Influence of Overdensity on the Burstiness of Star Formation in the Early Universe

Krittapas Chanchaiworawit[1*], Wissarut Jareonsupapon[1], Gunmethus Cherdchoochavalit[1,2], and Narenrit Thananusak[1,3]

[1]National Astronomical Research Institute of Thailand (Public Organization), 260 Moo 4, Don Kaew, Mae Rim, Chiang Mai, 50180 Thailand
[2]Department of Physics, Faculty of Science, Chiang Mai University, Chiang Mai, 50200 Thailand
[3]Thailand Academy of Sciences Program, Ministry of Higher Education, Science, Research and Innovation, Faculty of Graduate Studies, Mahidol University, 999 Phutthamonthon Sai 4 Road, Salaya, Nakhon Pathom 73170 Thailand
***Email: krittapas@narit.or.th**

Introduction

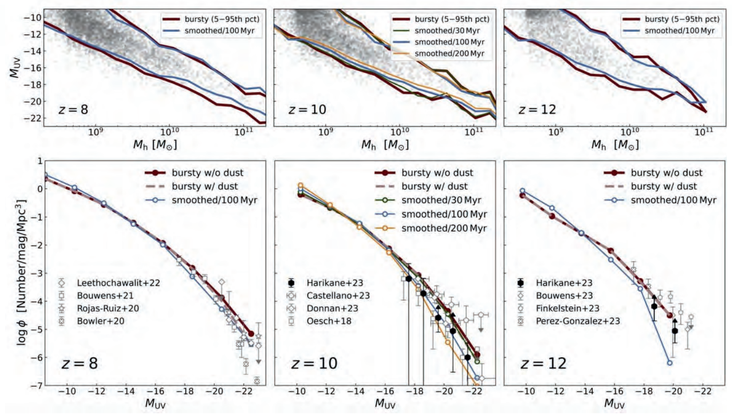


Figure 1: Excess at the bright ends of LFs of galaxies from HST and JWST survesys from redshift 8 to 12 (Sun et al. 2023).

- **Cosmic dawn and the UV-luminosity function problem:** Recent JWST observations have revealed a surprisingly large population of UV-bright galaxies in the first billion years after the Big Bang. These objects are shown as a surplus at the bright end of the ultraviolet luminosity function, challenging standard hierarchical galaxy–formation models. At the same time, active galactic nucleus (AGN) contamination is insufficient to explain this excess. It points to "**peaky/bursty star formation activity**" as a plausible explanation (e.g., Sun et al. 2023).
- **Burstiness of star formation:** Theoretical work shows that at high redshift, elevated gas fractions shorten dynamical timescales. Feedback from supernovae cannot establish equilibrium, leading to highly fluctuating star–formation histories; galaxies cycle between rapid bursts and temporary quiescent phases (Faucher–Giguère 2018). Observational diagnostics such as the ratio of Hα-derived SFR to UV-derived SFR and the scatter of the star-forming main sequence (SFMS) reveal increased variability in low-mass galaxies.
- **Role of environment:** Early galaxy overdensities and proto-clusters may accelerate growth by funneling gas along filaments and increasing interaction rates. Simulation studies (e.g., FOREVER22) predict similar SFMS slopes for field and proto-cluster galaxies. But the proto-cluster populations extend to higher masses and higher SFRs due to a greater fraction of massive galaxies (Morokuma–Matsui et al. 2025). The central question of our study is how environmental overdensity influences the burstiness and duty cycle of star formation.

Methods

1. **Data and sample selection:** We analysed galaxies at redshifts z≈5–10 using publicly available JWST surveys (e.g., JADES, CEERS, PRIMER, GLASS, and others), complemented by HST data. Overdense regions were identified by constructing surface-density maps in narrow redshift slices. Spectroscopic confirmations from JWST/NIRSpec or slitless grisms were used when available; otherwise, photo–z was used to verify membership. Field galaxies were drawn from outside the overdense regions of the same surveys.
2. **Spectral energy distribution (SED) fitting:** Multi-band photometry was fit with parametric star-formation histories using the CIGALE code (Bouquien et al. 2019) to derive stellar masses (M*) and 100-Myr-averaged star-formation rates (SFR_{100Myr}). Dust attenuation and metallicity were also constrained.
3. **Instantaneous SFR:** Emission-line fluxes of Balmer lines (Hβ or Hα) or [O III] obtained from JWST spectra were corrected for dust and converted to instantaneous SFR_{inst}.
4. **Burstiness parameter:** We defined a burstiness parameter $B=SFR_{inst}/SFR_{100\,Myr}$, B>1 indicate current bursts relative to the long-term average, whereas B<1 suggests post-burst quenching. The distribution of the B–parameter was compared for galaxies in overdense environments and in the field.
5. **Star-forming main sequence (SFMS):** The relation between SFR_{100Myr} and M* was derived separately for overdense and field galaxies to assess shifts in slope, normalization, and scatter.

