

Morphology and molecular gas scaling relations in quenched galaxies

Lapo Fanciullo^{1*}, Hsi-An Pan¹, Lihwai Lin², and the JINGLE team²

¹ Department of Physics, Tamkang University, New Taipei City, Taiwan
² Institute of Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan

*lfanciullo.astro@gmail.com



Summary

Star formation is a fundamental process driving galaxy evolution. One key step in understanding how galaxies grow and transform is to find out what processes may turn a regular **star-forming** (or **main sequence**) galaxy into a **quenched** galaxy where very little star formation takes place. A central question is whether quenching is driven by a lack of molecular gas (the star formation “fuel”), by a loss of efficiency in the gas-to-star transformation, or a mixture of the two.

In this work, we compile molecular gas measurements traced by CO emission from several major published and ongoing surveys, including JINGLE I & II, xCOLD GASS, EDGE-CALIFA, ALMaQUEST, MASCOT and VERTICO. We compensate for the heterogeneous methodology between surveys by adopting stellar masses and star-formation rates from a single catalog and by recalculating the molecular gas masses with a fixed CO flux-to-molecular mass conversion factor. This final dataset yields a sample of more than 1,000 galaxies with homogeneously-derived molecular gas measurements, covering the full range of star formation regimes. The sample is further enriched by ancillary data on morphological classifications.

Our analysis of the sample shows that (1) Both loss of fuel and loss of star-formation efficiency can take place, and quenching is most extreme when both are present; (2) The average galaxy morphology differs between main sequence and quenched galaxies, and the difference is greater when efficiency-driven quenching is present. We also find that results can be significantly affected by the method for estimating star formation rates and by the choice to include/exclude galaxies with CO upper limits. This invites caution when making cross-survey comparisons. Such a comprehensive, quantitative analysis has not been possible with previous studies limited to much smaller samples.

Data from surveys

We get molecular gas masses from the following CO surveys:

- JINGLE II [1] (CO[2-1])
- xCOLD GASS [2] (CO[1-0])
- ALMaQUEST [3] (CO[1-0])
- EDGE-CALIFA [4] (CO[2-1] and [1-0])
- MASCOT [?] (CO[1-0])
- VERTICO [??] (CO[2-1])

Since not all surveys use the same parameters to convert CO flux to H₂ mass, we recalibrate their results to be consistent with a flux-to-mass conversion factor $\alpha_{\text{CO}} = 4.35 M_{\odot} (\text{K km s}^{-1} \text{pc}^2)^{-1}$ and a [2-1]/[1-0] line luminosity ratio $r_{21} = 0.7$

We obtain the stellar mass (M^*) and star formation rate (SFR) for our dataset from the MPA/JHU catalog (SDSS DR7) [5]

We obtain morphological information (Sérsic index, i.e., central concentration) from the NASA-Sloan Atlas [6]

Overall, we have data for 783 galaxies with detected CO and 285 galaxies with 3σ upper limits.

Quantities of interest

Stellar Mass, M^*

Star formation rate, SFR

Molecular gas mass, M_{H_2}

Derived quantities:

