Not just $PAH_{3.3}$: why galaxies turn red in the Near-Infrared

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1. Introduction

Dusty galaxies have been detected by observations in the MIR and FIR as well as at sub-millimeter wavelengths.

Their infrared luminosity mainly originates from intense dust-enshrouded bursts of star formation.

They can also host powerful active nuclei triggered by nuclear accretion onto their central black holes.

1. Introduction

One of the best fields studied so far with JWST is the one containing the galaxy cluster Abell 2744 (A2744) at z = 0.3 (R.A. = 00:14:20.952, decl. =-30:23:53.88).

- NIRCam observations in 8 bands (F090W, F115W, F150W, F200W, F277W, F356W, F410M, F444W) from 0.8 to 4.5 μm over 46.5 square arcmin
- including JWST/NIRISS slitless spectroscopy, JWST/NIRCAM slitless spectroscopy (GO-3516), JWST/NIRSpec multi-object spectroscopy, HST gris, and ground-based spectroscopy

1. Introduction

Vulcani et al. (2023) have characterized the NIR and MIR colors of cluster member galaxies in A2744 and galaxies in the coeval field ($0.15<z<0.55$).

a galaxy population with a surprisingly red F200W-F444W color – called red outliers – that does not clearly stand out in any other integrated galaxy property.

- emission from the 3.3 μm PAH feature due to dust enshrouded star formation
- hot dust emission from an obscured AGN; emission lines from ionized gas ...

The PAH3.3 feature is weak compared to the well studied PAH features observed at longer wavelengths.

prominent in IR luminous starburst galaxies and obscured AGN associated with star formation activities

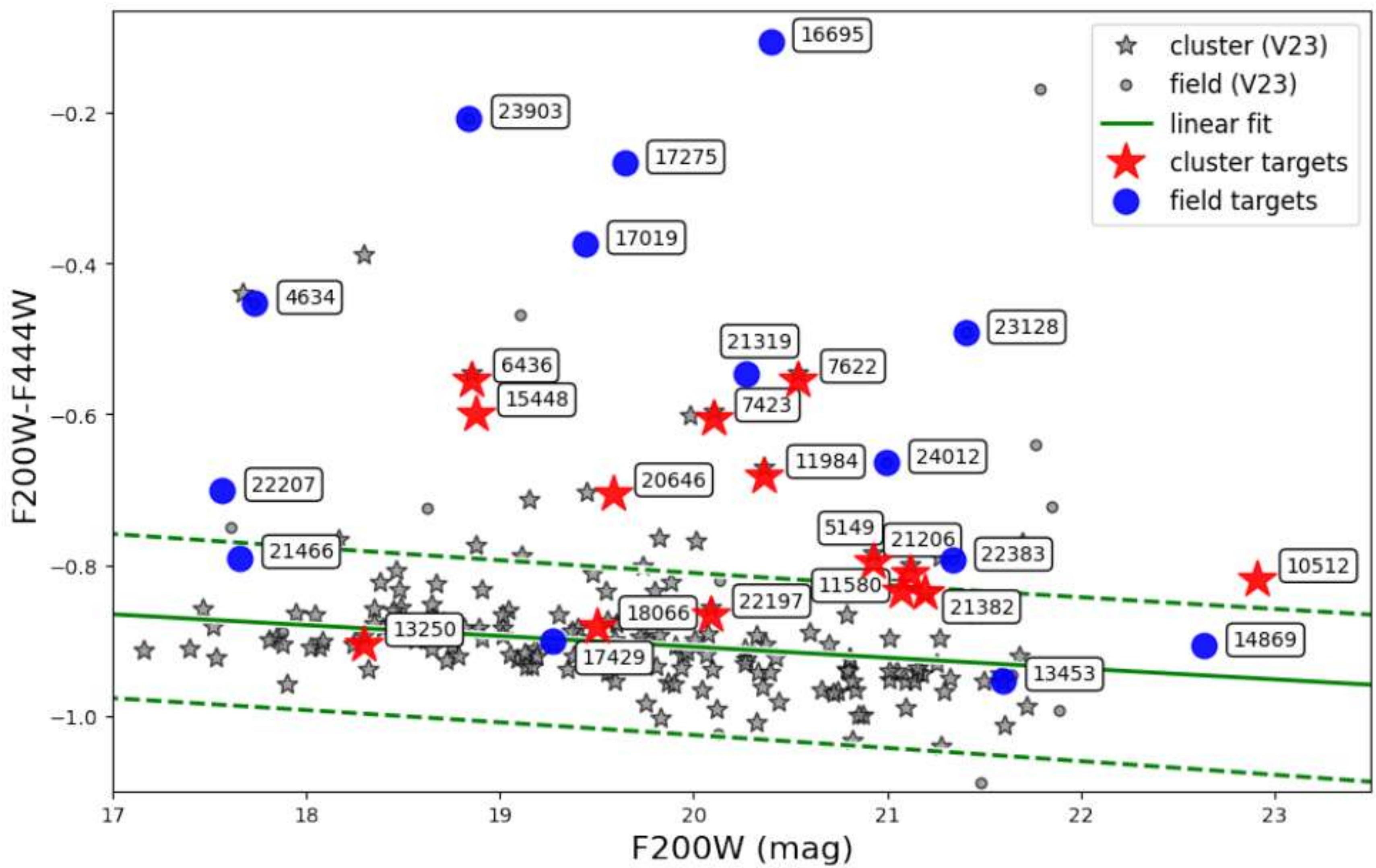
2. Observations

The sample of cluster and field galaxies (Vulcani et al. 2023)
The cluster sample includes 167 galaxies, field sample 19.