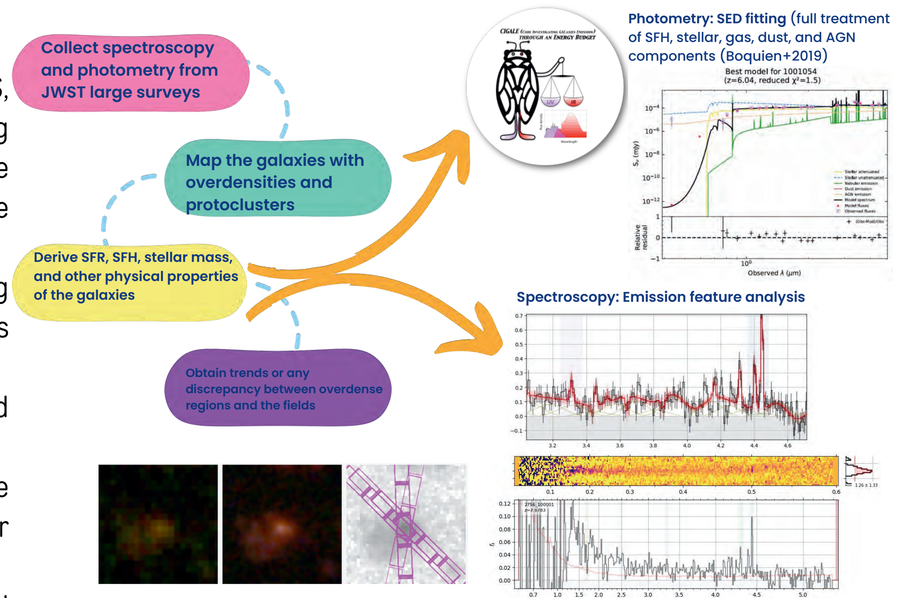


Figure 2: Flow chart diagram of the methods and analysis plan.



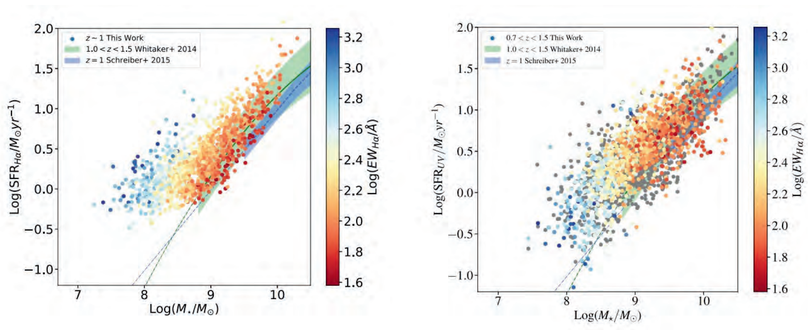


Figure 3: (Left) UNCOVER fields with available grism spectra and NIRSpec MSA spectra targeting galaxies at Z>7. (Right) Signs of rising/bursty SF activities from Z>1.4 using HST grism spectra (Atek et al. 2022)

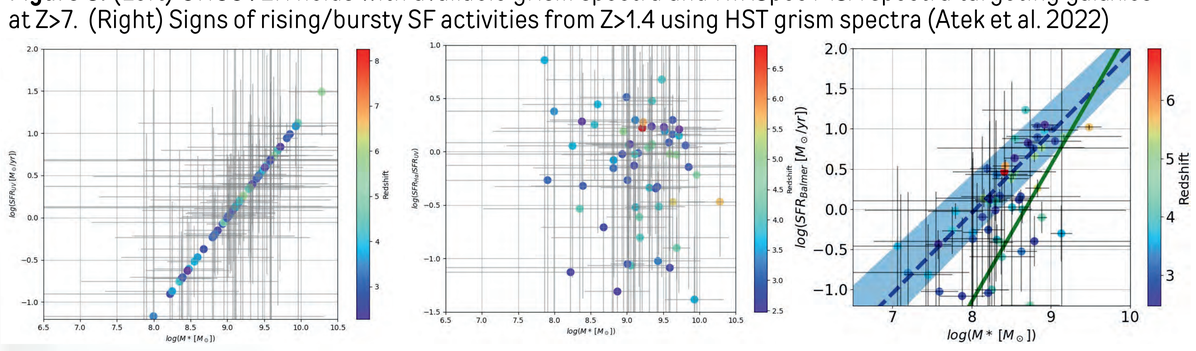


Figure 4: Results of emission lines analysis of galaxies at Z=3–8 in UNCOVER field, showing diverse SFR_{inst} and diverged SFMS at lower mass end.

