JANUS Bimetric Cosmology: A Theoretically Consistent Framework for JWST High-Redshift Galaxies

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Abstract

We present a comprehensive analysis of JANUS bimetric gravity as an alternative to ΛCDM cosmology for explaining massive galaxies observed by JWST at $z > 9$. JANUS posits two coupled gravitational sectors with opposite-sign masses, characterized by density ratio $\xi_0 = 64.01 \pm 0.3$ (constrained by Type Ia supernovae). Building on fundamental energy conservation, we derive structure growth enhancement $f_{\rm accel} = \sqrt{\xi_0} = 8.00$ from bimetric Jeans equations, establishing complete theoretical consistency from expansion to galaxy formation. Analyzing 108 JWST galaxies across 25 bins in redshift-mass space ($9 < z < 14.3$, $8.0 < \log M_*/M_\odot < 10.5$), we compute stellar mass functions via Sheth-Tormen halo abundance matching. The critical advance: incorporating *independent* constraints on star formation efficiency ($\epsilon < 0.15$) from IllustrisTNG/THESAN hydrodynamical simulations breaks the cosmology-astrophysics degeneracy. Results: (1) JANUS achieves $\chi^2 = 63.8$ with physically plausible $\epsilon = 0.15$, (2) ΛCDM yields $\chi^2 = 96.4$ requiring unphysical $\epsilon = 0.023$, (3) $\Delta\chi^2 = +32.6$ favors JANUS at 5.7σ significance. JANUS requires *standard* astrophysics ($\epsilon \sim 0.10$–0.15) consistent with simulations, while ΛCDM demands extreme/unphysical parameters. The framework achieves predictive power with *single parameter* ξ_0 fixed by SNIa, determining both expansion history and structure formation. This work establishes JANUS as a viable, theoretically consistent alternative to ΛCDM for early Universe observations.

1 Introduction

1.1 JWST Challenge to ΛCDM

The James Webb Space Telescope (JWST) has discovered massive, evolved galaxies at unprecedented redshifts $z > 10$, including spectroscopically confirmed systems at $z \sim 12$–14 with stellar masses $M_* \sim 10^9$–$10^{9.5} M_\odot$ (3; 4; 5). These observations challenge ΛCDM structure formation: at $z = 12$, the Universe is only 370 Myr old, leaving limited time for massive galaxies to form via hierarchical clustering.

1.2 JANUS Bimetric Gravity

JANUS (1), developed by Jean-Pierre Petit and collaborators over four decades, proposes a radical alternative: two coupled gravitational sectors with *opposite-sign masses*. The positive sector (ρ_+, ordinary matter) and negative sector (ρ_-, "negative mass dark matter") interact gravitationally with density ratio:

$$\xi_0 \equiv \frac{|\rho_-|}{\rho_+} \tag{1}$$

Key predictions:

1. **Expansion:** Equivalent to ΛCDM with emergent dark energy (no Λ needed)
2. **Structure growth:** Enhanced by factor $\sqrt{\xi_0}$ due to negative-mass compression
3. **Galaxy formation:** Accelerated by factor ~ 8, enabling massive galaxies at $z > 10$

1.3 Previous Constraints on ξ_0

Petit & d'Agostini (2018) (2) constrained $\xi_0 = 64 \pm 6$ from JLA supernova sample (740 SNe Ia, $z < 1.3$). Our independent analysis reproduces $\xi_0 = 64.01 \pm 0.3$ with Pantheon (1048 SNe Ia).

1.4 This Work

We present the first *theoretically consistent, observationally validated* JANUS framework:

Theoretical advances (v8–v12):

- Derive expansion from energy conservation

- Derive $f_{\text{accel}} = \sqrt{\xi_0}$ from Jeans equations (no free parameters)
- Establish consistency: SNIa $\to \xi_0 \to$ expansion + structure

Observational advances (v9–v11):

- Extend from 16 extreme galaxies to 108-galaxy sample
- Population-level stellar mass functions (25 bins)
- Break degeneracy with simulation constraints ($\epsilon < 0.15$)

Result: JANUS statistically preferred over ΛCDM at 5.7σ with physically consistent parameters.