Specific star formation rate, $s\text{SFR} = \text{SFR} / M^*$

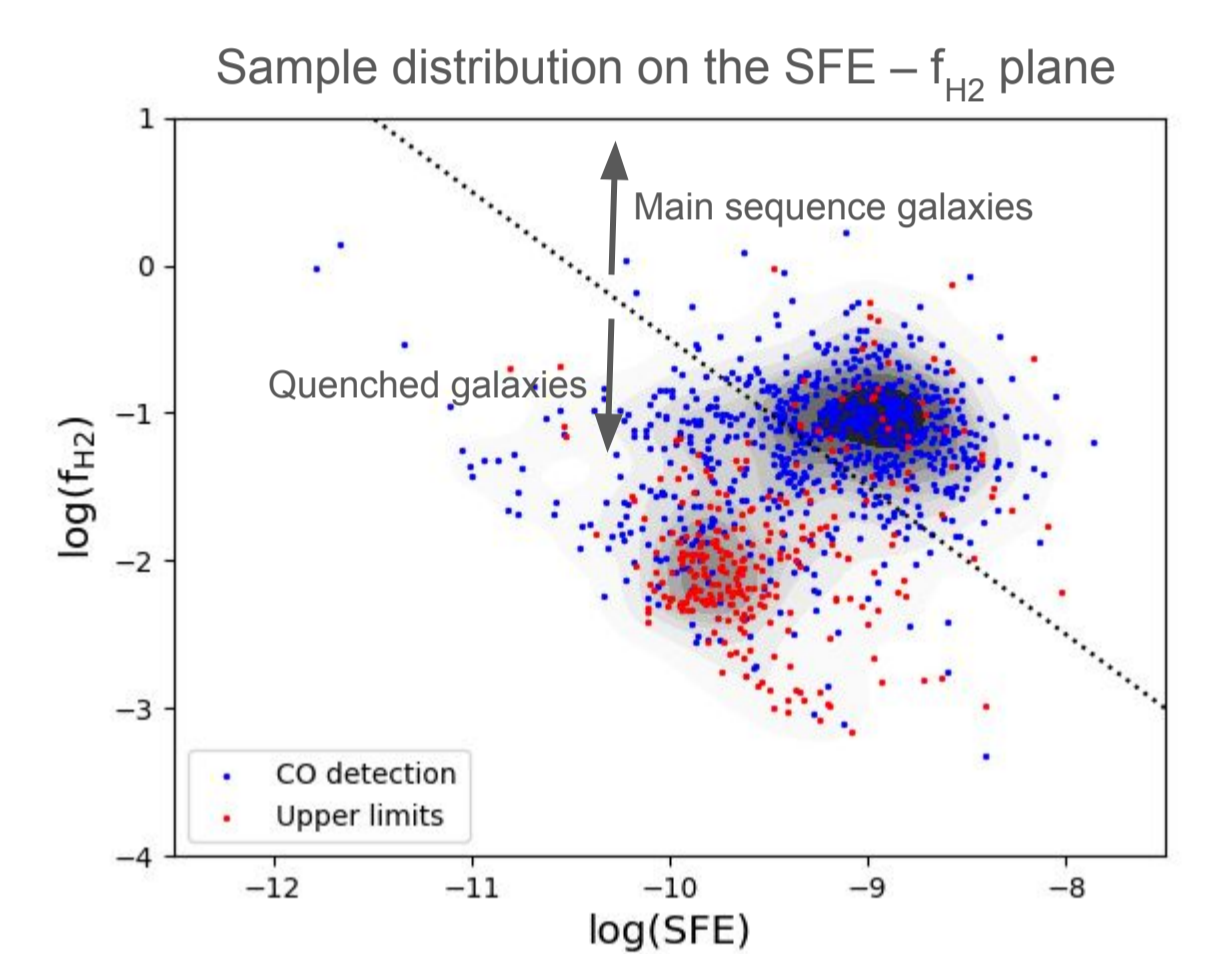
