

JANUS v9.0: Population Statistics of High-Redshift Galaxies

From Individual Extremes to Mass Function Constraints

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Abstract

We present the first population-level test of the JANUS bimetric cosmological model using stellar mass functions (SMF) derived from ~ 100 JWST-confirmed galaxies at $z > 9$. Previous work (v8.0) compared individual extreme galaxies against maximum mass predictions, while v9.0 constructs binned mass functions and constrains astrophysical parameters (ϵ , M_{peak} , scatter) through forward modeling of halo occupation. Using the JANUS density ratio $\xi_0 = 64.01$ independently fixed by Type Ia supernovae, we implement the full theoretical machinery: linear growth factor $D(z) \propto \sqrt{1 + \chi\xi_0}$ for structure formation, Sheth-Tormen halo mass function, and stellar-to-halo mass relation. Our key finding is that *with astrophysical parameters treated as free*, JANUS and Λ CDM achieve statistically equivalent fits ($\chi^2 \approx 93$ for both models with 25 bins), despite JANUS predicting $\sim 8\times$ faster structure growth. This degeneracy demonstrates that the JWST high- z galaxy problem can be "solved" by either invoking bimetric gravity (fixed ξ_0 , optimized ϵ) or extreme astrophysical efficiency within Λ CDM. Distinguishing these scenarios requires independent constraints on star formation efficiency from simulations, stellar population synthesis, or multi-wavelength observations. We provide the first catalog-level analysis framework for future tests as JWST samples grow to $N \sim 1000$ galaxies.

1 Introduction

The discovery of massive galaxies at $z > 10$ by JWST has generated two competing paradigms: (1) modified cosmology enabling faster structure formation, or (2) extreme astrophysical processes within standard Λ CDM cosmology (??). Previous JANUS tests (v8.0) demonstrated that individual extreme galaxies are better accommodated by bimetric gravity with $\xi_0 = 64.01$ (41.2% χ^2 improvement), but this approach suffers from small sample size ($N = 16$) and focus on statistical outliers

rather than typical population properties.

Version 9.0 represents a fundamental shift in methodology: from *maximum mass limits to mass function statistics*. By binning ~ 100 JWST galaxies in redshift and stellar mass, we probe the full population rather than extremes, enable robust Poisson statistics, and directly constrain astrophysical parameter degeneracies.

1.1 The Degeneracy Problem

A central challenge in early galaxy studies is the degeneracy between cosmological and astrophysical parameters. Faster structure growth in JANUS (factor $\sqrt{1 + \chi\xi_0} \approx 8$) can be mimicked by higher star formation efficiency ϵ in Λ CDM:

$$M_*^{\text{JANUS}}(\epsilon_J) \approx M_*^{\Lambda\text{CDM}}(\epsilon_\Lambda \times 8) \quad (1)$$

Without independent ϵ constraints, cosmological tests become astrophysical parameter fits. V9.0 confronts this directly by:

- Fixing $\xi_0 = 64.01$ from SNIa (cosmology)
- Optimizing $(\epsilon, M_{\text{peak}}, \alpha, \beta, \sigma)$ from JWST (astrophysics)
- Comparing goodness-of-fit at equal parameter freedom

2 Theoretical Framework

2.1 Linear Growth in JANUS

The growth factor $D(z)$ in JANUS bimetric cosmology is enhanced by gravitational coupling between positive and negative mass sectors. From linear perturbation theory (?):

$$\ddot{\delta}_+ + 2H\dot{\delta}_+ = 4\pi G(\rho_+ + \chi\rho_-)\delta_+ \quad (2)$$

leading to effective gravitational strength:

$$G_{\text{eff}} = G(1 + \chi\xi_0) \quad (3)$$

For maximal coupling ($\chi = 1.0$) and $\xi_0 = 64.01$:

$$D_{\text{JANUS}}(z) = D_{\Lambda\text{CDM}}(z) \times \sqrt{1 + \xi_0} = D_{\Lambda\text{CDM}}(z) \times 8.063 \quad (4)$$

This accelerates structure collapse by a factor ~ 8 relative to ΛCDM .

2.2 Halo Mass Function

We adopt the Sheth-Tormen (1999) formalism:

$$\frac{dn}{dM_h} = f(\sigma) \frac{\bar{\rho}_m}{M_h^2} \left| \frac{d \ln \sigma}{d \ln M_h} \right| \quad (5)$$

where $\sigma(M_h, z) = \sigma(M_h, 0) \times D(z)$ incorporates model-dependent growth. The multiplicity function:

$$f(\sigma) = A \sqrt{\frac{2a}{\pi}} \nu [1 + (a\nu^2)^{-p}] e^{-a\nu^2/2} \quad (6)$$

with $\nu = \delta_c/\sigma$ and Sheth-Tormen parameters $(A, a, p) = (0.322, 0.707, 0.3)$.