GLASS JWST program ERS-1324
UNCOVER program GO-2561
Directors Discretionary Time Program 2756
VLT/MUSE spectroscopy
The JWST NIRSpec Program GO-3073

their sample includes 28 galaxies, 20 of which are red outliers and 8 are galaxies with normal color

3. Photometric properties



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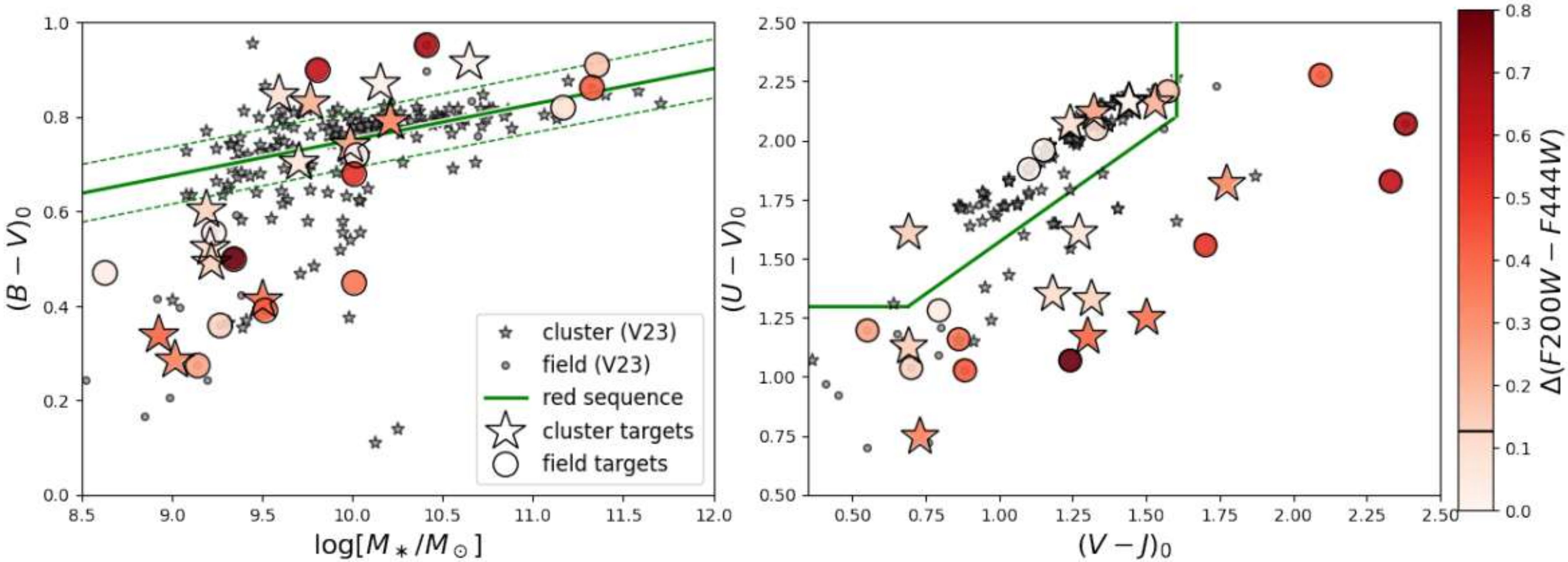
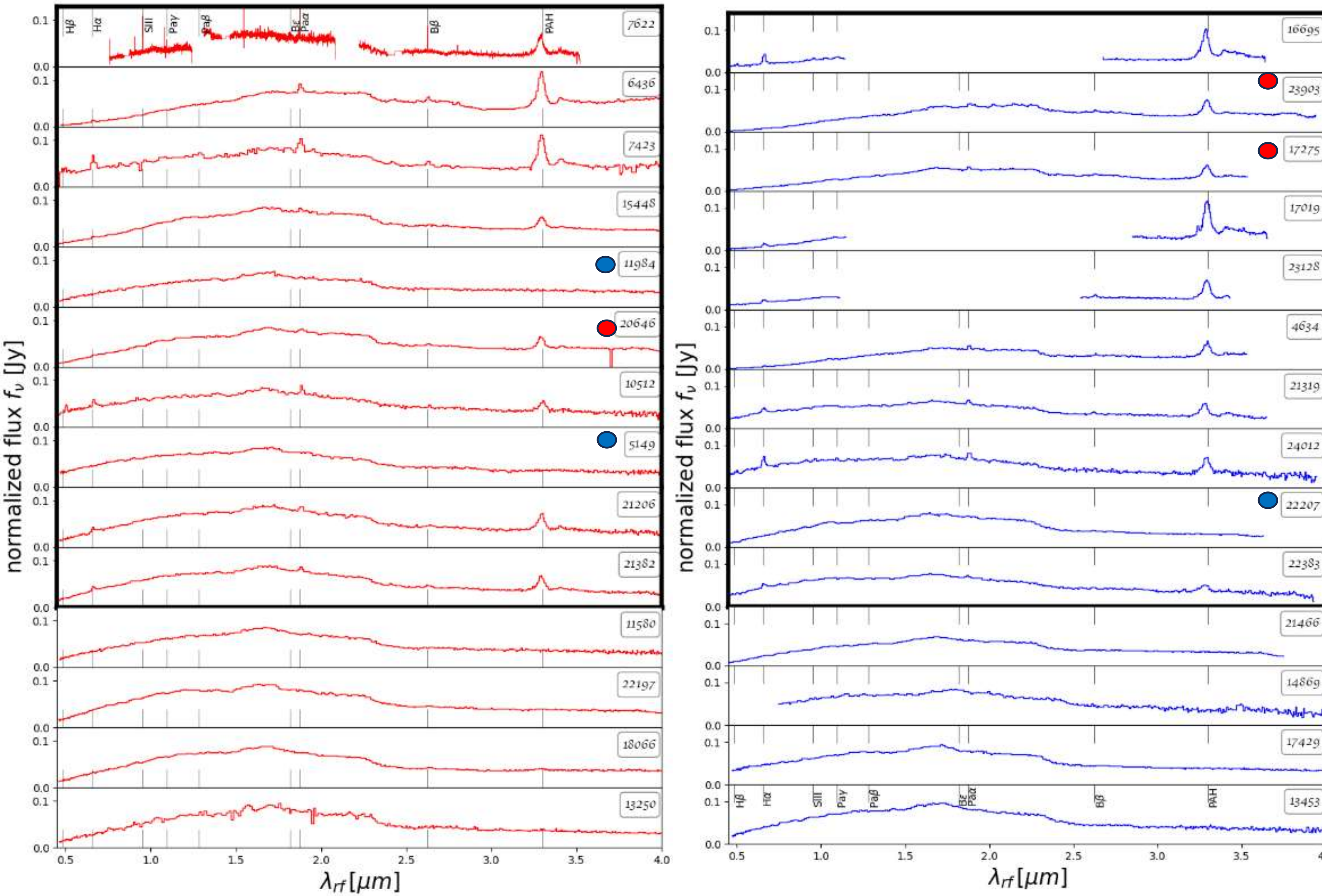


