ZFOURGE SEDs Which Failed to be Modeled by CIGALE

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1 Introduction

This report investigates 555 galaxies from the ZFOURGE Chandra Deep Field South (CDFS) field which failed to be processed by CIGALE [1] during Ollie's initial work. I begin with my data reduction and CIGALE preparation methods. I present statistics which compare these failed galaxies to the entire CDFS population. I then propose potential reasons why CIGALE was unable to process these galaxies, and make adjustments to allow them to pass CIGALE. I am not qualified enough to determine if an individual galaxy's SED as determined by CIGALE is a valid result, but I can provide some example SEDs of failed galaxies that have been adjusted to successfully run through CIGALE.

2 Methods

2.1 Data preperation and reduction

The FourStar Galaxy Evolution Survey (ZFOURGE) [4] data was obtained from VizieR, specifically the zf_cdfs and cdfsz catalogues. Data processing was done with Python in Jupyter notebooks. First, I selected a list of 555 galaxies in the CDFS field which originally failed to be processed by CIGALE. Columns were removed or rearranged using Astropy data tables to match the format required by CIGALE. Additionally, the names of column headers were matched to filter names in the calibration folder of the VizieR data. The filter data for CIGALE which Ollie used was provided by Michael Cowley.

2.2 CIGALE parameters

It is important to consider that the original 555 failed galaxies were found on CIGALE version 2020.0 by Ollie. The version of CIGALE that I used is version 2022.1. When running these 555 galaxies through CIGALE, only 34 galaxies still failed to be modeled. I believe the most likely reason for this is the difference in version of CIGALE.

The parameters used for CIGALE in pcigale.ini were similar to the parameters originally used by Ollie, except for number of compute cores, number of blocks, and the removal of all luminosity and color filters in the restframe_parameters section, of which I did not have.

I did not alter the available options for SED modelling modules such as main stellar population age or e-folding time. Increasing the range of these parameters should result in fewer galaxies failing at the cost of longer computing time. I do not understand how tweaking the parameter space may affect the quality of the resulting SED models, nor did I have the computational resources, so I did not change it.

2.3 Failed galaxy statistics

Tool for OPerations on CAtalogues and Tables (TOPCAT) was used to visualize the properties of the failed galaxies by comparing

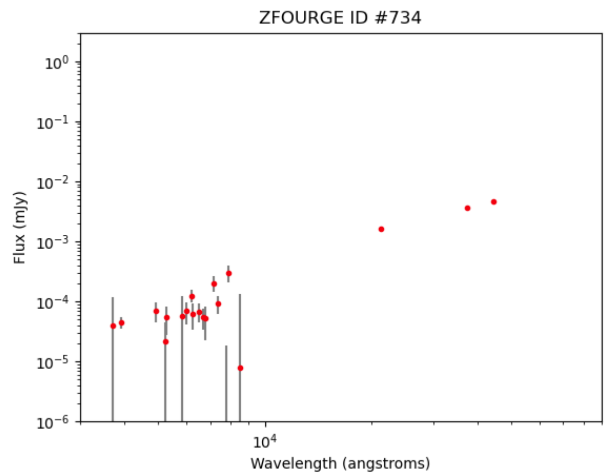


Figure 1: The photometric data of galaxy number 734. Note that wavelength values were estimations of a central wavelength with a peak transmissivity from the filter data.

to the entire CDFS set and by looking for unusual patterns. In addition to the ZFOURGE CDFS set, other overlapping surveys such as JADES were used to look for any large differences in redshift.

SEDs that could not be modeled by CIGALE were visualized by plotting the photometric data as flux against wavelength in Python with Matplotlib. An example of this can be seen in figure 1. Many galaxies had negative fluxes in certain filters which are not represented on this plot.

