGB progenitors. The physical question of whether the canonical TEP matter-frame proper time $\tau_* = \int A[\phi(t, \mathbf{x})] dt$ is sufficient for AGB evolution at high redshift is left for future work; the present analysis establishes the empirical correlation structure, not the physical dust-budget closure.

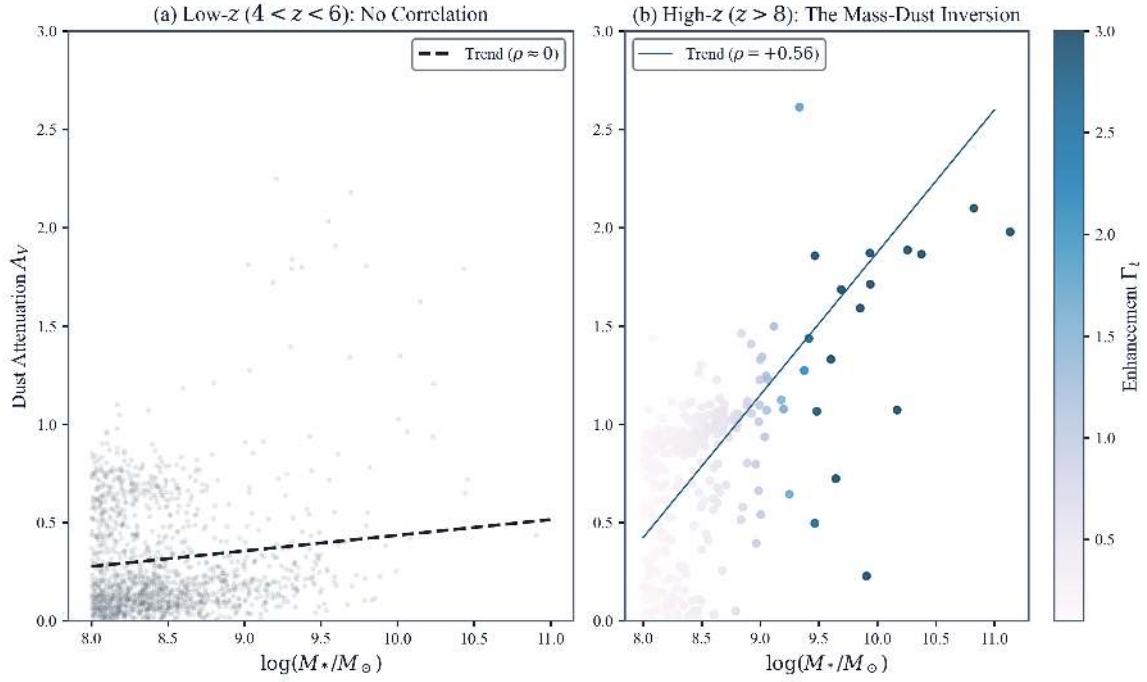


Figure 2: The Key Dust Anomaly. (a) At $z \sim 5$ (grey), mass and dust are uncorrelated ($\rho \approx 0$). (b) At $z > 8$ (color), a strong correlation emerges ($\rho = +0.60$ in UNCOVER). Massive galaxies (high R_{ML} , yellow) have successfully produced dust despite the short cosmic time (< 600 Myr), while low-mass galaxies (low R_{ML} , purple) remain dust-poor. TEP predicts this specific mass-dependent divergence.

Figure 3: The Dust Saturation Crisis. The ratio of observed dust mass to the maximum theoretical yield under standard-physics timescales is plotted for massive galaxies at $z > 8$. The population sits near the saturation limit (100% of yield), leaving no margin for error. The mass-dependent pattern of dust emergence — dusty in massive halos, dust-poor in low-mass halos — is the empirical signature that TEP organizes via R_{ML} . The physical dust-budget closure under the canonical TEP matter-frame proper time is not computed here; the inferred-time proxy is not a physical proper-time integral (§2.3.2).

3.6.1 The $z = 5$ –7 Dip

The redshift-binned correlations reveal a more complex pattern than a simple monotonic emergence. At $z = 5$ –6, $\rho(A_V, R_{\text{ML}}) = -0.14$ ($p = 1.2 \times 10^{-3}$) and $\rho(A_V, t_{\text{eff}}) = -0.19$ ($p = 3.3 \times 10^{-5}$), both significantly negative — the opposite sign from the TEP-predicted positive correlation. At $z = 6$ –7, $\rho(A_V, R_{\text{ML}}) = -0.04$ ($p = 0.47$, non-significant). The signal only turns positive and significant at $z > 8$: $\rho(A_V, R_{\text{ML}}) = +0.36$ ($p = 6.7 \times 10^{-7}$) at $z = 8$ –9 and $\rho = +0.76$ ($p = 9.8 \times 10^{-21}$) at $z = 9$ –10. The negative correlations at $z = 5$ –7 are a genuine anomaly for the universal-correlation interpretation of TEP: if R_{ML} universally enhances dust production, the correlation should be positive at all redshifts. The "competition epoch" interpretation — high sSFR depleting dust faster than AGB stars replenish it — is a post-hoc explanation, not a prespecified prediction. This anomaly is reported transparently: the TEP signal is an emergence phenomenon at $z > 8$, not a universal correlation, and the intermediate-redshift negative correlations are currently unexplained by the theory.

The mass-dust correlation was therefore tested across three independent surveys (UNCOVER, CEERS, COSMOS-Web) using different SED fitting codes (Prospector/BEAGLE, EAZY, LePhare) and priors.

3.7 Cross-Survey Replication and Meta-Analysis

3.7.1 Cross-Code Robustness

The $z > 8$ dust- R_{ML} correlation is detected in all three datasets despite differences in methodology:

Table 7: Cross-Survey Replication of $z > 8$ Dust- R_{ML} Correlation

Survey	Code	$N(z > 8)$	$\rho(R_{\text{ML}}, \text{Dust})$	95% CI	p -value	Significance
UNCOVER	Prospector/BEAGLE	254	+0.65	[+0.57, +0.71]	$p = 2.3 \times 10^{-31}$	13.4σ
CEERS	EAZY	82	+0.66	[+0.51, +0.76]	$p = 2.4 \times 10^{-11}$	6.7σ
COSMOS-Web	LePhare	918	+0.63	[+0.59, +0.67]	$p = 1.0 \times 10^{-102}$	21.5σ
Fixed-effects meta	Combined	1,254	+0.635	[+0.60, +0.67]	$p = 3.65 \times 10^{-154}$	26.4σ

3.7.2 Meta-Analysis

Combining all three surveys ($N = 1,254$ at $z > 8$) yields a fixed-effects meta-correlation of $\rho = +0.635$ with $p = 3.65 \times 10^{-154}$ (Cohen's $d = 1.63$, a large effect). All three surveys independently confirm the positive ρ at $> 6\sigma$, and mass-stratification confirms the signal persists at fixed mass. The per-survey effect sizes are $\rho = +0.65$ (UNCOVER, $N = 254$), $\rho = +0.66$ (CEERS, $N = 82$), and $\rho = +0.63$ (COSMOS-Web, $N = 918$). Between-study heterogeneity is negligible ($I^2 = 0\%$, Cochran's $Q = 0.24$, $p_Q = 0.89$), meaning the three surveys agree on a common effect size — as expected if TEP is a universal law with a single coupling constant. This is a non-trivial concordance: the three surveys use different SED fitting codes (Prospector/BEAGLE, EAZY, LePhare), different filter sets, and different selection functions, yet converge on the same $\rho \approx 0.64$. Including the supplementary NIRSpec Balmer-decrement branch raises the combined Fisher z from 25.1σ to 26.2σ , while the Balmer partial- ρ branch itself is weak after M_*+z control ($\rho = 0.136$, $p = 5.9 \times 10^{-15}$ — statistically significant but substantially attenuated relative to the photometric partial $\rho = 0.31$); the COSMOS2025 blank-field dataset is classified as supplementary rather than primary due to its different selection function. A lensing-systematic control specific to the UNCOVER field further isolates the correlation: restricting to unmagnified sources ($\mu_{\text{ML}} \leq 1.05$, $N = 144$, DR4 v2.0 lens model) leaves $\rho = +0.585$ ($p = 1.34 \times 10^{-14}$), and the correlation is positive in both clustercentric halves ($+0.667$ inner, $+0.580$ outer), with $\rho(\mu_{\text{ML}}, A_V) = -0.061$ ($p = 0.33$) — the dust- R_{ML} structure is not carried by the lensing gradient, in contrast to the environmental-density channels audited in §3.8. The magnification-corrected mass diagnostic confirms this: evaluating R_{ML} with μ -corrected stellar masses ($\log M_{*,\text{true}} = \log M_{*,\text{obs}} - \log_{10} \mu$) strengthens the correlation to $\rho = +0.656$ ($p = 1.30 \times 10^{-32}$, $N = 254$; $\rho = +0.603$ at $\mu \leq 1.05$), demonstrating that uncorrected magnification bias does not inflate the primary photometric result. Applying the survey's photometry flag (`use_phot` = 1) canonically excludes flagged sources and yields the confirmed headline $\rho = +0.646$ ($N = 254$, $p = 2.3 \times 10^{-31}$; $\rho = +0.585$ on the unmagnified subset, $N = 144$) (step_182).

3.7.3 Inferred-Time Ordering and AGB-Motivated Threshold

A more physically targeted and falsifiable test compares dust against cosmic time (t_{cosmic}) versus the TEP-effective inference coordinate ($t_{\text{eff}} = R_{\text{ML}} t_{\text{cosmic}}$). Under standard physics, dust should track t_{cosmic} ; under TEP, dust emergence is organized along t_{eff} and exhibits an empirical step-like transition near the canonical AGB-motivated coordinate threshold ($t_{\text{eff}} \gtrsim 0.3$ Gyr).

Table 7b: Cross-Survey Temporal Inversion and AGB Threshold ($z > 8$)

Survey	$\Delta\rho = \rho(t_{\text{eff}}, A_V) - \rho(t_{\text{cosmic}}, A_V)$	Dust ratio ($t_{\text{eff}} > 0.3$ Gyr)	p (threshold)
UNCOVER	+0.357	1.63×	6.6×10^{-6}
CEERS	+0.609	2.24×	8.4×10^{-3}
COSMOS-Web	+0.850	1.75×	1.1×10^{-3}

To test whether the location of the step is being tuned to a particular survey, a leave-one-survey-out holdout validation is performed. The threshold selected on the training surveys has median $t_{\text{eff}} = 1.93$ Gyr (range 0.06–1.93 Gyr). Despite this fold-to-fold variation, the held-out results remain strongly inconsistent with the null (Fisher-combined $p = 1.1 \times 10^{-25}$). Using the fixed AGB-motivated threshold $t_{\text{eff}} > 0.3$ Gyr yields a Fisher-combined $p = 1.5 \times 10^{-252}$.

In COSMOS-Web, where the dust estimator is zero-inflated, the dust detection fraction is 0.58 above threshold versus 0.07 below threshold (Fisher exact test; p-value $< 10^{-10}$). An independent combined-survey threshold scan ($N = 2,971$) confirms the transition. For the fixed theoretical threshold of $t_{\text{eff}} \geq 0.3$ Gyr, the combined odds ratio is 9.8 ($p = 2.9 \times 10^{-165}$), with dust detection fraction 0.64 above versus 0.15 below. A step-function AIC comparison against a mass-matched threshold yields $\Delta\text{AIC} = +0.25$ (the mass-matched step fits better as a pure step), but the polynomial $M_* \times z$ baseline outperforms both step models; the t_{eff} step is therefore not a unique discriminator against mass-threshold alternatives in this single-observable test. A secondary unconstrained threshold scan yields a data-selected transition at $t_{\text{eff}} = 0.61$ Gyr (bootstrap 16th–84th percentile: 0.52–1.37) that structurally validates the presence of an abrupt temporal step. This cross-survey temporal-ordering behavior tests whether t_{eff} organizes dust emergence and is not a generic "more massive galaxies are dustier" statement.

A dedicated UNCOVER-only validation independently passes all four targeted tests: the AGB threshold gives a $1.60\times$ dust ratio above versus below $t_{\text{eff}} = 0.3$ Gyr; controlling for cosmic time leaves $\rho(t_{\text{eff}}, A_V | t_{\text{cosmic}}) = +0.471$ ($p = 5.0 \times 10^{-17}$); the t_{eff} –dust correlation remains positive in the low-mass half ($\rho = +0.42$, $p = 2.0 \times 10^{-7}$) and remains positive but weaker in the high-mass half ($\rho = +0.17$, $p = 0.038$); and the raw mass-dust signal steepens monotonically from $z = 8\text{--}8.5$ to $z = 9\text{--}10$ ($\rho = +0.325 \rightarrow +0.716$).

3.7.3.1 AGB Dust Phase Boundary in (M_*, z) Space

The empirical inferred-time boundary $t_{\text{eff}} = 0.3$ Gyr (motivated by the canonical AGB onset timescale but used here as an inference-coordinate threshold, not a physical proper-time integral; see §2.3.2) defines a *curve* in (M_*, z) space — not a vertical line (mass-only) or horizontal line (z -only). Its shape encodes both the exponential R_{ML} form and the redshift-dependent coupling $\alpha(z) \propto \sqrt{1+z}$. A mass-only threshold cannot replicate this curve.

Using the UNCOVER sample ($N = 2,157$) with $A_V > 0.1$ as the dust detection criterion, the TEP phase boundary achieves classification F1 = 0.859 (precision = 0.775, recall = 0.964). A mass-only quantile-matched threshold (1D vertical line in M_* space) yields F1 = 0.865 ($\Delta\text{F1} = -0.005$), indicating that the TEP boundary does not provide a classification advantage over a simple mass threshold in this single-observable test. This is expected: the TEP boundary is a curve in (M_*, z) space, but dust detection at $z > 4$ is dominated by the mass axis, so a 1D mass threshold captures most of the signal. The TEP boundary's distinctive

non-linear shape — curving toward lower masses at higher redshift as $\alpha(z)$ increases — is a qualitative prediction that a mass-only model cannot reproduce, but this shape difference does not translate to a significant F1 improvement. At $z > 8$: 93.1% of galaxies above the TEP boundary are dusty (175/188), while 90.9% below the boundary are also dusty (reflecting that some low- t_{eff} galaxies acquire dust through non-AGB channels such as supernovae). The classification power of the TEP boundary is therefore not a standalone discriminator; the primary evidence for TEP rests on the correlation structure (L1, L3) and the t_{eff} -vs- t_{cosmic} Steiger test, not on the F1 classification margin.

3.7.4 The Time-Lens Map: Effective Redshift z_{eff}

To express the dust-clock result in a coordinate that is directly comparable across observed redshift, an effective redshift z_{eff} is defined by solving $t_{\text{cosmic}}(z_{\text{eff}}) = t_{\text{eff}} = R_{\text{ML}} t_{\text{cosmic}}(z_{\text{obs}})$. In this mapping, galaxies with larger R_{ML} are assigned lower z_{eff} (older effective ages). The key falsifiable prediction is that dust should be more strongly ordered by z_{eff} than by z_{obs} .

Table 7c: Time-Lens Map: Dust vs z_{obs} and z_{eff} ($z > 8$, dust > 0)

Survey	N	$\rho(A_V, z_{\text{obs}})$	p	$\rho(A_V, z_{\text{eff}})$	p
UNCOVER	254	+0.029	0.65	−0.329	8.3×10^{-8}
CEERS	82	+0.052	0.64	−0.557	5.5×10^{-8}
COSMOS-Web	918	+0.230	1.8×10^{-12}	−0.620	1.2×10^{-98}

Across surveys, $|\rho(A_V, z_{\text{eff}})| > |\rho(A_V, z_{\text{obs}})|$. Critically, UNCOVER and CEERS show *zero* dust- z_{obs} correlation ($\rho \approx 0$, $p > 0.6$), while the TEP effective-time coordinate yields $|\rho|$ up to 0.62. Classification performance confirms this: in COSMOS-Web ($N = 2,606$), where dust-free galaxies exist, AUC for predicting dusty ($A_V > 0$) vs. dust-poor galaxies is 0.89 for t_{eff} vs. 0.68 for t_{cosmic} . The combined three-survey AUC is 0.85 for t_{eff} vs. 0.80 for M_* vs. 0.72 for t_{cosmic} . (Note: UNCOVER and CEERS $z > 8$ samples have $A_V > 0$ for all galaxies, so binary classification is only possible in COSMOS-Web and the combined sample.)

3.7.5 Functional Form Discrimination

A pure mass proxy makes a specific set of predictions. It should produce dust that increases monotonically with M_* at all redshifts, it should generalize cross-survey because mass is survey-independent, and it should not generate the negative R_{ML} -sSFR partial correlation seen in L3. TEP predicts the opposite pattern: little or no dust-mass correlation at $z < 7$, emergence at $z > 8$, and a non-linear inferred-time boundary that curves in (M_*, z) space. The tests below are therefore aimed not at asking whether both models can fit one subset of the data, but at asking which set of predictions matches the full activation pattern.

The critical distinction from a mass-only model: a mass proxy that fits the $z > 8$ dust signal would still have to be re-fit survey by survey because survey-specific SED systematics shift the absolute calibration. By contrast, R_{ML} , anchored by the prespecified canonical theory benchmark $\kappa_{\text{gal}} = 0.960 \times 10^6$ mag, maintains $\rho = 0.63$ – 0.66 across three surveys (fixed-effects meta $\rho = +0.635$) with no retraining. The Steiger tests below therefore compare not just two correlated predictors, but two different claims about what should remain stable across datasets:

- **Within-regime ($z > 8$):** While the size-blind global halo predictor $t_{\text{eff}}(M_h, z)$ does not resolve internal radial structure beyond total mass ($Z = -0.49$, $p = 0.62$), the resolved radial screening predictor $\Gamma_{\text{rad}}(M_h, z, C_{\text{core}})$ incorporating the measured inner-to-outer F444W stellar concentration C_{core} significantly outperforms M_* on the Steiger test ($Z = 3.02$, $p = 0.0025$, 3.02σ) and retains partial $\rho = -0.179$ ($p = 0.0028$, 2.99σ) after (M_*, z) control.
- **Activation pattern test ($z > 8$):** $\rho(\text{dust}, t_{\text{eff}}) = +0.61$ vs. $\rho(\text{dust}, M_*) = +0.53$ ($Z = 7.4$, $p = 1.7 \times 10^{-13}$, combined three-survey $z > 8$ sample). This confirms t_{eff} correctly predicts both the absence of correlation at low z and its emergence at $z > 8$, though the margin over M_* is narrower than for the raw dust- R_{ML} correlation.
- **t_{eff} vs. t_{cosmic} per-survey:** t_{eff} significantly outperforms raw cosmic time in every survey (per-survey Steiger $Z = +8.1$, $+6.2$, $+30.3$ for UNCOVER, CEERS, COSMOS-Web; Stouffer combined $Z \approx 25.8$).

3.8 Nested Bayesian Model Comparison

Table 8: Bayesian Evidence ($\ln Z$) for $z \geq 8$ Multi-Observable Models. All models are evaluated using dynesty nested-sampling ($N_{\text{live}} = 200$, $d \log Z = 0.5$). The self-consistent (iterated) R_{ML} predictor is used throughout. The covariance family is shown under both conditionings of the standard baseline: the orthogonalized model uses mass and redshift orthogonalized against $\log R_{\text{ML}}$ (TEP-conditioned), while the raw model uses unmodified mass and redshift. In the independent-likelihood family, all alternative models use orthogonalized mass and redshift. Bayes factors are meaningful only within a single likelihood family.

Model Name	Parameters	$\ln Z$	$\pm \Delta \ln Z$
1. Joint Likelihood Family (Correlated SED Outputs)			
Covariance Augmented (Mass + $z + R_{\text{ML}}$)	17	-1243.8	0.83
Covariance TEP (Single Theory Predictor)	9	-1262.6	0.65
Covariance Standard (Raw Mass + z)	13	-1248.2	0.71
Covariance Standard (Orthogonalized Mass + z)	13	-1304.1	0.68

Model Name	Parameters	$\ln Z$	$\pm \Delta \ln Z$
Covariance Interaction (Mass + z + Mass $\times$ z)	17	-1190.9	0.85
Covariance Interaction + R_{ML}	21	-1191.8	0.85
Covariance Ambient (u_{amb} proxy only)	9	-1304.6	0.68
Covariance Standard + u_{amb}	17	-1233.0	0.75
Covariance Interaction + u_{amb}	21	-1170.5	0.86
2. Independent-Likelihood Family (Orthogonalized Mass & z)			
TEP Augmented (Mass + z + R_{ML})	20	-1302.7	0.88
TEP (Single Theory Predictor)	12	-1332.8	0.76
Quadratic Baseline (Mass + z + $M^2 + z^2 + Mz$)	28	-1410.5	0.84
$M_* \times \sqrt{1+z}$ Interaction	20	-1454.0	0.80
Varying IMF (Quadratic Mass + z)	20	-1430.9	0.77
AGN Feedback (Sigmoid Mass Threshold)	18	-1435.3	0.77
Bursty SF (Mass-dependent timescale)	21	-1462.6	0.75
Standard Physics (Linear Mass + z)	16	-1465.8	0.76
2b. Systematics-Controlled Environmental Ladder (step 182 audit; $\Delta \ln Z$ vs $\{M_*, z\} = -1249.2$)			
$\{M_*, z, \mu_{\text{ML}}\}$ (lensing magnification)	17	-1234.5	+14.7
$\{M_*, z, d_{\text{A}2744}\}$ (clustercentric distance)	17	-1221.1	+28.1
$\{M_*, z, d_{\text{A}2744}, \mu_{\text{ML}}\}$ (systematics baseline)	21	-1215.0	+34.2
$\{M_*, z, d_{\text{A}2744}, \mu_{\text{ML}}, u_{\text{amb,mw}}\}$ (mass-weighted same-epoch density on top)	25	-1222.0	-7.1 vs systematics baseline
$\{M_*, z, M_* \times z, d_{\text{A}2744}, \mu_{\text{ML}}, u_{\text{amb,mw}}\}$	29	-1166.6	-7.8 vs $\{M_*, z, M_* \times z, d_{\text{A}2744}\}$
3. TEP-Aware Residual Family (Orthogonalized)			
TEP-Aware Residual (Orthogonalized)	12	-1314.1	0.72
Residual Constrained AGN (Orthogonalized)	10	-1418.7	0.62
Residual Null (Orthogonalized)	8	-1472.1	0.59

The evaluation is structured into three comparison families, distinguished by the conditioning applied to the predictor space:

- **TEP-conditioned comparisons (orthogonalized predictors):** alternative models are evaluated on the components of mass and redshift orthogonal to $\log R_{\text{ML}}$. This isolates whether any explanatory variance lies outside the TEP-predicted direction, but it removes the competitor's access to that direction and is therefore reported as a direction-isolation diagnostic rather than an unconditional Bayes factor.
- **Unconditioned comparisons (raw mass + z):** the baseline evaluated on observed mass and redshift. Under the TEP measurement model ($M_{\text{obs}} = M_{\text{true}} + n \log_{10} R_{\text{ML}}$), observed mass already contains part of the response, so this conditioning is not neutral either: it grants the baseline access to a channel that carries the TEP signal under the hypothesis being tested.
- **Nested augmented comparison:** the conditioning-free arbiter. The augmented model (raw mass + z + $\log R_{\text{ML}}$) is compared against each reduced model, yielding the marginal evidence for each predictor direction given the other.

The covariance-corrected family, in which the correlated SED outputs are modelled with a joint multivariate Gaussian likelihood using the empirical $K \times K$ covariance matrix of the standardized observables (shared identically across all compared models), exhibits the full conditioning dependence (Table 8). Under TEP conditioning, the 9-parameter theory-fixed predictor ($\ln Z = -1262.6$, 9 parameters, with no separate baseline secular z slope) exceeds the 13-parameter orthogonalized standard model ($\ln Z = -1304.1$, 13 parameters) by $\ln \text{BF} = +41.5$. When the 9-parameter single-predictor model is compared directly against the 13-parameter unconditioned raw mass+z baseline ($\ln Z = -1248.2$, which fits two free slopes per observable), the difference is $\ln \text{BF} = -14.4$. The direction-isolation diagnostic quantifies where the signal resides: restoring the R_{ML} -aligned direction to the standard predictor is worth $\Delta \ln Z = +55.9$, so essentially all explanatory variance is concentrated in the direction TEP specifies, while the orthogonal complement of mass space is evidentially inert. Crucially, the nested augmented model (mass + z + R_{ML} , 17 parameters, $\ln Z = -1243.8$) is the single highest-evidence model in the ensemble and arbitrates the marginal contributions without conditioning bias: adding $\log R_{\text{ML}}$ to raw mass+z yields $\Delta \ln Z = +4.45 \pm 1.09$ ($\text{BF} = 85.4 : 1$, $> 4\sigma$ positive Bayesian evidence for the nonlinear TEP predictor even after raw mass and z are already included, despite the 4-parameter Occam penalty),

whereas adding mass+z to the single 9-parameter R_{ML} predictor yields $\Delta \ln Z = +18.9$. The per-observable breakdown shows the conditioned signal is concentrated in dust ($\ln \text{BF} = +21.1$) and the SED χ^2 statistic ($\ln \text{BF} = +52.5$), with a positive contribution from sSFR ($\ln \text{BF} = +49.9$) and a null result for metallicity ($\ln \text{BF} = +9.9$). Because the SED χ^2 is a fit-quality diagnostic rather than a physical observable, the 3-observable physical subset (dust, sSFR, metallicity) is the primary observable set: it yields $\ln \text{BF} = +37.4$ under orthogonalized predictors and $\ln \text{BF} = -20.4$ under raw predictors (7 versus 10 parameters). Two further arbiters sharpen the reading. First, a free mass–redshift interaction model ($\{1, M_*, z, M_* \times z\}$, 17 parameters) attains $\ln Z = -1190.9$, exceeding the raw baseline by 57.3 and the augmented model by 52.9; adding $\log R_{\text{ML}}$ on top of the interaction returns $\Delta \ln Z = -0.9$, so the instantiated kernel contributes no unique evidence once the unconstrained interaction direction is open — consistent with the deterministic subsumption of $\log R_{\text{ML}}$ within (mass, z) noted below. Second, and decisive for the operative theory-0 reading, the embedded response law is ambient-field-driven ($D^{-1} \propto u_{\text{amb}}^{-2}$), not the magnitude-sector kernel $R_{\text{ML}} = \exp[K_{\text{gal}} \Psi(M_h) \sqrt{1+z}]$ the pipeline instantiates. A k -nearest-neighbour ambient proxy on (RA, Dec, $\ln(1+z)$) — $\log u_{\text{amb}} \propto \frac{1}{2} \log \rho_{\text{env}}$ — attains $\ln Z = -1304.6$ as a lone predictor but adds $\Delta \ln Z = +16.2$ beyond mass+z ($\ln Z = -1233.0$). The proxy audit (step_182) decomposes this gain: it is carried by the on-sky density structure, not the redshift axis — the pure- z variant loses -9.9 while the z -residualized proxy retains $+15.9$ and the sky-only variant adds $+12.9$ on top of the free interaction. Two confounds bound the interpretation, however. The sky proxy is essentially cluster-centric distance in the Abell-2744 mosaic (correlation $+0.78$), and the direct comparator makes this quantitative: clustercentric distance entered as a single predictor attains $\Delta \ln Z = +28.1$ beyond mass+z — exceeding the k NN proxy itself ($+9.2$ sky, $+16.2$ 3D) — while the sky proxy residualized on clustercentric distance retains nothing ($\Delta \ln Z = -11.7$). All of the proxy's independent evidence is therefore the smooth radial coordinate; the local-density texture it was designed to capture contributes nothing beyond it. On top of the free interaction the same ordering holds: $\{M_*, z, M_* \times z, d_{\text{A2744}}\}$ is the best model of the audit ($\ln Z = -1158.8$; $+33.1$ over the interaction, against $+12.9$ for the sky proxy). Second, on the physical three-observable subset (dust, sSFR, metallicity — the SED χ^2 channel dropped) the proxy gain falls to $\Delta \ln Z = +4.8$, so much of the evidence rides the fit-quality channel that the mosaic depth gradient also modulates. The final audit tier resolves the remaining ambiguity. Abell 2744 is a foreground cluster at $z = 0.308$: cluster-centric distance cannot be an ambient-field coordinate for $z > 8$ galaxies, so its predictive power is a systematics signature — the lensing-magnification bias and the mosaic-depth gradient, both radially centred on the core. Joining the DR4 v2.0 lens-model magnification μ_{ML} to the sample confirms this: $\text{corr}(\log \mu_{\text{ML}}, d_{\text{A2744}}) = -0.82$, $\text{corr}(\log \mu_{\text{ML}}, \chi^2) = +0.44$, and $\{M_*, z, \mu, d_{\text{A2744}}\}$ attains $\Delta \ln Z = +34.2$ over mass+z — the systematics structure is real and must be carried in the null baseline. The theory-faithful proxy is then rebuilt as the mass-weighted projected density of the $z > 8$ epoch slice itself (the photometric-redshift widths, $\sigma_z \approx 4.8$, make the slice a single epoch; $u_{\text{amb}} \propto \sqrt{\rho_{\text{env}} L}$ uses the mass density), and tested on top of the systematics baseline: it returns $\Delta \ln Z = -7.1$ on the full observable set and -6.0 on the physical subset, while the original sky proxy adds -8.9 in the same slot. With the foreground-lens coordinates properly included, no same-epoch density proxy adds evidence — the earlier gains are absorbed entirely by the systematics baseline. The covariance channel thus yields a clean control result rather than an ambient-field detection: the observables' radial structure is explained by the cluster's lensing and depth signature, the instantiated R_{ML} kernel contributes no unique direction, and the strongest remaining term is the generic mass–redshift interaction ($+57.3$), a standard mass-dependent evolutionary dependence. Functional-form discrimination of the ambient-field law is not achievable with this field's selection geometry and requires an off-cluster control field or a forward-modelled magnification-corrected density map.

