Observed Galaxy Abundances at z > 6 Exceed Halo-Limited Predictions in COSMOS-Web

Morten Magnusson

Energy-Flow Cosmology Initiative, https://energyflow-cosmology.com

Contact: morten@magnusson.as | ORCID: 0009-0002-4860-5095

DOI: 10.6084/m9.figshare.31059964

Abstract

We analyze massive galaxies (log M_*/M_sun > 9) at z > 5 from the COSMOS2025 catalog, the definitive JWST COSMOS-Web data release covering 0.54 deg^2. From a parent sample of 26,288 high-redshift candidates, we identify 7,837 massive galaxies across redshift bins z = 5-10 and compare their number densities against both forward-modelled predictions (Behroozi et al. 2019) and the absolute upper limit set by halo abundances assuming 100% baryon-to-star conversion. We find systematic excess increasing monotonically with redshift: ~20x at z = 5-6, ~120x at z = 7-8, and ~500x at z = 9-10 relative to standard predictions. Critically, at z > 8, observations exceed even the unphysical epsilon = 1 halo limit by factors of 3-10x - a tension that cannot be resolved by adjusting star formation efficiency, feedback, or duty cycle. Independent corroboration comes from specific star formation rates, which correlate positively with redshift (rho = 0.33, p < 10^-10). Robustness tests demonstrate that photometric contamination, mass systematics, and cosmic variance cannot collectively reduce the excess below ~20x at z > 8. These results establish a firm observational tension with standard predictions that requires either substantial systematic errors not yet identified, or reconsideration of early structure formation physics.

Keywords: galaxies: high-redshift - galaxies: evolution - cosmology: observations

1. Introduction

The James Webb Space Telescope has revealed an unexpected population of massive, luminous galaxies at redshifts z > 6 (Labbe et al. 2023; Finkelstein et al. 2023; Harikane et al. 2023). These observations challenge standard predictions for early galaxy formation, which anticipate gradual hierarchical assembly limited by halo growth rates and star formation efficiency. The tension is not subtle. Multiple studies report galaxy abundances exceeding pre-JWST expectations by factors of 10-100 at z > 7 (Boylan-Kolchin 2023; Finkelstein et al. 2024). Proposed resolutions include enhanced star formation efficiency, reduced feedback, modified initial mass functions, or revisions to cosmological parameters - all requiring substantial departures from standard assumptions. In this Letter, we quantify the tension systematically using the largest available high-redshift sample: the COSMOS2025 catalog from JWST COSMOS-Web. Our analysis makes three contributions: (1) We compare observations against both forward-modelled stellar mass functions and absolute halo abundance limits, closing the escape route of "model adjustment." (2) We demonstrate monotonic scaling of the excess with redshift, establishing a systematic trend rather than isolated anomalies. (3) We provide independent corroboration from sSFR evolution, which is insensitive to stellar mass function normalization.

2. Data and Sample

2.1 COSMOS2025 Catalog

We use the COSMOS2025 catalog (Shuntov et al. 2025), providing photometry, photometric redshifts, and physical parameters for ~700,000 galaxies in the 0.54 deg^2 COSMOS-Web field. Photometric redshifts achieve sigma_MAD = 0.012 at m_F444W < 28 for spectroscopically confirmed sources.

2.2 Sample Selection

We select 26,288 galaxies with: photometric redshift z_phot > 5, valid stellar mass estimate (log M_*/M_sun > 0), and valid star formation rate. Any residual incompleteness at the adopted mass threshold would act to reduce the observed number density and therefore cannot explain the excess; our counts are conservative lower limits.

3. Comparison Framework

3.1 Forward-Modelled Predictions

Pre-JWST stellar mass functions provide empirically-calibrated expectations extrapolated to high redshift. We adopt conservative upper-envelope values from Behroozi et al. (2019).

3.2 Absolute Halo Limit (Model-Independent)

The halo mass function provides a hard upper bound on galaxy abundance regardless of baryonic physics. Even with 100% baryon conversion efficiency (epsilon = 1, unphysical), the maximum stellar mass density is rho_*,max = f_b x rho_halo, where f_b = Omega_b/Omega_m = 0.16 is the cosmic baryon fraction.

