Probing cosmic dawn with wide-range galaxy SED models

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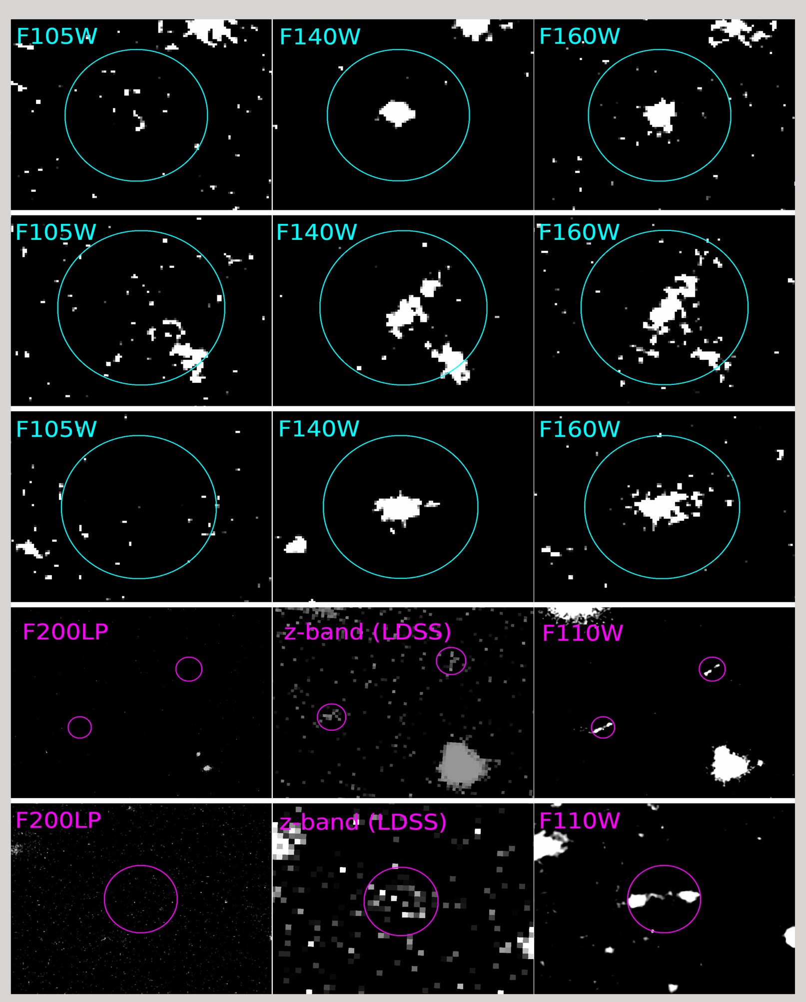
Background and Motivation

While the formation of galaxies and galaxy clusters is well-understood, the mechanics behind these processes become less and less well-known the further observations go back in time. Surveys such as CANDELS and RELICS have managed to find a large number of confirmed or candidate high-z (z ~5.5) galaxies (Salmon et al 2020). However, there is a marked decline in the number of observations below an H magnitude of 24; as a result there are very few old galaxies bright enough to perform spectroscopic analysis on them.

It follows then that any galaxy detected at sufficient brightness within this cosmic dawn period is a potential candidate for study as one of the earliest star-forming galaxies in our Universe. Establishing a method of accurately confirming whether or not a suspected high-z candidate is such rather than a particularly dim low-z interloper is critically important for this line of study. We present the results of one such methodology.

Galaxy Detection

The basis of this work is five galaxies all detected at an H magnitude of ~< 24, identified from HST imaging of over 120 massive galaxy clusters. Multiband observations were taken of the five galaxies, three as part of the Sloan Digital Sky Survey (referred to here as SDSS-1, -2, and -3) and two via the South Pole Telescope (referred to here as SPT0216-26 and SPT 0304-54). The proximity to massive clusters suggests that the galaxies used here are likely to be gravitationally lensed, and thus observationally bright while intrinsically faint. Such use of gravitational lensing means that high signal-to-noise analysis can be done on galaxies that would normally be too dim to allow for such. This approach was pioneered by the Hubble Frontier Fields survey (Lotz et al 2017) and the RELICS survey (Coe et al 2019); however the scale of this search is three times greater than that of the next closest.



