Generating synthetic observations for the James Webb Space Telescope

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Motivation

With the launch of the JWST an avalanche of data on the high redshift Universe is currently being taken. For example, F. D'Eugenio et al. 2023 [1] have observed the most distant nebular-line detection to date at $z = 12.5$ with JWST/NIRSpec spectroscopy. It is imperative therefore that we have the best theoretical models to understand this data. One way of comparing models with data is to forward model the emission from theoretical galaxies and compare in this observer space. Here we choose to use the 2013 version of the Maraston models [2] with updated calibrations for their novel treatment of the thermally-pulsating asymptotic giant branch (TP-AGB).

Methods

We use CLOUDY, a spectral synthesis code designed to simulate the physical conditions within a gas cloud to predict the resultant spectrum of the emission.

We provide CLOUDY with the physical properties of the gas cloud, such as ionization parameter (the dimensionless ratio between the number of ionizing photons and the number of hydrogen atoms) and hydrogen density.

We also provide CLOUDY with the external source of radiation that photoionizes the cloud, which is the Maraston model.

We run CLOUDY with Sciama, a High Performance Compute Cluster.

We use Synthesizer to create the inputs for CLOUDY, to renormalize the outputs from CLOUDY to the original model, and analyse the emission lines!

Results

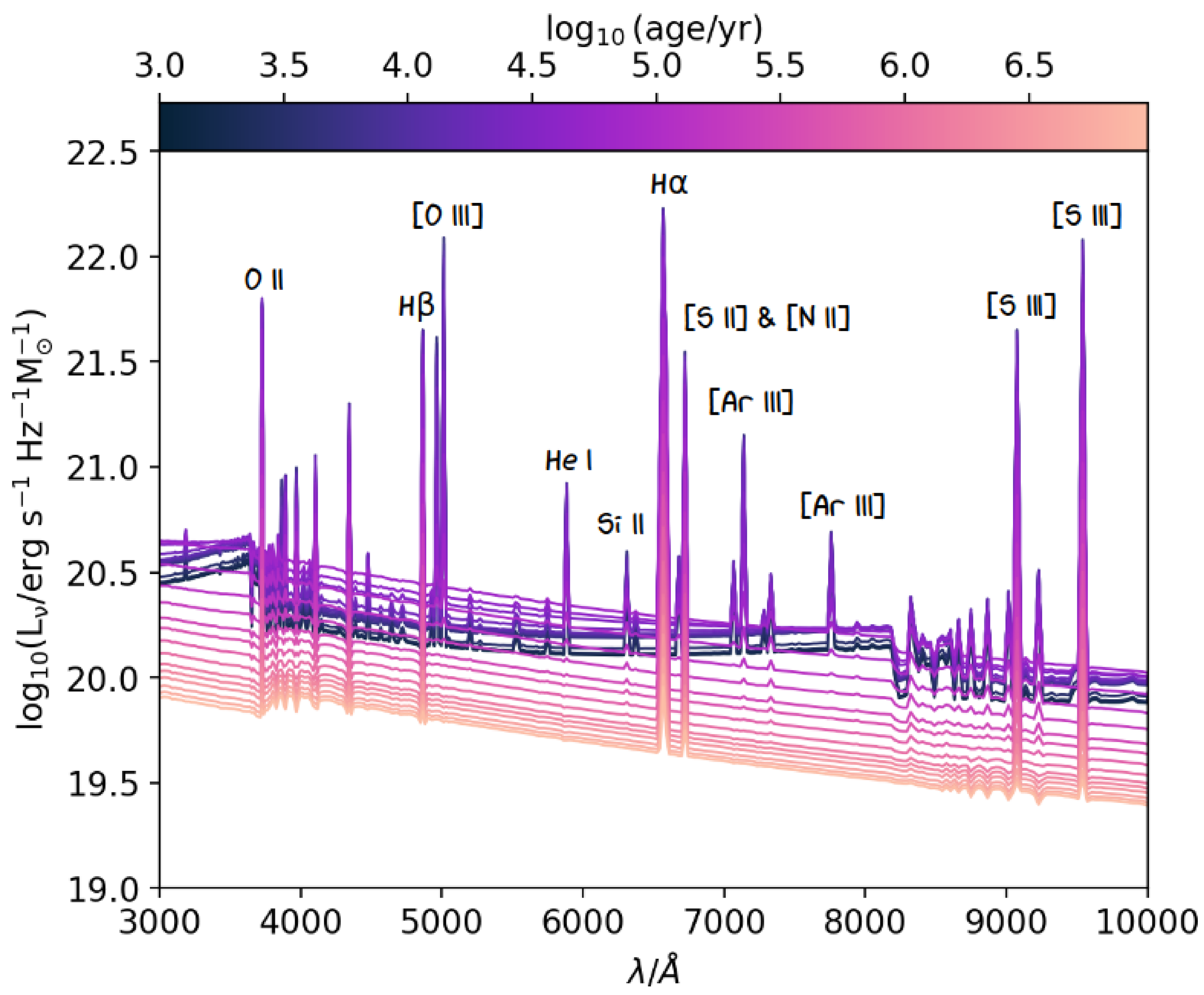
As seen in the top Figure on the right, emission lines were successfully added to the modelled Maraston spectra. Here we can see how the emission lines from species such as oxygen, hydrogen, and nitrogen in their various ionization states change as a function of the age of the stellar population. As expected, the youngest populations with ages of $10^5 - 10^7$ years have the most ionizing photons and therefore the most emission lines. This plot was done for solar metallicity and a fixed ionization parameter of 0.01, but we find that reducing the ionization parameter from 10^1 to 10^{-3} reduces the strength of some of the lines and affects the contribution from the nebula continuum.