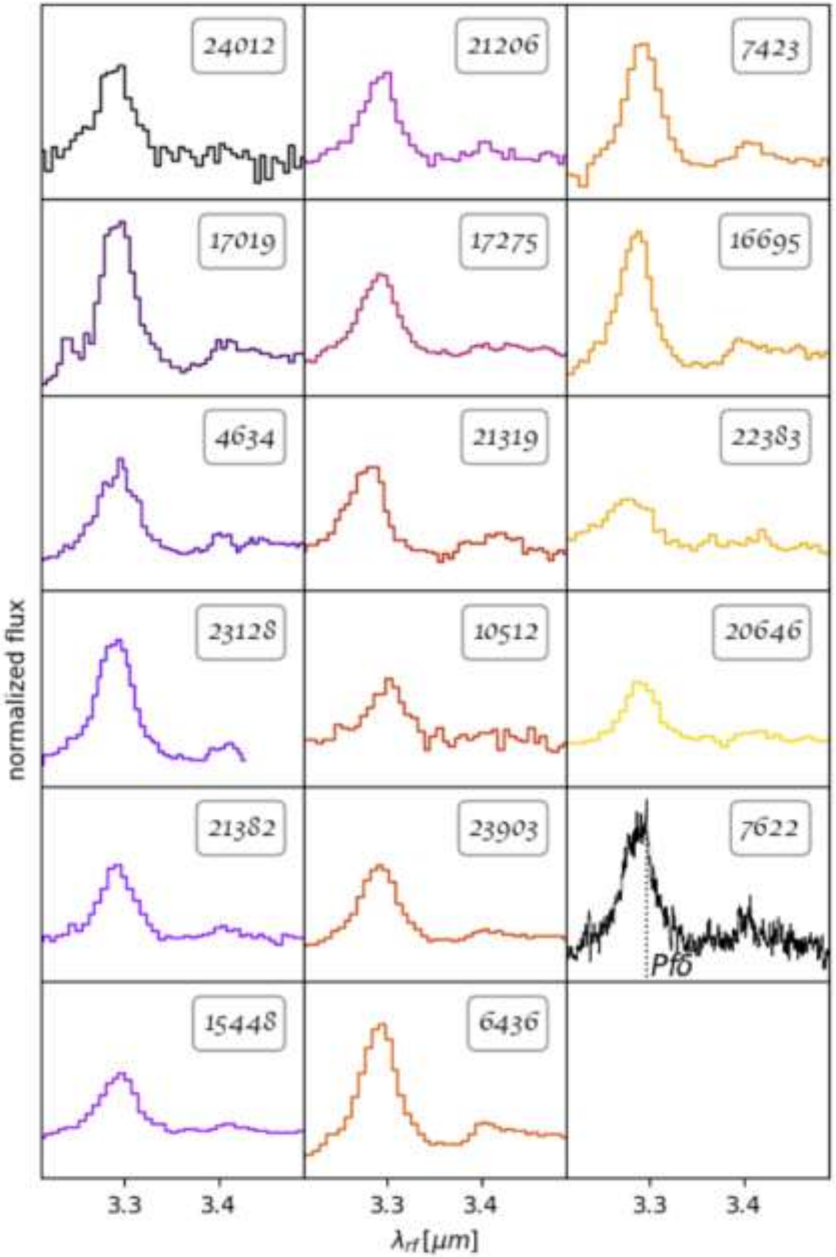
by Santini et al. (2023). Focusing on the color-mass diagram, three red outliers lie above the red sequence (17275, 23903 and 20646), defined by fitting the entire cluster relation adopting a 3σ clipping method, four are on the red sequence (22207, 4634, 15448, 11984) and the rest are in the blue cloud. 23903 is the only galaxy in the sample that has broad lines indicative of AGNs in the MUSE spectra (Vulcani et al. 2023). Considering the non red outliers, three are above (11580, 18066, 13250), three are on (22197, 17429, 21466) and two are below (14869, 13453) the red sequence. Considering the UVJ diagram, four red

three are on (22197, 17429, 21466) and two are below (14869, 13453) the red sequence. Considering the UVJ diagram, four red outliers (5149, 11984, 22207, 20646) and six normal galaxies (17429, 13453, 11580, 21466, 13250, 18066) are located in the passive region, while the rest are in the star forming/dusty region. While the two diagnostic tools, which have a different sensibility to the presence of dust, present a coherent view for the non red outliers, they depict a different picture for the red outliers, highlighting the peculiarity of the population.