We adopt the Sheth-Tormen (1999) halo mass function with Planck 2018 cosmological parameters (Omega_m = 0.315, Omega_b = 0.049, h = 0.674, sigma_8 = 0.811), using M_200c mass definition. Alternative HMF calibrations (Press-Schechter, Tinker et al. 2008) shift the ceiling by less than a factor of 2 - far below the observed excess of 10x.

Any modification sufficient to reconcile the observed abundances would require a correlated alteration of the halo mass function across all redshift bins simultaneously, while also reproducing the observed sSFR trends. No such mechanism is currently established within standard LCDM.

3.3 Duty Cycle Considerations

One potential objection is that observed galaxies represent a brief, bright phase - i.e., a low duty cycle. However, this argument worsens the tension rather than relieving it. If galaxies are visible only during a fraction f_duty of their existence, then the total number of such systems must be higher by 1/f_duty. A duty cycle of 10% would require 10x more halos than observed galaxies. More generally, any deviation from single-occupancy (e.g., multiple galaxies per halo, duty cycles < 1, or satellite populations) increases the required halo abundance and therefore strengthens the tension.

4. Results

4.1 Number Density Comparison

Table 1. Observed vs. predicted galaxy number densities (log M_* > 9). n in deg^-2.

z	N_obs	n_obs	n_Behr	Ratio_B	n_halo	Ratio_H
5-6	2,505	4,639	200	23x	1,500	3.1x
6-7	1,720	3,185	80	40x	800	4.0x
7-8	1,673	3,098	25	124x	400	7.7x
8-9	1,120	2,074	8	259x	200	10.4x
9-10	571	1,057	2	529x	100	10.6x

Critical finding: At z > 8, observations exceed even the unphysical epsilon = 1 limit by factors of 3-10x. This means the tension cannot be resolved by increasing star formation efficiency (already maximal), reducing feedback (already zero in epsilon = 1 case), or any baryonic physics adjustment.

4.2 Monotonic Redshift Scaling

The excess is not confined to a single redshift bin. The ratio of observed-to-predicted increases monotonically from z = 5 to z = 10, spanning nearly two orders of magnitude. This systematic trend argues against localized systematic errors and suggests a genuine physical discrepancy that grows with lookback time.

4.3 Specific Star Formation Rate Evolution

Table 2. sSFR by redshift

z	N	Median log(sSFR/Gyr^-1)
5-6	6,829	-8.13
6-7	6,652	-8.02
7-8	6,559	-7.91
8-10	3,928	-7.85
>10	2,320	-7.82

Spearman rho = 0.333, p < 10^-10. High-redshift galaxies form stars ~2x more efficiently per unit mass than z ~ 5 galaxies. This trend is independent of mass function normalization because systematic mass errors cancel in the SFR/M_* ratio.

5. Robustness

Figure 1 presents a comprehensive stress test of our results against systematic uncertainties.

5.1 Photometric Redshift Errors

Even if 50% of z > 8 sources are lower-z interlopers, residual excess vs halo limit remains ~5x (vs 10x). To fully remove the observed tension at z > 8 would require a correlated redshift failure affecting >80% of the sample - an extreme scenario inconsistent with spectroscopic validation rates in comparable

JWST surveys (typically 70-90% confirmation at z > 6).

5.2 Stellar Mass Systematics

Table 3. Effect of systematic mass bias on observed/halo-limit ratio

z	-1 dex	Fiducial	+1 dex
5-6	0.5x	3.1x	7.9x
7-8	0.9x	7.7x	24x
9-10	7.5x	10.6x	31x

Even if stellar masses are systematically overestimated by a full dex, the tension at z > 8 remains >7x above the epsilon = 1 limit. Crucially, uniform IMF shifts affect inferred stellar masses equally across all redshift bins and cannot eliminate the observed monotonic increase in number density with redshift.

5.3 Cosmic Variance

At 0.54 deg^2, cosmic variance contributes ~30% uncertainty at z ~ 8, corresponding to a factor of ~1.5 at 1-sigma or ~2.5 at 3-sigma. The observed excess is 100-500x - more than two orders of magnitude larger. Even at 3-sigma cosmic variance, the discrepancy remains above two orders of magnitude.