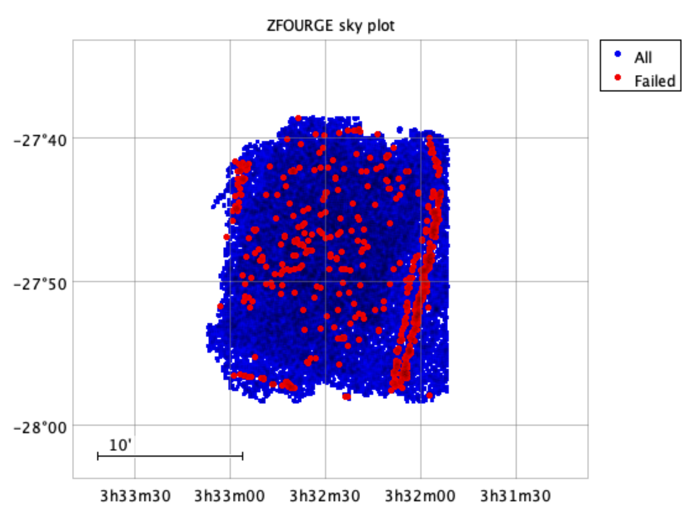
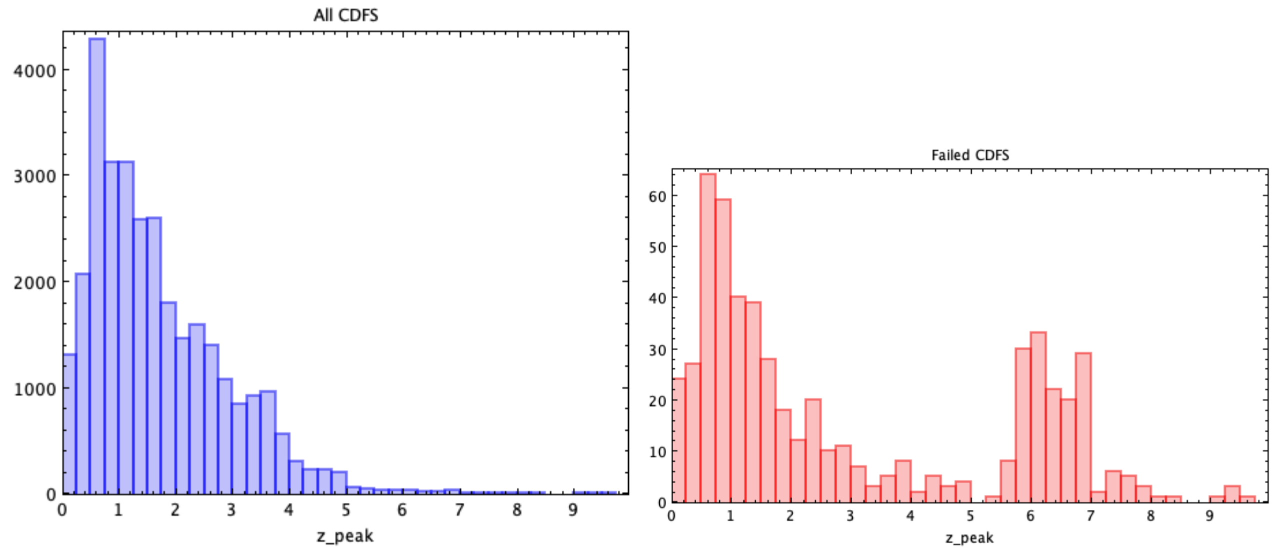


Figure 2: A sky plot of the ZFOURGE CDFS field, with failed galaxies in red.



(a) Photometric redshift distribution of all CDFS galaxies. **(b)** Photometric redshift distribution of failed CDFS galaxies.

Figure 3: Histograms of photometric redshift within (a) the entire CDFS set and (b) only the failed set.

3 Results

Figure 2 displays an interesting pattern in the location of failed galaxies: a distinct stripe of failed galaxies on the right side of the CDFS field area. This suggests there may be an issue somewhere in the process of imaging and processing galaxies in this region. The majority of galaxies within this stripe were able to be processed, yet this is a hard cutoff separating a region with higher failure rates.

Figure 3 compares the distribution of photometric redshifts between the failed galaxies and the whole CDFS set. The failed galaxies exhibit a bimodal distribtution with modes at z = 1 and z = 6. The mode at z = 1 is shared with the rest of the set, but not the z = 6 mode.

If the failed galaxies had a more uniform distribution, it would indicate low quality photometric redshifts for all values. However, this is not the case. This may be a problem with the EAZY [2] program used to determine these photometric redshifts in which it determines redshift along a bimodal probability distribution.

