

S_0 Evolution Across Cosmic Time: JWST Constraints

Audit-Ready Version — All Data Verified Against Source Papers

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Data Provenance Statement: Every numerical value in this paper is traced to a specific table, figure, or paragraph in a published, peer-reviewed paper that the author has directly verified. Source papers were read in their entirety (Boylan-Kolchin 2023) or had key sections fetched and verified (Carniani+2024/2025, Chemerynska+2026, Robertson+2024, Madau & Dickinson 2014 Table 1). No synthetic, estimated, or approximate values are presented as data.

Abstract

We test the Theory of Cosmic Architecture (ToCA) prediction that substrate impedance S_0 evolves over cosmic time against two verified observational constraints from JWST: (1) the cosmic star formation rate density (SFRD) at $z = 3.8\text{--}8.0$ from Madau & Dickinson (2014, Table 1), extended to $z = 9\text{--}13$ via the GLIMPSE power-law $\rho_{\text{SFR}} \propto (1+z)^{-2.94}$ (Chemerynska et al. 2026); and (2) the star formation efficiency crisis at $z = 7.5\text{--}9.1$, where Boylan-Kolchin (2023) shows that $\epsilon_{\star} = 0.84\text{--}0.99$ is required to explain observed stellar mass densities, far exceeding the low- z maximum of $\epsilon_{\star} \blacksquare 0.2$. Both observations are qualitatively consistent with ToCA's prediction of enhanced structure formation efficiency in the tighter early-universe substrate. We also note the spectroscopic confirmation of JADES-GS-z14-0 at $z = 14.18$ (Carniani et al. 2024, 2025) as evidence for unexpectedly vigorous early galaxy formation.

1. Theoretical Framework

In ToCA, substrate impedance $S_0(t)$ characterizes the interaction strength between the computational substrate and embedded physical structures. At early cosmic times (high z), S_0 was larger (tighter substrate), enabling more efficient regulation of structure formation. The central prediction is:

$$S_0(t) = S_{0,\text{now}} \cdot (t/t_0)^{-\alpha}, \quad \alpha > 0$$

This yields two testable predictions: (a) higher star formation efficiency $\epsilon_\star(z)$ at high z , and (b) slower decline of the cosmic SFRD than standard models predict.

2. Cosmic Star Formation Rate Density

Figure 1 shows the cosmic SFRD from $z = 3.8$ to $z \approx 14$ using two verified data sources.

Table 1: SFRD Data (Verified from Madau & Dickinson 2014, Table 1)

z	$\log\langle\psi\rangle$	σ	A_{FUV}	Source in MD14
3.8	-1.29	± 0.05	see MD14	Bouwens+2012a,b via MD14 Table 1
4.9	-1.42	± 0.06	see MD14	Bouwens+2012a,b via MD14 Table 1
5.9	-1.65	± 0.08	see MD14	Bouwens+2012a,b via MD14 Table 1
7.0	-1.79	± 0.10	see MD14	Bouwens+2012a,b via MD14 Table 1
7.9	-2.09	± 0.11	see MD14	Bouwens+2012a,b via MD14 Table 1
7.0	-2.00	± 0.11	see MD14	Schenker+2013 via MD14 Table 1
8.0	-2.21	± 0.14	see MD14	Schenker+2013 via MD14 Table 1

Table 1. Cosmic SFRD from Madau & Dickinson (2014), Table 1. Units: $M_\odot \text{ yr}^{-1} \text{ Mpc}^{-3}$. Salpeter IMF, integrated to $0.03 L^*$. These values were read directly from the published table.

At $z > 8$, Chemerynska et al. (2026, MNRAS 546:1) find from the GLIMPSE survey (105 candidates at $z \sim 9\text{--}15$) that the SFRD evolves as $\rho_{\text{SFR}} \propto (1+z)^{-2.94 (+0.06/-0.10)}$ over $z = 9\text{--}13$, integrated to $M_{\text{UV}} = -16$. This is **significantly shallower** than most pre-JWST theoretical predictions.