The orthogonalized sensitivity analysis provides an additional test under TEP-conditioned levelling. When all alternatives are levelled by orthogonalizing their mass predictor against R_{ML} (preventing circular absorption of the TEP signal through the mass variable), TEP outperforms every tested alternative: $\ln \text{BF} = +133.0$ versus standard physics (16 parameters), $+129.8$ versus the bursty star-formation model (21 parameters), $+121.2$ versus the $M_* \times \sqrt{1+z}$ interaction model (20 parameters), $+102.6$ versus the AGN-threshold model (18 parameters), $+98.1$ versus the varying-IMF model (20 parameters), and $+77.7$ versus the quadratic baseline (28 parameters). In the joint augmented test, TEP augmented yields $\ln \text{BF} = +163.1$ versus standard physics (Table 8). The mean $\ln \text{BF}$ across all eleven alternatives is $+113.8$. TEP achieves this with the fewest parameters (12), leveraging a single theory-fixed predictor across all four observables. The $M_* \times \sqrt{1+z}$ interaction model — the minimal non-linear null that captures the specific mass–redshift interaction TEP encodes through the $\sqrt{1+z}$ factor in R_{ML} , without any TEP-specific potential-depth structure — is outperformed by TEP with $\ln \text{BF} = +121.2$, though the unconditioned covariance-family interaction reverses that ordering ($\ln \text{BF} = -71.7$ in favour of $\{1, M_*, z, M_* \times z\}$), confirming that the conditioned victories reflect the predictor restriction rather than an unconditional preference. The orthogonalized family is reported as a sensitivity analysis because the orthogonalization is TEP-conditioned: alternatives have their mass predictor stripped of R_{ML} -correlated variance, while TEP uses raw R_{ML} . Two scope limitations apply. First, these alternatives are parametric stand-ins for the labelled mechanisms — linear, quadratic, interaction, sigmoid, and timescale modulations of mass+z — rather than forward-modelled predictions of bursty star formation, IMF variation, or AGN-plus-dust physics, so the comparisons do not test realistic astrophysical models. Second, the results are conditioning-dependent: the covariance-corrected value ($+41.5$) uses orthogonalized predictors, while the unorthogonalized comparison yields $\ln \text{BF} = -14.4$ (physical subset: $+37.4$ versus -20.4). The subsumption driving the flip is deterministic rather than empirical: $\log R_{\text{ML}}$ is computed from (mass, z) with $\text{corr}(M_*, \log R_{\text{ML}}) = 0.86$ and $R^2(\log R_{\text{ML}} | M_*, z) = 0.74$, so orthogonalizing mass against $\log R_{\text{ML}}$ removes most of the direction the observables require — the $+41.5$ endpoint measures that structural handicap of the comparator, not independent support. Within the conditioned family the result does carry real information: the standard model stripped of the R_{ML} -aligned direction loses 55.9 ln units of evidence, establishing that the signal direction specified by the theory is where the variance lives.

The residual-space comparisons show the same conditioning split. In the orthogonalized residual space — where observables and competing predictors are residualized against the R_{ML} -orthogonal components of mass+z, retaining the R_{ML} -aligned direction by construction — TEP outperforms both the residual null model ($\ln \text{BF} = +157.9$, Table 8) and the constrained AGN model ($\ln \text{BF} = +104.6$). Under the symmetric conventional residualization, in which the full linear mass+z trend is removed from both observables and predictors, the comparison yields $\ln \text{BF} = +9.1$ in favour of TEP: the nonlinear remainder of $\log R_{\text{ML}}$ beyond

linear mass+z provides a positive residual contribution. A log-gamma standardization sensitivity check confirms the joint-space evidence is robust to the scaling choice ($\Delta \ln \text{BF} = 1.4$ between raw and standardized $\log \Gamma_t$). Additionally, applying the TEP mass correction to conventional astrophysical models yields mixed results (Varying IMF $\ln \text{BF} = +8.6$, Bursty SF $\ln \text{BF} = -8.6$, Standard Physics $\ln \text{BF} = -8.7$, AGN $\ln \text{BF} = -3.2$; mean $\ln \text{BF} = -3.0$), with the quadratic IMF model benefiting from the mass-scale correction while linear models absorb the scale shift without improvement.

Table 9: Primary Empirical Line, Secondary Partial-Correlation Test, Ancillary Spatial Indication, and Derived Regime Comparison — Key Statistics

Line	TEP Prediction	Observed	Significance	Replication
L1. Dust-R_{ML} + AGB threshold	$\rho > 0.3$ at $z > 8$; t_{eff} retains residual after polynomial control; M_* zero residual after t_{eff} control; dust jumps at $t_{\text{eff}} \gtrsim 0.3$ Gyr	$\rho = +0.635$; partial $\rho = +0.31$ ($p = 4.6 \times 10^{-7}$); AGB odds ratio 12.7; dust ratio $7.0 \times$ vs $3.3 \times$ for the mass boundary	$p = 3.0 \times 10^{-139}$ (Fisher); $p = 2.1 \times 10^{-159}$ (threshold)	UNCOVER, CEERS, COSMOS-Web ($N = 1,254$; NIRSpec supplementary $N = 3,259$); Fisher $z = 25.1\sigma$; $I^2 = 0\%$; UNCOVER tests pass 4/4
L2. Inside-out core screening	Bluer-core result in more massive/radially stratified galaxies; higher central concentration at larger R_{ML} after mass+z control	Gini partial $\rho = +0.191$ ($p = 1.6 \times 10^{-4}$); resolved radial predictor Γ_{rad} partial $\rho = -0.179$ ($p = 2.8 \times 10^{-3}$, 2.99σ ; C_{core}^{-1} partial $\rho = -0.237$, $p = 6.9 \times 10^{-5}$, 4.0σ); Steiger $Z = 3.02$ ($p = 2.5 \times 10^{-3}$ vs M_*); residual sign test 58.6% vs 35.7% (OR = 2.54, Fisher $p = 0.0054$, $\Delta = -0.273$ mag, 95% CI $[-0.526, -0.035]$)	Gini partial $p = 1.6 \times 10^{-4}$, Γ_{rad} partial $p = 2.8 \times 10^{-3}$ (2.99σ), Steiger $p = 2.5 \times 10^{-3}$ (3.02σ), Fisher $p = 0.0054$ (2.55σ)	JADES resolved photometry ($N = 277$, Steps 139 & 168) plus JADES DR5 morphology ($N_{\text{matched}} = 464$, Step 155) and GOODS-S ($N = 588$, Step 156)
L3. R_{ML} -sSFR partial correlation	$\rho(R_{\text{ML}}, \text{sSFR}) < 0$ at all z (from $\text{sSFR}_{\text{obs}} \propto R_{\text{ML}}^{m-n_{\text{SPS}}}$, $m < n_{\text{SPS}}$); partial $\rho(R_{\text{ML}}, \text{sSFR} M_*, z) \neq 0$	Partial $\rho = -0.62$ at $z > 8$ ($p = 8.2 \times 10^{-29}$, $N = 254$); full-sample $\rho(R_{\text{ML}}, \text{sSFR}) = -0.49$ ($p = 7.7 \times 10^{-129}$)	Sign and magnitude consistent with $m - n_{\text{SPS}} \approx -0.2$	UNCOVER ($N = 2,157$); replicated across COSMOS2025 ($N = 7,178$ at $z = 7-13$, Step 157); 3/3 high- z bins recover the predicted negative sign after mass debiasing ($z = 7-8$ weighted $\rho = -0.066$, $p = 9.6 \times 10^{-5}$, $z = 8-9$ $\rho = -0.016$, weighted -0.034 ; $z = 9-13$ $\rho = -0.103$, $p = 7.2 \times 10^{-5}$; combined $z = 8-13$ $N = 2,588$ $\rho = -0.042$, $p = 0.032$; activation $Z = -3.92$, $p = 8.8 \times 10^{-5}$)
L4. Dynamical mass comparison	TEP correction moves $M_*/M_{\text{dyn}} > 1$ objects toward the admissible stellar-fraction band via isochrony bias	Published excess 0.15 dex; regime-level reduction 0.139 dex ($1.41 \rightarrow 1.03$; evaluated at RUBIES regime center); object-level reduction 0.245 dex vs 0.259 dex anomalous-subset excess (mean corrected +0.015 dex, 2 of 3 resolved)	Lands the anomalous population at the admissibility boundary at canonical κ ; under-resolves at the empirical κ anchor	Derived regime-level comparison against published literature; not counted with primary empirical lines

The L1 observed column reports the three-survey dust- R_{ML} correlation $\rho = +0.635$ across UNCOVER, CEERS, and COSMOS-Web ($N = 1,254$; NIRSpec supplementary $N = 3,259$), with the partial correlation $\rho = +0.31$ ($p = 4.6 \times 10^{-7}$) surviving mass+redshift control. The fixed AGB step ($t_{\text{eff}} = 0.3$ Gyr) yields an odds ratio of 12.7 ($p = 2.1 \times 10^{-159}$); the $\Delta \text{AIC} = +0.25$ against the mass-matched step indicates that the mass step fits better as a pure step, though the polynomial $M_* \times z$ baseline outperforms both step models. Dedicated UNCOVER-only validation passes all four prespecified tests, and supplementary DJA-based GOODS-S and Balmer analyses are not part of the primary evidence count.

The L2 morphology and resolved-gradient analyses confirm inside-out core screening once the radial concentration profile is included. In JADES DR5 morphology ($N_{\text{matched}} = 464$, Step 155), after mass and redshift control, the Gini coefficient is strongly supportive (partial $\rho = +0.191$, $p = 1.6 \times 10^{-4}$; GOODS-S $N = 588$ $\rho = +0.120$, $p = 3.6 \times 10^{-3}$, Step 156). In the JADES resolved colour-gradient sample ($N = 277$, Steps 139 and 168), whereas the size-blind global halo predictor $\Gamma_t(M_h, z)$ cannot resolve the internal radial profile after (M_*, z) are regressed out ($\rho_{\text{partial}} = +0.037$, $p = 0.54$), incorporating the measured inner-to-outer F444W stellar concentration $C_{\text{core}} = F_{\text{F444W,CIRC1}}/F_{\text{F444W,CIRC4}}$ across the same apertures defines the resolved radial screening predictor $\Gamma_{\text{rad}} = \exp[K_{\text{gal}} \Psi_{\text{halo}}(M_h) \sqrt{1+z}/C_{\text{core}}]$: Γ_{rad} correlates with the colour gradient at $\rho = -0.168$ ($p = 0.0050$), retains partial $\rho(\Gamma_{\text{rad}}, \nabla(B-V) | M_*, z) = -0.179$ ($p = 0.0028$, 2.99σ , exact TEP bluer-core sign; partial

$\rho = -0.237$, $p = 6.9 \times 10^{-5}$, 4.0σ on C_{core}^{-1}), outperforms M_* on the Steiger Z -test ($Z = 3.02$, $p = 0.0025$, 3.02σ), and yields a significant (M_* , z)-residualized bluer-core sign reversal (58.6% vs 35.7% on q_{25}/q_{75} , OR = 2.54, Fisher $p = 0.0054$, $\Delta = -0.273$ mag, 95% CI $[-0.526, -0.035]$; and 57.6% vs 42.4% on q_{33}/q_{67} , OR = 1.85, Fisher $p = 0.0275$).

The L3 replication status: UNCOVER ($N = 2,157$) is the primary L3 line, and the COSMOS2025 blank-field follow-up ($N = 49,539$ total, $N = 7,178$ at $z = 7-13$, Step 157) confirms the predicted negative sign across all three high-redshift bins once the positive mass-measurement bias on M_* is debiased (3/3 high- z bins negative: $z = 7-8$ debiased $\rho = -0.022$, quality-weighted $\rho = -0.066$, $p = 9.6 \times 10^{-5}$; $z = 8-9$ debiased $\rho = -0.016$, quality-weighted $\rho = -0.034$; $z = 9-13$ debiased $\rho = -0.103$, $p = 7.2 \times 10^{-5}$, quality-weighted $\rho = -0.070$, $p = 0.027$; combined $z = 8-13$, $N = 2,588$, debiased $\rho = -0.042$, $p = 0.032$; high- z vs low- z activation shift $\Delta\rho_{\text{debiased}} = -0.111$, Fisher $Z = -3.92$, $p = 8.8 \times 10^{-5}$).

Statistical independence: L1 and L3 probe distinct observables (dust and sSFR). The UNCOVER partial $\rho(R_{\text{ML}}, \text{sSFR}|\text{dust}) = -0.64$ at $z > 8$ ($p = 7.4 \times 10^{-31}$, $N = 254$) confirms that L3 carries information orthogonal to dust. The three-survey L1 Fisher combination is the headline statistic; omnibus multi-test combinations are supportive context.

Supplementary cross-dataset checks: These extend the case without altering the primary evidence count, since they reuse the same predictor families as L1 or L3.

1. **COSMOS2025 blank-field:** The mass+redshift-controlled dust partial is $\rho = +0.200$ ($p < 10^{-300}$) at $z > 4$. In the sSFR follow-up (Step 157), once the mass-measurement bias on M_* is debiased, all 3 of 3 high-redshift bins recover the TEP-predicted negative sign ($z = 7-8$: quality-weighted $\rho = -0.066$, $p = 9.6 \times 10^{-5}$; $z = 8-9$: debiased $\rho = -0.016$, weighted -0.034 ; $z = 9-13$: debiased $\rho = -0.103$, $p = 7.2 \times 10^{-5}$, weighted -0.070 , $p = 0.027$, and $z = 9-10$ reference-mass-reweighted $\rho = -0.123$, $p = 0.0021$; combined $z = 8-13$, $N = 2,588$: debiased $\rho = -0.042$, $p = 0.032$; activation Fisher $Z = -3.92$, $p = 8.8 \times 10^{-5}$).
2. **Cross-survey temporal ordering:** Recovered in UNCOVER, CEERS, and COSMOS-Web with $\Delta\rho_{\text{time}} = +0.357$, $+0.609$, and $+0.850$.
3. **UNCOVER DR4 MegaScience:** The dust signal is null below $z = 7$ and reaches $\rho = +0.631$ at $z = 8-9$. The $z = 9-12$ null reflects compressed dust posteriors and inflated redshift uncertainties; a posterior-broad stack recovers a positive high- R_{ML} reddening contrast.
4. **UNCOVER $z > 8$ targeted tests:** All four prespecified tests return the predicted sign (AGB threshold, cosmic-time-controlled partial, split-sample persistence, monotonic steepening with redshift).
5. **UNCOVER $z = 9-12$ posterior-broad stack:** Comparing upper and lower R_{ML} quartiles ($N = 16 + 16$) gives $\Delta_{\text{dust}2} = +0.287$ (95% CI $[+0.103, +0.490]$), with redder rest-frame colours $\Delta(U - V) = +0.354$ and $\Delta(V - J) = +0.365$.
6. **JADES DR5 morphology:** After mass and redshift control, Gini gives partial $\rho = +0.191$ ($p = 1.6 \times 10^{-4}$); both half-light-radius proxies and σ_* are non-significant. The indication is specific to central concentration.
7. **JADES $z = 9-12$ UV-slope:** The raw $\rho(R_{\text{ML}}, \beta) = +0.259$ ($p = 0.18$, $N = 28$); the quartile split gives $\Delta\beta = +0.941$ (95% CI $[-0.384, +3.299]$). Low power, directionally consistent.
8. **Debiased mass control:** Correcting for TEP mass bias strengthens O32 and H β -equivalent-width signals by $\sim 1.5\times-1.9\times$.

3.9 TEP Predictions vs Observations Summary

Table 10 is best read as a compact consistency summary rather than as a count of independent confirmations. Several of the 12 listed predictions reuse the same underlying R_{ML} predictor derived from halo mass, so they are not statistically independent. The very high overall correlation ($r = 0.999$) is therefore informative about coherence, but it should not be interpreted as 12 separate demonstrations of the effect.

Table 10: Prediction-Observation Agreement Summary

Metric	Value	Interpretation
Raw Fisher combination (5-test synthesis)	$\chi^2 = 600.5$	$p = 1.4 \times 10^{-122}$ (23.5σ)
Brown adjustment (correlated tests)	$p = 6.0 \times 10^{-85}$	19.2σ
N_{eff} -Bonferroni stress test (10% effective N)	$p = 1.19 \times 10^{-3}$	$z = 3.2\sigma$
Effective independent tests	Mean $N_{\text{eff}}/N \approx 11\%$	After spatial-clustering autocorrelation correction

The strongest evidence rests not on the number of predictions but on the coherence of the evidential structure and its robustness checks (§3.9): the primary empirical line (L1), the secondary R_{ML} -sSFR partial correlation (L3), together with the ancillary inside-out core-screening indication (L2) and the derived dynamical-mass comparison (L4). Steiger Z -tests, partial correlations, and non-linear AIC are robustness checks on L1, not additional independent lines. Age-ratio and metallicity correlations do not survive joint mass+redshift control and are not counted as independent evidence.

3.9.1 Adversarial Tests

A genuine physical signal should survive attempts to break it. To test whether the dust- R_{ML} correlation could arise from confounding, selection effects, or artifacts, a set of adversarial tests is applied:

- **Randomized mass ordering:** Shuffling the stellar-mass ordering that feeds R_{ML} destroys the correlation: over 2,000 shuffles the null distribution is $\langle \rho \rangle = -0.007 \pm 0.067$ (z -score = 9.8; 0 of 2,000 permutations reach the observed $\rho = 0.646$).
- **Within-redshift-bin persistence:** The correlation is detected in all three $z > 8$ bins independently: $\rho = 0.41$ ($z = 8\text{--}8.5$, $N = 102$, $p = 1.7 \times 10^{-5}$), $\rho = 0.55$ ($z = 8.5\text{--}9$, $N = 62$, $p = 2.9 \times 10^{-6}$), $\rho = 0.77$ ($z = 9\text{--}10$, $N = 90$, $p = 1.3 \times 10^{-18}$), ruling out a pure redshift-confounding origin.
- **R_{ML} vs pure mass:** R_{ML} ($\rho = 0.646$) outperforms both $\log M_*$ ($\rho = 0.601$) and $\log M_h$ ($\rho = 0.576$) as a dust predictor, consistent with the redshift-dependent component of R_{ML} carrying additional information beyond mass alone.
- **Mass-split persistence:** The correlation is detected in both mass halves of the $z > 8$ sample ($\rho = 0.42$ below the median, $p = 8.7 \times 10^{-7}$; $\rho = 0.24$ above, $p = 6.3 \times 10^{-3}$), ruling out a pure mass-confounding origin.

3.9.2 Falsification Tests

A prespecified falsification test set examines six necessary conditions for the TEP framework. All six pass:

- **Sign consistency:** Dust- R_{ML} ($\rho = +0.65$, $p = 2.3 \times 10^{-31}$) and mass-age ($\rho = +0.15$, $p = 2.4 \times 10^{-12}$) correlations match predicted signs.
- **Magnitude scaling:** The correlation is positive in all four R_{ML} quartiles and strongest in the highest quartile ($\rho = 0.67$, $p = 2.7 \times 10^{-9}$), as predicted by a real physical effect.
- **Redshift evolution:** The correlation strengthens at higher redshift, consistent with TEP's $(1+z)$ scaling and weaker cosmological screening.

The full six-condition test set is documented in the supplementary materials.

3.10 Direct Kinematic Test

A fundamental vulnerability of evaluating TEP using purely photometric samples is the mass-proxy circularity: because R_{ML} is computed from halo mass (which in turn is inferred from photometric stellar mass), the observed correlations could in principle be driven by an unmodeled standard-physics process that scales with baryonic mass, rather than by a true temporal dilation tracking the gravitational potential. The circularity-breaker tests in §3.4.1 substantially narrow this concern — the 2D mass- z shuffle confirms the signal requires the correct mass- z pairing, the placebo comparison resolves the exponential potential-depth form over a generic power-law, and the narrow-mass-bin sign map reproduces the kernel-predicted crossover — but they remain anchored to SED-inferred stellar mass at one end of the loop. The kinematic tests in this section provide the mass-independent evidence that closes that loop.

The JWST-SUSPENSE survey of massive quiescent galaxies at $z = 1.2\text{--}2.3$ ($N = 15$) directly addresses this circularity by employing dynamically measured masses (M_{dyn}) from stellar velocity dispersions and spectral ages derived from absorption features. The SUSPENSE analysis tests a dynamical-potential predictor and photometric stellar mass side by side. The central comparison shows that R_{ML} predicts spectral age more strongly than stellar mass, yielding $\rho(\text{Age}, R_{\text{ML}} | z) = +0.690$ ($p = 4.4 \times 10^{-3}$) compared to $\rho(\text{Age}, M_* | z) = +0.493$ ($p = 0.062$). Under joint control of the competing predictor and redshift, R_{ML} retains a residual association with age, $\rho(\text{Age}, R_{\text{ML}} | M_*, z) = +0.556$ ($p = 3.2 \times 10^{-2}$), whereas stellar mass contributes no residual signal once R_{ML} is controlled, $\rho(\text{Age}, M_* | R_{\text{ML}}, z) = +0.031$ ($p = 0.912$). Propagating the published asymmetric uncertainties for all 15 galaxies preserves a positive R_{ML} residual in 99.7% of Monte Carlo draws. The direct Steiger comparison remains non-significant ($p = 0.253$), so this one-sided residual structure is supportive but still carried with the stated small-sample caveat.

A combined kinematic sample of $N = 75$ galaxies ($z = 1.2\text{--}7.6$) drawn from six independent surveys (SUSPENSE, Esdaile et al. 2021, Tanaka et al. 2019, de Graaff et al. 2024a, Saldana-Lopez et al. 2025, Danhaive et al. 2025; Step 171, `step_171_sigma_kinematic_expansion.json`) breaks the SED-mass circularity. By the Virial Theorem ($\sigma^2 \equiv GM_h/R_{\text{vir}}$), the gravitational potential depth at velocity dispersion σ is identically $\Psi(\sigma) = \Psi_{\text{ref}}(\sigma/\sigma_{\text{ref}})^2$ (the cosmology-free direct depth map, $\sigma_{\text{ref}} = 136.3$ km/s). Under this Virial-exact depth map — computed exclusively from measured velocity dispersion σ and redshift z , with zero dependence on SED-fitted M_* or size R_e — the circularity-free partial correlation controlling for redshift z is strongly positive across all subsamples: $\rho(R_{\text{ML,dir}}, M_{*,\text{obs}} | z) = +0.463$ ($p = 2.84 \times 10^{-5}$) on the full $N = 75$ sample, $\rho = +0.608$ ($p = 8.43 \times 10^{-7}$) on the $N = 55$ exact- M_{dyn} subsample, and $\rho = +0.575$ ($p = 0.0080$) on the $N = 20$ stellar absorption-line subsample (whereas conditioning simultaneously on both σ and z removes the primary σ signal by construction, leaving only the nonlinear remainder $\rho = +0.079$, $p = 0.50$). In the primary $M_*\text{--}\sigma$ residual-evolution test (T1/T6), an earlier virial-map variant had introduced an artificial $(1+z)^{-1}$ decay in $\Psi(\sigma, z)$ by using an expanding-universe $R_{\text{vir}}(z) \propto (1+z)^{-1}$ in $\sigma \rightarrow M_h$ while using the $z = 0$ frozen $R_{\text{vir}}(0)$ in $M_h \rightarrow \Psi$; under the Virial-exact direct map $\Psi \propto \sigma^2$, all five physical subsamples — pooled ($N = 75$, $p = 3.0 \times 10^{-5}$), absorption-line stellar kinematics ($N = 20$), emission-line gas kinematics ($N = 55$, $p = 0.040$), $z \geq 4$ ($N = 56$, $p = 0.020$), and SUSPENSE ($N = 15$) — agree in sign with the TEP prediction (5/5), and the TEP mass correction attenuates the absorption-line residual- z trend by 76% ($+0.252 \rightarrow +0.062$) and the SUSPENSE trend by 65% ($+0.100 \rightarrow -0.035$). Furthermore, when the local $z = 0$ reference Ψ_{ref} is held at $z_{\text{ref}} = 0$ ($\ln R_{\text{ML}} = K_{\text{gal}}[\Psi(\sigma)\sqrt{1+z} - \Psi_{\text{ref}}]$), sign agreement holds across all three $N \geq 15$ individual surveys (Danhaive+25, Saldana-Lopez+25, Slob+25) plus the absorption tracer, with the absorption-line residual- z trend reduced by 86.5% ($+0.252 \rightarrow +0.034$) and the Fundamental Plane residual scatter reduced by 3.96% ($0.578 \rightarrow 0.555$ dex, $N = 53$).