It could just as easily be the case that these redshifts are accurate, and that higher galaxies fail more often that low redshift galaxies. An linear increase in failed galaxies proportional to redshift would be expected, however we observe a distinct change after $z \approx 5$ in the whole CDFS set. The occurrence of z > 5 galaxies in the CDFS set is distinctly lesser that z < 5 galaxies. This is not the case for the failed subset.

This occurrence of failed galaxies above $z \approx 5$ is seen again in figure 4. JADES data was used to compare the redshift values. Galaxy coordinates were matched in TOPCAT to only select galaxies in common with the ZFOURGE and JADES CDFS surveys.

In red: galaxies with the ZFOURGE value use = 1. In green: galaxies which failed to be modeled by CIGALE. A distinct separation can be seen at $z \approx 5$. While failed galaxies do exist beneath this threshold, all galaxies above $z \approx 5$ are failed galaxies.

This suggests an issue with CIGALE's parameter space that does not allow for galaxies above a certain age. Using the online cosmology calculator by Edward Wright [6], the age of the universe at z = 5.6 is estimated to be 1.029 billion years old. Subtracting

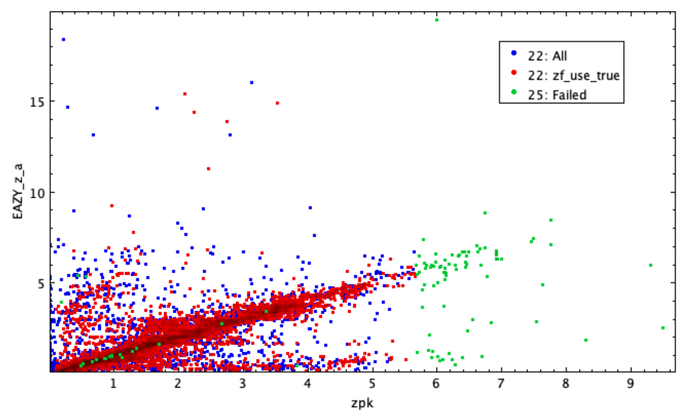


Figure 4: A plot of photometric redshift against photometric redshift. X-axis: redshift from the ZFOURGE data. Y-axis: redshift from the JADES data.

this from a current age of the universe of 13.720 billion years, we find that a galaxy at z = 5.6 would be 12.691 billion years old.

Within CIGALE's paramter file "pcigale.ini", the parameters `tau_main` and `age_main` have a range of values between 1000 to 11000 and 500 to 11000 respectively. These are in millions of years, so indeed, a universe with a redshift of 5.6 has an age that exceeds the parameter space given to CIGALE.

While increasing the range of these parameters may help these galaxies pass CIGALE, it is important to consider how accuracy may be affected. It may be the case that these are such high-redshift galaxies because EAZY had poor data when calculating photometric redshift.

$$\sigma_{NMAD} = 1.48 \times median(\frac{|\Delta z - median(\Delta z)|}{1 + z_{spec}}). \qquad (1)$$

In figure 5, the normalized mean absolute deviation (NMAD) between the ZFOURGE and JADES data was found using equation 1. This formula was referenced from equation 2 in "ZFOURGE

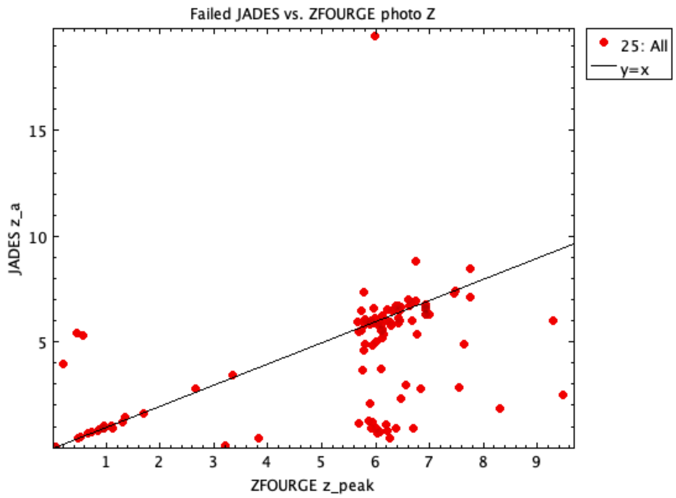


Figure 5: The same plot from figure 4, with only the failed data subset.