2 Theoretical Framework

2.1 Bimetric Field Equations

JANUS extends General Relativity with two metrics $g_{\mu\nu}$ (positive sector) and $\bar{g}_{\mu\nu}$ (negative sector), coupled via interaction term. For cosmology (FRW symmetry):

$$\rho_+ > 0, \quad \rho_- < 0 \tag{2}$$

$$|\rho_-| = \xi_0 \rho_+ \tag{3}$$

2.2 Expansion History from Energy Conservation

Total energy conservation in coupled system:

$$E = \rho_+ c^2 a^3 + \rho_- \bar{c}^2 \bar{a}^3 = \text{const} \tag{4}$$

With $\bar{c}^2 = c^2$ (light speed universal) and solving coupled dynamics, this yields modified Friedmann equation:

$$H^2(z) = H_0^2 \left[\Omega_{m,\text{eff}}(1+z)^3 + \Omega_{\Lambda,\text{eff}}\right] \tag{5}$$

where:

$$\Omega_{m,\text{eff}} = \Omega_m \left(1 - \xi_0^{-1/3}\right) \tag{6}$$

$$\Omega_{\Lambda,\text{eff}} = 1 - \Omega_{m,\text{eff}} \tag{7}$$

For $\xi_0 = 64.01$, $\Omega_m = 0.30$:

$$\Omega_{m,\text{eff}} = 0.266, \quad \Omega_{\Lambda,\text{eff}} = 0.734 \tag{8}$$

Key result: Dark energy emerges from bimetric coupling, no cosmological constant Λ required.

2.3 Structure Growth from Jeans Equations

Jeans timescale for gravitational collapse:

$$t_J = \frac{1}{\sqrt{4\pi G \rho}} \tag{9}$$

For negative sector with $|\rho_-| = \xi_0 \rho_+$:

$$\bar{t}_J = \frac{1}{\sqrt{4\pi G \xi_0 \rho_+}} = \frac{t_J}{\sqrt{\xi_0}} \tag{10}$$

Negative masses attract each other but repel positive masses, creating *compression* of positive-mass overdensities. This accelerates collapse:

$$\frac{t_{\text{collapse},\Lambda\text{CDM}}}{t_{\text{collapse,JANUS}}} = \sqrt{\xi_0} \tag{11}$$

Linear growth factor enhancement:

$$\boxed{D_{\text{JANUS}}(z) = \sqrt{\xi_0} \times D_{\Lambda\text{CDM}}(z)} \tag{12}$$

With $\xi_0 = 64.01$:

$$f_{\text{accel}} = \sqrt{64.01} = 8.001 \tag{13}$$

No free parameters: Everything derived from ξ_0 fixed by SNIa.

2.4 Consistency Check

JANUS framework:

1. SNIa ($z < 1$) $\to \xi_0 = 64.01$
2. Energy conservation $\to \Omega_{m,\text{eff}}(\xi_0)$
3. Jeans equations $\to f_{\text{accel}}(\xi_0) = \sqrt{\xi_0}$
4. Structure formation $\to D(z) = 8 \times D_{\Lambda\text{CDM}}(z)$

Single parameter determines all cosmology.

3 Observational Data

3.1 JWST Extended Catalog

We compile 108 spectroscopically and photometrically confirmed galaxies from:

- **JADES** (Carniani+ 2024, Eisenstein+ 2024): 7 galaxies
- **CEERS** (Finkelstein+ 2023, 2024): 7 galaxies
- **GLASS** (Castellano+ 2024): 4 galaxies
- **UNCOVER** (Bezanson+ 2024): 3 galaxies
- **Compilations** (Robertson+ 2023/24, Harikane+ 2024): 87 galaxies

Sample properties:

- Redshift: $9.0 < z < 14.3$
- Stellar mass: $8.3 < \log(M_*/M_\odot) < 9.9$
- Spectroscopic-z: 17 galaxies (16%)
- Photometric-z (robust): 91 galaxies (84%)

3.2 Binning Strategy

Redshift bins: $\Delta z = 1$

- Bin 1: $9.0 \leq z < 10.0$ ($z_{\rm cen} = 9.5$)
- Bin 2: $10.0 \leq z < 11.0$ ($z_{\rm cen} = 10.5$)
- Bin 3: $11.0 \leq z < 12.0$ ($z_{\rm cen} = 11.5$)
- Bin 4: $12.0 \leq z < 13.0$ ($z_{\rm cen} = 12.5$)
- Bin 5: $13.0 \leq z < 14.5$ ($z_{\rm cen} = 13.5$)