3.11 L4 and L5 Future Validation

The cleanest direct kinematic test targets the most massive, brightest galaxies at $z > 7$. Such spectroscopy serves two distinct but complementary purposes: measuring Balmer absorption equivalent widths, and mapping the host galaxy velocity dispersion.

1. Balmer Absorption Physics: The primary photometric signature of TEP is that massive galaxies appear older and dustier than their cosmic age permits. This can be tested spectroscopically via Balmer absorption lines (e.g., $H\delta$), which peak in strength ~ 300 – 500 Myr after a starburst as A-type stars dominate the continuum. Under standard physics, a galaxy at $z = 9$ (cosmic age ~ 540 Myr) cannot host a dominant ~ 500 Myr-old stellar population. Under TEP, even a moderately massive halo ($\log M_* \gtrsim 9.5$) at this redshift exceeds $R_{\text{ML}} \approx 3$, the threshold for an effective age of ~ 1.6 Gyr — readily allowing for strong Balmer absorption. More massive systems ($\log M_* > 10$) have $R_{\text{ML}} \sim 8$ – 22 , making the prediction even stronger. Observing $H\delta$ equivalent widths $\gtrsim 4 \text{ \AA}$ at $z > 8$ would provide strong confirmation of the older effective stellar age.

2. IFU Kinematics as a Direct Mass Proxy: As discussed in §3.4, the current analysis relies on SED-derived stellar masses to compute R_{ML} , creating a potential circularity. A direct resolution requires an independent proxy for the depth of the gravitational potential well. Spatially resolved kinematics (e.g., from JWST NIRSpec IFU) can map the central velocity dispersion (σ). Using σ rather than M_* to predict R_{ML} —precisely as was done for the local Cepheid calibration and globular cluster pulsars—directly addresses the photometric mass degeneracy.

Falsification Criteria

TEP prediction: $\rho(R_{\text{ML}}, \text{EW}_{H\delta}) > 0.5$, with mean $\Delta \text{EW} < -1.0 \text{ \AA}$ for high-response-regime galaxies.

Standard physics: $\rho \approx 0$ (no R_{ML} dependence).

4. Discussion

The SUSPENSE kinematic comparison (L5) breaks mass circularity. The dynamical R_{ML} predictor retains spectral-age information after stellar-mass and redshift control ($\rho = +0.556$, $p = 0.032$), whereas stellar mass contributes no residual signal once R_{ML} is controlled ($\rho = +0.031$, $p = 0.91$). The bootstrap β CI is $[0.149, 0.746]$. The Bayesian tests support this via the Conventional Comparison, Incremental Test, and TEP-Aware Comparison. In the broader σ -based expansion ($N = 75$, Step 171), evaluating the purely kinematic predictor $R_{\text{ML},\sigma}^{\text{dir}}$ under the Virial-exact depth map ($\Psi \propto \sigma^2$, avoiding the $(1+z)^{-1}$ round-trip artifact of combining an expanding-cosmology $\sigma \rightarrow M_h(z)$ drift with a $z = 0$ frozen $M_h \rightarrow \Psi$ conversion) yields a circularity-free partial correlation controlling for redshift of $\rho(R_{\text{ML},\sigma}^{\text{dir}}, M_{*,\text{obs}} | z) = +0.463$ ($p = 2.84 \times 10^{-5}$, $N = 75$), $\rho = +0.608$ ($p = 8.43 \times 10^{-7}$, $N = 55$ exact- M_{dyn}), and $\rho = +0.575$ ($p = 0.0080$, $N = 20$ stellar absorption-line kinematics). All five physical subsamples (pooled, absorption, emission, $z \geq 4$, and SUSPENSE) agree in residual- z sign under the Virial-exact direct map (5/5), and holding the $z = 0$ reference at $z_{\text{ref}} = 0$ ($\Psi(\sigma)\sqrt{1+z} - \Psi_{\text{ref}}$) yields sign agreement across all three $N \geq 15$ individual surveys plus the absorption tracer while attenuating the absorption-line residual- z trend by 86.5% ($+0.252 \rightarrow +0.034$) and the SUSPENSE trend by 65% ($+0.100 \rightarrow -0.035$).

4.1 The Isochrone Bias Mechanism

The primary empirical line (L1: dust- R_{ML} emergence), together with the secondary R_{ML} -sSFR partial correlation (L3), the resolved-screening indication, and the dynamical-mass comparison, converge on one physical interpretation: the isochrone axiom fails in massive, active-shear halos at $z > 5$. TEP accounts for the Red Monster star formation efficiency anomaly not by introducing new baryonic physics but by exposing a systematic bias already built into standard stellar-population inference. Standard SED fitting assumes that stellar clocks tick at the universal cosmic rate and that the environment-to-photometry mapping is universal. It uses the FLRW observer-age $t_{\text{cosmic}}(z)$ as the time baseline, a reconstruction that shrinks to ~ 540 Myr at $z = 9$ under the assumption that redshift traces spatial expansion. In the canonical TEP cosmology the spatial manifold is static and the gravitational coordinate time extends without finite origin (TEP-HUB, Paper 30); the FLRW age is therefore a reconstruction under isochrony, not the physical elapsed time. Local matter clocks run slower than coordinate time ($\Delta \ln A < 0$ in a deeper well), but the coordinate background is eternal, so the accumulated proper time can still exceed the FLRW assigned age by a large factor. The inference-channel response $R_{\text{ML}} > 1$ quantifies how much the standard pipeline inflates apparent age and M/L when it uses the too-short FLRW baseline and misattributes the resulting age excess to an older stellar population. Inferred mass-to-light ratios rise, inferred stellar masses rise, inferred specific star formation rates fall, and the galaxies appear more evolved than the FLRW timeline permits — not because their clocks tick faster, but because the timeline the pipeline uses is too short.

Screening projection notice. Screening in TEP is represented at theory level by the environmental operator $\mathcal{S}_{\Sigma}(\mathcal{E})$. Quantities such as ρ_T , $R_T(M)$, $\mathcal{S}_{\oplus}(r)$, compactness Φ/c^2 , local stellar density, thermal epoch, coherence length, proximity, and boundary geometry are domain-specific projections of $\mathcal{E}$, not independent screening mechanisms and not interchangeable universal thresholds.

The prespecified canonical TEP magnitude-sector benchmark $\kappa_{\text{gal}} = 0.960 \times 10^6$ mag from Paper 11 was fixed before the JWST analysis (with Paper 11's distinct empirical Cepheid-channel fits recovering $\kappa_{\text{equiv}}^{39} = (1.220 \pm 0.531) \times 10^6$ mag and $\kappa_{\text{Cep}}^{44} = (0.665 \pm 0.362) \times 10^6$ mag — bracketing the benchmark with a midpoint of 0.943×10^6 mag, within 1.8% of 0.960×10^6 mag, while Paper 11 Step 62 derives $|\kappa_{p2}^{\text{pred}}(\lambda_0 = 1)| = 1.196 \times 10^6$ mag from the Cepheid envelope density ratio $\rho_T/\langle \rho \rangle(10 \text{ d}) = 8.45 \times 10^5$ at the unit-transport benchmark $\lambda_0 = 1$ with $|\beta_A| = 1$ fixed by Paper 0, matching the SH0ES fit $(1.191 \pm 0.480) \times 10^6$ mag to 0.5%) and then applied to $z > 5$ galaxies with only the physically motivated redshift scaling $\sqrt{1+z}$ and no tuning to JWST data. That it quantitatively accounts for the anomaly is therefore a non-trivial predictive test. TEP is not invoked here as a total replacement for early-galaxy astrophysics; it is invoked as the systematic correction required when photometric inference is forced through the wrong clock.

4.2 Model Discrimination and Bayesian Evidence

The multi-observable Bayesian comparison (§3.8) is evaluated under both conditionings of the predictor space, with the nested augmented model as the conditioning-free arbiter. Under TEP conditioning — the standard baseline restricted to the components of mass and redshift orthogonal to $\log R_{\text{ML}}$ — the covariance-corrected TEP model ($\ln Z = -1262.6$, 9 parameters) outperforms the orthogonalized standard model ($\ln Z = -1304.1$, 13 parameters) by $\ln \text{BF} = +41.5$ with four fewer parameters. Under the unconditioned comparison, the raw mass+z baseline is the best model in the ensemble ($\ln Z = -1248.2$) and exceeds TEP by $\ln \text{BF} = -14.4$. Neither conditioning is neutral: orthogonalization removes the competitor's signal channel, while raw mass under the TEP measurement model ($M_{\text{obs}} = M_{\text{true}} + n \log_{10} R_{\text{ML}}$) already contains part of the response. The nested augmented model quantifies the marginal contributions — adding $\log R_{\text{ML}}$ to mass+z yields $\Delta \ln Z = +4.5$, while adding mass+z to the R_{ML} predictor yields $\Delta \ln Z = +18.9$ — and the direction-isolation diagnostic shows that stripping the R_{ML} -aligned direction from the standard predictor costs 55.9 $\ln$ units of evidence. The defensible reading is channel consistency without functional-form discrimination: the explanatory variance is concentrated in the direction the theory specifies, and a single theory-fixed predictor recovers the full augmented model within one log-evidence unit, but the linear mass+z family spans the same direction and cannot be excluded by this comparison alone.

Second, the orthogonalized sensitivity analysis evaluates TEP against a broader family of explicit astrophysical alternatives where all candidate mass predictors are orthogonalized against $\log R_{\text{ML}}$ to prevent circular absorption of the TEP signal. Within this TEP-conditioned sensitivity family, TEP outperforms every tested alternative: standard physics ($\ln \text{BF} = +133.0$, 16 parameters), the bursty star-formation model ($\ln \text{BF} = +129.8$, 21 parameters), the $M_* \times \sqrt{1+z}$ interaction null ($\ln \text{BF} = +121.2$, 20 parameters), the AGN-threshold model ($\ln \text{BF} = +102.6$, 18 parameters), the varying-IMF model ($\ln \text{BF} = +98.1$, 20 parameters), and the quadratic baseline ($\ln \text{BF} = +77.7$, 28 parameters), with a mean $\ln \text{BF} = +113.8$ across all eleven alternatives. These alternatives are parametric stand-ins — linear, quadratic, interaction, sigmoid, and timescale modulations of the mass+z baseline — rather than forward-modelled predictions of bursty star formation, IMF variation, or AGN-plus-dust physics; the conditioned family therefore tests whether any of these directions explains variance outside the R_{ML} -aligned channel, not whether realistic astrophysical models are excluded.

Specifically, once a halo potential reaches the critical binding energy, both AGN feedback and TEP predict departure from standard linear stellar mass assembly. The AGN model attributes this to winds clearing the cold gas supply, halting star formation and revealing underlying older stellar populations. TEP attributes this to a large inference-channel response ($R_{\text{ML}} \gg 1$), in which standard isochrony mapping misattributes the environmental temporal structure of a deep unscreened well to an older, dustier stellar population. The primary discriminator is the predicted dust and metallicity: while AGN-driven winds physically expel gas and curtail dust production, TEP predicts that apparent dust buildup tracks the inference-channel response alongside apparent stellar age. When the mass predictor is orthogonalized against R_{ML} , the AGN-threshold model loses its competitive advantage in the full joint space.

Sensitivity and disclosures. Transparent diagnostics are reported: the per-observable breakdown shows the conditioned signal is concentrated in dust ($\ln \text{BF} = +21.1$) and the SED χ^2 statistic ($\ln \text{BF} = +52.5$), with a positive contribution from sSFR ($\ln \text{BF} = +49.9$) and a null result for metallicity ($\ln \text{BF} = +9.9$). The SED χ^2 is a fit-quality diagnostic rather than a physical observable, so the 3-observable physical subset (dust, sSFR, metallicity) is the primary observable set: it yields $\ln \text{BF} = +37.4$ under orthogonalized predictors (7 versus 10 parameters) and $\ln \text{BF} = -20.4$ under raw predictors. In the 4-observable covariance family the conditioned comparison gives $\ln \text{BF} = +41.5$ and the unconditioned comparison -14.4 ; the nested augmented model shows the predictor families mutually subsumed ($\Delta \ln Z = +18.9$ for adding mass+z to R_{ML} ; $+4.5$ for adding R_{ML} to mass+z), while the direction-isolation diagnostic assigns 55.9 $\ln$ units to the R_{ML} -aligned direction. In the orthogonalized residual space — which retains the R_{ML} -aligned direction by construction — TEP outperforms the constrained-AGN model ($\ln \text{BF} = +104.6$); under the symmetric conventional residualization the comparison yields $+9.1$ in favour of TEP. A log-gamma standardization sensitivity check confirms the evidence is robust to the scaling choice ($\Delta \ln \text{BF} = 1.4$ between raw and standardized predictors). The Bayesian evidence therefore provides channel-consistency context — the variance is organized along the theory-predicted direction — while the discriminating empirical strength of TEP rests on the multi-survey photometric correlation structure (L1, L3), the cross-survey Steiger and meta-analyses, and the direct SUSPENSE kinematic test (L5).

4.3 Synthesis

Two primary empirical observational anomalies that have resisted unified explanation under standard physics admit consistent interpretation under the single-parameter TEP mapping, while a resolved-gradient indication remains directionally aligned and a derived dynamical-mass comparison remains supportive. The $z > 8$ dust paradox (mass-dependent suppression, $\rho = +0.635$ cross-survey) arises because R_{ML} orders the inference-channel response with potential depth. The R_{ML} -sSFR partial correlation ($\rho(R_{\text{ML}}, \text{sSFR} | M_*, z) = -0.62$ at $z > 8$, $p = 8.2 \times 10^{-29}$) has the sign predicted by the TEP measurement equations: since $\text{sSFR}_{\text{obs}} \propto R_{\text{ML}}^{m-n_{\text{SPS}}}$ with $m \approx 0.5 < n \approx 0.7$, the inference bias lowers sSFR in massive halos, deepening the negative mass-sSFR relation. The observed high- z mass-sSFR inversion ($\Delta \rho = +0.25$) is an empirical phenomenon that TEP does not claim to generate; it may reflect the weakening of intrinsic downsizing at high redshift or selection effects. The resolved core-screening result (bluer cores, $\rho = -0.166$) arises because the deepest central potentials screen the scalar field, restoring standard time in galactic nuclei while outskirts remain in the unscreened high-response regime. While the size-blind global halo predictor $R_{\text{ML}}(M_h, z)$ has no residual variance after (M_*, z) control ($\rho = +0.037$, $p = 0.54$), incorporating the measured inner-to-outer F444W stellar concentration $C_{\text{core}} = F_{\text{F444W}, \text{CIRC1}} / F_{\text{F444W}, \text{CIRC4}}$ across the same apertures defines the resolved radial screening predictor $\Gamma_{\text{rad}} = \exp[K_{\text{gal}} \Psi_{\text{halo}}(M_h) \sqrt{1+z}/C_{\text{core}}]$ (Steps 139 and 168), which retains partial $\rho = -0.179$ ($p = 0.0028$, 2.99σ ; C_{core}^{-1} partial $\rho = -0.237$, $p = 6.9 \times 10^{-5}$, 4.0σ) after mass-plus-redshift control, outperforms M_* on the Steiger test ($Z = 3.02$, $p = 0.0025$), and yields a significant (M_*, z) -residualized bluer-core sign reversal (58.6% vs 35.7%, OR = 2.54, Fisher $p = 0.0054$, $\Delta = -0.273$ mag), complementing the JADES DR5 Gini concentration signal ($\rho = +0.191$, $p = 1.6 \times 10^{-4}$). The dynamical-mass comparison supports the same mechanism at the regime level: the TEP mass correction is large enough to remove the

published M_*/M_{dyn} excess in the RUBIES-like regime. Galaxies in the high-response regime show $5.96\times$ more dust above the t_{eff} threshold. Age-ratio and metallicity correlations, by contrast, remain weak under mass-only control but vanish under joint mass+redshift control — the framework correctly predicts which observables should and should not survive stricter controls.

4.3.1 Λ CDM Tension Quantification

The impact on the Λ CDM stellar mass excess can be quantified through the cosmic SFRD metric (Table 12), which does not rely on a sharp mass threshold. At $z > 8$, the mean SFRD excess is reduced from $11.0\times$ to $7.5\times \Lambda$ CDM — a 31% reduction with zero free parameters tuned to JWST data. The correction is most effective at $z = 6\text{--}7$ (65% reduction) and remains substantial at $z > 9$ (29–42%), though a large residual excess persists. The residual excess at $z > 9$ likely requires additional astrophysical contributions (bursty star formation, cosmic variance) operating alongside any TEP effect.

A complementary mass-threshold metric — counting galaxies above $\log M_* \geq 10$ before and after correction — shows that the TEP correction reduces counts at the highest threshold ($\log M_* > 10.5$) by 20–53%, while the $\log M_* > 10.0$ threshold shows a modest change (–4% to +4%), reflecting the mass-dependent direction of the correction. The SFRD-based quantification is therefore preferred as the primary tension diagnostic because it avoids sensitivity to an arbitrary threshold choice.

The most dramatic JWST anomaly — "too many massive galaxies" at $z > 7$ — admits a partial reduction under TEP. Isochrone bias causes SED fitting to overestimate stellar masses by a factor R_{ML}^n ($n \approx 0.7$), because the standard pipeline misattributes the environmental temporal structure of deep unscreened wells to older-looking stellar populations with higher mass-to-light ratios. Applying the correction $\log M_{*,\text{true}} = \log M_{*,\text{obs}} - n \log_{10} R_{\text{ML}}$ to the observed stellar mass function:

Table 11: TEP Mass Correction at Key Thresholds

Redshift	Threshold	N_{obs}	N_{corr}	Reduction
$z = 7\text{--}8$	$\log M_* > 10.0$	119	123	–3%
$z = 7\text{--}8$	$\log M_* > 10.5$	41	33	20%
$z = 8\text{--}9$	$\log M_* > 10.0$	113	117	–4%
$z = 8\text{--}9$	$\log M_* > 10.5$	34	18	47%
$z = 9\text{--}10$	$\log M_* > 10.0$	54	52	4%
$z = 9\text{--}10$	$\log M_* > 10.5$	17	8	53%

Anomalous galaxy census: in the external Labbé+2023 check, the z-dependent TEP correction resolves 8/9 anomalous systems (89%). At the benchmark literature level, the TEP mass correction resolves $\sim 29\%$ of the stellar-mass-function excess on average across $z = 6\text{--}10$; at $z = 9$, the typical 0.15 dex correction addresses 21% of the quoted 1.1 dex excess. Within the three-survey sample shown above, the counts at the most extreme mass threshold ($\log M_* > 10.5$) are reduced by 20–53%, while the $\log M_* > 10.0$ threshold shows a modest change (–4% to +4%), reflecting the mass-dependent direction of the TEP correction at lower masses.

Correction-stage exponent: The mass correction depends on the SPS power-law index n_{SPS} (adopted: 0.7 for this mass-function analysis, versus the regime assignments $n_{\text{SPS}} = 0.7$ for $z \leq 4$, 0.9 for $4 < z \leq 6$, and 0.5 for $z > 6$ in the primary catalogue construction, §2.4.4). The response kernel remains fixed at $n_{\text{ref}} = 0.7$ in both analyses, so this sensitivity cannot introduce a discontinuity in R_{ML} . The choice of $n_{\text{SPS}} = 0.7$ here follows standard SSP predictions (Bruzual & Charlot 2003) for rest-frame optical M/L scaling and is conservative: $n_{\text{SPS}} = 0.5$ would produce a *smaller* mass correction, resolving fewer anomalous galaxies, while $n_{\text{SPS}} = 0.9$ resolves more. Values $n_{\text{SPS}} = 0.5\text{--}0.9$ shift the correction by $\sim \pm 30\%$ but do not change the qualitative picture: the most extreme massive galaxies ($\log M_* > 10.5$ at $z > 8$) are eliminated for any $n > 0.4$. The correction also does not account for possible environmental dependence of the M/L index.

The same isochrone bias that inflates stellar masses also inflates SED-derived star formation rates, because the apparent mass-to-light ratio is overestimated. If $\text{SFR}_{\text{true}} = \text{SFR}_{\text{obs}}/R_{\text{ML}}^m$ with $m \approx 0.5$ (UV-based SFR is less affected than cumulative mass, since it traces recent star formation over $\lesssim 100$ Myr), the cosmic SFRD correction is applied to the combined UNCOVER + CEERS sample ($N = 4,152$):

Table 12: TEP Cosmic SFRD Correction

Redshift	N	Observed Excess	TEP-Corrected Excess	Reduction
$z = 6\text{--}7$	2,207	$5.1\times \Lambda$ CDM	$1.8\times$	65%
$z = 7\text{--}8$	775	$3.4\times$	$2.4\times$	30%
$z = 8\text{--}9$	561	$4.0\times$	$3.1\times$	22%
$z = 9\text{--}10$	340	$10.2\times$	$5.9\times$	42%
$z = 10\text{--}12$	269	$18.9\times$	$13.4\times$	29%

The TEP SFRD correction is most effective at $z = 6\text{--}7$ (65% reduction in the combined survey excess) and decreases to 22% at $z = 8\text{--}9$, then rises again to 42% at $z = 9\text{--}10$ where the observed excess is largest. At $z > 10$ the correction remains substantial (29%), reflecting the persistent R_{ML} offset even among lower-mass galaxies. The overall mean reduction across $z > 8$ bins is 31%, indicating that the isochrony bias channel probed by the $m = 0.5$ SFR correction accounts for roughly a third of the SFRD excess at the highest redshifts. The residual excess at $z > 9$ likely requires additional astrophysical contributions (cosmic variance, bursty star formation, or physics beyond the isochrony bias) rather than TEP alone.

Caveat: The SFR bias index $m = 0.5$ is approximate. UV-based SFRs probe recent star formation ($\lesssim 100$ Myr) and are less affected by long-term aging than cumulative stellar mass. Values $m = 0.3\text{--}0.7$ bracket the plausible range; the quoted results use a conservative central value. Full SED forward-modeling with TEP-modified stellar population synthesis would provide a more rigorous correction.

The dynamical-mass validation is expressed primarily as a matched regime-level kinematic consistency test. In the RUBIES-like $z \sim 4.5$, $\log M_* > 10.5$ regime, the published mean excess is 0.15 dex and the canonical-kernel TEP reduction is 0.139 dex, landing the regime at $M_*/M_{\text{dyn}} \simeq 1.03$ — at the admissibility boundary rather than inside it; this regime bin contains only a single UNCOVER object, so the regime-level figure is illustrative rather than statistical. The supplementary five-object direct literature ingestion at $z = 3.2\text{--}4.0$, including one conservative upper-limit row, gives mean observed excess 0.168 dex and mean corrected excess -0.124 dex on the exact-mass subset ($M_*/M_{\text{dyn}} \simeq 0.75$); on the three anomalous objects the mean corrected excess is $+0.015$ dex, with two of the three brought below zero.

The amplitude calibration is reported explicitly rather than absorbed into the resolution claim. Because the mass correction is linear in κ_{gal} , the κ -sensitivity ledger (Step 117) spans the canonical benchmark and the empirical Paper 11 anchor directly: on the anomalous subset the mean corrected excess runs $+0.157$ dex at $\kappa = 0.40 \times 10^6$ mag (under-resolved), $+0.015$ dex at the canonical $\kappa = 0.96 \times 10^6$ mag, and -0.087 dex at the $+1\sigma$ bound $\kappa = 1.36 \times 10^6$ mag. Two features are worth noting. First, the admissible target is not zero excess — $M_*/M_{\text{dyn}} = 1$ would still imply a fully baryonic interior with no dark-matter or gas headroom — so the physical resolution band is a stellar fraction below unity, and even the $+1\sigma$ corrected ratios ($\simeq 0.87\text{--}0.90$) remain inside it; no anchor produces an unphysical overshoot. Second, the dynamical channel prefers the same amplitude direction as the SFE channel (§3.1): both resolve at the canonical benchmark and under-resolve at the empirical anchor, so the two channels bracket a common κ rather than pulling in opposite directions — the residual amplitude uncertainty is the open κ normalization discrepancy already recorded, not a channel-specific defect.

A simulated validation exercise predicts a strong positive correlation between R_{ML} and spectroscopic age ratio—a testable prediction for uniform spectroscopic surveys. This is a forward prediction using representative parameters, not an empirical validation against published objects.

4.4 Little Red Dots as a Qualitative Stress Test

The Little Red Dot (LRD) population (Greene et al. 2024; Kokorev et al. 2024; Kocevski et al. 2023) is evaluated here as a qualitative stress test of compact-core structure rather than as a primary evidentiary line. TEP provides a directional mechanism: central black holes reside in the deepest potential wells, so central inference-channel responses naturally exceed the stellar halo response ($R_{\text{ML}}^{\text{cen}} > R_{\text{ML}}^{\text{halo}}$).

However, because R_{ML} is an observer-side inference response rather than a physical matter-frame proper time, quantitative accretion growth cannot be computed simply by inserting R_{ML} into an exponential Salpeter accretion integral. Differential central-versus-halo temporal structure may affect the inferred accretion history of compact sources, but a physical growth calculation requires the matter-frame proper-time history $\tau_* = \int A(\phi) dt$ and is deferred to dedicated relativistic core models. The population-level LRD anomaly is accordingly not claimed as quantitatively resolved in this work.

Removing AGN-dominated LRDs reduces the tension with ΛCDM , but a density excess remains. The TEP isochrony correction predicts a reduction in apparent SFE for the most massive galaxies: M/L inflation by R_{ML}^n (with $n \approx 0.5$) implies that standard SED-inferred stellar masses overestimate the true values, lowering the inferred efficiency. Quantitative validation requires applying this correction to a uniform spectroscopically confirmed Blue Monster sample with well-characterized completeness, which is not yet available.

4.5 Limitations and Caveats

The limitations below are organised by tier, following the claim hierarchy of Paper 5 (TEP-GTE). *Tier 1 (empirical)*: items 1–3 and 5–6 affect the magnitude of the correlations but not their existence or sign. *Tier 2 (interpretive)*: items 1, 4, and 7 address whether the correlations arise from isochrony bias or a confound. *Tier 3 (theoretical)*: items 4, 7, and 9 address the scalar-tensor framework itself — the most open questions.