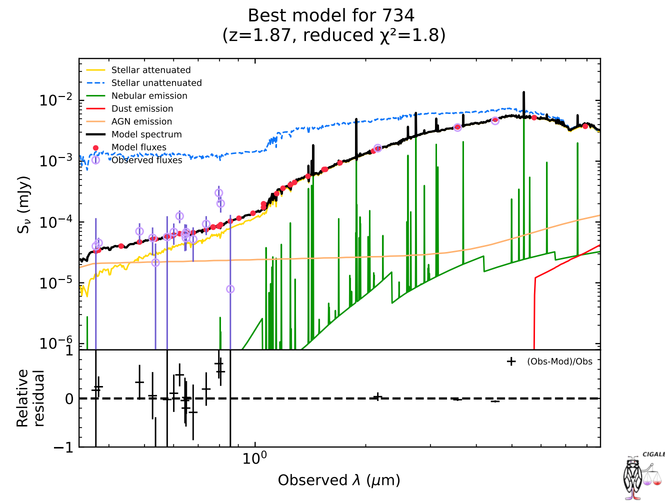


Figure 6: An example of a failed galaxy that was successfully modelled by CIGALE version 2022.1.

catalogue of AGN candidates" by Cowley et al. (2016) [3]. For the failed galaxies, the redshift $\sigma_{NMAD} = 0.11486$ between the ZFOURGE and JADES data.

In "Galaxy Stellar Mass Functions From ZFOURGE/CANDELS" (2014) [5], Tomczak et al. find the normalized median absolute deviation between the ZFOURGE spectroscopic and photometric redshifts. σ_{NMAD} was found to be 0.018 for a selected high-quality subset of the ZFOURGE survey.

These numbers should not be directly compared because they are the deviations between two separate data sets. However, it provides some context on the quality of redshifts in the entire ZFOURGE set.

$$Q_z = \frac{\chi^2}{N_{filt} - 3} \frac{z_{99}^{up} - z_{99}^{low}}{p_{\Delta z = 0.2}}. \quad (2)$$

One other way to determine photometric redshift qualities is the Q_z field produced by EAZY. Equation 2 is the formula used to calculate Q_z, referenced from equation 8 in "EAZY: A Fast, Public Photometric Redshift Code" [2]. A higher Q_z value indicates a lower quality redshift value. When excluding outlying Q_z values above one million, the failed data set has an average Q_z of 598 (n = 553) and the CDFS set has an average Q_z of 394 (n = 30779). As expected, the failed data set has lower quality photometric redshift predictions on average.

4 Conclusion

The 555 ZFOURGE galaxies were unable to be processed by CIGALE primarily because of low-quality photometric redshifts. Whether this is something that can be corrected in a program like EAZY or is simply due to unusable photometric data is undetermined. I make the following observations:

1. Almost all galaxies with a redshift indicative of an age that exceeds CIGALE's age parameters will fail.

2. Failed galaxies form a pattern when plotted by position in the sky.

3. Most failed galaxies were able to be modelled on a newer version of CIGALE, probably due to a bug fix or an increase in CIGALE's capabilities.

Figure 6 is an example of a successful CIGALE output for a failed galaxy. It would be worth investigating if these models are of good quality. If not, it may be the case that these galaxies simply do not have enough data to produce quality science. Consider that the ZFOURGE CDFS set contains 30911 galaxies, of which 555 failed CIGALE version 2020.0, and of which only 34 failed on CIGALE version 2022.1. Otherwise, redshifts can be re-evaluated with EAZY or an alternative, or matched with other data sets. There were very few matches between the failed ZFOURGE galaxies and the JADES data set.

It is worth investigating how adjusting the CIGALE age parameters affects the quality of the output, as increasing the maximum age will allow more data to be incorporated. If making this change to include more data will reduce the quality of the overall CIGALE outputs, it may not be worth including these galaxies.

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