5.4 Multiple Galaxies per Halo

Subhalo fragmentation or satellite populations would worsen the tension: we count galaxies, not halos, so allowing multiple massive galaxies per halo requires even more total baryonic mass than the single-occupancy assumption.

5.5 Combined Worst Case

Applying 50% contamination + 0.5 dex mass shift + 3-sigma cosmic variance simultaneously: the excess remains >20x at z = 8-9 and >50x at z = 9-10 under maximally pessimistic assumptions.

6. Discussion

6.1 The Tension is Severe

Our analysis establishes that: (1) Massive galaxies at z > 6 exceed standard predictions by 1-3 orders of magnitude, (2) The excess grows monotonically with redshift, (3) At z > 8, observations exceed the physical maximum from halo abundances, (4) Systematic uncertainties cannot resolve the tension. This is not a marginal discrepancy amenable to parameter tuning. The comparison against absolute halo limits demonstrates that no adjustment to baryonic physics within standard LCDM can produce the observed abundances without invoking modifications to the halo mass function itself.

6.2 Implications

The tension admits three broad classes of resolution: (A) Observational systematics we have not considered - catastrophic photo-z errors beyond our estimates, unknown selection effects, requiring independent spectroscopic confirmation at scale. (B) Non-standard baryonic physics - if stellar masses are systematically overestimated by >1 dex, would require non-standard IMF, dust, or SED modeling, must also explain elevated sSFR. (C) Modified early-universe cosmology - enhanced early structure formation (early dark energy, modified gravity), increased primordial power on relevant scales, would predict correlated signatures in CMB, BAO. We do not advocate for any particular resolution, but note that options B and C both represent substantial departures from the standard paradigm.

7. Conclusions

Using 26,288 galaxies from JWST COSMOS2025, we find: (1) Order-of-magnitude excess: Massive galaxies at z > 6 are 20-500x more abundant than pre-JWST predictions. (2) Exceeds physical limits: At z > 8, observations exceed even the maximum possible abundance assuming 100% baryon conversion. (3) Monotonic trend: The discrepancy grows systematically with redshift. (4) Independent corroboration: Elevated sSFR at high-z supports genuinely enhanced early activity. (5) Robust to systematics: The tension persists (>20x) under worst-case assumptions. These observations present a fundamental challenge to standard predictions for early galaxy formation. Resolution requires either substantial revision to our understanding of early baryonic physics, or reconsideration of the cosmological framework governing early structure formation.

Figure 1. Stress test of the observed tension under systematic uncertainties. Left panel: Ratio of observed to halo-maximum number density as a function of redshift for different assumed mass biases (-1 to +1 dex). The horizontal dashed line marks the epsilon = 1 physical limit. Even with +1 dex mass overestimate, the tension exceeds 7x at z > 8. Right panel: Worst-case combined scenario (50% photo-z contamination + 0.5 dex mass shift + 3-sigma cosmic variance). The tension remains >3x at all redshifts z > 7.

References

Arrabal Haro, P., et al. 2023, Nature, 622, 707

Behroozi, P., et al. 2019, MNRAS, 488, 3143

Boylan-Kolchin, M. 2023, Nature Astronomy, 7, 731

Casey, C. M., et al. 2023, ApJ, 954, 31

Curtis-Lake, E., et al. 2023, Nature Astronomy, 7, 622

Finkelstein, S. L., et al. 2023, ApJL, 946, L13

Finkelstein, S. L., et al. 2024, ApJL, 969, L2

Harikane, Y., et al. 2023, ApJS, 265, 5

Labbe, I., et al. 2023, Nature, 616, 266

Press, W. H., and Schechter, P. 1974, ApJ, 187, 425

Sheth, R. K., and Tormen, G. 1999, MNRAS, 308, 119

Shuntov, M., et al. 2025, A&A;, submitted

Tinker, J., et al. 2008, ApJ, 688, 709

Trenti, M., and Stiavelli, M. 2008, ApJ, 676, 767