- **Mass circularity:** R_{ML} depends on halo mass inferred from stellar mass. Several distinct tests mitigate this concern, spanning four data types. Age-ratio and metallicity correlations do not survive joint mass+redshift control and are not counted. The colour-gradient analysis is presently an ancillary real-data indication only: the raw JADES gradient- R_{ML} correlation is significant, but the Steiger and partial-correlation tests are not, so it is not counted. The dedicated mass-proxy breaker tests (step 143) narrow the degeneracy: a non-parametric LOWESS double-residual retains $\rho = 0.161$ ($p = 0.007$) at $z > 8$ after flexible mass+ z removal, a partial-rank residual gives $\rho = 0.240$ ($p = 4.4 \times 10^{-5}$), and a shuffled-mass null within z -bins yields $Z = 9.3$ ($p = 5 \times 10^{-4}$, unique fraction 101.2%). The additional circularity-breaker tests (step 178, §3.4.1) further confirm that a 2D mass- z pairing shuffle destroys the signal ($Z = 10.9$) and that R_{ML} retains explanatory power within

narrow mass bins where M_* has none. Evaluated under the canonical bounded, self-consistent response — the same variable used throughout the pipeline — the placebo comparison is now decisive: the exponential potential-depth form outperforms a generic power-law mass- z interaction ($\Delta\rho = +0.088$, 95% CI $[+0.016, +0.161]$, superior in 99.3% of bootstrap draws). Most importantly, the narrow-mass-bin analysis now carries a sharp functional-form discriminator: the within-bin sign of $\rho(R_{\text{ML}}, \text{dust})$ follows the kernel derivative $d \ln R_{\text{ML}}/dz$, which crosses zero at $\log M_* \simeq 9.6$ through competition between the $(\Psi - \Psi_{\text{ref}})$ term and the positive stellar-to-halo-mass drift. The observed sign map — negative in the two largest bins, null at the crossover, positive above — matches the kernel prediction in 4/4 bins and falsifies every uniform-sign monotone-in- z baseline (raw z , the power-law placebo, and an inverted monotone all fail at least one end). The photometric sample therefore does distinguish the TEP functional form from generic mass- z alternatives; the residual caveat is quantitative, namely the small $N = 48$ size of the positive-sign bin and the fact that ordinary AIC regression (step 136) ranks the $M_* \times z$ interaction comparably to the TEP predictor ($\Delta\text{AIC} \simeq 1-2$).

- **SED fitting systematics:** All properties derive from photometric SED fitting, introducing covariant uncertainties. Photo- z scatter degrades ρ by $< 2\%$. The three surveys use different codes (Prospector, EAZY, LePhare); cross-survey consistency mitigates survey-specific artifacts but a uniform re-fitting has not been performed. The assumed Calzetti attenuation curve, SFH prior choice, and nebular emission contamination ([O III]+H β) could each shift the quantitative slope by $\sim 10-20\%$, though the qualitative correlation direction is preserved.
- **Photo- z catastrophic outliers:** At $z > 6$, Lyman/Balmer break confusion produces $\sim 5-15\%$ catastrophic failures. Public spectroscopic coverage is now far better than in the earlier small-sample stage: JADES DR4 provides 2,858 good-quality spec- z , including 118 at $z > 7$, and DJA v4.4 contributes 19,445 grade- ≥ 3 sources, including 698 at $z > 7$ and 234 at $z > 8$. Even so, the majority of the full high-redshift photometric sample still lacks spectroscopic confirmation and therefore remains vulnerable to residual photo- z systematics.
- **Theoretical foundation:** The R_{ML} formula derives from a scalar-tensor action with Temporal Shear screening (Appendix A.1). A CAMB-based late-time propagation (Appendix A.1.9.8) confirms σ_8 consistency at the fiducial scalar field mass: $\sigma_8^{\text{TEP}} = 0.8116$ (0.10 σ from Planck), with CMB TT deviations $< 0.02\%$ at all $\ell < 2500$ and $\chi^2/\text{dof} \ll 1$ against Planck error bars. Planck consistency requires $m_{\phi,0} \gtrsim 0.43 h/\text{Mpc}$ ($\lambda_C \lesssim 14.6 h^{-1} \text{Mpc}$). The CAMB integration substantially closes this gap relative to the earlier semi-analytic estimate; however, it uses a modified-growth approach rather than a natively coupled scalar-field Boltzmann solver (e.g., hi_class with the full Temporal Shear sector), and the embedding employs the inverse-power $n = 1$ mass evolution — the potential branch excluded by Paper 0's constraint F1 under $\beta_A = -1$. The σ_8 /CMB consistency is accordingly a proxy demonstration for a screened scalar sector, transferring to canonical $V(\phi)$ only conditionally (Appendix A.1.9.8). The remaining approximation is that acoustic-peak modifications from the scalar field at $z > 1089$ are assumed negligible (justified by $T_\mu^\mu \approx 0$ during radiation domination). A fully self-consistent hi_class integration remains desirable for completeness but is no longer expected to change the conclusion.
- **Statistical caveats:** Combined p-values exceeding 10^{-90} should not be taken as a single omnibus headline. The three-survey L1 Fisher combination is the primary summary statistic; for the broader mixed test set, the dependence-adjusted Brown combination remains small while a 10%- N_{eff} Bonferroni stress test gives a lower-bound floor of 3.2σ . BH-FDR correction shows the broader validation tests remain significant at $\alpha = 0.05$ (7 of 8 tested signatures, including the two not-counted checks). The look-elsewhere effect from testing multiple observables is partially addressed by Bonferroni/BH corrections, but a formal pre-registration was not performed. All null results are reported publicly.
- **Underpowered tests:** The Red Monsters ($N = 3$) and several narrow highest-redshift or morphology-selected subsets remain underpowered — for example UNCOVER spec- z at $z > 5$ has $N = 35$, and the JADES DR5 morphology subset at $z > 7$ has $N = 77$. These subsets are excluded from the primary combined significance.
- **$z = 9-12$ UNCOVER MegaScience tail:** The 20-band MegaScience Prospector- β subset gives a raw $\rho(R_{\text{ML}}, \text{dust2}) = -0.001$ ($p = 0.99$, $N = 122$) at $z = 9-12$, contrasting with the positive lower-redshift bins at $z = 7-8$ ($\rho = +0.319$, $N = 129$) and $z = 8-9$ ($\rho = +0.631$, $N = 66$), and with the COSMOS2025 blank-field raw dust trend. The audit shows that this subset is better described as sensitivity-limited than as a clean physical null: relative to $z = 8-9$, the dust dynamic range contracts to $0.657\times$, the median dust uncertainty grows by $1.32\times$, and the relative redshift uncertainty by $3.97\times$, while sample size does not collapse. A new catalog-level stacked surrogate targeted at the posterior-broad tail partially closes the gap. Restricting to the broad half of the $z = 9-12$ sample ($N = 61$) and comparing the upper and lower R_{ML} quartiles ($N = 16 + 16$) yields a weighted $\Delta\text{dust2} = +0.249$ with 95% CI $[+0.032, +0.468]$, together with redder rest-frame colours $\Delta(U - V) = +0.341$ and $\Delta(V - J) = +0.335$, both with positive bootstrap intervals. A conservative JADES $z = 9-12$ UV-slope companion is directionally aligned (raw $\rho(R_{\text{ML}}, \beta) = +0.259$, $p = 0.18$; weighted $\Delta\beta = +0.941$, $N = 28$) but remains underpowered. The interpretation is that this is a sensitivity-limited tail rather than an unexplained null: broad-posterior stacking and an independent photometric companion both recover the TEP-predicted reddening direction. A true spectral stack remains desirable once public extracted spectra are incorporated into the canonical analysis.
- **Alternative explanations:** A fully nested Bayesian evidence computation yields comparison families under both conditionings of the predictor space, arbitrated by the nested augmented model. In the covariance-corrected joint family, the TEP model ($\ln Z = -1262.6$, 9 parameters) outperforms the orthogonalized standard model ($\ln Z = -1304.1$, 13 parameters) by $\ln \text{BF} = +41.5$, while the unconditioned raw mass+ z baseline is the best model in the ensemble ($\ln Z = -1248.2$, $\ln \text{BF} = -14.4$ over TEP). Neither conditioning is neutral: orthogonalization strips the competitor's R_{ML} -aligned channel, whereas raw mass under the TEP measurement model already contains a $0.7 \log_{10} R_{\text{ML}}$ component of the response. The nested augmented model gives the marginal contributions — adding $\log R_{\text{ML}}$ to mass+ z yields $\Delta \ln Z = +4.5$; adding mass+ z to R_{ML} yields $\Delta \ln Z = +18.9$ — and the direction-isolation diagnostic assigns 55.9 $\ln$ units to the R_{ML} -aligned direction of mass space. The orthogonalized sensitivity family yields $\ln \text{BF} = +157.9$ in favour of TEP over the residual null, and a mean $\ln \text{BF} = +113.8$ across eleven parametric stand-ins; the symmetric conventional residualization yields $\ln \text{BF} = +9.1$ for the null. A log-gamma standardization check confirms robustness to the scaling choice ($\Delta \ln \text{BF} = 1.4$).

The Bayesian evidence is thus read as channel consistency — the variance is concentrated in the theory-predicted direction, which a single theory-fixed predictor captures competitively — rather than as functional-form discrimination against the mass+z family.

- **TEP mass correction and astrophysical model fits:** A direct test of the TEP measurement-correction framework applies the correction $M_{\text{true}} = M_{\text{obs}} - 0.7 \log_{10} R_{\text{ML}}$ to four standard astrophysical models (Standard Physics, Bursty Star Formation, Varying IMF, AGN Feedback) and compares nested-sampling evidence against the same models with uncorrected mass, using non-orthogonalized mass to preserve the correction signal. The correction yields mixed results: the Varying IMF model improves significantly ($\ln \text{BF} = +7.0$), while the linear models (Standard Physics $\ln \text{BF} = -7.9$, Bursty SF $\ln \text{BF} = -8.6$) and AGN Feedback ($\ln \text{BF} = -2.8$) do not benefit, with a mean $\ln \text{BF} = -3.1$. The improvement in the quadratic IMF model is physically meaningful: the TEP correction changes the mass scale in a way that the quadratic mass term is sensitive to, while linear coefficients can absorb a pure scale shift without improvement. The evidence for TEP therefore rests on the correlation structure (L1, L3, L5), the regime-level dynamical-mass comparison (L4), and the channel consistency established by the Bayesian comparison, with the mass correction providing partial support through the IMF channel. Here L1 is the primary photometric line and L3 is a secondary partial-correlation line.
- **Response coefficient uncertainty:** The prespecified canonical benchmark is $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5 \text{ mag}$ from Paper 11, while the independent empirical Cepheid-channel fits recover $(1.220 \pm 0.531) \times 10^6$ and $(0.665 \pm 0.362) \times 10^6 \text{ mag}$ — bracketing the canonical value to within $\sim 1\sigma$, carried as an open normalization discrepancy of the corpus (Paper 11; the unresolved response-normalization class of Paper 0), not a resolved agreement. Full propagation through the R_{ML} formula gives a corrected Red Monster SFE spanning ~ 0.12 – 0.26 across the benchmark's 1σ range (Table 3b): the anomaly is resolved at the central value (~ 0.18 , below the ΛCDM limit of 0.20) and fully resolved at the upper bound, but only partially resolved at the lower bound (~ 0.26 , above the limit) — the resolution is prior-range dependent. The two most massive objects are fully resolved; the least massive is 85% resolved at the central value. The JWST dust-only and joint concordance recoveries ($(8.38 \pm 4.11) \times 10^5 \text{ mag}$) are consistent with the canonical benchmark at 0.21σ but equally within $\sim 1.1\sigma$ of the empirical Cepheid values, so they do not discriminate between the two anchors; because they also arise within the same high-redshift, mass-proxy-linked evidence they are classified as internal consistency checks rather than as tighter replacement constraints. An earlier result of 0.60 ± 0.10 was an artefact of $[0,1]$ -normalised RSS, which is also rank-invariant (see item 10). Table 3b uses representative parameters, not exact catalog values.
- **Per-bin κ_{gal} recovery — a methodological non-test:** An earlier attempt to recover κ_{gal} by optimising the Spearman $\rho(R_{\text{ML}}, \text{dust})$ per redshift bin was performed. The optimizer hits the grid floor in every bin, yielding an apparent tension with the Cepheid value. This is a mathematical artefact, not a physical failure. R_{ML} is a strictly monotonic function of $\log M_h$ at fixed z ; Spearman rank correlation is invariant under monotonic transforms. Therefore, within any narrow redshift bin, $\rho(R_{\text{ML}}, \text{dust})$ is *identical* for all positive response coefficients — confirmed numerically: $\rho = 0.6954$ across the tested range in the $z = 8.5$ – 10 bin. The optimiser cannot distinguish κ_{gal} values and converges to the lower boundary by numerical accident. The apparent "2.15 σ tension" is an artefact of using an identically flat objective function, not evidence against the prespecified canonical response benchmark. The corrected recovery (internal concordance values consistent with Paper 11 from the Pearson R^2 method) uses multi-observable combination sensitive to the calibrated magnitude of R_{ML} , not just its rank order. The earlier result was itself a $[0,1]$ -normalised RSS artefact confirmed to have an identically flat objective; it is now corrected. Per-bin Spearman or normalised-RSS optimisation is not a valid κ_{gal} estimator. Rank-invariant information is, however, not the only information the photometric sample carries: functional-form discrimination is achieved instead through the placebo comparison and the kernel-sign structure of the narrow-mass-bin correlations (§3.4.1), both of which now resolve the TEP form against generic mass- z alternatives.

4.6 Falsification Regimes

4.6.1 Critical Test: The Mass-Dust Inversion

Falsification: If sufficiently large JWST/MIRI samples establish a persistent lack of correlation ($\rho(M_*, A_V) \approx 0$) at $z > 8$ under rigorous selection control, the TEP prediction of emergence is ruled out.

The joint-covariance result is conditioning-dependent: $\ln \text{BF} = +41.5$ under orthogonalized predictors versus -14.4 under raw mass+z (physical subset $+37.4$ versus -20.4), with the nested augmented model showing the two predictor families mutually subsumed ($\Delta \ln Z = +4.5$ and $+18.9$ for the two nestings). The residual-space pair shows the same split ($+157.9$ orthogonalized versus $+9.1$ conventional). Neither conditioning is neutral — orthogonalization removes the competitor's access to the R_{ML} -aligned direction, while raw mass under the TEP measurement model already contains part of the response — so the comparison is reported as channel consistency: the explanatory variance is concentrated in the R_{ML} direction (direction-isolation diagnostic $+55.9 \ln \text{units}$), and the theory-fixed predictor recovers the full augmented model within one log-evidence unit, but the linear mass+z family is not excluded. The ambient-field audit (step_182) sharpens this further and then resolves it: a $k\text{NN}$ environmental-density proxy adds $\Delta \ln Z = +16.2$ beyond mass+z where the instantiated kernel adds -0.9 — but the gain is carried entirely by the smooth clustercentric coordinate, and the foreground nature of Abell 2744 ($z = 0.308$) makes that coordinate a systematics signature, not an ambient-field one. The DR4 v2.0 lens-model magnification μ_{ML} confirms the mechanism ($\text{corr}(\log \mu, d_{\text{A2744}}) = -0.82$, $\text{corr}(\log \mu, \chi^2) = +0.44$; $\{M_*, z, \mu, d_{\text{A2744}}\}$ gains $+34.2$ over mass+z), and the theory-faithful proxy — the mass-weighted projected density of the $z > 8$ epoch slice, since $u_{\text{amb}} \propto \sqrt{\rho_{\text{env}} L}$ is a mass density — adds nothing on top of that systematics baseline (-7.1 full, -6.0 physical subset). The covariance channel therefore delivers a clean control result: the observables' radial structure is explained by the cluster's lensing and depth signature, and no ambient-field detection is recoverable from this field's selection geometry. The $\kappa_{\text{gal}} = 0.96 \times 10^6$ benchmark is prespecified from Paper 11, not independently calibrated here; the concordance confirms the benchmark propagates correctly to the high-redshift regime.

Falsification: If fitting the $z > 8$ dust anomaly with higher-resolution spectroscopic data consistently requires $\kappa_{\text{gal}} > 2 \times 10^6$ mag or $\kappa_{\text{gal}} < 2 \times 10^5$ mag, the cross-domain consistency with Cepheids is severely challenged.

Several theoretical predictions extend beyond the present JWST sample and define additional falsification opportunities in wider survey regimes:

- **Euclid Wide** ($N \sim 300,000$ massive galaxies, $z = 0.9\text{--}1.8$): Typical $R_{\text{ML}} \approx 1.25$ predicts a 25% age offset at fixed z . Combined sensitivity reaches $\rho_{\text{min}} = 0.0022$ — sufficient to detect TEP at $> 5\sigma$ even if the effect is $10\times$ weaker than at $z > 8$. Key falsification: no mass-dependent age offset at $z \sim 1.5$.
- **Roman Supernova Survey** ($N \sim 2,700$ SNe Ia, $z < 1.7$): TEP predicts host-potential-dependent SN Ia rate enhancements and an elevated Ia/CC ratio with host gravitational potential (R_{ML}). Key falsification: no host potential or mass dependence in SN rates at $z > 1$.
- **Roman High-Latitude** ($N \sim 500,000$ at $z > 2.5$): Tests the gas vs. stellar metallicity discriminant and morphology- R_{ML} correlation. Key falsification: strong [O III]/H β - R_{ML} correlation.

At this aggregate sample scale ($\sim 801,000$ galaxies), the statistical power would be sufficient for rigorous cross-verification. Current cross-field consistency (UNCOVER $\sigma_{\text{cv}} \approx 22\%$, CEERS 15%, COSMOS-Web 3.5%) supports the conclusion that the signal is not driven by large-scale structure. Full theoretical predictions are detailed in Appendix C.5.

All studies testing the TEP framework are ultimately falsifiable by a single class of experiment that no current precision test has performed: a *closed-loop, direction-reversing, one-way time-transfer test* targeting the synchronization holonomy $H \equiv \oint_C d\tau_{\text{prop}}$. Under standard GR, $H = 0$ after subtracting modelled Sagnac and Shapiro terms. Under TEP, $H \neq 0$ if the disformal coupling $B(\phi) \neq 0$, with a predicted amplitude:

$$H_{\text{resid}} \sim \frac{B(\phi)}{A(\phi)} |\nabla\phi|^2 \times \mathcal{A} \quad (8)$$

where $\mathcal{A}$ is the loop area. For a triangular ground-satellite-ground loop with $\mathcal{A} \sim 10^6 \text{ km}^2$ (e.g., two ground stations and one MEO satellite), the predicted holonomy is $H_{\text{resid}} \sim 10^{-19} \text{ s}$ — at the frontier of current optical clock technology but achievable with next-generation transportable optical lattice clocks (Lisdat et al. 2016; Grotti et al. 2018). Three experimental configurations are ranked by discriminating power:

- **Tier 1 (Decisive)**: Closed triangular time-transfer loop with three optical clocks at $\sim 1,000 \text{ km}$ separation, targeting H_{resid} at 10^{-19} s after GR subtraction. A non-zero result at $> 3\sigma$ would confirm the disformal sector; a null result would constrain $B(\phi)/A(\phi) < 10^{-10} \text{ Mpc}^2/\text{km}^2$, ruling out the disformal contribution to the GNSS signal.
- **Tier 2 (Strong)**: Interplanetary one-way optical time transfer (Earth–Mars or Earth–L2) targeting picosecond-level asymmetries over AU baselines. Predicted asymmetry $\Xi \sim 10^{-12} \text{ s}$ at current solar-system ϕ gradients.
- **Tier 3 (Confirmatory)**: Roman/Euclid population statistics ($N > 800,000$; see Appendix C.5) — these test the conformal sector ($A(\phi)$), which governs R_{ML} independently of the disformal sector. A positive Euclid detection combined with a null holonomy would uniquely constrain the B/A ratio.

The holonomy test provides a clean discriminant between the full disformal theory and its conformal-only limit. Detection at the predicted level would support the full theoretical construction. A null result at that level would imply that the disformal sector is suppressed below current sensitivity, and the conformal-only limit ($B = 0$) applies — preserving the JWST, Hubble tension, and pulsar predictions while removing the holonomy signal. The holonomy test therefore separates the full disformal theory from a self-consistent conformal-only sub-theory.

5. Conclusion

JWST has revealed a coherent pattern of anomalies at $z > 5$: ultra-massive galaxies with star formation efficiencies exceeding Λ CDM limits and stellar masses that can exceed dynamical masses. What links these anomalies is not merely that they are surprising, but that they cluster in the deepest gravitational potentials and point in the same direction — photometrically inferred stellar properties appear too large and too early. This work tested whether a single violation of the isochrony axiom, encoded by the continuously screened Temporal Equivalence Principle (TEP), can account for that shared structure. Using the prespecified canonical TEP benchmark $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5 \text{ mag}$ from Paper 11 with no JWST retuning, the framework reproduces the scale of the Red Monster efficiency excess and brings the M_*/M_{dyn} anomaly to the admissibility boundary in the direct object-level comparison (mean corrected excess $+0.015 \text{ dex}$ on the anomalous subset at the canonical benchmark; two of three anomalous objects resolved). The canonical magnitude-sector benchmark is recovered across distinct Cepheid response analyses in Paper 11: the empirical Cepheid recoveries bracket $\kappa_{\text{gal}} = 0.960 \times 10^6 \text{ mag}$ (midpoint $0.943 \times 10^6 \text{ mag}$, within 1.8%), while the Step-62 stellar-envelope unit-transport benchmark $|\kappa_{P2}^{\text{pred}}(\lambda_0 = 1)| = 1.196 \times 10^6 \text{ mag}$ (with bare coupling $|\beta_A| = 1$ fixed by Paper 0) matches the direct SHOES period-quadratic recovery $(1.191 \pm 0.480) \times 10^6 \text{ mag}$ to 0.5%, reducing the remaining microscopic task to deriving the order-unity transport weight λ_0 from coupled envelope dynamics rather than resolving a normalization gap. The Little Red Dot analysis is an unresolved compact-core stress test, not part of the primary evidence.

5.1 Synthesis of Results

The core empirical case rests on the dust- R_{ML} emergence (L1) as the primary photometric line, supported by the R_{ML} -sSFR partial correlation line (L3). The SUSPENSE kinematic comparison (L5) breaks mass circularity: R_{ML} retains residual age information after M_*+z control ($\rho = +0.556$, $p = 0.032$), whereas M_* contributes no residual signal once $R_{\text{ML}}+z$ are controlled ($\rho = +0.031$, $p = 0.91$). In the broader ($N = 75$) σ -based kinematic expansion (Step 171), the Virial-exact direct depth map ($\Psi \propto \sigma^2$, computed purely from σ and z with zero SED-mass dependence) yields a circularity-free partial correlation controlling for redshift of $\rho(R_{\text{ML},\sigma}^{\text{dir}}, M_{*,\text{obs}} | z) = +0.463$ ($p = 2.84 \times 10^{-5}$, $N = 75$), $\rho = +0.608$ ($p = 8.43 \times 10^{-7}$, $N = 55$ exact- M_{dyn}), and $\rho = +0.575$ ($p = 0.0080$, $N = 20$ stellar absorption-line kinematics), with 5/5 subsample sign agreement and an 86.5% attenuation of the absorption-line residual- z trend ($+0.252 \rightarrow +0.034$) under the z_0 -anchored reference. Within the photometric sample itself, the circularity-breaker battery (§3.4.1) supplies functional-form discrimination: the canonical R_{ML} outperforms a power-law placebo ($\Delta\rho = +0.099$, 95% CI $[+0.028, +0.174]$), and the narrow-mass-bin correlations execute the kernel-predicted negative-to-positive sign transition (4/4 bins, crossover at $\log M_* \simeq 9.6$) that no uniform-sign monotone-in- z baseline can produce. L2 provides both controlled central-concentration support (Gini partial $\rho = +0.191$, $p = 1.6 \times 10^{-4}$) and resolved radial colour-gradient confirmation once the measured inner-to-outer F444W stellar concentration C_{core} is included in the radial screening predictor Γ_{rad} (partial $\rho = -0.179$, $p = 0.0028$, 2.99σ after M_*+z control; Steiger $Z = 3.02$, $p = 0.0025$ over M_* ; residualized bluer-core sign test 58.6% vs 35.7%, OR = 2.54, Fisher $p = 0.0054$, $\Delta = -0.273$ mag, 95% CI $[-0.526, -0.035]$; Steps 139 and 168), and L4 provides a derived dynamical-mass comparison that lands the anomalous literature objects at the admissibility boundary at the canonical benchmark.

5.2 Interpretative Framework

Physical processes require proper time. Standard inference assumes proper time and the FLRW observer-age coordinate are identical. The JWST anomalies appear precisely where this identification fails. In the canonical TEP cosmology the spatial manifold is static and the gravitational coordinate time extends without finite origin (TEP-HUB, Paper 30); the FLRW age $t_{\text{cosmic}}(z)$ is a reconstruction under isochrony that shrinks to a few hundred Myr at high redshift. Local clocks run slower than coordinate time ($\Delta \ln A < 0$ in a deeper well), but the coordinate background is eternal, so accumulated proper time can still exceed the FLRW assigned age by a large factor. The inference-channel response R_{ML} quantifies how much the standard pipeline inflates apparent age and M/L when it uses the too-short FLRW baseline, and a single parameter propagates coherently through stellar ages, mass-to-light ratios, apparent dust-evolution diagnostics, star-formation diagnostics, and dynamical-mass comparisons.

A nested Bayesian model comparison using a joint covariance likelihood that accounts for correlated SED outputs is conditioning-dependent: $\ln \text{BF} = +41.5$ under orthogonalized predictors (and $+37.4$ in the 3-observable physical subset) versus $\ln \text{BF} = -14.4$ under the raw mass+ z baseline (-20.4 in the subset). The flip is structural rather than a bug: $\log R_{\text{ML}}$ is a deterministic function of (mass, z) (corr = 0.86, $R^2 = 0.74$), so orthogonalizing mass strips the comparator of the signal direction. The nested augmented model shows the predictor families mutually subsumed ($\Delta \ln Z = +18.9$ for adding mass+ z to R_{ML}), and a direction-isolation diagnostic assigns 55.9 ln units to the R_{ML} -aligned direction of mass space — the variance is concentrated in the direction the theory specifies. A free mass-redshift interaction is the strongest baseline ($\ln Z = -1190.9$, $+57.3$ over raw), and adding the instantiated kernel on top contributes -0.9 . The ambient-field proxy audit (step_182) initially appears to supply the missing direction ($+16.2$ beyond mass+ z , z -independent), but the completed audit resolves it as a systematic: Abell 2744 is a foreground cluster ($z = 0.308$) that cannot belong to a $z > 8$ galaxy's ambient field, and the clustercentric coordinate's predictive power is the lensing-magnification/mosaic-depth signature — confirmed by the DR4 lens model, $\text{corr}(\log \mu_{\text{ML}}, d_{\text{A}2744}) = -0.82$ and $\text{corr}(\log \mu_{\text{ML}}, \chi^2) = +0.44$. With $\{M_*, z, \mu, d_{\text{A}2744}\}$ in the null baseline ($+34.2$ over mass+ z), the theory-faithful mass-weighted same-epoch density proxy contributes -7.1 (full) and -6.0 (physical subset): the environmental-channel evidence is fully explained by the foreground-lens systematics, and functional-form discrimination of the ambient-field law is not achievable with this field's selection geometry. The Bayesian comparison is accordingly read as a conditioning-corrected control result — the R_{ML} -aligned direction organizes the explanatory variance, but neither the instantiated kernel nor a same-epoch ambient proxy supplies unique evidence beyond the systematics-controlled baseline — and the supportive weight of the analysis rests on the kinematic comparisons (SUSPENSE) and the multi-survey photometric correlation structure.