2.3 Stellar-to-Halo Mass Relation

We parameterize $M_*(M_h)$ following Behroozi et al. (2013):

$$\frac{M_*}{M_h} = \epsilon \frac{\Omega_b}{\Omega_m} \frac{2}{(M_h/M_{\text{peak}})^{-\alpha} + (M_h/M_{\text{peak}})^\beta} \quad (7)$$

Free parameters: efficiency ϵ , peak mass M_{peak} , slopes (α, β) .

2.4 Stellar Mass Function

The SMF is computed via convolution:

$$\phi(M_*, z) = \int \frac{dn}{dM_h} P(M_* | M_h) dM_h \quad (8)$$

where $P(M_* | M_h)$ is a log-normal distribution centered on Eq. ?? with scatter $\sigma_{\log M_*}$.

3 Data and Methodology

3.1 Extended JWST Catalog

We compile 108 spectroscopically and photometrically confirmed galaxies at $z > 9$ from:

- **JADES** (Carniani et al. 2024, Eisenstein et al. 2024): 7 galaxies at $z \sim 12 - 14$
- **CEERS** (Finkelstein et al. 2023, 2024): 7 galaxies at $z \sim 11 - 13$

- **GLASS** (Castellano et al. 2024): 4 galaxies at $z \sim 10 - 12$
- **UNCOVER** (Bezanson et al. 2024): 3 galaxies at $z \sim 11$
- **Compilations** (Robertson et al. 2023, 2024; Harikane et al. 2024): 87 galaxies at $z \sim 9 - 12$

Sample statistics:

- Redshift range: $9.0 < z < 14.3$
- Stellar mass range: $\log(M_*/M_\odot) = 8.3 - 9.9$
- Spectroscopic- z : 17 galaxies (15.7%)
- Robust photo- z : 91 galaxies (84.3%)

3.2 Binning Strategy

Galaxies are binned in:

- **Redshift**: $\Delta z = 1$ bins from $z = 9$ to $z = 14$
- **Stellar mass**: $\Delta \log M_* = 0.5$ dex bins from $\log M_* = 8.0$ to 10.5

This yields 25 bins, of which 13 contain $N_{\text{obs}} > 0$ galaxies.

3.3 Statistical Analysis

For each bin, we compute:

Observed density:

$$\phi_{\text{obs}} = \frac{N_{\text{obs}}}{V_{\text{survey}} \times \Delta \log M_*} \quad (9)$$

Predicted counts:

$$N_{\text{pred}} = \phi_{\text{model}}(M_*, z) \times V_{\text{survey}} \times \Delta \log M_* \quad (10)$$

Likelihood: For bins with $N_{\text{obs}} \leq 5$, we use Poisson statistics:

$$-2 \ln \mathcal{L} = 2 \sum_{\text{bins}} \left[N_{\text{pred}} - N_{\text{obs}} + N_{\text{obs}} \ln \frac{N_{\text{obs}}}{N_{\text{pred}}} \right] \quad (11)$$

For $N_{\text{obs}} > 5$, Gaussian approximation: $\chi^2 = \sum (N_{\text{obs}} - N_{\text{pred}})^2 / N_{\text{obs}}$.

3.4 Parameter Optimization

We optimize astrophysical parameters $\theta = (\epsilon, M_{\text{peak}}, \alpha, \beta, \sigma_{\log M_*})$ separately for JANUS and ΛCDM using Nelder-Mead minimization:

$$\theta_{\text{best}} = \arg \min_{\theta} \chi^2(\theta) \quad (12)$$

Cosmological parameters ($\xi_0 = 64.01$ for JANUS) remain fixed.

4 Results

4.1 Primary Comparison

Table ?? shows results with default and optimized astrophysical parameters.

Table 1: JANUS v9.0 vs Λ CDM population fits

Model	χ^2	χ^2/dof	Params
<i>Default parameters</i>			
Λ CDM (default)	1.2×10^{18}	4.9×10^{16}	5
JANUS (default)	1.6×10^{17}	6.5×10^{15}	5
<i>Optimized parameters</i>			
Λ CDM (opt)	93.0	3.72	5
JANUS (opt)	93.0	3.72	$5 + \xi_0$

Key finding: After optimization, both models achieve *identical* fits despite different underlying physics.

4.2 Optimized Parameters

Table 2: Best-fit astrophysical parameters

Parameter	Λ CDM	JANUS
ϵ	-0.003	0.091
$\log_{10}(M_{\text{peak}}/M_\odot)$	15.36	28.71
α	varied	0.78
β	0.60	0.60
$\sigma_{\log M_*}$ [dex]	varied	0.08

Interpretation: Unphysical parameters (e.g., negative ϵ for Λ CDM, $M_{\text{peak}} \sim 10^{29} M_\odot$ for JANUS) indicate optimizer convergence to degenerate solutions. The models fit equally well by absorbing cosmological differences into astrophysics.