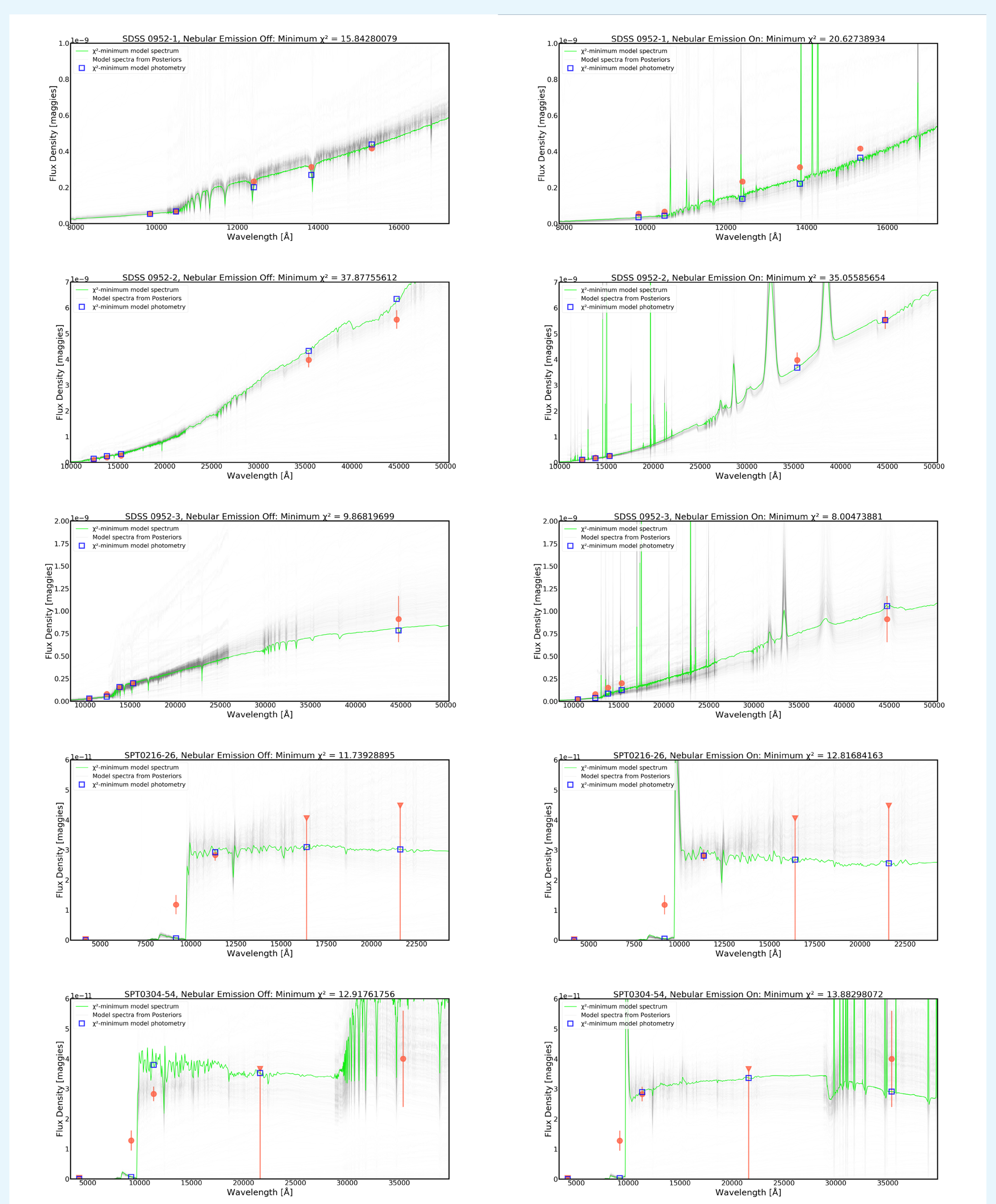
The five galaxies as they appear across multiple wavelengths. Top to bottom: SDSS 0952-1, 0952-2, 0952-3, SPT 0216-26, SPT 0304-54. Note that both SPT galaxies appear as multiple images and are therefore likely strongly lensed and highly magnified.

Prospector Modeling

The majority of this work was done using the modeling software Prospector, a Python codebase designed around creating spectral energy distributions based on real or simulated observational data; in the case of this projectm the modularity inherent to the software was a key motivating factor, as this would allow any models developed to search over multiple parameter spaces with little need to change the code while the robustness of the modeling software was necessary in order to create usable models from the limited data available at the time.