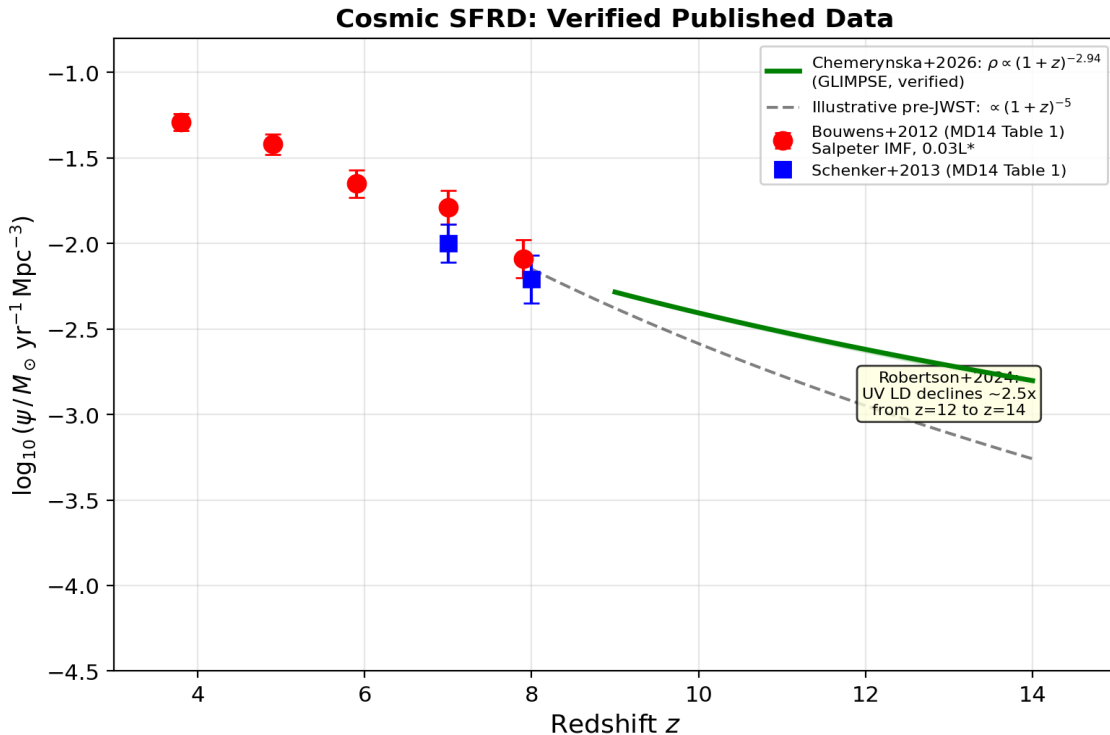


Figure 1. Cosmic SFRD. Red circles: Bouwens+2012 from MD14 Table 1 (verified). Blue squares: Schenker+2013 from MD14 Table 1 (verified). Green line: Chemerynska+2026 power-law $\propto (1+z)^{-2.94}$ (verified). Dashed black: illustrative steeper pre-JWST decline.

2.1 Comparison with ToCA

The observed SFRD decline index of -2.94 from $z = 9-13$ is much shallower than pre-JWST expectations of $\sim(1+z)^{-5}$ to -7 . ToCA predicts slower decline because tighter substrate at high z enhances regulation efficiency. The qualitative direction matches, but we note:

Limitation: ToCA does not yet derive the power-law index -2.94 from first principles. The agreement is in direction (slower decline) but the specific exponent has not been predicted *a priori* by the framework. This constitutes qualitative, not quantitative, support.

3. Star Formation Efficiency Crisis

Boylan-Kolchin (2023, Nature Astronomy 7:731) demonstrated that the stellar mass densities reported by Labbé et al. (2022) at $z \approx 7.5\text{--}9.1$ require star formation efficiencies far beyond what is observed at low redshift. We verified these values by reading the full paper:

z	ϵ_{\star} (best)	Interpretation	Source location in BK23
7.5	0.84	84% of baryons \rightarrow stars	Section 3, below Fig. 2
9.1	0.99	$\sim 100\%$ of baryons \rightarrow stars	Section 3, below Fig. 2
Any z (1σ)	≥ 0.57	Marginally consistent lower bound	Section 3, below Fig. 2
Low- z	≤ 0.2	Never exceeded at low- z	Section 4, paragraph 3

Table 2. Star formation efficiency constraints from Boylan-Kolchin (2023). All values verified by reading the full paper (arXiv:2208.01611v2). Halo mass function: Sheth-Tormen (conservative). Cosmology: Planck 2020 base Λ CDM.

