The Evolving Origin of Star-forming Clumps at 2 < z < 9: Merger- to Instability-Dominated Transition Revealed in JWST NIRCam Legacy Fields

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Abstract

Giant star-forming clumps are common in high-redshift galaxies, but whether they form *in-situ* by violent disk instability (VDI) or *ex-situ* through mergers is still debated. We built a homogeneous census of clumps at 2 < z < 9 from public JWST/NIRCam imaging, detecting sub-kpc clumps automatically in the rest-frame UV. The dominant channel changes with time: **mergers at z ≳ 4.5, VDI at z ≲ 4.5**, with VDI-driven inward migration helping to build galactic bulges.

7,988 galaxies at 2 < z < 9

2,741 clumpy galaxies

4,220 UV clumps detected

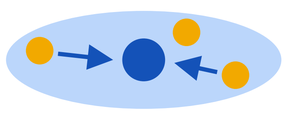
777 arcmin² · 5 legacy fields

Keywords: galaxy evolution, high-redshift galaxies, star-forming clumps, JWST

Introduction

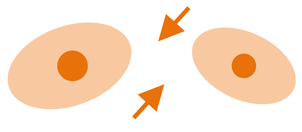
Clumps host 10–50% of a galaxy's star formation at z ~ 2. HST studies reached only z ≲ 3; JWST now reaches z ~ 9. Our team also found that massive quiescent galaxies build dense cores within ~1 Gyr (Haryana et al. 2025, 2026). Could migrating clumps drive this?

IN-SITU · VDI



- Gas-rich, turbulent disk breaks up (Toomre Q < 1)
- Fed by cold streams
- Clumps migrate inward → bulge

EX-SITU · mergers



- Accreted satellites / companions
- Merger-induced instabilities
- No ordered age pattern

Key question: which channel makes the clumps, and does it change across cosmic time?

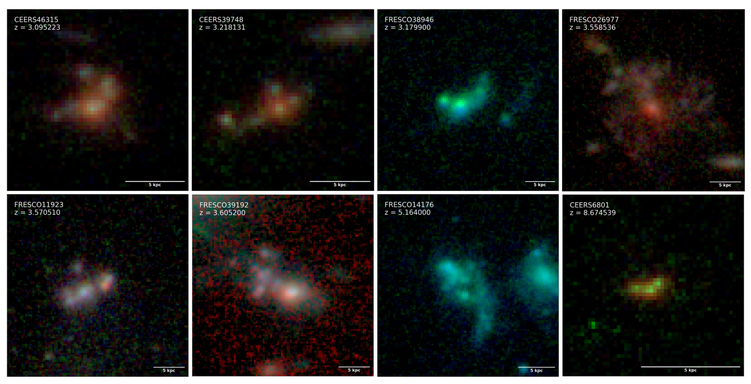


Figure 1. Clumpy galaxies at z ≈ 3–9 seen by JWST/NIRCam (bar: 5 kpc).

Research Method

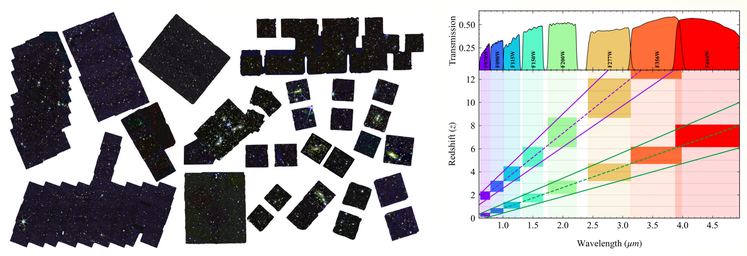


Figure 2. DJA mosaics of the five fields (left) and the filter tracing rest-frame UV at each redshift (right, purple).

Field	Area (arcmin²)	5σ F444W (mag)
CEERS (EGS)	107.8	28.6
GOODS-North	94.4	27.97
GOODS-South	72.8	28.20
PRIMER-UDS	293.5	27.9
PRIMER-COSMOS	208.8	28.0
Total	**777.3**	**–**