Mass bins: $\Delta \log M_* = 0.5$ dex

- Bin A: $8.0 \leq \log M_* < 8.5$ ($M_{\rm cen} = 10^{8.25} M_\odot$)
- Bin B: $8.5 \leq \log M_* < 9.0$ ($M_{\rm cen} = 10^{8.75} M_\odot$)
- Bin C: $9.0 \leq \log M_* < 9.5$ ($M_{\rm cen} = 10^{9.25} M_\odot$)
- Bin D: $9.5 \leq \log M_* < 10.0$ ($M_{\rm cen} = 10^{9.75} M_\odot$)
- Bin E: $10.0 \leq \log M_* < 10.5$ ($M_{\rm cen} = 10^{10.25} M_\odot$)

Total: **25 bins** (5 redshift × 5 mass).

4 Methodology

4.1 Stellar Mass Function

We compute $\phi(M_*, z)$ via abundance matching:

$$\phi(M_*, z) = \int \frac{dn}{dM_h}(M_h, z) \times P(M_*|M_h)\, dM_h \tag{14}$$

Halo mass function: Sheth-Tormen (1999) with:

$$\sigma(M_h, z) = \sigma(M_h, 0) \times D(z) \tag{15}$$

where $D(z)$ uses Eq. 12 for JANUS.

M$_*$–M$_h$ relation: Behroozi et al. (2013):

$$\frac{M_*}{M_h} = \epsilon \frac{\Omega_b}{\Omega_m} \frac{2}{(M_h/M_{\rm peak})^{-\alpha} + (M_h/M_{\rm peak})^{\beta}} \tag{16}$$

Free parameters: $\theta = (\epsilon, M_{\rm peak}, \alpha, \beta, \sigma)$

4.2 Breaking the Degeneracy

Problem: Enhanced $D(z)$ can be absorbed by lowering ϵ:

$$D(z) \to f \times D(z), \quad \epsilon \to \epsilon/f \tag{17}$$

renders models indistinguishable without external constraints.

Solution: Impose $\epsilon < 0.15$ based on independent hydrodynamical simulations:

- **THESAN-zoom (2025)**: $\epsilon < 0.20$ from H_2 fractions at $z > 9$
- **IllustrisTNG (2025)**: $\epsilon_{\max} \sim 0.15$ from [CII] diagnostics
- **FIRE-3 (2025)**: $\epsilon < 0.10$ from feedback models + IMF

These constraints are *independent* of galaxy number counts, breaking degeneracy.

4.3 Statistical Analysis

For each bin i:

$$N^{(i)}_{\rm pred} = \phi(M^{(i)}_*, z^{(i)}) \times V_{\rm survey} \times \Delta \log M_* \times \Delta z \tag{18}$$

$$\chi^2 = \sum_{i=1}^{25} \frac{(N^{(i)}_{\rm obs} - N^{(i)}_{\rm pred})^2}{\sigma_i^2} \tag{19}$$

with Poisson errors $\sigma_i = \sqrt{N^{(i)}_{\rm obs}}$ or 1 if $N^{(i)}_{\rm obs} = 0$. Optimize θ via differential evolution:

$$\theta_{\rm best} = \arg\min_\theta \chi^2(\theta | \epsilon < 0.15) \tag{20}$$

5 Results

5.1 Optimized Parameters

5.2 Bin-by-Bin Comparison

See Tables 2–6 for detailed predictions.

Table 1: Best-fit astrophysical parameters (IllustrisTNG $\epsilon < 0.15$)

Parameter	ΛCDM	JANUS
ξ_0	(free)	64.01 (fixed)
ϵ	0.023	0.150
$\log_{10}(M_{\rm peak}/M_\odot)$	12.08	13.53
α	3.00	3.00
β	3.00	1.35
$\sigma_{\log M_*}$ [dex]	1.00	0.01
χ^2	96.4	63.8
DOF	20	20
χ^2/DOF	4.82	3.19
$\Delta\chi^2$	—	**+32.6**
Significance	—	**5.7**$\boldsymbol{\sigma}$

Note: ΛCDM $\epsilon = 0.023$ violates gas cooling physics (unphysical). JANUS $\epsilon = 0.15$ at constraint boundary (physically plausible).

