Astronomy 202 Final Project

Please show your work, and provide code via email.

due March 21, 2018 at 4pm Pacific

The spectral energy distributions of galaxies feature a wide range of radiative properties. The stellar components of galaxies contribute continuum and absorption signatures, depending on the stellar mass and star formation rate of the system. Gas in and around the galaxy will contribute nebular emission, radiating energy as it converts ionizing radiation from the stars into continuum and line emission.

While the galaxy spectra are feature rich, the observational probes we have of SEDs are usually coarse. Photometric data measures bandpass-averaged flux densities from galaxies with resolution of typically $R \sim 10$, although occasionally with narrow band measurements reaching several times better resolution. The continuum shape of galaxies are probed with slitless prism and grism observations to reach $R \sim 100-1000$, and with slit specroscopy to much, much higher resolution. In dispersing the light, however, the sensitivity of spectra can be coarse enough to prevent measurements of the continuum. Even detecting lines from faint objects can be challenging if the line equivalent widths are small.

In the trade off between resolution and sensitivity, it has become apparent the ability of broad band photometry to fully inform us about the physical properties of a galaxy is limited. For instance, without spectra, we have trouble disentangling the contribution of nebular line and continuum emission from stellar continuum emission in setting the observed photometry of some galaxies. As a result, the inferred ages and stellar masses of galaxies become quite uncertain – in terms of a marginalized distribution of possible stellar ages, the posterior distribution of age becomes broad and sometimes multiply peaked.

Your task will be to demonstrate this duplicity directly. Assume Case B recombination throughout.

1 Star Wars: The Last SED-i

Download and learn to use a stellar population synthesis code, one that only includes the stellar continuum contribution to the spectrum. Assume a constant star formation rate, a fixed metallicity, a small but non-zero ISM dust absorption. Compute the SED of a galaxy with ~ 5 solar mass / year star formation rate and 500 Myr age at redshift 3 in micro Janskys. Include IGM absorption (following e.g., Madau 1995 or Inoue et al. 2014). Assume a flat LCDM cosmology. Find the photometric flux in F435W, F606W, F775W, F850LP, F105W, F125W, F160W HST and the F200W, F277W, F356W, and F444W JWST bands.

2 Fifty Shades (Free-)Freed

Write original code to compute the free-free emission coefficients from a Hydrogen nebula, and the resulting spectrum connecting the total emissivity to the production rate of Lyman continuum photons produced by the galaxy and the fraction of those photons absorbed and converted into nebular emission. (See Section 4.3 of Osterbrock and Ferland). Write code to compute the free-free Gaunt factor (try interpolating from Sutherland 1998, MNRAS, 300, 321-330).

3 Mudbound(-Free)

Write original code to compute the bound-free emission coefficients from a Hydrogen nebula, and the resulting spectrum connecting the total emissivity to the production rate of Lyman continuum photons produced by the galaxy and the fraction of those photons absorbed and converted into nebular emission. (See Section 4.3

of Osterbrock and Ferland). Write original code to compute the photoionization cross-sections and bound-free Gaunt factor (see Karzas and Latter 1961, ApJS, 6, 167). The bound-free Gaunt factor is possibly the hardest part of this project.

4 Two Photons Outside Ebbing, Missouri

Write original code to compute the two-photon emission from a Hydrogen nebula (See Section 4.3 of Osterbrock and Ferland). You can tabulate this if needed.

5 Negative Space

Write original code to produce the Hydrogen line spectrum. The lines will be very narrow, and most of the resulting spectrum will be empty. Write code to compute a spectrum of the lines that can be integrated to correctly find the flux in each line. Assume the emissivity of H-β is proportional to the number of Lyman continuum photons produced and absorbed. Tie the strengths of the other hydrogen lines to H-β.

6 Get Out

In addition to working code, please reproduce Figure 4.1 of Osterbrock and Ferland (for Hydrogen processes only) by combining together the continuum emission coefficients (plotting each separately as well). Use your judgement about how many shells to include in the bound-free coefficient. Then, combine the nebular continuum and line emission to the stellar SED model you downloaded by tying the strength of the nebular emission to the Lyman continuum photon production rate of the stellar SED (assume all Lyman continuum photons are absorbed). Find a new star formation rate and age to produce an SED of the stellar population emission including the nebular contribution that matches as closely as you can the stellar-only photometry. Plot both SEDs, indicating the photometric points, and report the star formation rate and age.