1 Public JWST/NIRCam data
DAWN JWST Archive (DJA), 5 legacy fields

2 Sample selection
photo-z (eazy-py), CIGALE · $M_* \geq 10^8\ M_\odot$

3 Smooth host model
starlet wavelet scales > PSF (0.16″), then subtracted

4 Clump detection
residual peaks > 3σ, off-centre, > 8% of host UV light

5 Completeness correction
fake-clump injection–recovery per mass & z bin

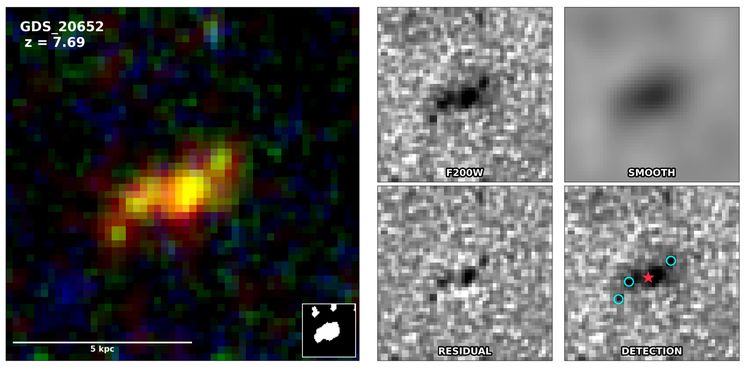


Figure 3. Detection steps for GDS_20652 (z = 7.69): F200W, smooth model, residual, clumps (cyan).

Three tests of clump origin

1 Age gradient
older clumps near the centre → VDI migration

2 Merger rate
can mergers alone explain the clumpy fraction?

3 Environment
does clumpiness rise with local density?

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Discussion & Result

1 Clumpy galaxies are common

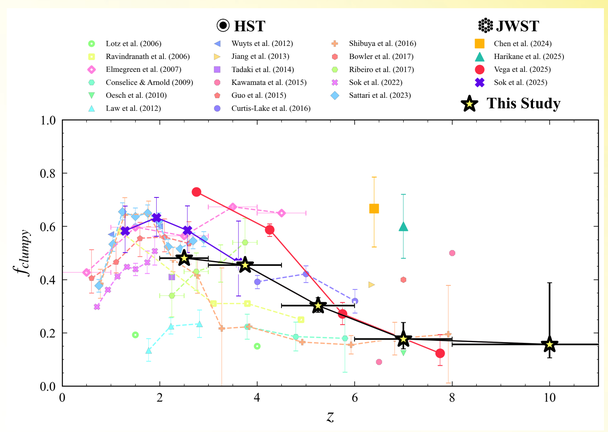
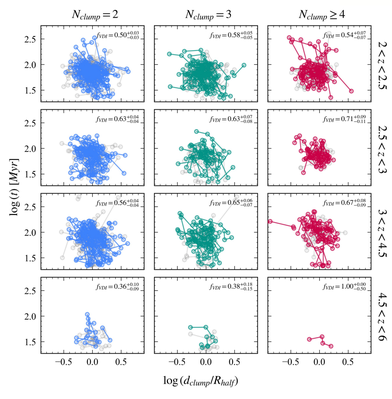


Figure 4. Clumpy fraction vs. redshift (stars) compared with HST and JWST studies.

Peaks at **~50% at z ≈ 2–3** (cosmic noon) and stays **~20% at z ≈ 7–9**. Clumps favour gas-rich, massive disks, not starbursts.

2 Clumps migrate inward



~50%

of clumpy galaxies have older clumps nearer the centre, out to z ~ 6

Strongest at 2.5 < z < 3; weaker in 2-clump systems (more mergers).

Figure 5. Clump age vs. distance from centre (colour = significant inward-ageing gradient).

3 Mergers suffice only at z > 4.5

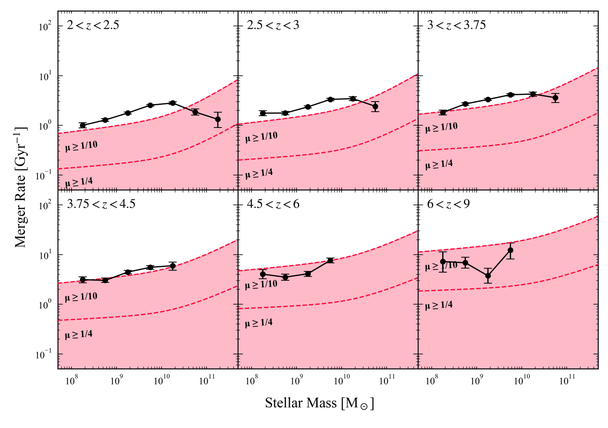


Figure 6. Merger rate needed if all clumpy galaxies were mergers (black) vs. Illustris (red band).

Below z = 4.5 mergers are not enough, so VDI must contribute. Environment matters only at 2.5 < z < 3.

Conclusion

f_{clumpy} ~20% **Merger-dominated** | f_{clumpy} ~50% **VDI-dominated**

z ≈ 9 ← earlier (cosmic dawn) | transition z ≈ 4.5 | later (cosmic noon) → z ≈ 2

- Clump formation shifts from mergers to disk instability at **z ≈ 4.5**.
- Migrating clumps may build the dense cores of massive quiescent galaxies.
- Next: NIRSpec IFU + ALMA kinematics to confirm clump origin.