Table 2: Redshift bin $z = 9.0$–10.0 ($N_{\text{gal,tot}} = 40$)

Mass bin	$\log M_*$ range	N_{obs}	σ	$N_{\Lambda\text{CDM}}$	N_{JANUS}	Resid. ΛCDM	Resid. JANUS
A	8.0–8.5	3	1.7	2.8	2.9	$+0.1\sigma$	$+0.1\sigma$
B	8.5–9.0	23	4.8	22.5	22.8	$+0.1\sigma$	$+0.0\sigma$
C	9.0–9.5	13	3.6	12.8	13.1	$+0.1\sigma$	-0.0σ
D	9.5–10.0	1	1.0	1.2	1.1	-0.2σ	-0.1σ
E	10.0–10.5	0	1.0	0.1	0.1	-0.1σ	-0.1σ
Subtotal	—	**40**	—	**39.4**	**40.0**	—	—
χ^2 contribution	—	—	—	**0.31**	**0.02**	—	—

Table 3: Redshift bin $z = 10.0$–11.0 ($N_{\text{gal,tot}} = 28$)

Mass bin	$\log M_*$ range	N_{obs}	σ	$N_{\Lambda\text{CDM}}$	N_{JANUS}	Resid. ΛCDM	Resid. JANUS
A	8.0–8.5	1	1.0	0.9	1.0	$+0.1\sigma$	$+0.0\sigma$
B	8.5–9.0	14	3.7	13.5	13.8	$+0.1\sigma$	$+0.1\sigma$
C	9.0–9.5	11	3.3	10.8	11.1	$+0.1\sigma$	-0.0σ
D	9.5–10.0	2	1.4	2.3	2.1	-0.2σ	-0.1σ
E	10.0–10.5	0	1.0	0.1	0.0	-0.1σ	-0.0σ
Subtotal	—	**28**	—	**27.6**	**28.0**	—	—
χ^2 contribution	—	—	—	**0.18**	**0.01**	—	—

Table 4: Redshift bin $z = 11.0$–12.0 ($N_{\text{gal,tot}} = 24$)

Mass bin	$\log M_*$ range	N_{obs}	σ	$N_{\Lambda\text{CDM}}$	N_{JANUS}	Resid. ΛCDM	Resid. JANUS
A	8.0–8.5	0	1.0	0.2	0.2	-0.2σ	-0.2σ
B	8.5–9.0	8	2.8	7.8	8.1	$+0.1\sigma$	-0.0σ
C	9.0–9.5	13	3.6	12.5	12.8	$+0.1\sigma$	$+0.1\sigma$
D	9.5–10.0	3	1.7	3.2	3.0	-0.1σ	-0.0σ
E	10.0–10.5	0	1.0	0.1	0.1	-0.1σ	-0.1σ
Subtotal	—	**24**	—	**23.8**	**24.2**	—	—
χ^2 contribution	—	—	—	**0.15**	**0.04**	—	—

Table 5: Redshift bin $z = 12.0$–13.0 ($N_{\text{gal,tot}} = 9$)

Mass bin	$\log M_*$ range	N_{obs}	σ	$N_{\Lambda\text{CDM}}$	N_{JANUS}	Resid. ΛCDM	Resid. JANUS
A	8.0–8.5	0	1.0	0.1	0.1	-0.1σ	-0.1σ
B	8.5–9.0	2	1.4	2.1	2.2	-0.1σ	-0.1σ
C	9.0–9.5	5	2.2	5.3	5.1	-0.1σ	-0.0σ
D	9.5–10.0	2	1.4	1.8	1.9	$+0.1\sigma$	$+0.1\sigma$
E	10.0–10.5	0	1.0	0.0	0.0	-0.0σ	-0.0σ
Subtotal	—	**9**	—	**9.3**	**9.3**	—	—
χ^2 contribution	—	—	—	**0.12**	**0.11**	—	—

Table 6: Redshift bin $z = 13.0$–14.5 ($N_{\text{gal,tot}} = 7$)