4.1 Spectral feature



4.1 Spectral feature



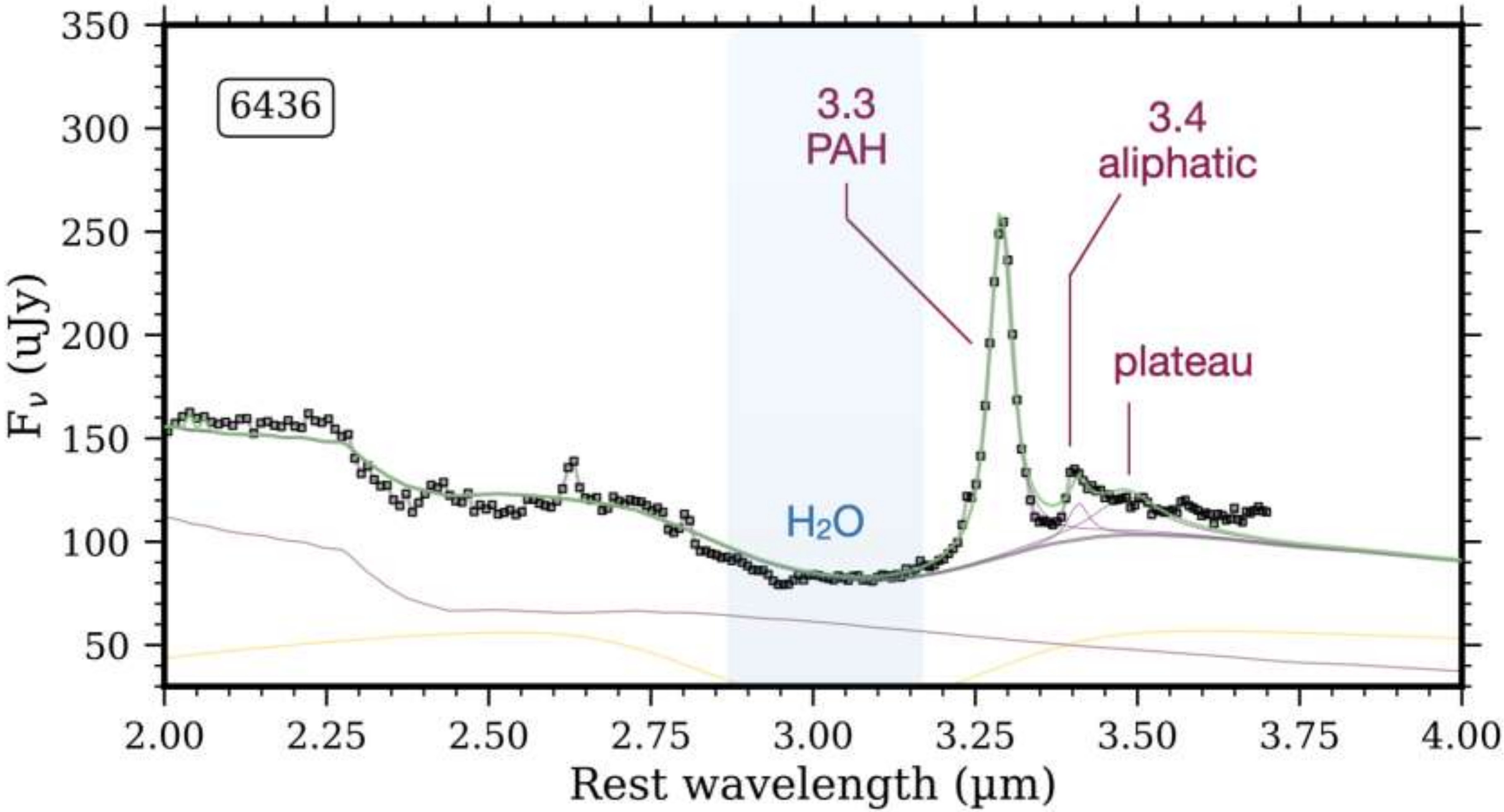
Two features are worth stressing: first of all, the galaxy with the broadest and shallowest feature is 23903, the one most likely hosting an AGN, even though no X-ray detection is associated to this source in the archival data. This is in agreement with pre-

Secondly, the only high resolution spectrum we have at our disposal shows evidence for the Pfδ emission, on top of the $PAH_{3.3}$ emission. In the same spectrum, sub-peaks can be also be detected in the 3.4μm band, and these are consistent with the existence of different C-H stretch emitting particles (Geballe et al.

the 3.3 μm aromatic feature changes from galaxy to galaxy. The variation of the 3.4 μm/3.3 μm ratio is indicative of the processing of dust particles in the ISM. The band intensity ratio