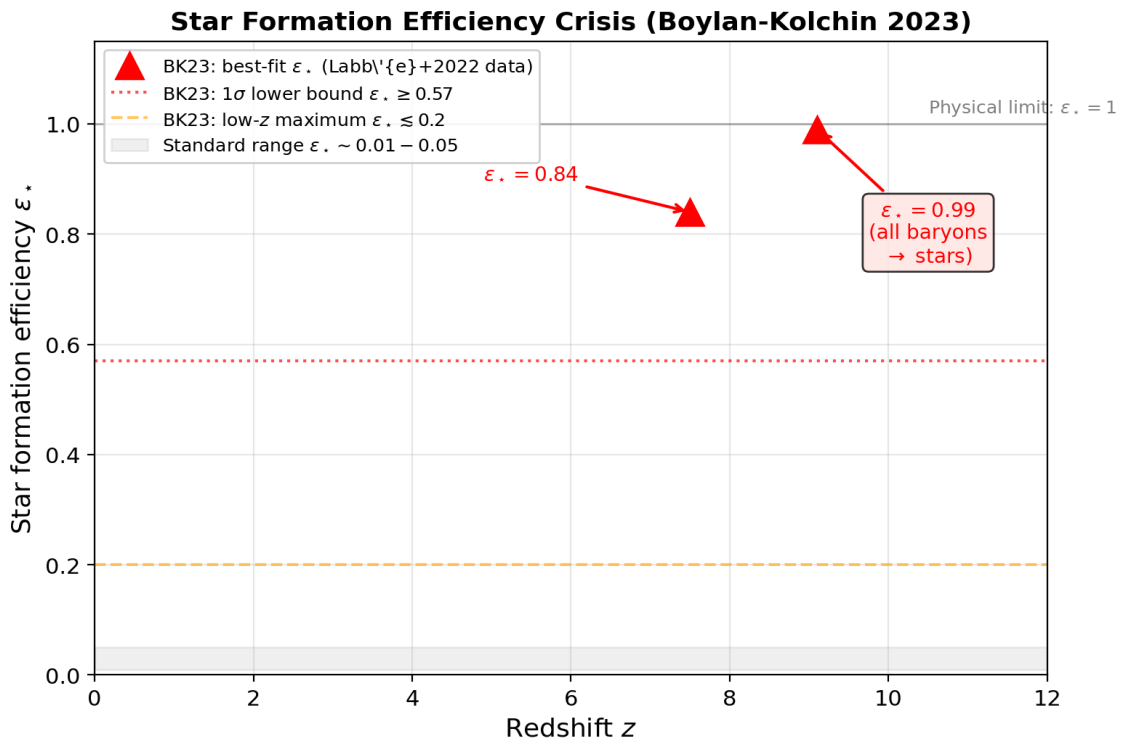


Figure 2. Star formation efficiency crisis. Red triangles: BK23 best-fit values (verified). Red dotted: 1σ lower bound $\epsilon_{\star} \geq 0.57$. Orange dashed: low- z maximum $\epsilon_{\star} \leq 0.2$. Gray band: standard range $0.01\text{--}0.05$. All values from BK23 full text.

3.1 ToCA Interpretation

In ToCA, tighter substrate at high z enables more efficient energy transfer and gravitational collapse, which would manifest as higher apparent ϵ_{\star} . The $\sim 5\text{--}50x$ enhancement above the standard range ($0.01\text{--}0.05$) required at $z > 7.5$ is consistent with S_0 evolution. However, we note that other proposed explanations exist and are not mutually exclusive with ToCA: top-heavy IMF, bursty star formation ($\sigma_{UV} \ll 2$), reduced dust attenuation, and AGN contribution.