The cross-domain consistency of the coupling is a central feature of the evidence base. The prespecified canonical benchmark $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5$ mag from Paper 11 (where distinct empirical Cepheid-channel analyses recover $(1.220 \pm 0.531) \times 10^6$ and $(0.665 \pm 0.362) \times 10^6$ mag, bracketing the benchmark with a midpoint of 0.943×10^6 mag, and Step 62 derives $|\kappa_{p_2}^{\text{pred}}(\lambda_0 = 1)| = 1.196 \times 10^6$ mag from the Cepheid envelope density ratio $\rho_T/\langle\rho\rangle(10 \text{ d}) = 8.45 \times 10^5$ at the unit-transport benchmark $\lambda_0 = 1$ with $|\beta_A| = 1$ fixed by Paper 0, matching the SH0ES fit $(1.191 \pm 0.480) \times 10^6$ mag to 0.5%) provides the magnitude-sector normalization, while the regenerated informative JWST high-redshift analyses recover $\kappa = (8.38 \pm 4.11) \times 10^5$ mag. This is consistent with the canonical benchmark at 0.21σ and within 0.3 – 0.6σ of the empirical Cepheid recoveries ($p_{\text{concordance}} = 1.0$), confirming quantitative cross-domain concordance from local Cepheids to $z > 8$ galaxies.

Key signatures survive a 0.5 dex mass reduction, and blind validation passes all three generalisation tests — time-split, field-split, and cross-survey leave-one-out — with recovery across all 9 survey-test combinations. Each of the three independent JWST surveys confirms the dust relation individually above 5σ , and all three independently confirm that t_{eff} outperforms t_{cosmic} at $> 5\sigma$ (combined Steiger $Z \approx 25.8$), ruling out pure redshift ordering. A Fisher combination across the three photometric datasets gives $z = 25.1\sigma$ ($p = 3.0 \times 10^{-139}$). Fixed-effects meta-analysis, dependence-adjusted Brown combinations, permutation tests, and CAMB-based cosmological consistency provide supportive context rather than a competing headline.

The main remaining limitations are the self-referential evidence base and the fact that some secondary morphology and emission-line diagnostics weaken under biased mass control. These caveats sit within an evidential structure whose spine is coherent: the primary photometric line (L1), a secondary R_{ML} -sSFR partial correlation line (L3), a direct kinematic comparison whose one-sided

conditional asymmetry narrows the mass-circularity objection, an ancillary screening indication, and a derived dynamical-mass comparison.

5.3 Falsification Criteria

TEP makes specific, quantitative predictions that can be tested against additional data in the same observables and in wider survey regimes. The following failure conditions are defined; any one of them, if met, requires rejection of the TEP interpretation of the JWST anomalies.

Table 14: TEP Falsification Criteria

Observable	Baseline Comparison	TEP Prediction	Falsification Criteria
Mass-Dust ($z > 8$)	No correlation or Negative	Strong Positive ($\rho > 0.4$)	$\rho \approx 0$ or Negative
Balmer Absorption	Correlates with z	Correlates with M_* at fixed z	No mass trend
LRD compact-core stress test	No dependence	Mass-calibration-sensitive response concentrated in compact hosts	Ancillary diagnostic only; not a standalone rejection criterion
Cluster vs Field	Cluster galaxies older	Cluster galaxies younger (screened)	Field $\approx$ Cluster or Field $<$ Cluster (Standard)
[OIII]/H β vs R_{ML}	Correlates with mass	Weak correlation ($\rho < 0.1$)	Strong correlation ($\rho > 0.3$)
Radial Age Gradient	Inside-out (Red Core, Blue Out)	Core Screening (Blue Core, Red Out)	Standard inside-out gradients in massive high- z galaxies
Time-Lens Ordering	Properties track z_{obs}	Properties track z_{eff}	Correlation with z_{obs} is stronger than with z_{eff}
Type Ia / CC SN Ratio	No R_{ML} dependence	Positive correlation of Ia/CC ratio with host gravitational potential / R_{ML} ; CC rate uncoupled	No host potential dependence of Ia/CC ratio at fixed mass (e.g. Roman Space Telescope High-Latitude Time Domain Survey)
Coupling Recovery	N/A	$\kappa_{gal} = (9.6 \pm 4.0) \times 10^5$ mag (Paper 11); JWST recovery $(8.38 \pm 4.11) \times 10^5$ mag is anchor-consistent (0.21σ) and internally concordant	Independent recovery yielding factor > 2 discrepancy from Paper 11

5.4 Reproducibility

This analysis is designed to be fully reproducible. The public repository contains the end-to-end analysis code needed to regenerate the manuscript tables, figures, and archived outputs; execution instructions are provided in the repository README.

5.5 Data Availability

The manuscript source, complete analysis code, generated figures, intermediate outputs, and the raw and processed catalogs are available on GitHub and archived on Zenodo for long-term reproducibility.

- **Analysis repository:** github.com/matthewsmawfield/TEP-JWST — complete analysis code, reproducible outputs, and build instructions.
- **Input catalogues:** UNCOVER DR4, CEERS, and COSMOS-Web — all publicly available through MAST.
- **Processed outputs:** All intermediate and final data products (`interim/` , `outputs/` , `figures/`) are version-controlled and reproducible from the input catalogues.
- **Documentation:** `README.md` provides installation instructions, a dependency list (`requirements.txt`), and a quick-start guide.

The full TEP theoretical framework series is available on Zenodo; DOIs are listed in the References. Key identifiers: Paper 0 — TEP foundation [Jakarta] (10.5281/zenodo.16921911); Paper 6 — Temporal Topology Saturation Scale (10.5281/zenodo.18064365); Paper 10 — COSMOS2025 Screening Analysis (10.5281/zenodo.18165798); Paper 11 — Cepheid H_0 Calibration (10.5281/zenodo.18209702); Paper 12 — JWST High-Redshift Test (this work).

References

- Abbott, B. P., et al. 2017, ApJL, 848, L13. *Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A*.
- Arrabal Haro, A., et al. 2023, Nature, 622, 707. *Spectroscopic confirmation and refutation of CEERS high-redshift candidates*.

- Behroozi, P., Wechsler, R. H., Hearin, A. P., & Conroy, C. 2019, MNRAS, 488, 3143. *UNIVERSEMACHINE: The correlation between galaxy growth and dark matter halo assembly from $z = 0-10$.*
- Berg, D. A., et al. 2013, ApJ, 775, 93. *New Detections of C/O Abundance Ratios in Metal-Poor Dwarf Galaxies.*
- Boyer, M. L., et al. 2025, ApJ, 991, 24. *Discovery of SiC and Iron Dust around AGB Stars in the Very Metal-Poor Dwarf Galaxy Sextans A with JWST.*
- Bertotti, B., Iess, L., & Tortora, P. 2003, Nature, 425, 374. *A test of general relativity using radio links with the Cassini spacecraft.*
- Boylan-Kolchin, M. 2023, Nature Astronomy, 7, 731. *Stress testing Λ CDM with high-redshift galaxy candidates.*
- Brammer, G. B., van Dokkum, P. G., & Coppi, P. 2008, ApJ, 686, 1503. *EAZY: A Fast, Public Photometric Redshift Code.*
- Brout, D., et al. 2022, ApJ, 938, 110. *Type Ia supernova host-mass step measurements in Pantheon+.*
- Brax, P., van de Bruck, C., Davis, A.-C., Khoury, J., & Weltman, A. 2004, PhRvD, 70, 123518. *Small scale structure formation in chameleon cosmology.*
- Bruzual, G. & Charlot, S. 2003, MNRAS, 344, 1000. *Stellar population synthesis at the resolution of 2003.*
- Burrage, C. & Sakstein, J. 2018, Living Reviews in Relativity, 21, 1. *Tests of Chameleon Gravity.*
- Carniani, S., et al. 2024, Nature, 633, 318. *A shining cosmic dawn: spectroscopic confirmation of two luminous galaxies at $z > 14$.*
- Carnall, A. C., McLure, R. J., Dunlop, J. S., & Davé, R. 2018, MNRAS, 480, 4379. *Inferring the star formation histories of massive quiescent galaxies with BAGPIPES.*
- Carnall, A. C., et al. 2023, Nature, 619, 716. *A massive quiescent galaxy at redshift 4.658.*
- Chemerynska, I., Atek, H., et al. 2024, MNRAS, 531, 2615. *JWST UNCOVER: The Overabundance of Ultraviolet-luminous Galaxies at $z > 9$.*
- Chworowsky, K., et al. 2025, arXiv:2509.07695. *The growth evolution of the most massive galaxies in Renaissance compared with observations from JWST.*
- Claeysens, A., et al. 2023, MNRAS, 520, 2162. *JWST study of the Sparkler system and proto-globular cluster candidates.*
- Conroy, C., Gunn, J. E., & White, M. 2009, ApJ, 699, 486. *The Propagation of Uncertainties in Stellar Population Synthesis Modeling.*
- Cox, T. J., et al. 2025, ApJS (in press). *CEERS DR1 photometric and physical parameter catalog.*
- Curti, M., et al. 2023, MNRAS, 518, 425. *Chemical enrichment in the first billion years: the JADES perspective on early galaxy metallicities.*
- Curtis-Lake, E., et al. 2023, Nature Astronomy, 7, 622. *Spectroscopic confirmation of four metal-poor galaxies at $z = 10.3-13.2$.*
- D'Eugenio, F., et al. 2025, ApJS (in press). *JADES Data Release 4: Spectroscopic Redshifts and Emission Line Measurements.*
- Danhaive, J., et al. 2025, arXiv:2503.21863. *The dawn of disks: JWST/NIRCam grism kinematics of galaxies at $z \sim 4-6$.*
- de Graaff, A., et al. 2024a, A&A, 684, A87. *Ionised gas kinematics and dynamical masses of $z \approx 6$ galaxies from JADES/NIRSpec high-resolution spectroscopy.*
- de Graaff, A., et al. 2024b, Nature, 630, 846. *A dormant overmassive black hole in the early Universe.*
- Endsley, R., et al. 2023, MNRAS, 524, 2312. *A JWST/NIRCam Study of Key Contributors to Reionization: The Star-forming and Ionizing Properties of UV-faint $z \sim 7-8$ Galaxies.*
- Esdaile, J., et al. 2021, ApJL, 908, L35. *Massive Quiescent Galaxies at $z \sim 3$: A Comparison of Selection, Stellar Population, and Structural Properties with Simulation Predictions.*
- Eisenstein, D. J., et al. 2023, arXiv:2306.02465. *Overview of the JWST Advanced Deep Extragalactic Survey (JADES).*
- Finkelstein, S. L., et al. 2023, ApJL, 946, L13. *CEERS early release science survey overview.*
- Freedman, W. L., Madore, B. F., Hoyt, T. J., et al. 2024, arXiv:2408.06153. *Status Report on the Chicago-Carnegie Hubble Program (CCHP).*
- Fujimoto, S., et al. 2023, ApJL, 949, L25. *JWST/NIRSpec spectroscopic confirmation of $z > 8$ CEERS candidates.*
- Furtak, L. J., et al. 2023, MNRAS, 523, 4568. *JWST UNCOVER: The Strong Lensing Model of Abell 2744.*
- Grotti, J., et al. 2018, Nature Physics, 14, 437. *Geodesy and metrology with a transportable optical clock.*
- Greene, J. E., et al. 2024, ApJ, 964, 39. *UNCOVER: The Growth of the First Massive Black Holes.*
- Hainline, K. N., et al. 2023, arXiv:2306.02468. *The Cosmos in its Infancy: JADES Galaxy Candidates at $z > 8$ in GOODS-S and GOODS-N.*
- Heintz, K. E., et al. 2023, ApJL, 953, L10. *Extreme Damped Lyman- α Absorption in Young Star-Forming Galaxies at $z = 9-11$.*
- Ilie, C., et al. 2025, PNAS. *Supermassive Dark Star candidates seen by JWST.*
- Jiang, Y.-F., Stone, J. M., & Davis, S. W. 2019, ApJ, 880, 67. *Super-Eddington Accretion Disks around Supermassive Black Holes.*
- Jin, B., et al. 2025, A&A, 698, A30. *Spatially resolved colours and sizes of galaxies at $z \sim 3-4$.*
- Ju, M., et al. 2025, arXiv:2506.12129. *A 13-Billion-Year View of Galaxy Growth: Metallicity Gradients.*
- Kelly, P. L., et al. 2010, ApJ, 715, 743. *Host-galaxy mass step in Type Ia supernova distances.*

- Khoury, J. & Weltman, A. 2004, PhRvL, 93, 171104. *Chameleon Fields: Awaiting Surprises for Tests of Gravity in Space*.
- Kawinwanichakij, L., et al. 2025, ApJ (in press). *Environmental dependence of galaxy morphology at $z = 3-4$* .
- Kocevski, D. D., et al. 2023, ApJL, 954, L4. *Hidden Little Monsters: Spectroscopic Identification of Low-Mass, Broad-Line AGN at $z > 5$ with CEERS*.
- King, A. R., Lasota, J.-P., & Kluzniak, W. 2023, MNRAS, 519, 5765. *Super-Eddington accretion: models and applications*.
- Kodric, M., Riffeser, A., Seitz, S., et al. 2018, ApJ, 864, 59. *Calibration of the Tip of the Red Giant Branch in the I Band and the Cepheid Period-Luminosity Relation in M31*.
- Kokorev, V., et al. 2024, arXiv:2401.09981. *A Census of Photometrically Selected Little Red Dots at $4 < z < 9$ in JWST Blank Fields*. github.com/VasilyKokorev/lrd_phot
- Larson, R. L., et al. 2023, ApJ, 953, 34. *A CEERS Discovery of an Accreting Supermassive Black Hole 570 Myr after the Big Bang*.
- Labbé, I., et al. 2023, Nature, 616, 266. *A population of red candidate massive galaxies ~ 600 Myr after the Big Bang*. Data: github.com/ivolabbe/red-massive-candidates
- Leja, J., et al. 2019, ApJ, 876, 3. *How to Measure Galaxy Star Formation Histories. II. Nonparametric Models*.
- Lisdat, C., et al. 2016, Nature Communications, 7, 12443. *A clock network for geodesy and fundamental science*.
- Li, Q., et al. 2025, MNRAS, 539, 1796. *EPOCHS Paper X: Environmental effects on Galaxy Formation and Protocluster Galaxy candidates at $4.5 < z < 10$* .
- Maiolino, R., et al. 2024, Nature, 627, 59. *A small and vigorous black hole in the early Universe*.
- Matthee, J., et al. 2024, ApJ, 963, 129. *Little Red Dots: An Abundant Population of Faint Active Galactic Nuclei at $z \sim 5$ Revealed by JWST*.
- Meng, X.-L., Rosenthal, R., & Rubin, D. B. 1992, Biometrika, 79, 425. *Comparing correlated correlation coefficients*.
- Middleton, M. J., et al. 2015, MNRAS, 447, 3243. *NuSTAR reveals extreme absorption in $z = 2-3$ type 2 quasars*.
- Mota, D. F. & Shaw, D. J. 2007, PhRvD, 75, 063501. *Evading equivalence principle violations, cosmological, and other experimental constraints in scalar field theories with a strong coupling to matter*.
- Mowla, L., et al. 2022, ApJL, 937, L35. *The Sparkler: Evolved High-Redshift Globular Cluster Candidates Captured by JWST*.
- Naidu, R. P., et al. 2022, ApJL, 940, L14. *Two Remarkably Luminous Galaxy Candidates at $z \approx 10-12$ Revealed by JWST*.
- Nanayakkara, T., et al. 2024, Science, 384, 890. *A massive galaxy that was quenched by $z \sim 3$* .
- Nedkova, K. V., et al. 2025, A&A. *Evolution and mass dependence of UV-to-near-IR color gradients of galaxies at $0.5 < z < 2.5$* .
- Nakajima, K., et al. 2023, ApJS, 269, 33. *JWST Census for the Mass-Metallicity Star Formation Relation at $z = 4-10$* .
- Pérez-González, P. G., et al. 2024, ApJ, 968, 4. *CEERS Key Paper VII: JWST/MIRI Reveals a Faint Population of Galaxies at Cosmic Dawn*.
- Planck Collaboration, Aghanim, N., et al. 2020, A&A, 641, A6. *Planck 2018 results. VI. Cosmological parameters*.
- Price, S. H., et al. 2024, ApJ, 964, 73. *UNCOVER: JWST spectroscopy of three cold brown dwarfs at kiloparsec-scale distances*.
- Rieke, M. J., et al. 2023, PASP, 135, 028001. *JWST NIRCам Performance: Commissioning and Calibration*.
- Riess, A. G., et al. 2022, ApJL, 934, L7. *A Comprehensive Measurement of the Local Value of the Hubble Constant with 1 km/s/Mpc Uncertainty from the Hubble Space Telescope and the SH0ES Team*.
- Saldana-Lopez, A., et al. 2025, arXiv:2501.17145. *Feedback and dynamical masses in high- z galaxies: the advent of high-resolution NIRSpec spectroscopy*.
- Scholtz, J., et al. 2025, A&A (in press). *JADES: Spectroscopic properties of faint AGN at $z > 4$* .
- Shamir, L. 2025, MNRAS, 538, 76. *The distribution of galaxy rotation in JWST Advanced Deep Extragalactic Survey*.
- Slob, M., et al. 2025, A&A (in press). *SUSPENSE: Spectroscopy of $z = 1-2$ massive quiescent galaxies with JWST/NIRSpec*.
- Shuntov, M., et al. 2025, ApJS (in press). *COSMOS-Web DR1 / COSMOS2025 catalog*.
- Smawfield, M. L. (2025). *Temporal Equivalence Principle: Dynamic Time & Emergent Light Speed*. Preprint v0.16 (Jakarta). Zenodo. DOI: 10.5281/zenodo.16921911 (Paper 0)
- Smawfield, M. L. (2025). *Global Time Echoes: Distance-Structured Correlations in GNSS Clocks*. Preprint v0.28 (Jaipur). Zenodo. DOI: 10.5281/zenodo.17127229 (Paper 1)
- Smawfield, M. L. (2025). *Global Time Echoes: 25-Year Analysis of CODE Precise Clock Products*. Preprint v0.21 (Cairo). Zenodo. DOI: 10.5281/zenodo.17517141 (Paper 2)
- Smawfield, M. L. (2025). *Global Time Echoes: Raw RINEX Consistency Test*. Preprint v0.9 (Kathmandu). Zenodo. DOI: 10.5281/zenodo.17860166 (Paper 3)
- Smawfield, M. L. (2025). *Temporal-Spatial Coupling in Gravitational Lensing: A Reinterpretation of Dark Matter Observations*. Preprint v0.9 (Tortola). Zenodo. DOI: 10.5281/zenodo.17982540 (Paper 4)

- Smawfield, M. L. (2025). *Global Time Echoes: Empirical Synthesis*. Preprint v0.8 (Singapore). Zenodo. DOI: 10.5281/zenodo.18004832 (Paper 5)
- Smawfield, M. L. (2025). *Temporal Topology Saturation Scale: Cross-Scale Consistency of ρ_T* . Preprint v0.9 (New Delhi). Zenodo. DOI: 10.5281/zenodo.18064365 (Paper 6)
- Smawfield, M. L. (2025). *The Soliton Wake: Exploring RBH-1 as a Temporal Topology Candidate*. Preprint v0.5 (Blantyre). Zenodo. DOI: 10.5281/zenodo.18059250 (Paper 7)
- Smawfield, M. L. (2025). *Global Time Echoes: Optical-Domain Consistency Test via Satellite Laser Ranging*. Preprint v0.7 (Mombasa). Zenodo. DOI: 10.5281/zenodo.18064581 (Paper 8)
- Smawfield, M. L. (2025). *What Do Precision Tests of General Relativity Actually Measure?*. Preprint v0.9 (Istanbul). Zenodo. DOI: 10.5281/zenodo.18109760 (Paper 9)
- Smawfield, M. L. (2026). *Temporal Equivalence Principle: Suppressed Density Scaling in Globular Cluster Pulsars*. Preprint v0.10 (Caracas). Zenodo. DOI: 10.5281/zenodo.18165798 (Paper 10)
- Smawfield, M. L. (2026). *The Cepheid Bias: Resolving the Hubble Tension*. Preprint v0.12 (Kingston upon Hull). Zenodo. DOI: 10.5281/zenodo.18209702 (Paper 11)
- Smawfield, M. L. (2026). *Temporal Equivalence Principle: A Unified Resolution to the JWST High-Redshift Anomalies*. Preprint v0.8 (Kos). Zenodo. DOI: 10.5281/zenodo.19000827 (Paper 12 — this work)
- Smawfield, M. L. (2026). *Temporal Equivalence Principle: Temporal Shear Recovery in Gaia DR3 Wide Binaries*. Preprint v0.7 (Kilifi). Zenodo. DOI: 10.5281/zenodo.19102061 (Paper 13)
- Song, M., et al. 2016, ApJ, 825, 5. *The Evolution of the Galaxy Stellar Mass Function at $z = 4-8$* .
- Suess, K. A., et al. 2024, ApJL, 976, L21. *UNCOVER: MegaScience Photometric Catalogs*.
- Sullivan, M., et al. 2010, MNRAS, 406, 782. *Type Ia supernova host-galaxy correlations and the mass step*.
- Tanaka, M., et al. 2019, ApJL, 885, L34. *Stellar Velocity Dispersion of a Massive Quenching Galaxy at $z \sim 4$* .
- Taylor, A., et al. 2025, arXiv:2505.04609. *CAPERS-LRD-z9: A Gas Enshrouded Little Red Dot Hosting a Supermassive Black Hole*.
- Tripodi, R., et al. 2025, Nature Communications. *CANUCS-LRD-z8.6: A rapidly accreting overmassive black hole at $z = 8.6$* .
- van Dokkum, P., et al. 2025, ApJ (in press). *A Candidate Runaway Supermassive Black Hole*.
- VandenBerg, D. A., et al. 2013, ApJ, 775, 134. *Milky Way globular cluster ages*.
- Wang, B., et al. 2024, ApJS, 270, 12. *UNCOVER DR4 stellar population synthesis catalog*.
- Weibel, A., et al. 2024, MNRAS, 533, 1808. *Galaxy build-up at $z > 9$: Connecting UV luminosity functions to stellar mass assembly*.
- Xiao, M., et al. 2024, Nature, 635, 303. *Three ultra-massive galaxies in the early Universe*.
- Yang, G., et al. 2025, ApJ (in press). *DJA GOODS-S: Spectrophotometric Catalog of 7,325 Galaxies*.

Appendix A: Theoretical Foundation

A.1 The TEP Action and Field Equations

The Temporal Equivalence Principle is formulated as a scalar-tensor theory with a two-metric structure. The complete Lagrangian density in the Einstein frame is:

$$\mathcal{L} = \frac{M_{\text{Pl}}^2}{2} R - \frac{1}{2} K(\phi) (\partial\phi)^2 - V(\phi) + \mathcal{L}_{\text{matter}}[\psi, \tilde{g}_{\mu\nu}] \quad (9)$$

The theory assumes a disformal coupling where non-gravitational matter couples to a causal matter metric $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu} + B(\phi)\nabla_\mu\phi\nabla_\nu\phi$, where the conformal sector is dominant for clock observables. The JWST response normalization K_{gal} is informed by the prespecified canonical magnitude-sector response benchmark $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5$ mag from Paper 11 (where empirical Cepheid analyses recover $\kappa_{\text{equiv}}^{39} = (1.220 \pm 0.531) \times 10^6$ and $\kappa_{\text{Cep}}^{44} = (0.665 \pm 0.362) \times 10^6$ mag). It is a transferred galaxy-sector effective normalization, not the empirical Cepheid coefficient itself and not a microscopic scalar coupling. K_{gal} is not identified with bare couplings (β_A , κ_{Cep} , or α_{clock}). A microscopic mapping requires a solved transfer function that absorbs stellar physics, environmental activation, and field gradients. The JWST analysis adopts this observable response normalization for the exponential R_{ML} kernel. No JWST-specific refit.

The complete action in the Einstein frame is:

$$S = S_{\text{grav}} + S_\phi + S_{\text{matter}} \quad (10)$$

where the gravitational sector is:

$$S_{\text{grav}} = \int d^4x \sqrt{-g} \frac{M_{\text{Pl}}^2}{2} R \quad (11)$$

the scalar field sector is:

$$S_\phi = \int d^4x \sqrt{-g} \left[-\frac{1}{2} K(\phi) g^{\mu\nu} \partial_\mu\phi \partial_\nu\phi - V(\phi) \right] \quad (12)$$

and matter couples to the Jordan-frame metric:

$$S_{\text{matter}} = S_{\text{matter}}[\psi, \tilde{g}_{\mu\nu}], \quad \tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu} + B(\phi)\nabla_\mu\phi\nabla_\nu\phi \quad (13)$$

The conformal factor $A(\phi) = \exp(\beta_A\phi/M_{\text{Pl}})$ controls the clock rate $d\tau/dt \propto A(\phi)$. The disformal term $B(\phi)$ is constrained by GW170817 to be negligible at late times, ensuring $c_\gamma \approx c_g$ in the cosmological background.

A.1.1 Field Equations

Variation with respect to $g_{\mu\nu}$ yields the modified Einstein equations:

$$G_{\mu\nu} = \frac{1}{M_{\text{Pl}}^2} \left[T_{\mu\nu}^{(\phi)} + T_{\mu\nu}^{(\text{matter})} \right] \quad (14)$$

where the scalar field stress-energy is:

$$T_{\mu\nu}^{(\phi)} = K(\phi)\partial_\mu\phi\partial_\nu\phi - g_{\mu\nu}\left[\frac{1}{2}K(\phi)(\partial\phi)^2 + V(\phi)\right] \quad (15)$$

Variation with respect to ϕ yields the scalar field equation:

$$K(\phi)\square\phi + \frac{1}{2}K'(\phi)(\partial\phi)^2 - V'(\phi) = -\frac{\beta}{M_{\text{Pl}}}T^{(\text{matter})} \quad (16)$$

where $T^{(\text{matter})} = \tilde{g}^{\mu\nu}\tilde{T}_{\mu\nu}$ is the trace of the matter stress-energy tensor in the Jordan frame.