In order to ensure that the widest possible model space was searched, each Prospector model was built using 8 free parameters, with each of those parameters extended over as wide a range as computational time would reasonably allow. The independent parameters fitted for here are (1) redshift, (2) age of the Universe at the time of galaxy formation, (3) stellar mass of the galaxy, and (4) gas ionization parameter of any surrounding nebulae. The star formation history was modeled as a delayed tau-burst model (Simha et al 2014) with (5) constant fractional star formation rate, (6) exponential decay constant, and (7) the cosmic time at which a burst of star formation occured. The presence of interstellar dust and the resultant loss of observed magnitude was modeled using the wavelength-dependent dust attenuation curve A(λ) (Calzetti et al 2017) with the (8) normalization factor of the attentuation curve as a free parameter α.

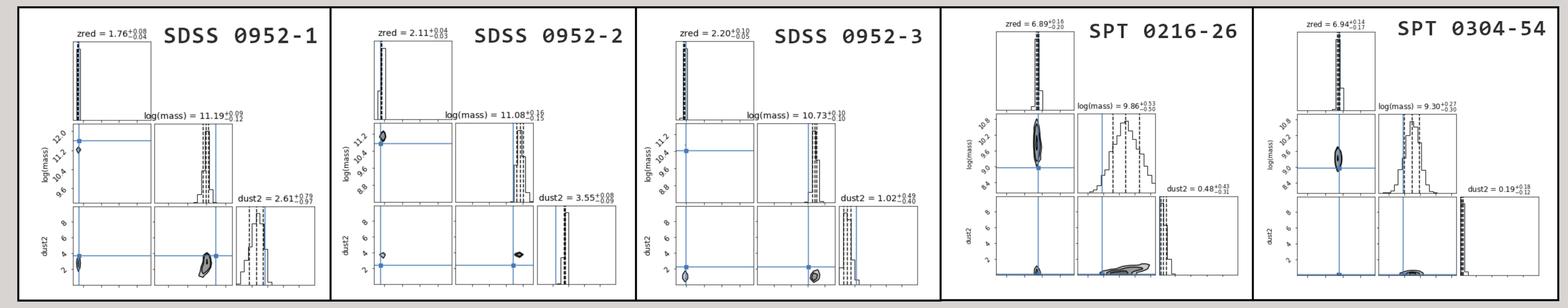
In each case, a sample selection of models was created from priors obtained from predictions based on the shape of the available data. These models were compared manually, and the set of priors that most closely matched the shape of the data were set as the initial parameters for the model to search from. The Python package dynesty was then used to estimate the Bayesian posteriors using dynamic nested sampling, a method of sampling that utliizes algorithmic methods from both MCMC and nested sampling fitting methods to allow for the creation of complex multi-modal probability distributions (Speagle 2019).



The finalized SED fits. Observational photometry is shown in red, with upper limits represented as red triangles. Note that the selected model spectrum (green) is one of multiple models that could potentially fit the data as represented by the model space derived from the complete set of priors (grey).

Results

With the priors given, each of the models was able to put tight constraints on the redshift, mass, and dust attenuation factor of the galaxies; with this we put forth the claim that the two SPT galaxies are active high-redshift galaxy candidates with low amounts of dust surrounding them, while the SDSS galaxies are low-z interlopers dimmed by surrounding dust.



The high constraining power of such a small dataset suggests that this methodology could be helpful in confirming high-z galaxy candidates in the future. Both of the SPT galaxies appear to be strongly lensed, meaning their intrinsic brightness is much fainter than the observed H magnitude of 24 and is likely closer to 26~28; within the current catalogues this would make them the only faint z > 6.5 galaxies observationally biright enough to be studied in high detail with the James Webb Space Telescope (Salmon et al 2018). While other surveys and analyses have found higher redshift lensed galaxies (Strait et al 2020), they are all much fainter than this sample and thus less likely to serve as good spectroscopic targets.

Summary and Discussion

As of now multiple limitations exist that limit the reliability of the derived SED models. The number of actual observations of each of the galaxies is fairly limited, with some of the data being modeled as an upper limit rather than a true observation. Furthermore, while Prospector allows for a robust range of models to be explored, the actual number of models it is possible to create and compare against the data is constrained by computational time, forcing a compromise between the range of the modeling space and the time spent obtaining each model.

However, even with these limitations the models were able to strongly confine (Error < 5%) the redshift and masses for both the low- and high-z cases and provide a comprehensive picture of the basic properties of each galaxy. Follow-up investigations of the SPT sources via Hubble are currently in process to further define the SED models. Further searches with deeper observational data and over a larger sample of galaxies hope to reinforce the efficacy of this methodology for more generalized use.

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