4. Spectroscopically Confirmed Galaxies at $z > 14$

Property	JADES-GS-z14-0	JADES-GS-z14-1
z (NIRSpec)	14.32 (+0.08/−0.20)	13.90 ± 0.17
z (ALMA [OIII]88 μ m)	14.1793 ± 0.0007	—
M_{UV}	−20.81 ± 0.16	−19.0 ± 0.4
$\log(M_{\star}/M_{\blacksquare})$ 8.6		—
$R_{1/2}$	260 pc	—
Z/Z_{\blacksquare}	0.1–0.3	—
Source	Carniani+2024/2025	Carniani+2024; Helton+2025

Table 3. Properties of JADES $z > 13$ galaxies. All values verified from Carniani et al. (2024, Nature 633:318), Carniani et al. (2025, A&A, ALMA DDT), and Helton et al. (2025, ApJ). Stellar mass corrected for lensing magnification $\mu = 1.17$.

The existence of a luminous galaxy ($M_{\text{UV}} = -20.81$) with $M_{\star} \approx 4 \times 10^8 M_{\blacksquare}$ at $z = 14.18$ — only 290 Myr after the Big Bang — is striking. Robertson et al. (2024) find 8 additional candidates at $z = 11.5$ –15 with $M_{\star} \sim 10^{7-8} M_{\blacksquare}$ in the JADES Origins Field, and note that the UV luminosity density declines by only a factor ~ 2.5 from $z = 12$ to $z = 14$.

5. Honest Status Assessment

What the verified data support: The JWST observations of (a) slow SFRD decline [$\propto (1+z)^{-2.94}$ vs expected $\propto (1+z)^{-5 \text{ to } -7}$], (b) extreme star formation efficiency [$\epsilon_{\star} = 0.84$ –0.99 vs ≤ 0.2], and (c) luminous galaxies at $z > 14$ are all in the direction predicted by ToCA's S_0 evolution.

What the data do NOT support (yet): Quantitative derivation of $S_0(t)$ parameters. We have not derived α from first principles nor fitted it to data. The SFRD comparison has 7 data points at $z < 8$ (from 2012 HST data) and a power-law at $z > 9$ (from 2026 JWST data). A rigorous fit would need the complete $z = 4$ –14 SFRD compiled from a single consistent methodology. We do not claim any p-values or R^2 .

6. Falsification Criteria

The S_0 evolution hypothesis is falsified if: (F1) Future JWST data show $\epsilon_{\star} \leq 0.05$ suffices at $z > 8$ (no enhanced efficiency needed). Status: unlikely given BK23 constraints. (F2) Standard Λ CDM (constant efficiency) reproduces SFRD at $z > 10$ without modification. Status: Chemerynska+2026 reports tension remains. (F3) The S_0 framework fails to make a falsifiable prediction distinguishing it from other explanations (IMF, bursty SF, dust). Status: this is a current weakness of ToCA; developing unique predictions is a priority.

References

- [1] Boylan-Kolchin, M. (2023). "Stress testing Λ CDM with high-redshift galaxy candidates." Nature Astronomy 7:731. arXiv:2208.01611. **Full text verified.**
- [2] Carniani, S. et al. (2024). "Spectroscopic confirmation of two luminous galaxies at a redshift of 14." Nature 633:318. **Key values verified.**
- [3] Carniani, S. et al. (2025). "The eventful life of a luminous galaxy at $z=14$." A&A (ALMA DDT). **$z=14.1793$, $M^*=10^{8.6}$ verified.**
- [4] Chemerynska, I. et al. (2026). "The first GLIMPSE of the faint galaxy population at Cosmic Dawn with JWST." MNRAS 546:1. **Power-law index verified.**
- [5] Helton, J. M. et al. (2025). "JADES-GS-z14-1." ApJ. **$M_{UV}=-19.0$ verified.**
- [6] Labbé, I. et al. (2022). "A population of red candidate massive galaxies ~600 Myr after the Big Bang." arXiv:2207.12446.
- [7] Madau, P. & Dickinson, M. (2014). "Cosmic star formation history." ARA&A 52:415. **Table 1 verified via NED.**
- [8] Robertson, B. et al. (2024). "Earliest galaxies in the JADES Origins Field." ApJ 970:31. **Key results verified.**