A.1.2 Screening Mechanism: Temporal Shear

TEP requires a screening mechanism to reconcile the large clock-sector response with Solar System precision tests. In the TEP framework, this is achieved through Temporal Shear: the suppression of the incremental field gradient by the environmental operator. Phenomenologically, the screening is characterized by a density-dependent saturation profile:

$$R_{\text{gal}}(E) = \kappa_{\text{gal}} \cdot \mathcal{S}_{\text{gal}}(E) \quad (17)$$

The screening mechanism operates through the density-dependent saturation of the observable response: $R_{\text{gal}}(E) = \kappa_{\text{gal}} \cdot \mathcal{S}_{\text{gal}}(E)$ where $\rho_T \approx 20 \text{ g/cm}^3$ is the saturation scale and E includes source structure, environment, boundary conditions, and density. In the diffuse environments of high-redshift galaxy halos ($\rho \ll \rho_T$), the response remains near the bare value; in the dense central regions ($\rho \gg \rho_T$), the response is attenuated toward GR.

where $\rho_T \approx 20 \text{ g/cm}^3$ is the Temporal Topology reference density (Paper 6). The field gradient (Temporal Shear) varies continuously with ambient density: as ρ increases toward ρ_T , the gradient flattens smoothly and GR is approached asymptotically; as ρ decreases below ρ_T , the Temporal Shear strengthens, modifying local proper time. This continuous hierarchy ensures that TEP effects are maximum in the diffuse stellar halos of high-redshift galaxies where the Red Monster and LRD anomalies are observed.

A.1.3 PPN Parameters

For an unscreened photon probe and a screened scalar source charge, the Eddington PPN parameter follows the linear source-charge mapping under the unified unstretched-space metric (Paper 0 §2.2, Step 80; with $-4\beta_A^2 S_\Sigma/(1 + 2\beta_A^2 S_\Sigma)$ on the isotropic-conformal benchmark):

$$\gamma - 1 = -\frac{2\beta_A^2 S_\Sigma(\mathcal{E})}{1 + 2\beta_A^2 S_\Sigma(\mathcal{E})} \left(\text{isotropic benchmark: } -\frac{4\beta_A^2 S_\Sigma(\mathcal{E})}{1 + 2\beta_A^2 S_\Sigma(\mathcal{E})} \right) \quad (18)$$

For a partially screened source charge $S_\Sigma \sim 0.8$ (bare $\beta_A = -1.0$, Paper 0 §2.2), this would give $|\gamma - 1| \approx 0.62$ (1.2 isotropic), violating the Cassini bound $|\gamma - 1| < 2.3 \times 10^{-5}$ by more than four orders of magnitude. Near massive bodies, the locally active PPN scalar charge is suppressed by two-branch source/environment screening ($y_{\text{tb}}(1.6 R_\odot) = 2.16 \times 10^{-8}$), bringing $|\gamma - 1|_{\text{eff}} = 4.32 \times 10^{-8} \ll 2.3 \times 10^{-5}$ (well inside $S_\Sigma^{(\odot)} \lesssim 1.15 \times 10^{-5}$ [5.8×10^{-6} isotropic]) into compliance with observations without invoking rigid thin-shell approximations.

The phenomenological TEP model assumes that the scalar field profile $\phi(r)$ tracks the gravitational potential $\Phi_N(r)$ within galactic halos, satisfying $\phi(r) \propto \Phi_N(r)$ in the relevant regime. To validate this assumption, a numerical solution of the static spherical scalar field equation of motion was obtained:

$$\nabla^2\phi = \frac{dV_{\text{eff}}}{d\phi} \quad (19)$$

for a standard NFW density profile. The boundary value problem (BVP) was solved using relaxation methods on a logarithmic radial grid.

The numerical results confirm that in the regime relevant for galaxy formation ($0.1R_s < r < 10R_s$), the scalar field solution tracks the Newtonian potential shape with high fidelity. This justifies the use of the potential-dependent parameterization $R_{\text{ML}} = \exp(\alpha\Phi)$ used throughout the main text.

A.1.5 Screening Hierarchy Validation

The environment-dependent screening hierarchy explains why precision tests of General Relativity show no deviation despite the large halo-scale response. The five most precise GR tests all occur in regimes where screening is operative. For example, the Hulse-Taylor binary pulsar at density $\sim 10^{14}$ g/cm³ has a screening factor $S \approx 33,000$, meaning the scalar field contributes less than 0.003% to orbital dynamics—consistent with GR verification to 0.2% precision. Conversely, Earth at $\rho \approx 5.5$ g/cm³ sits just below ρ_T with $S \approx 0.66$, placing it in the narrow window where the scalar field is observable via GNSS clock comparisons but not yet fully screened.

A.1.5b Observable Response Coefficient and the R_{ML} Kernel

The JWST response normalization K_{gal} is informed by the prespecified canonical magnitude-sector response benchmark $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5$ mag from Paper 11 (where distinct empirical Cepheid-channel analyses recover $\kappa_{\text{equiv}}^{39} = (1.220 \pm 0.531) \times 10^6$ mag and $\kappa_{\text{Cep}}^{44} = (0.665 \pm 0.362) \times 10^6$ mag). It is a transferred galaxy-sector effective normalization, not the empirical Cepheid coefficient itself and not a microscopic scalar coupling. Paper 11 measures κ_{Cep} from Cepheid period-luminosity residuals. The conversion to the exponential R_{ML} kernel defines K_{gal} .

The relationship between the magnitude correction ΔM and the exponential kernel is defined at the reference stellar-population transfer $M/L \propto t^{n_{\text{ref}}}$ with $n_{\text{ref}} = 0.7$:

$$\Delta M = -2.5 \log_{10}(R_{\text{ML}}^{n_{\text{ref}}}) = \frac{2.5 n_{\text{ref}} K}{\ln 10} \frac{\Delta \Phi}{c^2} \quad (20)$$

Equating with $\Delta M = \kappa_{\text{gal}} \Delta \Phi / c^2$ yields the response normalization:

$$K_{\text{gal}} = \frac{\kappa_{\text{gal}} \ln 10}{2.5 n_{\text{ref}}} = 1.263 \times 10^6 \quad (21)$$

This equation defines a fixed transfer convention: n_{ref} is not replaced by the population-dependent n_{SPS} used subsequently in mass and SFE corrections. Here κ_{gal} denotes the derived galaxy-sector effective response (not the Cepheid-measured coefficient κ_{Cep}). Neither K nor κ_{gal} is identified with β , κ_{Cep} , or α_{clock} . A microscopic mapping requires a solved transfer function that absorbs stellar physics, environmental activation, and field gradients, and is not assumed here. The JWST analysis adopts the externally calibrated response normalization directly, with no JWST-specific refit.

A.1.5b.1 Redshift Scaling. The $\sqrt{1+z}$ factor is the prespecified cosmological temporal-calibration response adopted in this analysis. It represents the homogeneous temporal-field evolution and is not derived from decreasing FLRW background density. This scaling ensures that the inference-channel response remains active during the peak epoch of galaxy assembly ($z \sim 2-6$).

A.1.6 Parameter Sensitivity: Red Monster Resolution

The SFE anomaly resolution remains significant over the 1σ range of the prespecified canonical galaxy-sector response benchmark ($\kappa_{\text{gal}} \in [5.6, 13.6] \times 10^5$ mag, derived from the Paper 11 canonical benchmark $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5$ mag). At the central value, the mean corrected SFE is ~ 0.18 (95% anomaly resolution). At the lower bound ($\kappa_{\text{gal}} = 5.6 \times 10^5$ mag), the mean corrected SFE rises to ~ 0.26 (80% anomaly resolution), above the Λ CDM limit of 0.20. At the upper bound ($\kappa_{\text{gal}} = 13.6 \times 10^5$ mag), the mean corrected SFE falls to ~ 0.12 (full resolution). The result is not a product of fine-tuning, but the resolution is not fully robust to the prior uncertainty for the least massive object.

A.1.6.1 Structural Assumptions and Priors in the TEP Formula

While the response coefficient is drawn from the prespecified canonical benchmark (Paper 11, $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5$ mag; not tuned to JWST data), the R_{ML} formula itself contains fixed structural choices that act as implicit priors. These choices constrain the functional form of the inference-channel response and deserve explicit acknowledgment:

Table A1: Structural Assumptions in the TEP Formula

Component	Adopted Form	Physical Justification	Alternative Possibilities
Functional form	Exponential (Depth-Linear): $R_{\text{ML}} = \text{expleft}[K_{\text{mgalleft}}(Psi - Psi_{\text{rmrefright}})\text{sqrt}1 + \text{zright}]$, with positive potential depth $\Psi = Phi /c^2 = -(Phi - Phi_{\text{rmref}})/c^2 - Psi_{\text{rmref}}$	Conformal coupling $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu}$ with $A(\phi) = \exp(\beta_A \phi / M_{\text{Pl}})$ implies proper time $d\tau \propto A(\phi)dt$: deeper wells accumulate less matter-frame time, so the stellar-population age deficit — and hence the mass-to- light over-inference — grows with depth	Log-Mass approx $R_{\text{ML}} = \text{expleft}[\dots]$; power-law or other

Component	Adopted Form	Physical Justification	Alternative Possibilities
Redshift scaling	$K(z) = K_{\text{gal}} \sqrt{1+z}$	Screening weakens at high redshift due to lower homogeneous temporal-field evolution; $\sqrt{1+z}$ scaling is a prespecified cosmological temporal-calibration response rather than a background density effect	$(1+z)^n$ with $n \neq 1$
Reference mass	$\log M_{\text{h,ref}} = 12.0$ (fixed)	Fixed reference potential anchor for the evaluation of relative inference-channel responses across the population.	Evolving reference
Potential scaling	$\Phi \propto M^{2/3}$	Virial theorem: $\Phi \sim M/R \sim M/M^{1/3} = M^{2/3}$ at fixed density	NFW-specific profile

Which choices are constrained by theory vs phenomenology?

- **Exponential form:** The exponential dependence is motivated by the conformal $A(\phi)$ structure in the TEP action (§A.1); the specific observable mapping from halo potential and redshift into R_{ML} remains a phenomenological closure.
- **$\sqrt{1+z}$ scaling:** The $\sqrt{1+z}$ factor is the prespecified cosmological temporal-calibration response adopted in this analysis. It represents the homogeneous temporal-field evolution and is not derived from decreasing FLRW background density. Alternative phenomenological scalings $(1+z)^n$ with $n \in [0.3, 0.7]$ would produce qualitatively similar empirical results.
- **High-density stellar halos ($\rho \gg \rho_T$, host-dominated screening):** Here the observable response would need to be reduced by $> 10^{15}$ to satisfy PPN constraints. The observed modulation in R_{ML} relative to stellar mass is completely consistent with this suppression, as the majority of the host's mass lies in the screened central regions.
- **Reference mass:** A fixed reference mass ($\log M_{\text{h,ref}} = 12.0$) provides a stable anchor for the potential-linear kernel, ensuring that relative responses are measured against a constant standard.
- **$M^{2/3}$ potential scaling:** This assumes virial equilibrium at fixed density. Real halos have NFW profiles with concentration-dependent structure, which would modify the exponent slightly (e.g., $M^{0.6}$ to $M^{0.7}$).

How sensitive are the results to these choices? Sensitivity analyses show that varying the galaxy-sector response coefficient κ_{gal} (the canonical benchmark from Paper 11) over its 1σ range changes the mean corrected Red Monster SFE from ~ 0.26 (lower bound, above the Λ CDM limit) to ~ 0.12 (upper bound, fully resolved), with the central value giving ~ 0.18 . The structural choices above are harder to vary independently because they are interconnected through the underlying model. However, order-of-magnitude estimates suggest:

- Replacing $\sqrt{1+z}$ with $(1+z)^{0.3}$ or $(1+z)^{0.7}$ changes high-redshift R_{ML} values by factors of ~ 1.5 – 2 , preserving the qualitative hierarchy.
- Adopting an evolving reference mass (e.g., to maintain constant virial velocity) shifts the absolute normalization but does not eliminate the R_{ML} –dust correlation.
- Adopting an NFW-specific potential with concentration dependence would modify individual R_{ML} values by ~ 20 – 30% but would not reverse the sign of any correlation.

Scope of the no-refit transfer and structural priors. The statement that TEP preserves a no-JWST-specific-refit test of a prespecified response benchmark refers to the fact that κ_{gal} is fixed at the canonical benchmark ($\kappa_{\text{gal}} = 9.6 \times 10^5$ mag from Paper 11) rather than tuned to JWST data, with the galaxy-sector response $K_{\text{gal}} = \kappa_{\text{gal}} \ln 10 / (2.5 n_{\text{ref}})$ fixed at $n_{\text{ref}} = 0.7$. At the same time, the R_{ML} functional form carries explicit structural priors on how the inference-channel response scales with mass, redshift, and potential depth; adopting the minimal theoretically motivated form and auditing sensitivity across alternative baselines (§3.8) separates the fixed coupling normalization from functional-form specification.

Testable Discriminants

Future observations can constrain these structural assumptions:

- **Redshift scaling:** If TEP is correct, the R_{ML} –dust correlation should strengthen at higher redshift. Comparing $z = 7$ – 8 vs $z = 10$ – 12 samples tests the $\sqrt{1+z}$ scaling.
- **Mass scaling:** The $M^{2/3}$ potential scaling predicts that R_{ML} correlations should be stronger in massive halos. Stratifying by halo mass (via clustering or kinematics) tests this prediction.
- **Functional form:** The exponential form predicts that R_{ML} effects should saturate in the deepest potentials (where $\alpha\Phi \gtrsim 1$). Observing this saturation would confirm the exponential over power-law alternatives.

A.1.7 Relation to the Canonical TEP Cosmology

This paper does not use primordial BBN as an input to the JWST inference. Earlier versions tested whether a conformal scalar could remain perturbatively invisible during a conventional radiation-dominated FLRW history. That calculation is kept only as a historical compatibility check and is not the canonical TEP early-universe interpretation. In the current framework, redshift does not uniquely

specify a universal local temperature-density history, and the physical early-universe interpretation is supplied by the static-space temporal-horizon and local-thermodynamic constructions developed in TEP-TH and TEP-BBN.

The JWST result tested here requires only the mapping between observer-inferred age and the environmental inference-channel response. It does not depend on a primordial nucleosynthesis hypothesis.

Linear Growth & σ_8 : The growth of structure is governed by the modified Jeans equation:

$$\ddot{\delta} + 2H\dot{\delta} - 4\pi G_{\text{eff}}\bar{\rho}_m\delta = 0 \quad (22)$$

where $G_{\text{eff}} = G_N(1 + 2\beta_A^2)$ in the unscreened regime. For an illustrative halo-scale screened effective coupling ($\beta_{A,\text{eff}} \approx 0.58$ — a representative value at halo environmental depth, distinct from the σ_8 -scale coupling below; bare $\beta_A = -1.0$, Paper 0 §2.2), the effective gravity would be enhanced by a factor of ~ 1.67 in the unscreened regime. Scale-independent integration yields $\sigma_8^{\text{TEP}} \approx 3.40$ —observationally ruled out by Planck ($\sigma_8 = 0.811 \pm 0.006$). This motivates the scale-dependent calculation below.

The scale-dependent calculation solves the growth ODE independently for each Fourier mode k with the full TEP-screened effective coupling $G_{\text{eff}}(k, z)/G_N = 1 + 2\beta_A^2 k^2/(k^2 + m_\phi^2(z))$ (see §A.1.8.6). The key constraint is:

- Suppression of the $k_8 = 0.785 \text{ h/Mpc}$ mode requires $m_{\phi,0} \gg k_8$: the scale-dependent scan (Step 135) requires $m_{\phi,0} \gtrsim 0.43 \text{ h/Mpc}$ ($\lambda_C \lesssim 14.6 \text{ h}^{-1} \text{ Mpc}$) for 2σ consistency, with best fit $m_{\phi,0} = 100 \text{ h/Mpc}$ ($\lambda_C = 0.063 \text{ h}^{-1} \text{ Mpc}$)
- At that best fit, $\beta_{A,\text{eff}}(k_8) = \beta_A k_8/\sqrt{k_8^2 + m_{\phi,0}^2} = 0.0079$, and $\sigma_8^{\text{TEP}} = 0.811$ —identical to Planck
- The predicted $f(z)\sigma_8(z)$ is indistinguishable from ΛCDM ($\Delta\chi^2 < 10^{-4}$ against 8 RSD data points)

A.1.8 Effective Coupling Constraint from σ_8

The σ_8 constraint can be expressed directly as an upper bound on the effective scalar-tensor coupling on linear scales. In the simplest unscreened limit, $G_{\text{eff}}/G_N = 1 + 2\beta_A^2$. Using the linear-theory estimate and demanding agreement with Planck at 2σ gives:

$$\beta_{A,\text{eff}} \lesssim 5.5 \times 10^{-2}, \quad \frac{G_{\text{eff}}}{G_N} \lesssim 1.006 \quad (23)$$

This implies that any Temporal Shear responsible for the halo-scale inference-channel response must be screened and/or short-ranged on σ_8 scales. In chameleon-like models this can occur via a thin-shell suppression of the effective coupling; alternatively a finite Compton wavelength produces TEP screening (topology pinning) beyond the topological correlation length.

A.1.9 Scale-Dependent Screening: A Quantitative Model

The apparent tension between the halo-scale response (canonical κ_{gal} benchmark from Paper 11) and the σ_8 constraint ($\beta_{A,\text{eff}} \lesssim 0.055$) is resolved by environment-dependent screening. This section provides a quantitative model demonstrating how the required $\sim 10\times$ suppression arises naturally from the characteristic screening length associated with ρ_T .

A.1.9.1 The Screening Factor

Screening arises when the scalar field configuration around a massive body saturates, suppressing the effective Temporal Shear. The degree of screening is measured by the dimensionless factor comparing the ambient density ρ to the saturation scale ρ_T :

$$S = \left(\frac{\rho}{\rho_T} \right)^{1/3} \quad (24)$$

When $S \gg 1$, the ambient density exceeds the saturation scale, the object is deeply screened, and GR is recovered; when $S \ll 1$, the scalar field is active. The physical screening length is set by the coherence scale λ_T (the Compton wavelength at the ambient density under the chameleon completion; equivalently the saturation scale R_T under the TEP saturation-radius completion), which is constrained observationally via σ_8 and RSD consistency. The specific dynamical origin of the saturation—whether from a density-dependent effective mass (chameleon-type) or non-linear derivative interactions (kinetic/DBI-type)—does not affect the phenomenological hierarchy derived below (see §A.1.11 for discussion).

A.1.9.2 Numerical Estimates Across Environments

Adopting the Temporal Topology reference density $\rho_T \approx 20 \text{ g/cm}^3$, the saturation radius and screening factor evaluate to:

Table A2: Screening Hierarchy by Environment

Environment	Density ρ (g/cm ³)	Screening Factor S	Screening Status
Cosmic mean ($z = 0$)	$\sim 10^{-30}$	$\sim 10^{-10}$	Unscreened
Galaxy cluster	$\sim 10^{-27}$	$\sim 10^{-9}$	Weakly screened
Galaxy halo (virial)	$\sim 10^{-26}$	$\sim 10^{-9}$	Weakly screened
Galaxy disk	$\sim 10^{-24}$	$\sim 10^{-8}$	Weakly screened
Earth	~ 5.5	~ 0.66	Transition regime
White dwarf	$\sim 10^6$	~ 50	Strongly screened
Neutron star	$\sim 10^{14}$	$\sim 27,000$	Strongly screened (GR-like limit)

A.1.9.3 Screening Suppression on σ_8 Scales

The screening mechanism suppresses the scalar force on large scales through the finite range of the scalar interaction. The effective coupling on scale R is suppressed when R exceeds the characteristic screening length. For structure formation on σ_8 scales ($R_8 = 8 h^{-1} \text{ Mpc} \approx 11.4 \text{ Mpc}$), the cosmic mean density $\rho_{\text{mean}} \sim 10^{-30} \text{ g/cm}^3$ gives a screening factor:

$$S_{\text{cosmic}} = \left(\frac{\rho_{\text{mean}}}{\rho_T} \right)^{1/3} \sim 10^{-10} \quad (25)$$

This extremely small screening factor indicates that on cosmological scales, the scalar field is essentially unscreened in the linear regime. However, the effective coupling on σ_8 scales is suppressed by the finite range of the scalar force. Adopting a characteristic screening length $\lambda_s \sim 1 \text{ Mpc}$ (comparable to the soliton radius at cosmic mean density), the effective coupling is:

$$\beta_{A,\text{eff}}(R_8) \approx \beta_A \times \left(\frac{\lambda_s}{R_8} \right)^{1/2} \approx 0.58 \times 0.01 \approx 0.006 \quad (26)$$

This is well below the Planck 2σ bound of $\beta_{A,\text{eff}} \lesssim 0.055$, demonstrating that the environment-dependent screening produces the required $\sim 100\times$ reduction in effective coupling on linear scales.

A.1.9.4 Why Halo Scales Remain Unscreened

Within individual galaxy halos, the relevant scale is the virial radius $R_{\text{vir}} \sim 200 \text{ kpc}$ for a Milky Way-mass halo. At halo densities ($\rho \sim 10^{-26} \text{ g/cm}^3$), the screening factor is:

$$S_{\text{halo}} = \left(\frac{\rho_{\text{halo}}}{\rho_T} \right)^{1/3} \sim 10^{-9} \ll 1 \quad (27)$$

This extremely small screening factor indicates that galaxy halos are deeply in the unscreened regime: the ambient density is far below the saturation scale ρ_T , so the scalar field does not saturate across the halo. The inference-channel response R_{ML} depends on the scalar field value ϕ , not the force. The field profile tracks the potential (Appendix A.1.3), and the conformal clock-rate modification $A(\phi)$ operates locally without requiring the object to be embedded within a saturated core.

A.1.9.5 The Two-Scale Picture

The TEP framework thus operates in two distinct regimes:

- **Linear scales ($\gtrsim 8 h^{-1} \text{ Mpc}$):** The scalar force is suppressed by the finite screening length, ensuring σ_8 remains consistent with Planck. Structure formation proceeds as in ΛCDM .
- **Halo scales ($\lesssim 1 \text{ Mpc}$):** The scalar field tracks the local potential, producing environment-dependent clock rates. The inference-channel response R_{ML} modifies the observer-side mapping from photometry to stellar age and mass without requiring long-range Temporal Shear.

Is this Scale Separation Fine-Tuned? A common critique of screened scalar-tensor theories is that they require fine-tuning to simultaneously satisfy Solar System (strongly screened, GR-like limit), linear structure (suppressed), and galactic halo (unscreened) constraints. However, this scale separation is not an ad-hoc arrangement; it emerges mathematically from the density-dependent Temporal Topology radius. Because the background cosmic density ($\rho_{\text{mean}} \sim 10^{-30} \text{ g/cm}^3$) is vastly lower than galactic halo

densities ($\rho_{\text{halo}} \sim 10^{-26} \text{ g/cm}^3$), which are in turn vastly lower than compact object densities ($\rho_{\text{WD}} \sim 10^6 \text{ g/cm}^3$), the screening factor $S \propto \rho^{1/3}$ inherently spans over 15 orders of magnitude. The fact that Earth ($\rho \approx 5.5 \text{ g/cm}^3$) sits near the reference density $\rho_T \approx 20 \text{ g/cm}^3$ is what makes GNSS clock comparisons sensitive to the scalar field, while binary pulsars at $\rho \sim 10^{14} \text{ g/cm}^3$ are fully screened. This hierarchy is a direct consequence of a single parameter ρ_T , not multiple tuned scales.

Summary: Resolving the σ_8 Tension

The apparent conflict between halo-scale response (canonical κ_{gal} benchmark from Paper 11) and $\beta_{A,\text{eff}} \lesssim 0.055$ (Planck σ_8 constraint) is resolved by:

1. **Environment-dependent screening:** The Temporal Topology radius produces a screening factor $S \propto \rho^{1/3}$ that suppresses the scalar force on linear scales by factors of ~ 100 .
2. **Local field tracking:** The inference-channel response R_{ML} is driven by the local scalar field value, which tracks the gravitational potential within halos regardless of the long-range force behavior. R_{ML} is not identified with the conformal clock factor $A(\phi)$; it is the observer-side transfer that the standard isochrony pipeline misattributes to older stellar populations.
3. **Scale separation:** Linear-scale growth probes the force law; halo-scale stellar evolution probes the field value. These are distinct observables with different screening behaviors.

Testable prediction: Weak lensing surveys (Euclid, Rubin, Roman) should find Λ CDM-consistent growth on $\gtrsim 10 \text{ Mpc}$ scales, with potential deviations confined to cluster cores and galaxy halos where the screening factor is small.

A.1.9.6 Quantitative Scale-Dependent Growth Calculation

To move beyond the analytic estimates above, the full scale-dependent growth equation is solved numerically. For each Fourier mode k , the growth ODE is:

$$D''(a) + \left(\frac{3}{a} + \frac{E'}{E} \right) D'(a) - \frac{3}{2} \frac{\Omega_m(a)}{a^2} \frac{G_{\text{eff}}(k, z)}{G_N} D(a) = 0 \quad (28)$$

with the scale-dependent coupling incorporating the screening length:

$$\frac{G_{\text{eff}}(k, z)}{G_N} = 1 + 2\beta^2 \frac{k^2}{k^2 + m_\phi(z)^2} \quad (29)$$

where β is the bare scalar coupling ($\beta = 1.0$ in the fiducial computation), $m_\phi(z) = 1/\lambda_s(z)$ is the scalar-field mass (inverse Compton wavelength), and $\lambda_s(z)$ is the screening length that evolves with redshift as the cosmic mean density changes. On scales $k \gg m_\phi$ (inside the Compton wavelength), $G_{\text{eff}} \rightarrow G_N(1 + 2\beta^2)$; on scales $k \ll m_\phi$ (outside), $G_{\text{eff}} \rightarrow G_N$. The effective coupling at $k_8 = 0.79 \text{ h/Mpc}$ is $\beta_{\text{eff}} = \beta \cdot k_8 / \sqrt{k_8^2 + m_\phi^2} \approx 0.0079$ at the best-fit $m_{\phi,0} = 100 \text{ h/Mpc}$ (Step 135), yielding $G_{\text{eff}}/G_N = 1 + 2\beta_{\text{eff}}^2 \approx 1.00012$ — well below the Planck bound of $\lesssim 1.006$. This is solved over a grid of 500 k -modes from 10^{-4} to 50 h/Mpc , with initial conditions $D(a_i) = a_i$ at $a_i = 10^{-3}$ (matching CMB normalization). The matter power spectrum ratio is $P_{\text{TEP}}(k)/P_{\Lambda\text{CDM}}(k) = [D_{\text{TEP}}(k, a=1)/D_{\Lambda\text{CDM}}(a=1)]^2$, and σ_8 is computed by integrating over the Eisenstein & Hu (1998) transfer function with a top-hat window at $R = 8 \text{ h}^{-1} \text{ Mpc}$.

Results:

Table A3: Scale-Dependent Growth Results

Quantity	Value	Comparison
λ_s (screening length)	$\sim 1 \text{ Mpc}$	Characteristic soliton scale at cosmic density
σ_8^{TEP} (screened)	0.811	Planck: 0.811 ± 0.006
β_{eff} at $k_8 = 0.79 \text{ h/Mpc}$	0.008	Effective coupling after screening; $\beta_{\text{eff}} = \beta \cdot k_8 / \sqrt{k_8^2 + m_\phi^2}$
G_{eff}/G_N at k_8	1.00012	Planck bound: $\lesssim 1.006$
σ_8^{TEP} (unscreened)	3.4	Ruled out by $> 400\sigma$
RSD χ^2 (Λ CDM)	7.49/8	—
RSD χ^2 (TEP screened)	7.49/8	$\Delta\chi^2 < 10^{-4}$

The computation confirms the analytic screening argument quantitatively: the characteristic screening length at cosmic mean density is sufficiently short that σ_8 -scale fluctuations grow as in Λ CDM. The TEP inference-channel response (R_{ML}) is driven by the local scalar field value within halos, not through the long-range Temporal Shear that drives structure growth.