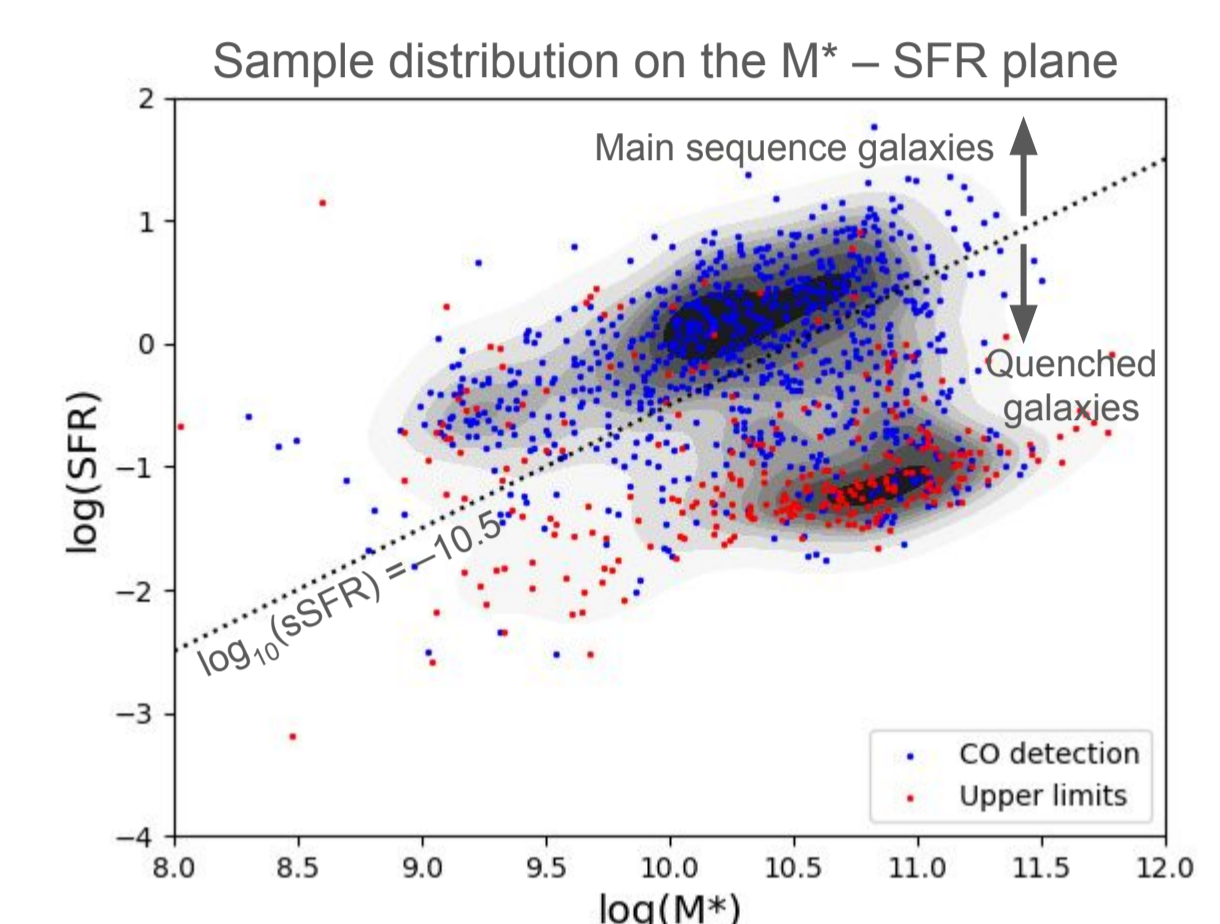
How actively a galaxy is forming stars relative to its mass.