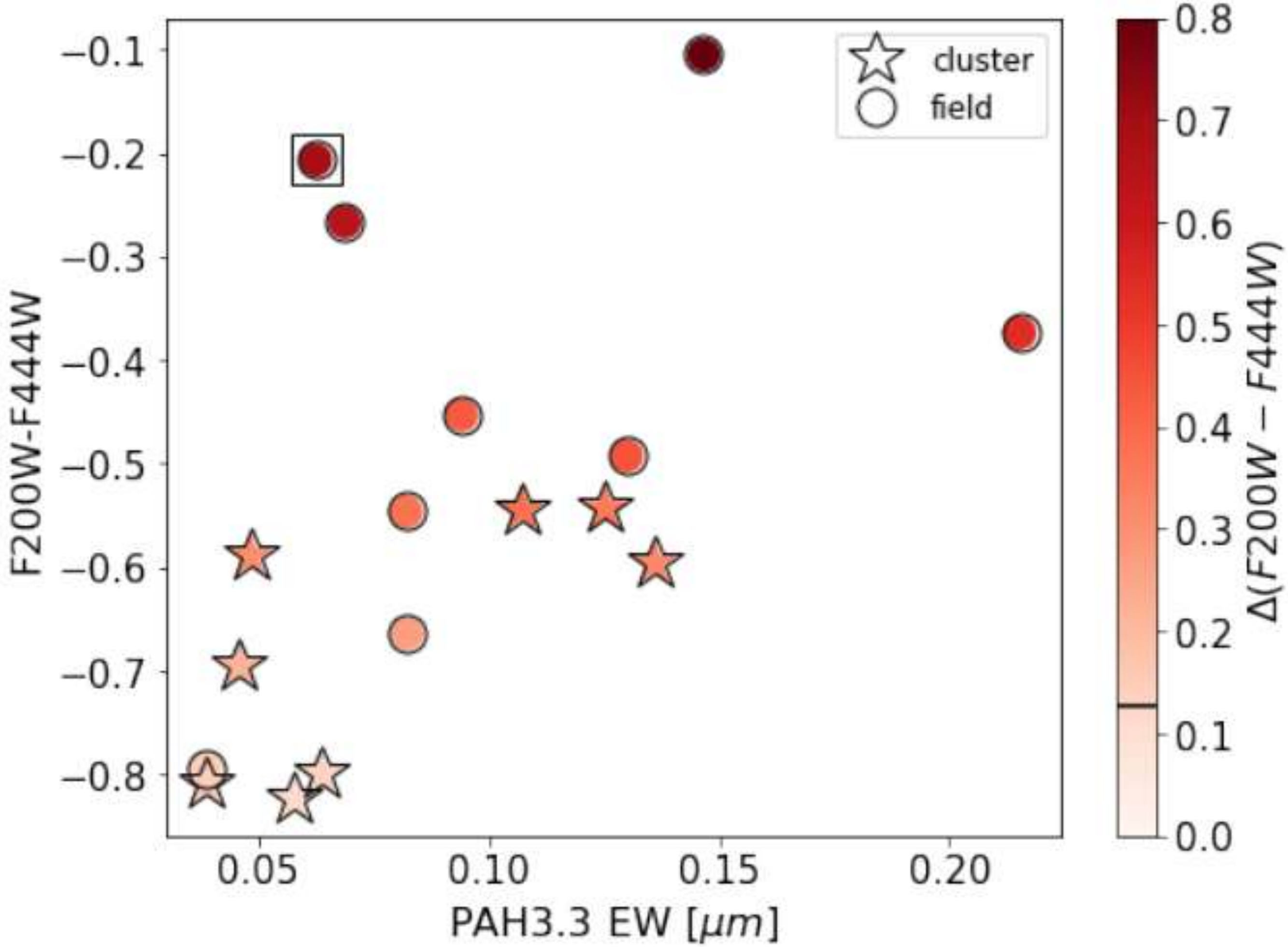
4.2 Emission line measurements

22 out 28 galaxies have a previously measured spectroscopic redshift from the literature.



