The emergence of the Star Formation Main Sequence with redshift unfolded by JWST

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ABSTRACT

We investigate the correlation between stellar mass ($M_\star$) and star formation rate (SFR) across the stellar mass range $\log_{10}(M_\star/M_\odot) \approx 6-11$. We consider almost 50,000 star-forming galaxies at $z \approx 3-7$, leveraging data from COSMOS/SMUVS, JADES/GOODS-SOUTH, and MIDIS/XDF. This is the first study spanning such a wide stellar mass range without relying on gravitational lensing effects. We locate our galaxies on the SFR – $M_\star$ plane to assess how the location of galaxies in the star-formation main sequence (MS) and starburst (SB) region evolves with stellar mass and redshift. We find that the two star-forming modes tend to converge at $\log_{10}(M_\star/M_\odot) < 7$, with all galaxies found in the SB mode. By dissecting our galaxy sample in stellar mass and redshift, we show that the emergence of the star-formation MS is stellar-mass dependent: while in galaxies with $\log_{10}(M_\star/M_\odot) > 9$ the MS is already well in place at $z = 5-7$, for galaxies with $\log_{10}(M_\star/M_\odot) \approx 7-8$ it only becomes significant at $z < 4$. Overall, our results are in line with previous findings that the SB mode dominates amongst low stellar-mass galaxies. The earlier emergence of the MS for massive galaxies is consistent with galaxy downsizing.

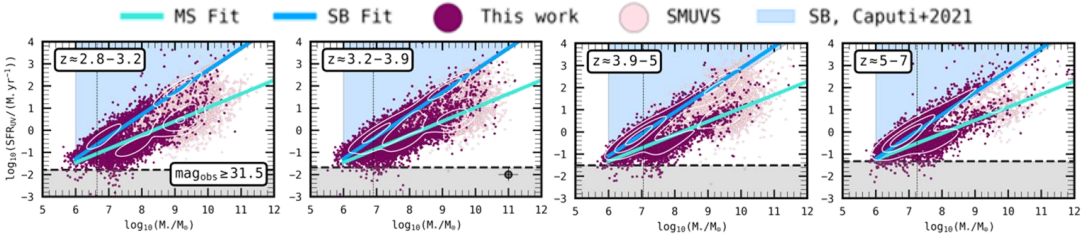


Figure 1. The SFR – $M_\star$ plane, showcasing all sources (JADES/GOODS-SOUTH + COSMOS/SMUVS) analyzed in this study, divided in redshift bins as indicated. The pale blue region marks the lower envelope for SB galaxies, based on the criteria from Caputi et al. (2017, 2021). Fits for the MS and SB are derived from Rinaldi et al. (2022). The gray shaded area represents the SFR threshold derived from the 2σ detection of the JADES images used in this work. The vertical dashed line in each panel refers to the stellar mass completeness (75%) of JADES sample at each redshift. The error bar showed in gray (upper right panel) indicate the median uncertainties on $M_\star$ and SFR. White contours are also presented to show the bimodality between MS and SB.

When did the star-forming MS sequence emerge ?

- The star-forming main sequence (MS; tight correlation on Ms-SFR plane) indicates that similar SF mechanisms exist for low- and high-Ms galaxies.
- Also, there are starburst (SB; log(sSFR) > -7.6 in this study) galaxies above MS.
- How the two SF modes (MS and SB) changes with Ms and z ?
- Investigate with very deep (JADES) and very wide (SMUVS) field multi-band data.
  - Ms obtained by (EAZY +) LePHARE SED fitting
    - First study to access down to Ms < 1e7 Msun without gravitational lensing.
  - SFR obtained from rest 1500A luminosity

↑ Fig.1: Ms vs SFR at z~3--7.

- A bimodality (MS and SB) exists for all redshifts.
- MS and SB converge at Ms < 1e7.