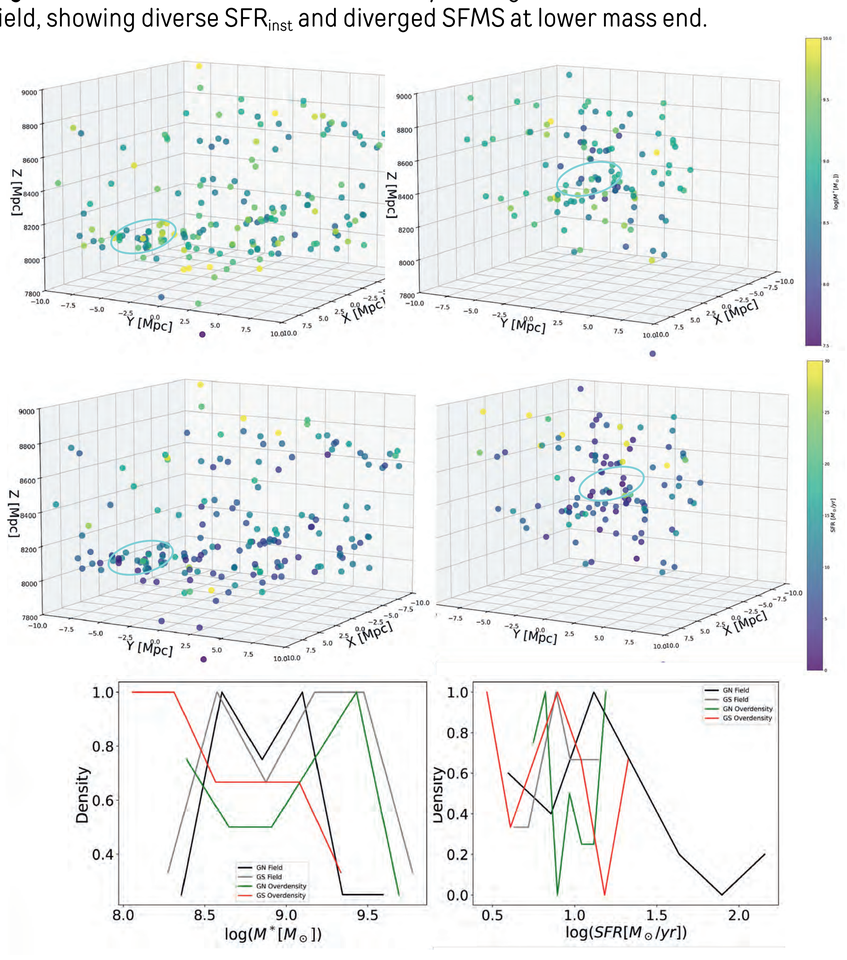


Figure 5: Stellar mass and SFR_{inst} of galaxies from JADES (GOODS-N and -S), respectively. The bottom pannel shows the rough histograms of M* and SFR_{inst} for each group (Overdensities and Fields) derived from SED–fitting.

Preliminary Results

1. **Burstiness distribution:** The sample shows a wide range of B–parameter. Some galaxies have B>5, meaning that their instantaneous SFRs are more than five times higher than their 100-Myr averages. Others have B~1–5, indicating rising SF activities. While around 40% of galaxies at z>6 have B<1. This diversity is consistent with the highly stochastic SFHs predicted by models of early galaxy evolution (e.g., Sun et al. 2023; Atek et al. 2022).
2. **Environmental dependence:** The fraction of galaxies with strong bursts (B>5) is slightly larger in overdensities than in the field. But the early results are not that clear–cut. Overdense galaxies also exhibit an elevated SFMS: at a given stellar mass, the average $SFR_{100\,Myr}$ is about 0.3–0.5 dex higher than that of field galaxies.
3. **Mass dependence of scatter:** The scatter in the SFMS increases towards lower masses, reflecting stronger burstiness in low-mass galaxies. This agrees with the finding from the JADES + AURORA sample that 41–60 % of galaxies have SFHs inconsistent with being constant and that burst timescales become shorter with increasing redshift (Clarke et al .2025).

Conclusion

- Star formation in the early Universe is inherently bursty. JWST observations across multiple surveys show that overdense regions host a higher fraction of intense star-bursting galaxies compared with the field, leading to elevated star-formation main sequences and rapid mass assembly.
- The influence of the environment is two–fold: proto-clusters and overdensities fuel bursts through enhanced accretion and interactions, but also promote rapid quenching via harassment, spin–up, and tidal stripping.
- Understanding the duty cycle and burstiness of early star formation is critical for interpreting the UV luminosity function, reconstructing galaxy growth, and constraining reionization models.

Future outlook:

- **Expanded spectroscopic surveys:** JWST Cycle-3 programs (e.g., SAPPHIRES) and future observations with Euclid and the Nancy Grace Roman Space Telescope will provide larger samples to map overdensity–burstiness relations at z>7.
- **Multi-wavelength follow-up:** ALMA, MIRI, and upcoming submillimetre facilities will trace dust and molecular gas to quantify the fuel reservoirs of bursts. Integral-field spectroscopy will allow spatially resolved studies of starburst-driven outflows and environmental interactions.
- **Advanced modelling:** Non-parametric and hierarchical SED-fitting frameworks with bursty priors will improve mass and SFR estimates.

References

- Atek et al. 2022, MNRAS, 511, 4464
- Boquien et al. 2019, A&A, 622, 103
- Clarke et al. 2025, arXiv:2510.06681v1
- Faucher–Giguère 2018, MNRAS, 473, 3717
- Morokuma–Matsui et al. 2025, arXiv:2504.06788v1
- Sun et al. 2023, ApJL 955 L35