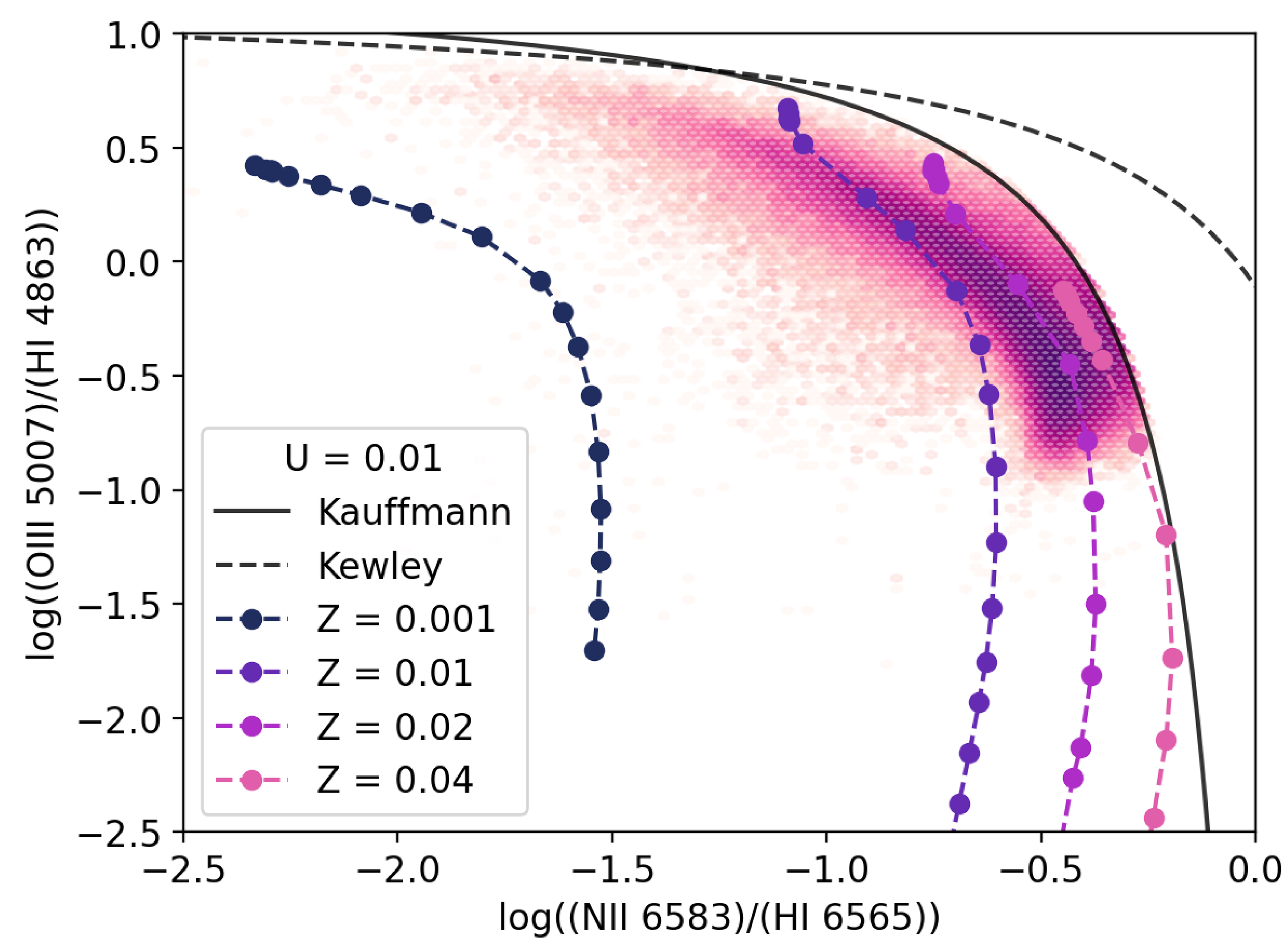
Using the luminosities of these emission lines, diagnostic plots can be made that can be used to infer properties of the population. One of these diagrams called the Baldwin–Phillips–Terlevich (BPT) diagram is commonly used to isolate the star-forming HII regions from regions excited by other mechanisms and sources like AGN. To separate these regions, the Kauffmann [3] and Kewley [4] lines are used. The BPT diagram for our models is shown on the bottom right for an ionization parameter of 0.01, along with SDSS data from 215,224 local star-forming galaxies. We see that the highest metallicity populations have higher nitrogen abundances due to secondary nitrogen production and therefore higher [N II] fluxes as expected. The relation between [O III] and metallicity is more complicated however, since varying the metallicity alters both the oxygen abundance and the collisional excitation rates of O++. In our work, we also find that lower ionization parameters increase the [N II] (and S II) fluxes, in line with other studies and observations in literature.