Looking into the Ms dependence

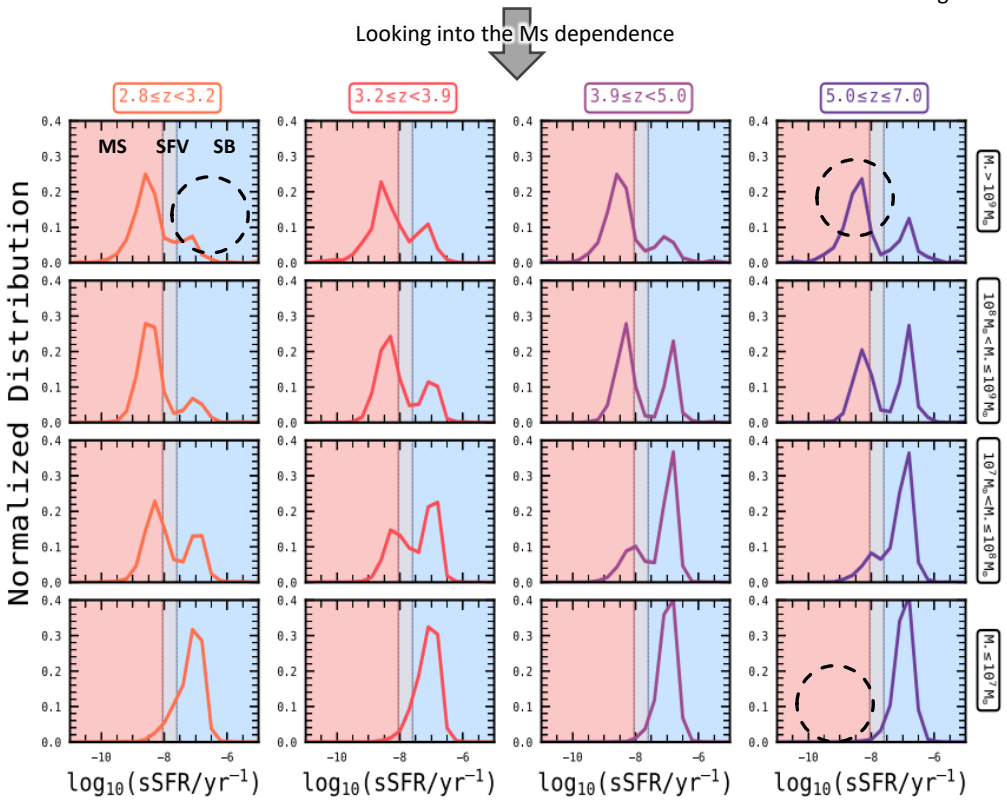


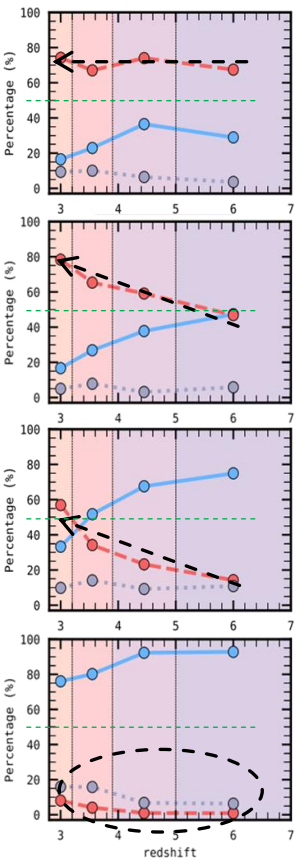
Figure 3. The sSFR distribution of the entire sample (JADES/GOODS-SOUTH + COSMOS/SMUVS) divided, this time, in four distinct stellar mass bins and four redshift bins. Each column refers to a specific redshift bin, while each row refers to a specific stellar mass bin. All 16 panels are color coded following Caputi et al. (2017): the star-formation MS for sSFR $> 10^{-8.05}$ yr^{-1}, the Starburst cloud for $10^{-7.60} < sSFR < 10^{-8.05}$ yr^{-1}, and the Star Formation Valley for $10^{-8.05}$ $yr^{-1} \leq sSFR \leq 10^{-7.60}$ yr^{-1}. Also in this case, as we did in Figure 2, to consider the different areas covered by JADES/GOODS-SOUTH (67.7 $arcmin^2$) and COSMOS/SMUVS (0.66 deg^2), we normalized the JADES/GOODS-SOUTH counts to match the COSMOS/SMUVS survey area, which is approximately 35 times larger than that of JADES/GOODS-SOUTH.

←Fig.3: Ms dependence on Ms vs SFR plane.

- MS (i.e., steady and secular SF) already established at z ~ 6 for Ms ~ 1e9 Msun.
  → Consistent with the downsizing scenario.
- SB is not popular for high-Ms especially at lower z (because significant events such as major mergers and violent disk instabilities are required to trigger intense SF, and those events may be rare at lower z.)
- No MS for low-Ms, but, SB is dominant. (because low-Ms galaxies could be easily bursty by such as minor mergers?)
  - Or it may just be that galaxies with SFR below the detection limit are being missed.

Redshift evolution

Fig.4: redshift evolution of the SF modes →



- MS becomes significant at lower-z and higher-Ms.
- For low-Ms, SB is popular at all redshift.

Figure 4. The evolution of the MS, SB, and SFV percentages with cosmic time in four stellar mass bins. Each panel has color bands corresponding to the four redshift bins analyzed in this study Also in this case, to consider the different areas covered by JADES/GOODS-SOUTH (67.7 $arcmin^2$) and COSMOS/SMUVS (0.66 deg^2), we normalized the JADES/GOODS-SOUTH counts to match the COSMOS/SMUVS survey area, which is approximately 35 times larger than that of JADES/GOODS-SOUTH.

- The emergence of MS is strongly dependent on Ms.
- The findings in this paper are consistent with the downsizing.