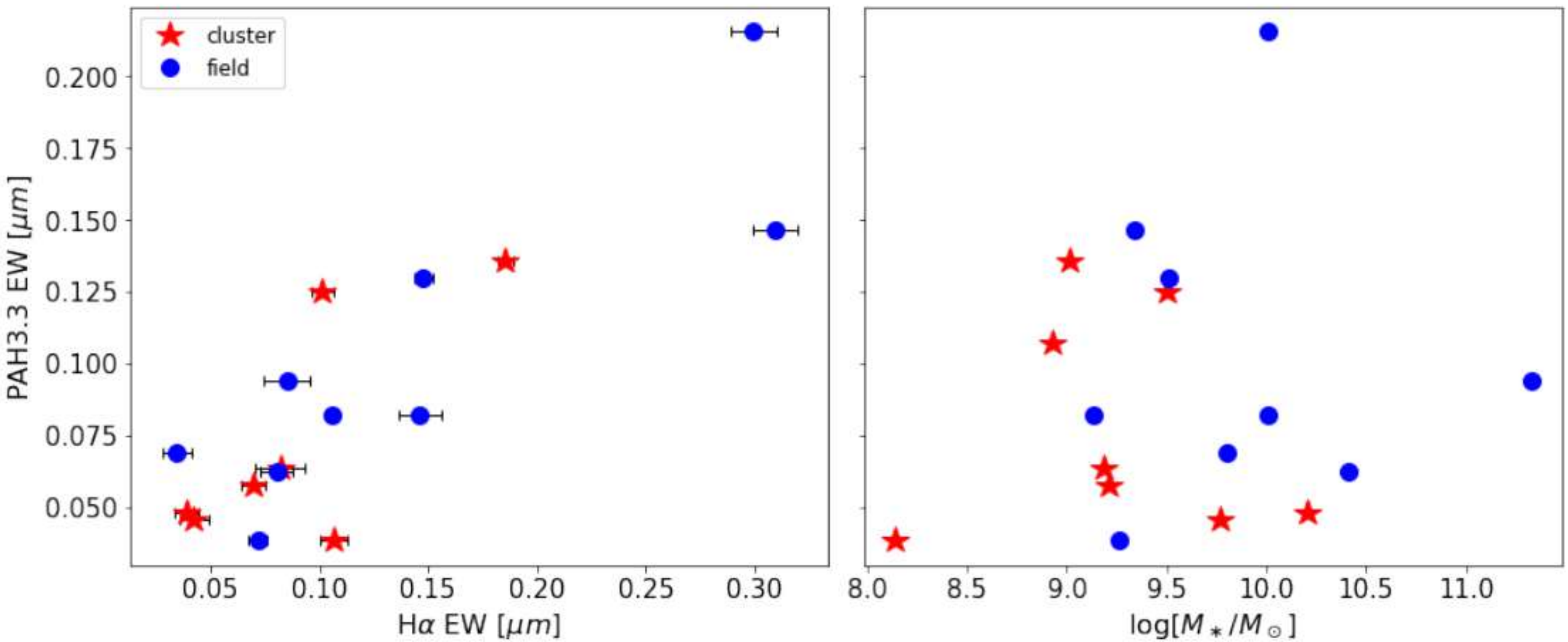
4.2 Emission line measurements

Figure 7 correlates the rest frame equivalent width (EW) of the PAH3.3 with the galaxy F200W-F444W color. A correlation .is seen, with redder galaxies having the tendency of also having higher EW values.



4.2 Emission line measurements

We further compare the PAH3.3 EW with the Hα EW (for the .galaxies for which this measurement is available) and with the galaxy stellar mass in Fig.8.

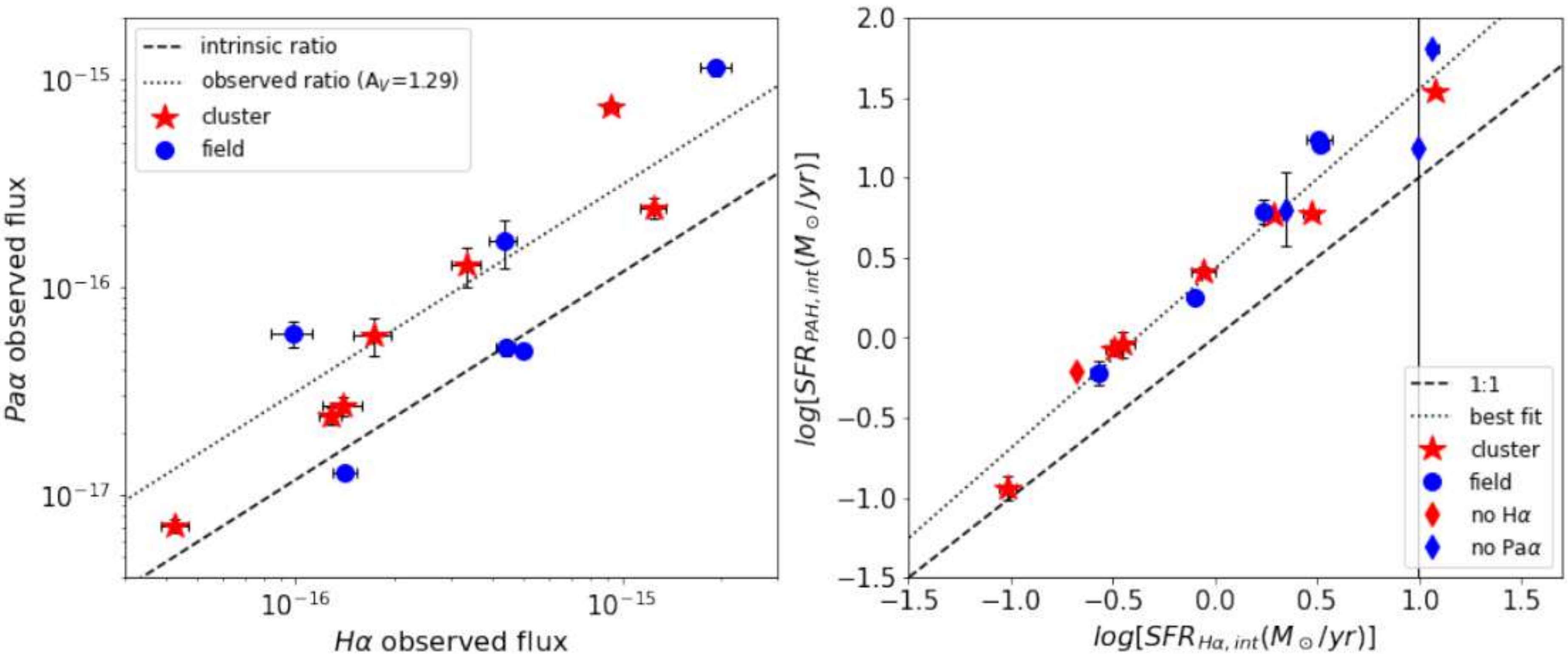


4.3 SFR from PAH

we measure SFRs from both the Hα and PAH3.3 fluxes and compare their values in Fig.9.

The left panel of Fig.9 shows the comparison between the observed Hα and Paα

The right panel of Figure 9 shows a tight correlation between the SFRs obtained from Hα and those obtained from the PAH3.3.



5. Discussion

5.1 Explaining the red excess

Overall, we have identified three populations of red outliers:

i) 14 emission line galaxies with also a clear PAH3.3 .in emission, which are mostly located below the optical red sequence;

ii) three galaxies with PAH3.3 in emission, but rather .weak emission lines (S/N of the Hα line between 5 and 10), mostly located above the optical red sequence;

iii) three passive galaxies.

All the non red outliers, regardless of their position on the rest frame (B-V)-stellar mass plane, are passive with no PAH3.3 in emission.