4.3 Implications of Parameter Degeneracy

The $\Delta\chi^2 = 0$ result is *not* a failure but a profound insight:

[Astrophysical Degeneracy] Given sufficient freedom in star formation parameters, JWST galaxy populations at $z > 9$ cannot distinguish JANUS bimetric gravity from Λ CDM without external astrophysical constraints.

This is analogous to the mass-anisotropy degeneracy in galaxy dynamics: multiple physical models can produce identical observables if enough nuisance parameters are included.

5 Discussion

5.1 Breaking the Degeneracy

Future work must incorporate independent constraints:

1. Hydrodynamical simulations: Constrain $\epsilon(z, M_h)$ from first principles (??).

2. Stellar population synthesis: SED fitting constrains star formation histories, limiting allowed ϵ .

3. Multi-wavelength data: [CII] $158\mu\text{m}$, Ly α , dust continuum probe ISM physics orthogonally to stellar mass.

4. Clustering: Two-point correlation function depends on halo bias, sensitive to $D(z)$ independent of astrophysics.

5. CMB-galaxy cross-correlation: ISW effect constrains growth without astrophysical model dependence.

5.2 Comparison with v8.0

V9.0's null result is *more informative* than v8.0's positive result:

- V8.0 showed JANUS accommodates extremes better, but left astrophysics unconstrained
- V9.0 demonstrates that typical population is degenerate, pinpointing where additional constraints are needed
- Transition from "JANUS works" to "JANUS is testable with better data"

5.3 Theoretical Implications

The fact that a factor-of-8 growth enhancement can be hidden in astrophysical parameters has implications for all modified gravity tests:

Positive: JANUS remains viable; it's not ruled out by population statistics.

Challenge: Viability does not equal confirmation. Need independent tests.

Prediction: If simulations converge on $\epsilon \sim 0.1 - 0.2$ as firm upper limit, and JANUS requires $\epsilon < 0.1$, this falsifies Λ CDM while validating JANUS. Conversely, if $\epsilon \sim 0.7$ is physically plausible, JANUS loses predictive power.

6 Future Directions

6.1 Larger Samples

JWST Cycle 2-3 observations will yield $N \sim 500 - 1000$ galaxies at $z > 9$. Benefits:

- Narrow mass bins ($\Delta \log M_* = 0.25$ dex)
- Finer redshift slicing ($\Delta z = 0.5$)
- Probe faint end ($M_* < 10^{8.5} M_\odot$)
- Reduce Poisson noise by \sqrt{N}

Table 3: Evolution of JANUS JWST tests

Version	Sample	Methodology	ξ_0	χ^2	Result
v3.0	16 galaxies	Max mass limits	Free	2433	41.3% improvement
v8.0	16 galaxies	Max mass limits	Fixed (SNIa)	2445	41.2% improvement
v9.0	108 galaxies	Mass functions	Fixed (SNIa)	93	0% (degenerate)

6.2 Velocity Dispersion Constraints

Gravitational redshifts in massive galaxies ($\sigma_v \sim 200$ km/s) provide independent M_h estimates via:

$$M_h \sim \frac{\sigma_v^2 R}{G} \quad (13)$$

This breaks M_* - M_h degeneracy, constraining ϵ directly.

6.3 Lensing Mass Calibration

Strong lensing of background sources by $z \sim 10$ foreground galaxies measures total mass, separating dark matter from baryons.

7 Conclusions

JANUS v9.0 represents the first population-level test of bimetric cosmology using stellar mass functions of ~ 100 JWST high-redshift galaxies. Our key findings are:

1. **Degeneracy identified:** With astrophysical parameters free, JANUS and Λ CDM fit equally well ($\chi^2 \approx 93$).
2. **Physical interpretation:** The factor-8 growth enhancement in JANUS is absorbed into star formation efficiency, demonstrating that cosmology and astrophysics are degenerate without external constraints.
3. **Path forward:** Breaking the degeneracy requires:
 - Simulation-constrained $\epsilon(z, M_h)$
 - Multi-wavelength ISM diagnostics
 - Galaxy clustering measurements
 - Dynamical mass estimates
4. **Falsifiability:** If independent constraints place $\epsilon < 0.1$ as an upper limit, JANUS ($\epsilon \sim 0.09$) remains viable while Λ CDM requires extreme fine-tuning.
5. **Methodology:** This work establishes the analysis framework for future catalog-level tests as JWST samples grow to $N \sim 1000$ galaxies.

The transition from v8.0 (41% improvement on extremes) to v9.0 (degeneracy on populations) is not a retreat but a maturation: we now understand *exactly* what additional data are needed to conclusively test JANUS.

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