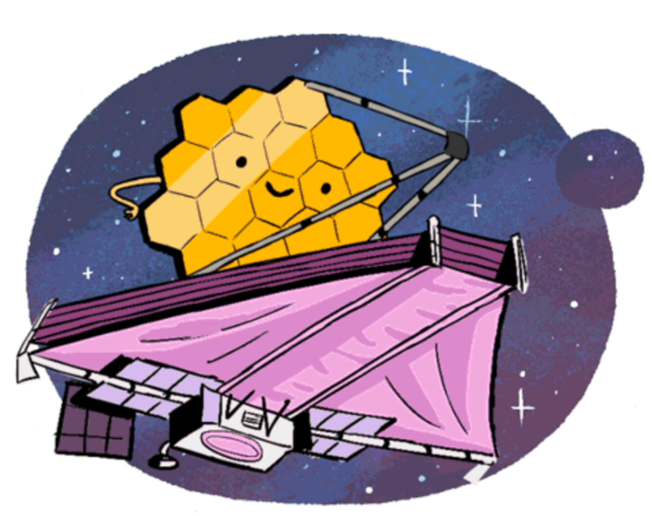
Conclusion

It is clear that this approach to modelling emission lines works well to produce observations that are similar to those observations of young star forming galaxies that JWST will observe. The next steps will be to apply these methods to the newest Maraston models containing the contribution from post-AGB stars with a UV upturn.

Then, we will add parametric star formation histories (e.g. logarithmic, truncated), apply these models to hydrodynamical simulations such as FLARES [5] and EAGLE [6], create mock images, and include these emission line models within fitting codes such as FIREFLY [7] to further constrain the properties of high-redshift galaxies with emission lines.







References

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