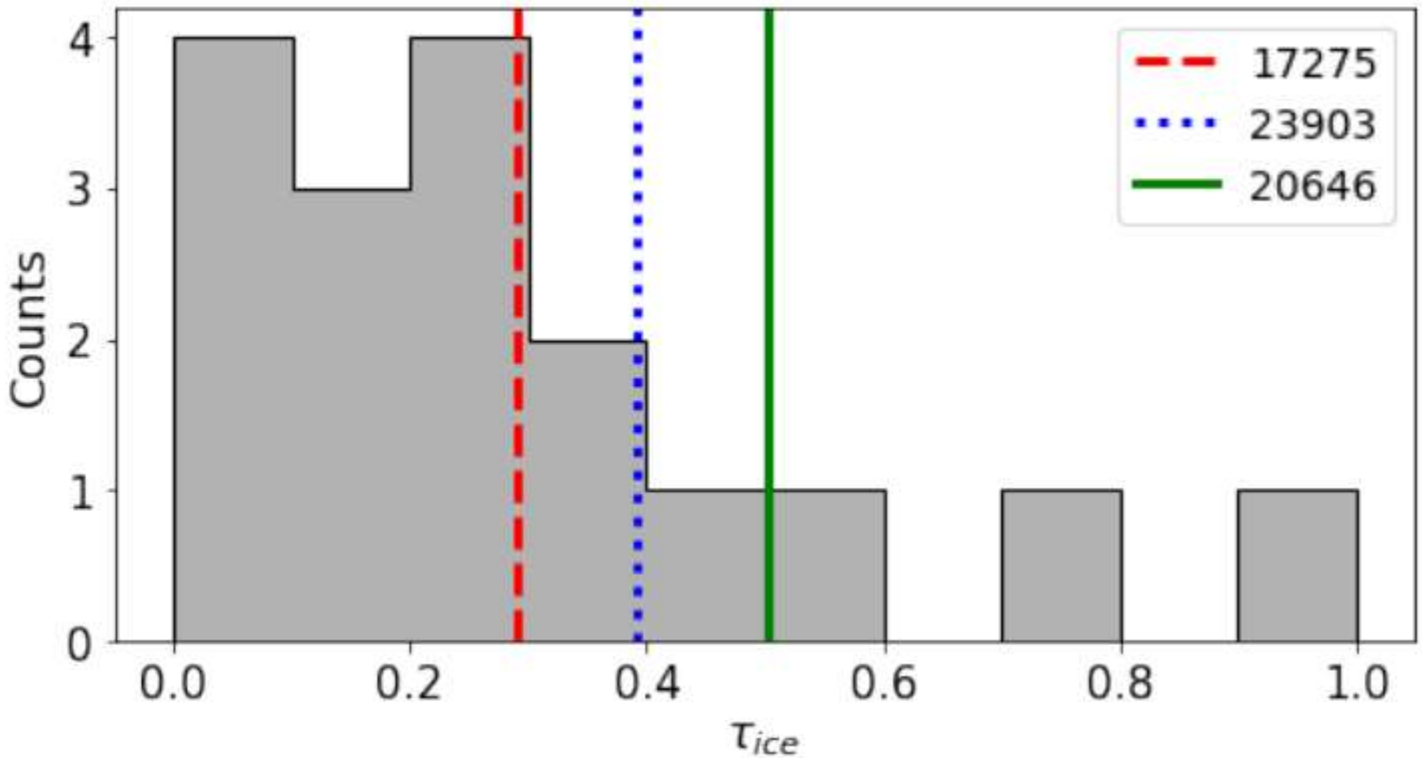
5.1 Explaining the red excess

In galaxies of the first group, the $PAH_{3.3}$ EW is of the order of 0.04-0.25 μm, its strength increases with increasing color excess, the dust extinction is moderate (average E(B-V) = 0.32) and SFRs range from 0.1 to 10 $M_{\odot}/yr$. The SFR from $PAH_{3.3}$ is about a factor of three higher than that inferred from Hα. This group

We investigate if the measured values of the $PAH_{3.3}$ EW are sufficient to justify by themselves the observed color excess. We