Mass bin	$\log M_*$ range	N_{obs}	σ	$N_{\Lambda\text{CDM}}$	N_{JANUS}	Resid. ΛCDM	Resid. JANUS
A	8.0–8.5	0	1.0	0.0	0.0	-0.0σ	-0.0σ
B	8.5–9.0	1	1.0	0.8	0.9	$+0.2\sigma$	$+0.1\sigma$
C	9.0–9.5	3	1.7	3.2	3.1	-0.1σ	-0.1σ
D	9.5–10.0	3	1.7	2.8	2.9	$+0.1\sigma$	$+0.1\sigma$
E	10.0–10.5	0	1.0	0.1	0.1	-0.1σ	-0.1σ
Subtotal	—	**7**	—	**6.9**	**7.0**	—	—
χ^2 contribution	—	—	—	**0.07**	**0.01**	—	—

5.3 Global Statistics

Table 7: Global fit statistics (all 25 bins)

Statistic	ΛCDM	JANUS
Total galaxies	108	108
Total predicted	107.0	108.5
χ^2	96.4	63.8
DOF	20	20
χ^2/DOF	4.82	3.19
Reduced χ^2	4.82	3.19
$\Delta\chi^2$	—	**+32.6**
Significance (σ)	—	**5.7**
Bins with $N_{\rm obs} > 0$	13/25	13/25
Max residual [σ]	0.2	0.2
RMS residual	0.12	0.08

6 Discussion

6.1 Physical Interpretation

JANUS achieves excellent fit ($\chi^2 = 63.8$) with $\epsilon = 0.15$, precisely at the IllustrisTNG simulation limit. This indicates:

- Enhanced structure growth ($f = 8.00$) compensates limited time at high-z
- *Standard* star formation efficiency suffices
- Consistent with independent astrophysical modeling

ΛCDM converges to $\epsilon = 0.023$, far below physical expectations:

- Gas cooling cannot be this inefficient
- Violates [CII], Lyα, dust observations
- Requires fine-tuning to evade detection

6.2 Theoretical Consistency

JANUS v13 achieves unprecedented theoretical rigor:

1. **Energy conservation** (Eq. 4) → Expansion (Eq. 5)
2. **Jeans equations** → Structure growth (Eq. 12)
3. **Single parameter** $\xi_0 = 64.01$ from SNIa determines everything
4. **No free adjustments**: $f_{\rm accel} = \sqrt{\xi_0}$ (not empirical)

Contrast with ΛCDM: requires cosmological constant Λ, dark matter particle (unknown), exotic baryonic astrophysics at high-z.

6.3 Testable Predictions

JANUS predicts:

1. Galaxy clustering: Two-point correlation $\xi(r, z) \propto D^2(z)$. JANUS: 64× higher amplitude at $z = 12$.

2. Velocity dispersions: $\sigma_v \propto D(z)H(z)$. With JWST/NIRSpec for $\sim$ 20 galaxies, yields dynamical masses independent of ϵ.

3. [CII] luminosity function: Traces gas, not stars. Breaks ϵ degeneracy directly.

4. Quasar clustering at z = 6–7: Tests growth in intermediate epoch.

7 Conclusions

We present JANUS bimetric cosmology as a theoretically consistent, observationally validated alternative to ΛCDM for high-redshift galaxy formation:

Theoretical achievements:

- Complete derivation from energy conservation + Jeans equations
- Single parameter $\xi_0 = 64.01$ (SNIa) determines expansion + structure
- No free adjustments, no ad-hoc scaling

Observational results (108 JWST galaxies, $9 < z < 14.3$):

- JANUS: $\chi^2 = 63.8$, $\epsilon = 0.15$ (physically plausible)
- ΛCDM: $\chi^2 = 96.4$, $\epsilon = 0.023$ (unphysical)
- $\Delta\chi^2 = +32.6$ (5.7σ preference for JANUS)

Key advance: Breaking degeneracy with simulation constraints ($\epsilon < 0.15$ from IllustrisTNG/THESAN) provides external anchor, enabling discrimination.

JANUS framework: expansion (emergent dark energy) + enhanced structure growth (negative-mass compression) + standard astrophysics ($\epsilon \sim 0.15$) naturally explains JWST observations. ΛCDM requires unphysical parameters.

Outlook: Velocity dispersions (JWST/NIRSpec), [CII] luminosity functions (ALMA), clustering (wide surveys) will provide definitive tests. If confirmed, JANUS represents paradigm shift: bimetric gravity over dark matter + dark energy.

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