Star formation efficiency, $\text{SFE} = \text{SFR} / M_{\text{H}_2}$

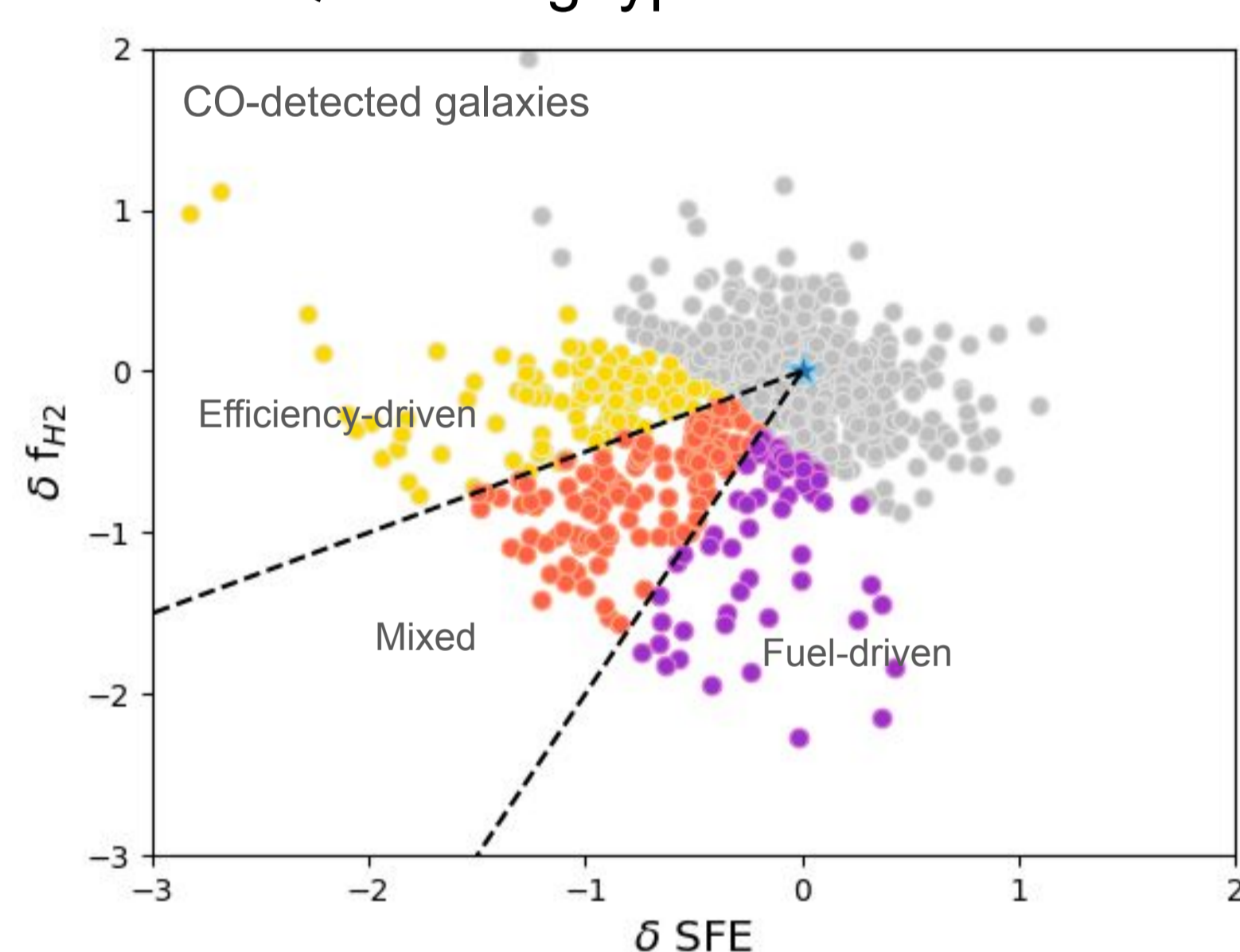
The star formation efficiency, how efficiently molecular gas is converted into stars.