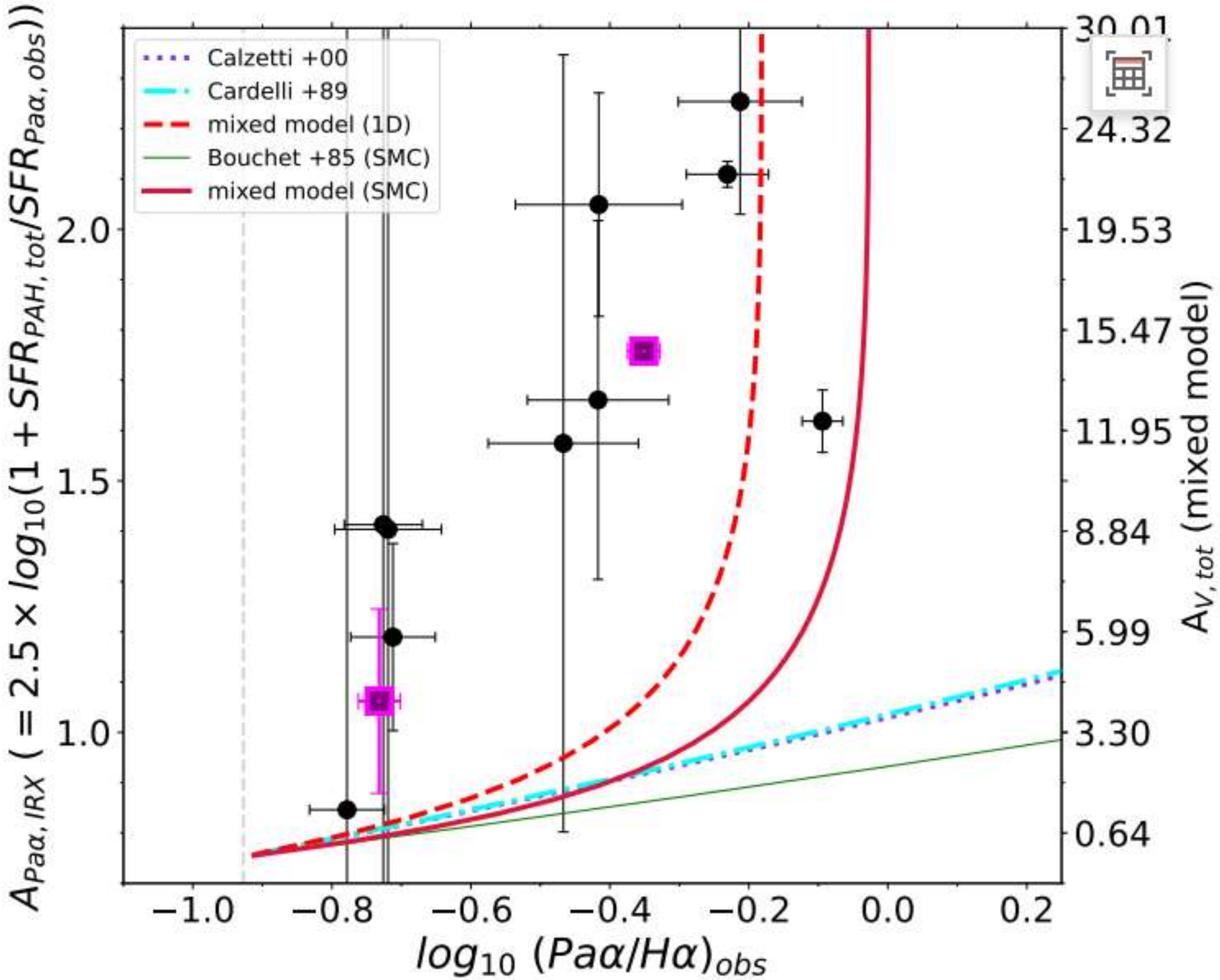
1.024 μm, the contribution of the line to the total F444W flux is 12.7%, which translates into a variation in galaxy color of 0.13 mag. This simple calculation indicates that while the PAH line is certainly non negligible, its presence alone can not explain the color excess, which can be as high as 0.6 mag. A contribution from the dust component is hence needed to explain the colors.

5.1 Explaining the red excess



Risaliti et al. 2003, 2006; Imanishi et al. 2006). According to the CAFE fit, Fig.10 shows that these three weak emission line galaxies have rather strong ice absorption, even though are not the strongest. We can therefore not firmly establish the presence of AGN. It is interesting to mention that the galaxy wit

5.2 The discrepancy between Hα and PAH



6. Summary

Vulcani et al. (2023) have unveiled the existence of a population of galaxies with surprisingly red F200W-F444W color that does not stands out in any other integrated property. This pop-

new spectroscopic observations taken with JWST/NIRSpec. The main results can be summarized as follows:

– Red outliers – defined as galaxies whose F200W-F444W color is redder than 3× the width of the red sequence of the entire population – can be subdivided in three groups: i) emission line galaxies with also a clear $\mathrm{PAH}_{3.3}$ in emission, which are mostly located below (i.e. bluer than) the optical red sequence; ii) galaxies with $\mathrm{PAH}_{3.3}$ in emission, but rather weak emission lines (S/N of the Hα line between 5 and 10), mostly located above (i.e. redder than) the optical red sequence; iii) passive galaxies. The first group is the most common.

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new spectroscopic observations taken with JWST/NIRSpec. The main results can be summarized as follows:

- In the emission line galaxies, the F200W-F444W color excess correlates with the EW of the $PAH_{3.3}$: the higher the excess, the higher the strength of the EW. Nonetheless, the presence of the PAH alone can not fully explain the color excess, as an EW of $\sim 0.1\mu m$ is expected to increase the color by only 0.13 mag.
- The weak emission line galaxies are also outliers in the F200W-F444W vs EW($PAH_{3.3}$) plane and are located above the red sequence. Spectral fitting identify a strong ice absorption features. This pieces of evidence point to the presence of an AGN.
- The passive galaxies have no $PAH_{3.3}$. Their red color is due to ageing of the stellar population.
- The non red outlier galaxies in our sample are all passive and have no $PAH_{3.3}$ in emission, confirming that the $PAH_{3.3}$ feature is linked to star formation activity.

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- Even within our small sample, a variety of $PAH_{3.3}$ profiles emerges, suggesting a variety of emitting molecules with a range of sizes. Also the relative importance of the 3.4 and 3.45 μm features and the 3.3 μm aromatic feature changes from galaxy to galaxy, indicative of a different chemical composition of the dust particles.
- In the star forming galaxies, both the intrinsic $PAH_{3.3}$ EW and flux correlate with the intrinsic Hα EW and flux, suggesting that they are produced by the same mechanism. Nonetheless, the dust corrected SFR from $PAH_{3.3}$ is a factor of 3 higher than the SFR obtained from Hα, suggesting red outliers are characterized by a significant amount of dust, that is not captured by the ratio of hydrogen lines.
- Overall, no clear differences are detected between cluster and field galaxies, in terms of occurrence and properties of the $PAH_{3.3}$ emission lines and of the galaxies. This result,