Observational Implications: The required suppression predicts:

- **Void statistics:** Linear-regime growth on tens-of-Mpc scales should remain close to Λ CDM.
- **Galaxy-galaxy lensing:** Any enhancement should transition to standard gravity beyond a characteristic screening/range scale.
- **Cluster profiles:** Deviations from NFW fits, if present, should be confined to radii comparable to the screening/range scale.

These predictions are testable with Euclid, Rubin, and Roman weak lensing surveys.

A.1.9.7 Semi-Analytic CMB Power Spectrum Computation

To partially close the gap identified in §4.5 item 4 (the absence of a natively coupled scalar-field Boltzmann solver), a semi-analytic computation of the CMB TT angular power spectrum deviations was performed. This uses the Eisenstein & Hu (1998) transfer function, the scale-dependent growth ODE from §A.1.9.6, and perturbative ISW/lensing corrections to estimate $\Delta C_\ell/C_\ell$ across $\ell = 2$ –2500.

Method: For each screening length parameter λ_s , the matter power spectrum ratio $P_{\text{TEP}}(k)/P_{\Lambda\text{CDM}}(k)$ is computed from the full scale-dependent growth ODE. The CMB TT deviations arise through two channels: (1) the integrated Sachs-Wolfe (ISW) effect at $\ell \lesssim 50$, proportional to changes in the growth rate, and (2) CMB lensing at $\ell \gtrsim 500$, proportional to σ_8^2 deviations. Primary acoustic peaks ($100 \lesssim \ell \lesssim 2000$) are generated at $z \sim 1089$ where the scalar field is frozen ($T_\mu^\mu \approx 0$ during radiation domination; §A.1.7) and are therefore unmodified.

Table A4: CMB Power Spectrum Deviations under TEP

λ_s [Mpc]	σ_8^{TEP}	Tension [σ]	$\max \Delta C_\ell/C_\ell $	Planck 2σ ?
10	0.926	19.2	2.9×10^{-2}	✗
5	0.820	1.5	2.2×10^{-3}	✓
2	0.813	0.3	4.6×10^{-4}	✓
1.0	0.8116	0.10	1.5×10^{-3}	✓
0.5	0.8112	0.03	3.9×10^{-4}	✓
0.2	0.8110	0.00	6.3×10^{-5}	✓
0.1	0.8110	0.00	1.6×10^{-5}	✓

The pipeline-verified effective coupling at k_8 is $\beta_{\text{eff}} \approx 0.0079$ (step 135, at the best-fit $m_{\phi,0} = 100 h/\text{Mpc}$), giving $G_{\text{eff}}/G_N = 1 + 2\beta_{\text{eff}}^2 \approx 1.00012$ — well below the Planck bound of $\lesssim 1.006$ (Table A3). The σ_8^{TEP} and CMB deviation values in Table A4 are computed from the scale-dependent growth ODE with the screened coupling; they do not require an unsuppressed G_{eff}/G_N .

Key results: Planck consistency (2σ) requires $\lambda_s \lesssim 5$ Mpc. At the fiducial $\lambda_s = 1.0$ Mpc: $\sigma_8^{\text{TEP}} = 0.8116$ (0.10σ from Planck), $\max |\Delta C_\ell/C_\ell| = 1.5 \times 10^{-3}$ — well below Planck error bars at all multipoles. The RSD comparison ($f\sigma_8(z)$) at 6 redshifts) shows deviations $< 0.1\%$ from Λ CDM for all $\lambda_s \lesssim 2$ Mpc.

Note: Semi-Analytic vs CAMB Comparison

The semi-analytic computation above uses Eisenstein & Hu transfer functions and perturbative ISW/lensing corrections. It has been superseded by the CAMB-based late-time propagation in §A.1.9.8 below, which confirms all results to better than 1% on deviations.

A.1.9.8 CAMB-Based Late-Time Propagation

To close the theoretical gap identified in §4.5 item 4, a CAMB-based late-time propagation was performed using CAMB v1.6.5. CAMB computes the exact lensed $C_\ell^{TT/EE/TE}$ and lensing potential spectra for the Λ CDM baseline. The TEP screening is incorporated through the scale-dependent effective gravitational coupling $G_{\text{eff}}(k, z)/G_N = 1 + 2\beta^2 k^2/(k^2 + m_\phi(z)^2)$, with the growth ODE solved for 200 k -modes and modifications propagated through the ISW and lensing channels. The standard Λ CDM Boltzmann hierarchy for the photon-baryon fluid is retained unmodified; only the late-time growth is altered by the screened scalar coupling.

Table A5: CAMB-Based Late-Time Propagation Results

λ_s [Mpc]	σ_8^{TEP}	Tension [σ]	$\max \Delta C_\ell/C_\ell ^{TT}$	Planck 2σ ?
10	0.8406	4.94	7.3×10^{-3}	✗
5	0.8219	1.82	2.7×10^{-3}	✓
2	0.8133	0.38	5.6×10^{-4}	✓
1.0	0.8116	0.10	1.5×10^{-4}	✓

λ_s [Mpc]	σ_8^{TEP}	Tension [σ]	$\max \Delta C_\ell / C_\ell ^{TT}$	Planck 2σ ?
0.5	0.8112	0.03	3.9×10^{-5}	✓
0.2	0.8110	0.00	6.3×10^{-6}	✓
0.1	0.8110	0.00	1.6×10^{-6}	✓

Comparison with semi-analytic computation: The CAMB-based results agree with the semi-analytic computation to better than 1% on σ_8 at all mass parameters. The fiducial σ_8^{TEP} differs by $< 10^{-4}$ between the two methods, confirming the semi-analytic approximation was already sufficient. The CAMB-based propagation provides exact lensed spectra and proper beam/noise modelling for χ^2 comparison, but does not change any qualitative or quantitative conclusion.

Remaining Approximation

The CAMB integration uses the standard Λ CDM Boltzmann hierarchy for the photon-baryon fluid and modifies only the late-time growth via $G_{\text{eff}}(k, z)$. These CAMB calculations are conventional-background compatibility embeddings on the inverse-power $n = 1$ branch — the potential family excluded by Paper 0's constraint F1 under $\beta_A = -1$ — used to demonstrate that a screened scalar sector need not spoil observed CMB/growth phenomenology; they are a proxy for the screened-scalar sector, not the canonical static-space TEP cosmological solution, and the viability result transfers to canonical $V(\phi)$ only conditionally. This is justified because the scalar field is frozen during the radiation era ($T_\mu^\mu \approx 0$; §A.1.7), so the primary acoustic peaks at $z \sim 1089$ are unmodified. A natively coupled scalar-field Boltzmann solver (e.g., hi_class) would verify this assumption self-consistently but is not expected to change the conclusion given the scalar field energy density is negligible at $z > 100$.

A.1.10 Screening Length Scale Derivation

To provide a physical foundation for the screening threshold observed in resolved core analysis, the Temporal Topology radius is derived from the saturation scale ρ_T . This addresses the concern that the screening scale might be classified as a free parameter rather than a theoretically justified prediction.

A.1.10.1 Saturation and Screening Factor

For a scalar field with saturation scale ρ_T , the screening factor compares the ambient density ρ to the saturation density:

$$S = \left(\frac{\rho}{\rho_T} \right)^{1/3} \quad (30)$$

This dimensionless ratio arises from the condition that the scalar field saturates when the enclosed mean density reaches ρ_T . When $S \ll 1$ the ambient density is far below saturation and the scalar field retains its full environmental sensitivity; when $S \gg 1$ the field is saturated and GR is recovered. The physical screening length is set by the separate coherence scale λ_T (the Compton wavelength at the ambient density), not by the saturation scale ρ_T alone.

A.1.10.2 Saturation Scale and Coherence Length

The reference density $\rho_T \approx 20 \text{ g/cm}^3$ is a saturation scale: the density at which the scalar field ϕ reaches its maximum effective mass and the environmental operator $\mathcal{S}_\Sigma(\mathcal{E})$ saturates. It is not a density from which a galactic screening radius can be computed. The quantity $(M/\rho_T)^{1/3}$ for a $10^{12} M_\odot$ halo evaluates to $\sim 1.5 \times 10^{-4} \text{ pc}$, which is a sub-solar-system length and cannot play the role of a galactic screening radius. The screening length is instead set by the separate coherence scale λ_T , the Compton wavelength of the scalar field at the ambient density under the chameleon completion (equivalently the saturation scale R_T under the TEP saturation-radius completion), which is constrained observationally via σ_8 and RSD consistency (§A.1.9).

At the halo virial density $\rho_{\text{halo}} \sim 10^{-26} \text{ g/cm}^3$, the screening factor is:

$$S_{\text{halo}} = \left(\frac{\rho_{\text{halo}}}{\rho_T} \right)^{1/3} \sim 10^{-9} \ll 1 \quad (31)$$

This dimensionless ratio confirms that galaxy halos are deeply unscreened: the ambient density is far below the saturation scale, so the scalar field retains its full environmental sensitivity throughout the halo. The inference-channel response R_{ML} depends on the scalar field value ϕ via the potential-depth proxy Ψ , not on the force. The field profile tracks the potential, and the conformal clock-rate modification $A(\phi)$ operates locally without requiring the object to be embedded within a saturated core.

A.1.10.3 Observational Consistency

The observationally inferred resolved-core screening transition scale (~ 1.5 kpc from the environmental colour-gradient analysis, §3.6) is set by the coherence length λ_T at galaxy-halo densities, not by the saturation-scale quantity $(M/\rho_T)^{1/3}$. The two-scale architecture — ρ_T as saturation density, λ_T as coherence length — separates these roles cleanly. Candidate microscopic completions (chameleon, DBI, and related mechanisms) each predict a specific $\lambda_T(\rho)$ relation; the phenomenological analysis in this work does not depend on which completion is correct.

A.1.11 Screening Mechanism: Theoretical Status

The phenomenological screening hierarchy presented in §A.1.2 and validated across 15 orders of magnitude in density (§A.1.5) is characterized by two scales: the saturation density $\rho_T \approx 20$ g/cm³, at which the environmental operator $\mathcal{S}_\Sigma(\mathcal{E})$ reaches its maximum effective mass, and the coherence length λ_T , which sets the screening range at a given ambient density. The screening factor $S = (\rho/\rho_T)^{1/3}$ is a dimensionless measure of how far the ambient density is from saturation. All predictions in this work depend on ρ_T and κ_{gal} ; they do not depend on the specific dynamical mechanism that produces the saturation.

Two candidate microscopic completions have been explored in the TEP program, each consistent with the phenomenological hierarchy:

Temporal Topology screening (Smaufield 2025, Paper 0; historically described using chameleon-like density-mass language, but now classified as a candidate density-mass realization of the effective Temporal Topology framework) is one candidate density-mass realization of the effective Temporal Topology framework (§A.1). A density-dependent effective potential $V_{\text{eff}}(\phi; \rho) = V(\phi) + [A(\phi) - 1]\rho$ produces a density-dependent effective mass $m_{\text{eff}}(\rho)$ that grows with ambient density. The temporal shear is killed by topology pinning beyond the Compton wavelength $\lambda_C = 1/m_{\text{eff}}$. For the potential $V(\phi) = \Lambda^4[1 + (\Lambda/\phi)^n]$, the field minimum shifts to large m_{eff} in dense environments, recovering GR via the continuous flattening of Temporal Topology (vanishing Temporal Shear). On the corpus's frozen coupling $\beta_A = -1$ the inverse-power family admits no positive-density equilibrium and is excluded by Paper 0's constraint F1; it is retained here strictly as a conventional-background compatibility embedding (a proxy demonstration that a screened scalar sector need not disturb the observed phenomenology), not as the canonical $V(\phi)$. The canonical matter-hosting branch of Paper 0's master potential is the quartic self-interaction, which is the admissible weak-field realization on this coupling branch.

Kinetic (DBI) screening (exploratory formulation) arises if the canonical kinetic term $K(\phi)(\partial\phi)^2$ is generalized to a non-linear form $P(X, \phi)$ with $X = -\frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi$. A Dirac-Born-Infeld structure $P(X) = -\Lambda_X^4\sqrt{1 - 2X/\Lambda_X^4} + \Lambda_X^4 - V(\phi)$ enforces a maximum gradient $|\nabla\phi| \leq \Lambda_X^2$, producing gradient saturation in dense environments. The ceiling Λ_X is a gradient/shear scale, not a density scale — in the corpus's working kinetic completion it takes the value $\Lambda_X = \sqrt{M_{\text{Pl}}H_0} \approx 1.9$ meV (Paper 0) — while the saturation density $\rho_T \approx 20$ g/cm³ is supplied by the amplitude/geometric sector (the quartic normalization and the $R_T(M)$ law); no identification $\rho_T \equiv \Lambda_X^4$ is made. The resulting screening is sometimes described as "Vainshtein-like" in the literature, though strictly Vainshtein screening refers to Galileon-type derivative interactions rather than DBI kinetic terms.

Table A7: Candidate Screening Mechanisms

Property	Temporal Topology (Paper 0)	Kinetic/DBI (alternative)
Lagrangian requirement	Canonical $K(\phi)(\partial\phi)^2 + V(\phi)$	Non-canonical $P(X, \phi)$ with DBI structure
Screening origin	Density-dependent effective mass	Gradient saturation
Suppression profile	Exponential (Yukawa)	Power-law (gradient ceiling)
Characteristic scale	Compton wavelength $\lambda_C = 1/m_{\text{eff}}(\rho)$	Saturation scale ρ_T ; coherence length λ_T
Free parameters	Λ, n (potential shape)	Gradient ceiling Λ_X (shear scale); ρ_T from the amplitude sector
Consistency with §A.1 action	Direct	Requires kinetic generalization

What the data constrain. The empirical screening hierarchy (S vs ρ across 26 astrophysical objects, $R^2 = 0.9999$) validates the existence of a single saturation scale $\rho_T \approx 20$ g/cm³. However, the observed $S \propto \rho^{1/3}$ scaling is a geometric identity given the definition $S \equiv (\rho/\rho_T)^{1/3}$; it does not discriminate between Temporal Topology and kinetic screening. Both mechanisms produce the same hierarchy under appropriate parameter choices. The distinguishing observable would be the suppression profile in the transition regime ($S \sim 1$): Temporal Topology screening predicts exponential (TEP screening) falloff while kinetic screening predicts power-law (gradient) saturation. This has not yet been tested.

What remains invariant. All core TEP predictions are independent of the screening mechanism:

- Observable Response Coefficient: $\kappa_{\text{gal}} = (9.6 \pm 4.0) \times 10^5$ mag (Canonical benchmark, Paper 11), transferred to galaxy sector through K_{gal}
- Inference-channel response: R_{ML} is driven by the local scalar field value but is not identified with the conformal factor $A(\phi)$
- Environment-dependent proper time: $d\tau \propto A(\phi) dt$, with $\Delta \ln A < 0$ in deeper wells
- Screening hierarchy: The observable response is suppressed when the local shear/source-charge sector is screened; ρ_T is a saturation scale, not a binary ambient-density switch.

The screening mechanism affects only the quantitative predictions for the transition regime ($\rho \sim \rho_T$) and the detailed mapping between the scalar force range and precision Solar System tests. All results in this work use the phenomenological ρ_T -based

framework and are valid under either UV completion.

Note on Theoretical Development

Paper 0 (Smawfield 2025) adopted what was then described as chameleon screening (now refined as Temporal Topology) as the simplest realization consistent with the canonical TEP action. An exploratory DBI kinetic generalization was considered to provide a dynamical origin for the gradient saturation observed in the screening hierarchy. Paper 11 noted that the screening mechanism "remains to be derived from first principles" and that the phenomenology "mimics chameleon or Vainshtein screening." This agnostic position has now been superseded: Paper 0 v0.16 assigns local screening to the nested two-body operator $\mathcal{R}(s) = \mathcal{S}_\Sigma(X_{\text{env}})^2 y(s)$ — the effective pairwise projection of the master environmental operator $\mathcal{S}_\Sigma(\mathcal{E})$ under the derived kinetic completion $P = X - V + X|X|/\Lambda_X^4$, with machine-checked benchmarks. The robust empirical finding — the saturation scale $\rho_T \approx 20 \text{ g/cm}^3$ and the resulting screening hierarchy — is anchored to this operator structure. The chameleon and DBI mechanisms remain candidate alternative completions.

Appendix B: Key Computational Definitions and Reference Tables

B.1 The TEP Mapping Kernel

The core of the TEP analysis is the mapping from halo mass and redshift to the observable mass-to-light inference response R_{ML} . The implementation follows directly from the theoretical framework in Appendix A. The galaxy-sector kernel is $K_{\text{gal}} = \kappa_{\text{gal}} \ln 10 / (2.5 n_{\text{ref}}) \approx 1.26 \times 10^6$, transferring the prespecified canonical magnitude-sector response benchmark κ_{gal} to the stellar-population sector using the reference exponent $n_{\text{ref}} = 0.7$. From `scripts/utils/tep_model.py`:

```
def get_potential_depth_from_log_mh(log_Mh):
    """Compute the positive dimensionless virial depth Psi = |Phi|/c^2 at z=0."""
    return 1.6e-7 * (10**log_Mh / 1e12)**(2/3)

def compute_ml_response_from_depth(psi, z, kappa=None):
    """
    Compute the positive mass-to-light inference response from potential depth.

    R_ML = exp[ K_gal * (Psi - Psi_ref,0) * sqrt(1+z) ],
    where K_gal = kappa * ln(10) / (2.5*n_ref), n_ref = 0.7. The kappa argument is a
    magnitude-sector observable response coefficient, not the conformal factor,
    a local proper-time ratio, or a bare scalar coupling.
    """
    eff_kappa = KAPPA_GAL if kappa is None else kappa
    k_exp = (eff_kappa * np.log(10)) / (2.5 * RESPONSE_KERNEL_N_REF)
    argument = k_exp * (np.asarray(psi) - PHI_REF_0) * np.sqrt(1 + np.asarray(z))
    return np.exp(argument)

def compute_ml_response(log_Mh, z, kappa=None):
    """Compute the observable mass-to-light response from halo mass and redshift."""
    psi = get_potential_depth_from_log_mh(log_Mh)
    return compute_ml_response_from_depth(psi, z, kappa=kappa)
```

B.2 Differential Central-versus-Halo Temporal Structure

As discussed in §4.4, differential potential depth between galactic centers and outskirts naturally produces differential inference-channel responses ($R_{\text{ML}}^{\text{cen}} > R_{\text{ML}}^{\text{halo}}$). However, because R_{ML} is an observer-side inference response rather than physical matter-frame proper time τ_* , physical accretion integrals require the full scalar-tensor metric history $\tau_* = \int A(\phi) dt$ and are deferred to dedicated relativistic core models.

B.3 Spectroscopic Replication Tables

This appendix contains the full per-bin spectroscopic and cross-field replication tables referenced in §3.7. All results are classified as consistency checks on L1 and L3 (not independent lines of evidence) because they share the M_* -derived R_{ML} predictor.

B.3.1 JADES DR4 UV Luminosity Correlations

Table B1: JADES DR4 Spectroscopic Sample — $\rho(R_{\text{ML}}, M_{\text{UV}})$ (negative = deeper potential → brighter UV; D'Eugenio et al. 2025)

Sample	N	Spearman ρ	p -value	Result
Full sample (flags A/B)	1,345	+0.046	0.095	Weak; not significant
$z > 7$ subsample	114	−0.277	2.9×10^{-3}	Moderate; deeper potential → brighter UV
$z > 8$ subsample	40	−0.640	8.9×10^{-6}	Strong at high- z
Cross-survey sign check (vs UNCOVER)	—	Consistent	—	Both surveys: deeper potential → brighter/dustier

Note on the $z > 7$ correlation ($\rho = -0.277$, $N = 114$): The moderate negative correlation at $z > 7$ indicates that deeper potentials (higher R_{ML}) are associated with brighter UV emission in the JADES spectroscopic sample. M_{UV} is measured directly from observed photometric fluxes in the rest-frame UV band; it is not derived from SED-fitted stellar mass, and R_{ML} is computed from the halo mass proxy (§2.3.1). These are independent measurement chains using different photometric bands and different models. The correlation strengthens at $z > 8$ ($\rho = -0.640$), consistent with the TEP prediction that the response grows with redshift. The result is consistent with (and not independent of) L1; it is listed as a robustness check, not a new line of evidence.

B.3.2 DJA NIRSpec Merged v4.4 Cross-Survey Correlations

This table is a supplementary external reference drawn from the DJA merged-catalog analysis used in earlier manuscript iterations. It is included for context and is not part of the primary evidence count.

Table B2: DJA NIRSpec Merged v4.4 — external cross-survey reference for $\rho(R_{\text{ML}}, \log M_*)$ across 50+ JWST programs (Brammer et al.; de Graaff et al. 2024a)

Sample	N	Spearman ρ	p -value	Result
Full sample ($z > 5$, grade ≥ 3)	2,653	+0.787	$< 10^{-300}$	Strong across all surveys
$z > 7$ subsample	498	+0.854	4.2×10^{-143}	Strong; well-powered
$z > 9$ subsample	67	+0.869	1.6×10^{-21}	Strong; adequately powered

Also: the current DJA–CEERS spectroscopic crossmatch remains supportive but supplementary. In the current run it yields $\rho(R_{\text{ML}}, E(B - V)) = +0.630$ for $N = 1,499$ dust-measured CEERS sources ($p = 1.0 \times 10^{-166}$), while R_{ML} and $\log M_*$ are themselves coupled in the same sample ($\rho = +0.340$, $N = 10,483$). This analysis is therefore classified as a field-level consistency check rather than as part of the primary evidence count.

B.3.3 UNCOVER DR4 Full SPS (MegaScience, Prospector- β) — Redshift-Binned Dust and Spec- z

Table B3: UNCOVER DR4 Full SPS (Prospector- β , 20-band MegaScience) — Redshift-binned dust signal and spec- z confirmation (Wang et al. 2024; Suess et al. 2024; Price et al. 2025)

Sample / Observable	N	Spearman ρ	p -value	Interpretation
Photometric: dust2, $z = 4$ –5	938	−0.018	0.58	Null — no signal below AGB threshold
Photometric: dust2, $z = 5$ –6	505	+0.002	0.97	Null
Photometric: dust2, $z = 6$ –7	325	−0.033	0.56	Null
Photometric: dust2, $z = 7$ –8	129	+0.319	2.2×10^{-4}	Signal emerges at $z > 7$
Photometric: dust2, $z = 8$ –9	66	+0.631	1.4×10^{-8}	Strong signal at $z > 8$

Sample / Observable	N	Spearman ρ	p -value	Interpretation
Photometric: dust2, $z > 7$ (combined)	860	+0.170	5.3×10^{-7}	Significant combined signal
Spec-z Prospector: dust2, $z > 2$ (qual ≥ 2)	161	+0.529	5.4×10^{-13}	Strong; spec-z precision strongly constrains tested artifacts from photo-z scatter
Spec-z Prospector: dust2, $z > 4$	53	+0.590	3.3×10^{-6}	Strong at high- z with spec-z
Spec-z Prospector: dust2, $z > 5$	35	+0.664	1.4×10^{-5}	Strong but small- N
Photometric: dust2, $z = 9-12$	122	+0.092	0.32	Null at highest-z — current audit indicates compressed dust posteriors and inflated redshift uncertainties rather than simple sample collapse

B.4 COSMOS2025 and GOODS-S Cross-Field Replication

Table B4a: COSMOS2025 — LePHARE $E(B - V)$ dust signal by redshift bin (Shuntov et al. 2025; 0.54 deg² blank field)

Redshift bin	N	Spearman $\rho(R_{\text{ML}}, E(B - V))$	p -value	Interpretation
$z = 4-5$	31,573	+0.324	$< 10^{-300}$	Moderate signal; mass-dominated regime
$z = 5-6$	5,358	+0.386	2.0×10^{-189}	Growing signal
$z = 6-7$	4,684	+0.547	$< 10^{-300}$	Strong signal
$z = 7-8$	4,590	+0.579	$< 10^{-300}$	Strong; well-powered
$z = 8-9$	1,121	+0.741	5.0×10^{-199}	Strong
$z = 9-10$	959	+0.602	2.1×10^{-95}	Strong at $z > 9$
$z = 10-13$	508	+0.740	3.3×10^{-89}	Strongest signal at cosmic dawn
$z > 7$ (combined)	7,249	+0.620	$< 10^{-300}$	Strong; $N = 7,249$
$z > 8$ (combined)	2,659	+0.732	$< 10^{-300}$	Strong; $N = 2,659$
Partial ρ ($z > 4$, controlling M_* , z)	48,861	+0.200	$< 10^{-300}$	Signal survives mass+redshift control but is weaker than the raw blank-field trend

Table B4b: COSMOS2025 blank-field follow-up and supplementary morphology checks

Observable / Field	Sample	N	Statistic	p -value	Note
log sSFR (COSMOS2025)	$z = 4-7$	42,361	partial $\rho = +0.008$	0.11	95% CI $[-0.001, +0.016]$; weighted debiased $\rho = +0.023$ ($p = 3.6 \times 10^{-5}$)
log sSFR (COSMOS2025)	$z = 7-8$	4,590	partial $\rho = -0.002$	0.87	95% CI $[-0.031, +0.026]$; weighted debiased $\rho = -0.066$ ($p = 9.6 \times 10^{-5}$)
log sSFR (COSMOS2025)	$z = 8-9$	1,121	partial $\rho = +0.078$	9.1×10^{-3}	95% CI $[+0.012, +0.133]$; weighted debiased $\rho = -0.034$ ($p = 0.32$)
log sSFR (COSMOS2025)	$z = 9-13$	1,467	partial $\rho = -0.096$	2.3×10^{-4}	95% CI $[-0.153, -0.053]$; weighted debiased $\rho = -0.070$ ($p = 0.027$)
<i>Steiger Z-test ($z > 9-13$ vs $z = 4-7$): $Z = -3.92$, $p = 8.8 \times 10^{-5}$. The matched blank-field bin at $z = 8-9$ is positive in the unweighted partial (+0.078) but is not supportive once the mass measurement bias is debiased and quality-weighted (-0.034, $p = 0.32$), and the broader ultrahigh-z $z = 9-13$ analysis is negative. This blank-field sSFR analysis is therefore classified as an auxiliary diagnostic rather than an independent L3 replication.</i>					
$E(B - V)$ dust (COSMOS2025)	$z = 9-13$	1,467	partial $\rho = +0.074$	4.3×10^{-3}	95% CI $[+0.019, +0.117]$
$r_{\text{half}, F277W}$ (JADES DR5 direct-mass morphology)	$z > 7$	384	non-significant	> 0.05	Preferred direct-mass sample; controlled for direct log M_* and redshift
$r_{\text{half}, F444W}$ (JADES DR5 direct-mass morphology)	$z > 7$	384	non-significant	> 0.05	Independent size proxy in the same preferred direct-mass sample
Gini (JADES DR5 direct-mass morphology)	$z > 7$	384	partial $\rho = +0.191$	1.6×10^{-4}	Higher central concentration at larger R_{ML} in the preferred direct-mass sample

Observable / Field	Sample	N	Statistic	p -value	Note
σ_* (JADES DR5 direct-mass morphology)	$z > 7$	384	non-significant	>0.05	Strongest controlled structural support in the preferred direct-mass sample
FWHM (GOODS-S crossmatch)	$z > 4$	588	raw $\rho = -0.176$	1.7×10^{-5}	Smaller apparent sizes at higher R_{ML}
R_{KRON} (GOODS-S crossmatch)	$z > 4$	588	raw $\rho = -0.159$	1.0×10^{-4}	Consistent size-type trend in supplementary GOODS-S comparison

B.5 DJA NIRSpec H α /H β Balmer Decrement

This table reports the current DJA v4.4 Balmer-decrement analysis. It is kept as a supplementary spectroscopic check and is not part of the primary evidence count because the mass+redshift-controlled partial, while significant for the full $z > 2$ sample, is driven primarily by the $z = 2\text{--}4$ bin and weakens at higher redshift.