Molecular gas fraction, $f_{\text{H}_2} = M_{\text{H}_2} / M^*$

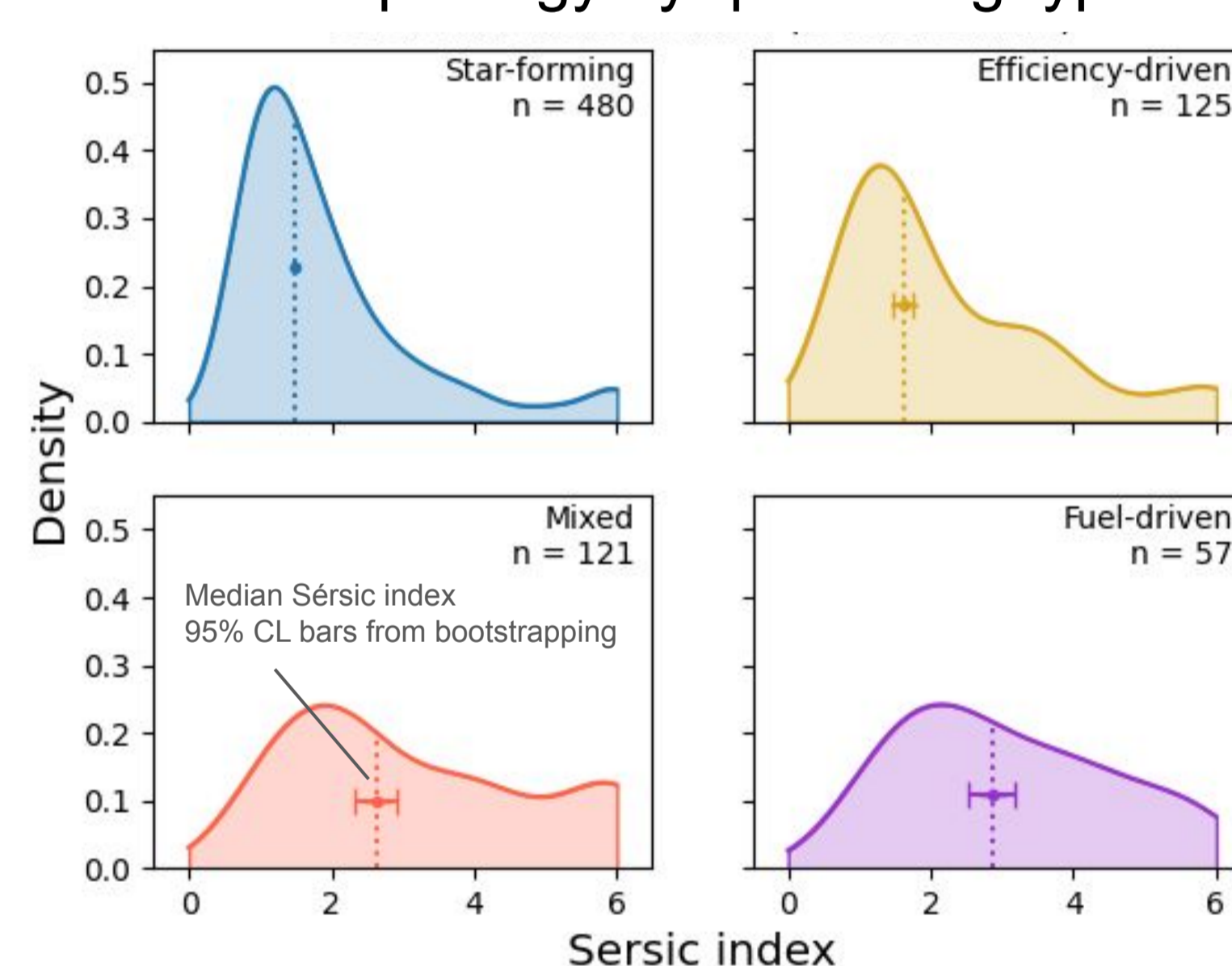
The abundance of molecular hydrogen in a galaxy relative to its mass, representing the “fuel” available for star formation