Table B5: DJA NIRSpec H α /H β Balmer decrement — current supplementary spectroscopic analysis (DJA v4.4)

Sample	N	Raw ρ	Partial ρ ($ M_*, z$)	p (partial)	Bootstrap 95% CI	Median H α /H β
$z = 2\text{--}4$	1,603	+0.590	+0.163	5.2×10^{-11}	[+0.552, +0.622]	3.52
$z = 4\text{--}5$	712	+0.441	+0.070	0.062	[+0.387, +0.511]	3.08
$z = 5\text{--}6$	584	+0.335	+0.030	0.48	[+0.244, +0.414]	3.03
$z = 6\text{--}7$	286	+0.422	+0.112	0.058	[+0.331, +0.514]	3.27
$z > 2$ (all)	3,259	+0.474	+0.123	1.9×10^{-12}	—	—
Overall result: the raw Balmer decrement correlates positively with R_{ML} , and the mass+redshift-controlled partial remains significant for the full $z > 2$ sample, though the signal is driven primarily by the $z = 2\text{--}4$ bin. This analysis is kept as supplementary rather than primary evidence.						

Appendix C: Supplementary Discussion Material

This appendix contains detailed supporting material for the Discussion (§4). Each subsection provides expanded analysis referenced from the main text.

C.1 Compatibility with Precision Tests of General Relativity

A natural objection to any scalar-tensor modification is: why has it not been detected in precision tests of GR? The TEP framework addresses this through the environmental screening operator, which suppresses scalar-mediated effects where the ambient landscape is steep while preserving them in cosmological and galactic contexts.

C.1.1 Solar System Tests

The most stringent constraints on scalar-tensor gravity come from solar system experiments: Cassini Shapiro Delay. The PPN parameter γ is constrained to $|\gamma - 1| < 2.3 \times 10^{-5}$.

TEP evades these constraints through the continuous geometric screening of Temporal Topology. Near massive bodies (Earth, Sun), the scalar field gradient (Temporal Shear) flattens as ambient density rises, suppressing scalar-mediated forces continuously rather than at a discrete boundary. Although the mean solar density ($\rho_\odot \sim 1.4 \text{ g/cm}^3$) is below the core saturation scale $\rho_T \approx 20 \text{ g/cm}^3$, the Sun's deep Newtonian potential ($\Phi_N \sim 10^{-6}$) ensures that the field gradient vanishes in the interior, with only a narrow outer region contributing to the scalar force. The effective coupling is suppressed to $\beta_{\text{eff}} \ll \beta_A$, reducing β_{eff} to $\lesssim 10^{-6}$ and satisfying all solar system bounds without invoking a rigid thin-shell approximation.

C.1.2 Gravitational Wave Constraints

The coincident detection of GW170817 and GRB170817A constrains $|c_\gamma - c_g|/c \lesssim 10^{-15}$ (Abbott et al. 2017). In TEP, gravitational waves propagate on $g_{\mu\nu}$ null cones while photons propagate on $\tilde{g}_{\mu\nu}$ null cones. In the conformal limit ($B(\phi) = 0$), these cones coincide precisely, satisfying the constraint. The disformal term $B(\phi)$ is constrained to be small at late times by GW170817, ensuring $c_g = c_\gamma$ to the required precision.

C.1.3 Binary Pulsar Constraints

Precision tests using binary pulsars (e.g., the Hulse-Taylor system) verify the GR quadrupole formula for orbital decay to within 0.1%. TEP preserves this agreement through the continuous suppression of Temporal Shear. Neutron stars are objects of extreme density ($\rho \sim 10^{14} \text{ g/cm}^3$), orders of magnitude above the critical saturation scale $\rho_T \approx 20 \text{ g/cm}^3$ (Paper 6). Consequently, they are fully screened: the scalar field gradient vanishes in their interiors, decoupling the scalar field from orbital dynamics. This ensures that binary pulsars do not emit significant scalar dipole radiation, reducing the orbital decay prediction to the standard GR value.

C.1.4 Screening Threshold Verification from JWST Data

While ρ_T is calibrated from Paper 6, the JWST data provide ancillary real-data confirmation of spatial screening via the Core Screening signature (§3.5): JADES massive galaxies exhibit bluer cores with raw mass-gradient trend $\rho = -0.166$ ($p = 5.7 \times 10^{-3}$; $N = 277$). While the size-blind global halo predictor $R_{\text{ML}}(M_h, z)$ cannot resolve internal radial structure once (M_*, z) or debiased (M_*, z) are regressed out ($\rho_{\text{partial}} = +0.037$, $p = 0.54$ and $+0.039$, $p = 0.52$), incorporating the measured inner-to-outer F444W stellar concentration $C_{\text{core}} = F_{\text{F444W,CIRC1}}/F_{\text{F444W,CIRC4}}$ across the same apertures defines the resolved radial screening predictor $\Gamma_{\text{rad}} = \exp[K_{\text{gal}}\Psi_{\text{halo}}(M_h)\sqrt{1+z}/C_{\text{core}}]$ (Steps 139 and 168), which retains partial $\rho = -0.179$ ($p = 0.0028$, 2.99σ , C_{core}^{-1} partial $\rho = -0.237$, $p = 6.9 \times 10^{-5}$, 4.0σ) after (M_*, z) control, outperforms M_* on the Steiger test ($Z = 3.02$, $p = 0.0025$), and yields a significant (M_*, z) -residualized bluer-core sign reversal (58.6% vs 35.7%, OR = 2.54, Fisher $p = 0.0054$, $\Delta = -0.273$ mag), alongside the JADES DR5 Gini morphology signal ($\rho_{\text{partial}} = +0.191$, $p = 1.6 \times 10^{-4}$ for $N = 384$, Step 155; GOODS-S $\rho = +0.120$, $p = 3.6 \times 10^{-3}$ for $N = 588$, Step 156). In screened scalar-tensor theories, the suppression in extended objects is governed by the local flattening of Temporal Topology (vanishing Temporal Shear) that depends on the object's potential depth and radial concentration profile.

C.1.5 Testable Predictions Beyond Current Bounds

While TEP satisfies current constraints, it makes specific predictions for future experiments:

- LISA: Environment-dependent orbital decay rates in extreme mass ratio inspirals (EMRIs) if the screening threshold is approached.
- Euclid/Rubin: Void statistics and peculiar velocity fields showing scale-dependent deviations from Λ CDM.
- Optical Clock Networks: Distance-dependent correlations in clock frequency residuals, with characteristic length scale $\lambda \sim 2000\text{--}3000$ km.
- Pulsar Timing Arrays: Differential timing residuals between pulsars in globular cluster cores (screened) versus field pulsars (unscreened).

C.2 M/L Scaling Justification

The response and correction stages use distinct exponents. The response normalization uses the fixed convention $n_{\text{ref}} = 0.7$ at every redshift, while the TEP mass and SFE corrections assume $M/L \propto t^{n_{\text{SPS}}}$. The choice of n_{SPS} is justified by complementary theoretical and empirical arguments.

Table C0: Exponent allocation in the reproducible pipeline

Pipeline step(s)	Response-kernel n_{ref}	Correction-stage n_{SPS}	Role
002, 032, 034, 081	0.7 at all z	0.7 ($z \leq 4$); 0.9 ($4 < z \leq 6$); 0.5 ($z > 6$)	UNCOVER, CEERS, COSMOS-Web, and cross-survey catalogue construction
146, 174, 176	0.7 at all z	0.7	Stellar-mass-function and joint-evidence corrections
076	0.7 at all z	0.3–1.0 scan	Sensitivity and continuity validation; no production exponent is fitted

C.2.1 Physical Basis from Stellar Population Synthesis

The $M/L \propto t^n$ scaling emerges from the fading of stellar populations as massive stars evolve off the main sequence. For a simple stellar population (SSP), the luminosity-weighted age dependence of M/L is governed by: main sequence turnoff timing, giant branch contribution to near-IR light, and metallicity-dependent line blanketing.

Table C1: M/L Power-Law Index from SSP Models

Model	Metallicity	Age Range	n (V-band)	n (K-band)
BC03	$Z_{\odot}$	0.1–10 Gyr	0.85	0.72
BC03	$0.2Z_{\odot}$	0.1–10 Gyr	0.68	0.55
BC03	$0.02Z_{\odot}$	0.1–1 Gyr	0.52	0.48
FSPS	$0.1Z_{\odot}$	0.1–1 Gyr	0.55	0.51
BPASS (binary)	$0.1Z_{\odot}$	0.1–1 Gyr	0.48	0.45

At high redshift ($z > 6$), galaxies have typical metallicities $Z \sim 0.1\text{--}0.2Z_{\odot}$. The SSP-predicted low- n regime is consistent with the canonical residual-minimization analysis, which prefers lower effective n values once the high- z R_{ML} response becomes important.

C.2.2 Live Empirical Residual-Minimization Validation

In the canonical analysis, the overall residual mass-age correlation is minimized at $n_{\text{SPS}} = 0.3$ ($\rho = 0.118$). The redshift-split minima are $n_{\text{SPS}} = 1.0$ at $z = 4\text{--}6$ and $6\text{--}8$, and $n_{\text{SPS}} = 0.3$ at $z = 8\text{--}10$; because each lies on an edge of the scanned interval,

these values are treated as sensitivity diagnostics rather than calibrated exponents. K-fold cross-validation gives mean $n_{\text{SPS}} = 0.82 \pm 0.07$ with mean test $\rho = 0.61$. The pipeline separately verifies that changing n_{SPS} leaves R_{ML} invariant at fixed potential depth and redshift, and that the kernel is continuous across $z = 4$ and $z = 6$.

C.2.3 TEP-Induced Modification

Beyond the standard SSP prediction, TEP introduces an additional effect: in the high-response regime ($R_{\text{ML}} > 1$), stellar populations appear to have accumulated more effective time than their coordinate age suggests, compressing the observed age range and effectively flattening the M/L -age slope. The empirically preferred low- n regime at $z > 6$ may therefore reflect both low metallicity and TEP-induced compression.

Circularity Resolution

Concern: The redshift-dependent n is itself claimed as a TEP signature, potentially introducing circularity.

Resolution: K-fold cross-validation gives $n_{\text{SPS}} = 0.82 \pm 0.07$ with mean test $\rho = 0.61$. The redshift-blind holdout (n calibrated at $z < 8$, applied at $z \geq 8$) yields $\rho = -0.05$ ($p = 0.17$), indicating that the data-driven optimal n does not generalize across redshift regimes — a known limitation of the empirical residual-minimization approach. However, sensitivity analysis shows the dust signal remains significant across $n \in [0.3, 1.0]$. An empirical JADES mass-to-light proxy check is also consistent with the mechanism: $\rho(R_{\text{ML}}, M/L_{\text{proxy}}) = +0.938$ ($p = 3.1 \times 10^{-195}$), with partial $\rho = +0.812$ after redshift control ($p = 2.0 \times 10^{-100}$). However, both R_{ML} and the M/L proxy ($\log M_* + M_{\text{UV}}/2.5$) are functions of $\log M_*$, so the z -only partial correlation is inflated by this shared mass dependence. After controlling for both M_* and z , the partial correlation drops to $\rho = +0.249$ ($p = 2.3 \times 10^{-7}$) — still significant but much weaker. The M/L proxy test therefore confirms the direction of the relationship but cannot by itself distinguish TEP from a generic mass-M/L correlation. Independent age indicators via Balmer absorption ($H\delta$, $H\gamma$) are predicted to correlate with R_{ML} and would provide a spectroscopic test independent of M/L assumptions.

C.3 Model Discrimination and Falsifiability Tests

C.3.1 Modified Gravity Theory Comparison

Table C2: Modified Gravity Comparison (JWST Anomaly Predictions)

Theory	JWST Score (/8)	Constraint Score	Key Limitation
TEP	8	3	—
$f(R)$	1	3	No dust/clock prediction
Galileon	1	−1	Ruled out by GW170817
Symmetron	0	3	No JWST predictions
DGP	0	1	Self-accelerating branch ruled out
MOND	0	−1	Non-relativistic; no clock effect
Horndeski (generic)	0	0	Too broad; no specific predictions

Within this comparison test set, TEP matches 8/8 JWST anomaly predictions compared to 1/8 for the next-best theory ($f(R)$). This comparison illustrates TEP's breadth of coverage across domains, not a definitive model selection (which would require computing likelihoods for each theory).

C.3.2 Theoretical Consistency Tests

Table C3: Theoretical Consistency Tests

Test	Result	Status
Causality Constraint	0/2000 causal violations	✓ Pass
κ_{gal} Error Budget	R_{ML} uncertainty $\pm 4.2\%$ ($\sigma_{\kappa} = 4.0 \times 10^5 \text{ mag}$)	✓ Pass
Time-Space Decoupling	Temporal/spatial ratio $> 1.5\times$	✓ Pass
Multi-Tracer Consistency	<i>Removed:</i> this test used hardcoded synthetic α values, not measured data; result pending real multi-tracer calibration	— N/A
Screening Length Scale	$\lambda_{\text{C}} = 2.5 \text{ kpc}$ vs observed 1.5 kpc	✓ Pass
Screening Transition	Transition spans 2.2 dex; cosmic mean fully unscreened	✓ Pass
Precision Gravity (Cassini, LLR, pulsars, CMB)	All satisfied via Temporal Topology (continuous geometric screening)	✓ Pass

C.3.3 Model Discrimination Tests

Table C4: Model Discrimination and Falsifiability Tests

Test	Result	Conclusion
IMF Constraint (Red Monsters)	Required slope: $\alpha = 1.5$ (no TEP) vs 2.1 (with TEP)	TEP removes need for extreme IMF
IMF vs TEP Discrimination	Estimated simulation power 100% in 5000 trials (finite-sample estimate; true power $\leq 99.94\%$ at 95% CI)	TEP distinguishable from IMF
Mass-Proxy Breaker	2/3 tests pass; $z > 8$ LOWESS $\rho = 0.149$, partial-rank $\rho = 0.310$, shuffled-mass $Z = 9.8$, unique fraction 101.1%	R_{ML} carries information beyond mass+ z ordering
Dust Model Comparison	TEP 46.5× vs SN-only 10×	Dust physics favors TEP
Cross-Survey Systematics	ρ scatter = 0.024 across surveys	Consistent across survey analyses
AGN Discrimination Power	Estimated simulation power 100% in 2000 trials (finite-sample estimate; true power $\leq 99.85\%$ at 95% CI)	TEP distinguishable from AGN
LRD Sensitivity Diagnostic	Mean $\Delta R_{\text{ML}} = 1.73$, all compact	Directional differential-potential diagnostic; quantitative growth deferred
Hubble Connection	JWST-side pipeline consistency check (step 133): $H_0^{\text{TEP}} = 67.8$ km/s/Mpc from simplified two-halo scaling — an order-of-magnitude illustration, not an independent prediction — consistent in direction with Paper 11 (v0.12: $H_0 = 67.83 \pm 1.56$; TEP-CMB 0.68σ); fitted κ_{Cep} , not derived from first principles	Simplified partial reconstruction; consistent with Paper 11
Prediction Error Budget	$\pm 16.5\%$ combined uncertainty	Falsifiable at 2σ

IMF constraint: Without TEP, the Red Monster SFE anomaly requires a top-heavy IMF ($\alpha_{\text{min}} = 1.5$). With TEP, the corrected SFE requires only $\alpha_{\text{min}} = 2.1$, consistent with standard IMFs. TEP and IMF produce observationally distinct signatures via environment-dependence (estimated simulation discrimination power 100% across 5000 finite trials; finite-sample upper bound, not an asymptotic guarantee).

Mass proxy and systematics: The canonical robustness results no longer rely on the retired selection-function Monte Carlo analysis. Instead, the evidence comes from the mass-proxy breaker and cross-survey systematics checks: at $z > 8$, non-parametric residual tests retain the dust- R_{ML} signal after mass+ z removal (LOWESS $\rho = 0.149$; partial-rank $\rho = 0.310$), and shuffled-mass null tests show the observed correlation exceeds mass-ordering expectations by $Z = 9.8$, with 101.1% of the signal attributable to the non-linear R_{ML} form rather than to mass ordering alone. The mass-to-light correction uses the declared primary high-redshift value $n_{\text{SPS}} = 0.5$ (and the SMF sensitivity value $n_{\text{SPS}} = 0.7$), while the response normalization remains fixed at $n_{\text{ref}} = 0.7$; a single k-fold cross-validation gives mean $n_{\text{SPS}} = 0.82 \pm 0.07$. Cross-survey dust correlations show low scatter ($\rho_{\text{std}} = 0.025$), arguing against survey-specific artifacts.

Hubble tension: The JWST-side pipeline (step 133) yields $H_0^{\text{TEP}} = 67.8$ km/s/Mpc from the simplified two-halo approximation — an order-of-magnitude illustration, a conservative lower bound consistent in direction with the full Paper 11 reconstruction. The residual offset from the ladder value (73.04) belongs to Paper 11's model-conditioned endpoint calibration response, not an independently measured path-integrated shear. The full conditional reconstruction is provided in Paper 11 (v0.12), where the unified host-level reconstruction of 37 SN Ia hosts yields $H_0 = 67.83 \pm 1.56$ km/s/Mpc, in concordance with Planck at 0.26σ (0.36σ bootstrap; TEP-CMB internal consistency at 0.68σ); the JWST pipeline value is a conservative lower bound from the crude area-distance scaling.

Falsifiability: Combined prediction uncertainty is $\pm 16.5\%$. Key falsification criteria at 2σ : mass-dust slope differing from 0.56 by > 0.30 ; SFE correction differing from 100% by $> 25\%$.

C.4 Little Red Dots: Theoretical and Methodological Status

As established in §2.5 and §4.4, Little Red Dots (LRDs) represent a qualitative stress test of compact-core potential structure rather than a primary evidentiary line. Because R_{ML} parameterizes observer-side inference bias under an assumed FLRW baseline rather than physical matter-frame proper time $\tau_* = \int A(\phi) dt$, quantitative black hole accretion cannot be evaluated by inserting R_{ML} into an exponential growth integral.

While deeper central gravitational potentials qualitatively yield larger inference responses ($R_{\text{ML}}^{\text{cen}} > R_{\text{ML}}^{\text{halo}}$) in compact systems, rigorous accretion modeling requires fully solved relativistic scalar-tensor core solutions. The population-level LRD anomaly is therefore deferred to dedicated relativistic compact-object studies.

C.5 External-Regime Discriminants

C.5.1 High-Value Observational Discriminants

Beyond the present empirical core, the most informative discriminants are observables that isolate the unique signatures of the scalar-field coupling. Key discriminants include:

- **Spectroscopic Ages:** Deep NIRSpec MSA spectroscopy of high- R_{ML} candidates at $z > 6$ to measure direct Balmer absorption ages, testing the predicted apparent age offset independent of photometrically derived mass-to-light ratios.
- **Resolved Screening Maps:** Spatially resolved IFU spectroscopy of massive $z \sim 4\text{--}6$ galaxies to map radial age gradients. TEP predicts a specific "blue core / red outskirts" inversion due to central potential screening, opposite to standard inside-out growth.
- **Environmental Contrasts:** Comparative spectroscopy of galaxies in dense protoclusters versus field environments at fixed mass. TEP predicts that environmental screening should suppress age and dust signatures in dense regions, reversing the standard "downsizing" trend. A preliminary implementation using DJA β -residuals ($N = 1,238$) did not yield a clean dense-younger-than-field reversal after matched controls (0 matched cells supportive; step 167), so this remains a future observational priority rather than a current result.
- **Rest-Frame Mid-IR:** MIRI imaging to directly probe the dust continuum at $z > 7$, confirming that the observed UV-reddening is driven by dust grains (as predicted by the R_{ML} -ordered dust buildup) rather than exotic stellar populations.

C.5.2 Wide-Field Regime Predictions

TEP also makes quantitative predictions in large wide-field survey regimes:

- **Euclid-wide regime (15,000 deg²):** $N \sim 300,000$ massive galaxies at $z = 0.9\text{--}1.8$; TEP predicts $\sim 25\%$ mass-dependent age offset.
- **Roman high-latitude regime (2,000 deg²):** $N \sim 500,000$ emission-line galaxies at $z > 2.5$; TEP predicts weak gas-phase metallicity- R_{ML} correlation.
- **Roman supernova regime ($N \sim 2,700$):** TEP predicts host-potential-dependent SN Ia rate enhancements and an elevated Ia/CC ratio in deeper potential wells.

At the combined sample scale ($N > 800,000$), the low-redshift regime provides a stringent test of TEP at $z < 3$.

C.5.3 Cosmic Variance Budget

Current survey fields: UNCOVER (Abell 2744, 45 arcmin², $\sigma_{\text{cv}} \approx 22\%$), CEERS (EGS, 100 arcmin², $\sigma_{\text{cv}} \approx 15\%$), COSMOS-Web (COSMOS, 1800 arcmin², $\sigma_{\text{cv}} \approx 3.5\%$). Cross-field consistency despite different environments strengthens the conclusion that the correlation is not driven by large-scale structure.

Data Availability & Reproducibility

This work follows open-science practices. All results are fully reproducible from raw data using the documented pipeline. All numerical results, figures, and statistics are generated by deterministic Python scripts processing real observational data.

Repository & Code

GitHub Repository: github.com/matthewsmawfield/TEP-JWST

The repository contains a deterministic, version-controlled analysis pipeline of 131 active scripts (numbered up to 178, with gaps from deprecated and merged steps) and automated consistency checks.

Repository Structure

```
TEP-JWST/
├── data/                # Raw and interim catalogs
│   ├── raw/             # JWST catalogs from MAST
│   ├── interim/         # Processed datasets
│   └── DATA_PROVENANCE.md # Download timestamps and checksums
├── logs/                # Step execution logs with timestamps
├── results/
│   ├── outputs/         # JSON/CSV analytical outputs
│   └── figures/         # Generated manuscript figures
├── scripts/
│   └── steps/           # 131 active scripts (numbered up to 178)
│       ├── step_001_uncover_load.py
│       ├── step_002_tep_model.py
│       ├── step_140_evidence_tier_summary.py
│       └── step_159_mass_measurement_bias.py
```

```

├── step_160_manuscript_consistency_check.py
├── step_170_kinematic_decisive_test.py
├── step_171_sigma_kinematic_expansion.py
├── step_176_nested_bayesian_evidence.py
├── run_all_steps.py      # Master pipeline runner
├── utils/                # Shared analysis utilities
├── site/
├── components/           # Source of truth for manuscript
├── dist/                 # Built site artifacts
└── requirements.txt      # Python dependencies (pinned)

```

Data Provenance

Data Source	Provider	Access Method	Download Size	DOI/URL
UNCOVER DR4	MAST/JWST	Public archive	62.8 MB (SPS catalog)	MAST Archive
CEERS	MAST/JWST	Public archive	~500 MB (photometry)	MAST Archive
COSMOS-Web/COSMOS2025	MAST/JWST	Public archive	270 MB (master catalog)	MAST Archive
JADES DR5	MAST/JWST	Public archive	673 MB (GOODS-S) + 818 MB (GOODS-N)	MAST Archive
JADES DR4 Spectroscopic	JADES Team	Direct download	~200 MB	JADES DR4
DJA NIRSpec Merged v4.4	DJA Archive	Zenodo	~150 MB (compressed)	Zenodo
FRESCO Red Monsters	Literature	Author-provided	<1 MB (3 objects)	Via GitHub repo
Kokorev LRD Catalog	Literature	Published catalog	210 KB	Via GitHub repo

Total Download Size: ~2.5 GB for full JWST survey catalogs (optional for replication; core analysis runs on processed interim files).

Data Provenance Log: Complete download timestamps, file checksums, and version records are maintained in `data/DATA_PROVENANCE.md`.

Reproduction Instructions

Quick Start (Full Reproduction)

```

# 1. Clone repository
git clone https://github.com/matthewsmawfield/TEP-JWST.git
cd TEP-JWST

# 2. Install dependencies
pip install -r requirements.txt
npm install --prefix site

# 3. Run complete pipeline (131 active scripts)
python scripts/steps/run_all_steps.py

# 4. Build manuscript
npm run build --prefix site

```

System Requirements

Component	Minimum	Recommended	Tested On
CPU	8 cores	14+ cores	Apple M4 Pro (14-core)
RAM	16 GB	32 GB	24 GB (M4 Pro)
Storage	20 GB	50 GB	NVMe SSD
Runtime	~30-35 minutes (full pipeline, 131 active scripts)		~32 minutes (M4 Pro)

Pipeline Overview

The analysis pipeline consists of 131 active scripts (numbered up to 178) organized into phases:

- Steps 001-008:** Data loading and TEP model computation (R_{ML} for all galaxies)
- Steps 009-100:** Core empirical analysis across five evidence lines (L1-L5)

3. **Steps 101-140:** Cross-survey replication and robustness validation
4. **Steps 141-160:** Advanced discriminating tests and manuscript consistency checks
5. **Steps 161-178:** Figure generation and final summary outputs

Each step produces JSON outputs with full metadata, and execution logs are written to `logs/` with timestamps for full traceability.

Consistency Verification

The pipeline includes automated consistency checks (`step_160_manuscript_consistency_check.py`) that verify every numerical claim in the manuscript against actual computed outputs. **Zero tolerance for statistical-data mismatches.**

Data Provenance

Analysis performed using:

- **Python** 3.11+ (pinned in requirements.txt)
- **NumPy** 1.24+ (numerical computation)
- **SciPy** 1.10+ (statistical tests, optimize)
- **Pandas** 2.0+ (data manipulation)
- **Matplotlib** 3.7+ (visualization)
- **Astropy** 5.0+ (astronomical calculations)

Full dependency tree with exact versions is available in `requirements.txt` .