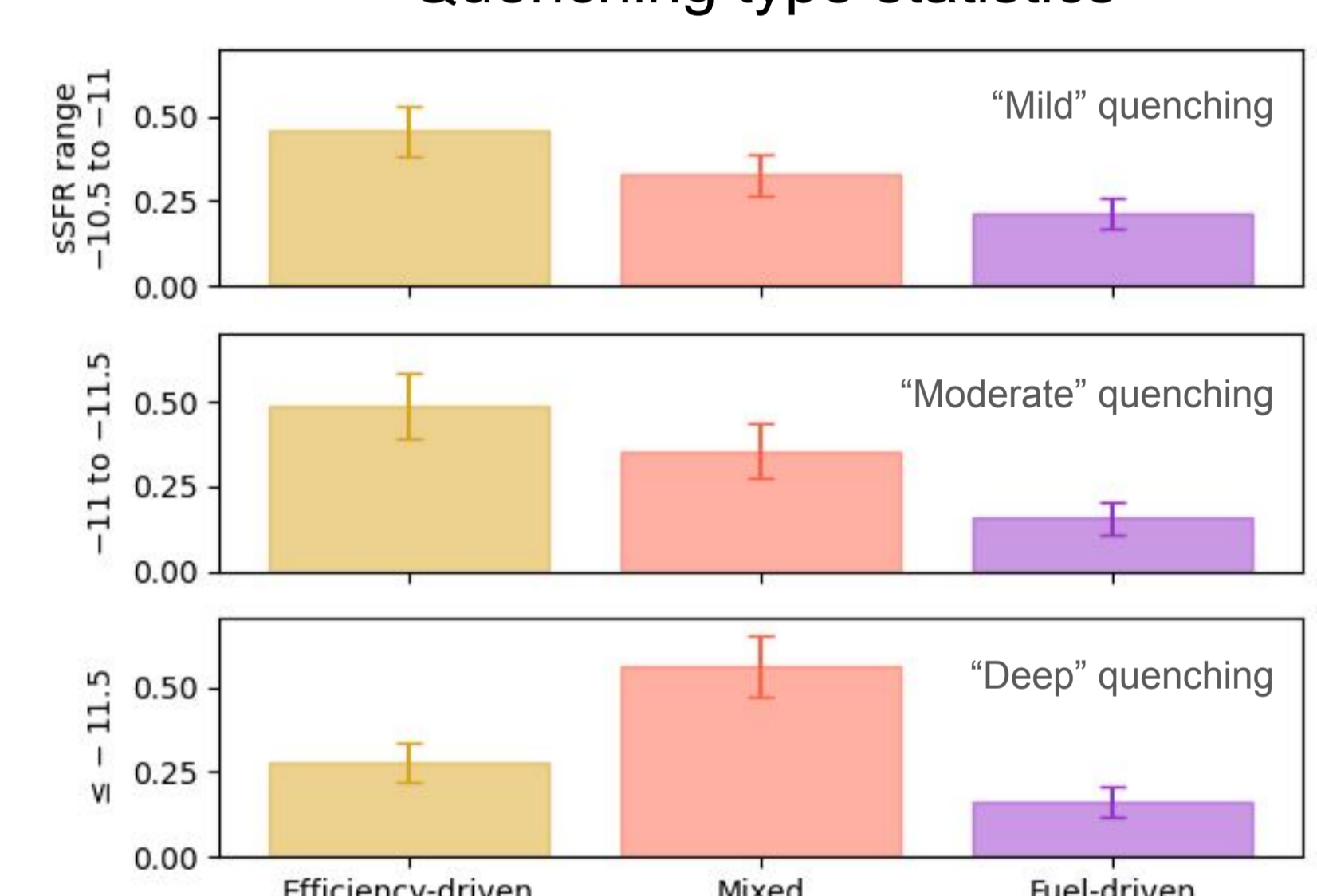
Quenching type classification



Morphology by quenching type



Quenching type statistics



We classify the quenched galaxies into three groups: we take the median f_{H_2} and SFE of the main sequence galaxies as a reference point and, for each quenched galaxy, we calculate the offset in $\log_{10}(f_{\text{H}_2})$ and $\log_{10}(\text{SFE})$ from the reference.

- If the offset in $\log_{10}(\text{SFE})$ is more than twice that in $\log_{10}(f_{\text{H}_2})$, the galaxy is classified as **efficiency-driven**;
- If the offset in $\log_{10}(f_{\text{H}_2})$ is more than twice that in $\log_{10}(\text{SFE})$, the galaxy is classified as **fuel-driven**;
- Otherwise, the galaxy is classified as **mixed**.

Since galaxies with CO upper limits alone may be misclassified using this scheme, **we focus on CO-detected galaxies.**

The morphology of galaxies differs between main sequence and quenched galaxies, and between different quenching types.

Main sequence are generally disklike, and their distribution has a strong peak at low Sérsic index. Quenched galaxies show a greater variety of forms, with a weaker peak and a fat tail at high Sérsic values (centrally concentrated, elliptical galaxies).

Compared to mixed and fuel-driven galaxies, however, the morphology distribution of efficiency-driven quenched galaxies is closer to that of the main sequence.

Is the relative abundance of quenching types a constant, or does it change with the amount of quenching?

We separated quenched galaxies into three bins based on sSFR: “mild”, “moderate” and “deep” quenching.

At mild and moderate quenching, efficiency-driven galaxies are the most common. However, the deep quenching bin is dominated by mixed galaxies.

Results and discussion

- The fact that quenched galaxies can be separated into different populations (fuel-driven, efficiency-driven and mixed) shows there are multiple possible paths to quenching.
- Morphology and quenching are not independent: quenched galaxies are more likely to be early-type (high Sérsic index).
 - The effect is more noticeable for mixed and fuel-driven quenching
 - The morphology distribution flattens with quenching in addition to shifting; i.e., a significant fraction of quenched galaxies retain a low Sérsic index.
- Galaxies with mild to moderate quenching tend to be efficiency-driven, while deeply quenched galaxies are more likely to be mixed. This may hold clues as to the evolution of quenching.

Limitations and future work

- The work is based on CO-detected galaxies. The exclusion of galaxies with only upper limits may affect the results. For instance, since upper limit galaxies tend to have higher Sérsic index, we may be underestimating the shift in morphology during quenching.
- Different surveys may significantly differ in galaxy parameter estimates, especially in the case of SFR. Comparisons with future surveys, or with previous results, need to account for the systematics thus induced.
- We plan to expand the analysis to other galactic properties, including AGN feedback and galactic environment.

Bibliography and references

[1] <https://www.eoobservatory.org/jcmt/science/large-programs/jingleii/>
 [2] Saintonge et al. 2017, ApJS, 233:22
 [3] Lin et al. 2020, ApJ, 903:145

[4] Colombo et al. 2025, A&A, 699:A366
 [5] <https://www.mpa.mpa-garching.mpg.de/SDSS/>
 [6] <https://nsatlas.org/>