DUE ON FRIDAY OCTOBER 11, 2019 — HARDCOPY PAPER SUBMISSION ONLY

GALAXIES: PROBLEM SET 3

Problem 1: Stellar metallicities [50 points]

For your previous problem set you had to make your own stellar population synthesis (SPS) model. In this exercise we will focus on stellar metallicities using the spectra of simple stellar populations. As such measurements require stellar absorption features, we need to use more sophisticated models. Install the python FSPS code following the instructions on http://dfm.io/python-fsps/current/

a. [12 points] Generate simple stellar populations (sfh=0) for three metallicities (logzsol=-0.5,0.0,0.5) for the Salpeter IMF. Assume no dust (dust_type=2, dust2=0). Make two figures. In the first figure show the spectra at solar metallicity for a range of ages (approximately 1 Gyr, 2 Gyr, 5 Gyr, 14 Gyr), and in the second figure show the spectra for a ~5 Gyr stellar population, but a range of metallicities. Zoom in on the region 5000-5400 Angstrom and use a log scale on the y-axis to better compare the absorption features. What can you conclude when comparing these figures?

In order to measure metallicities directly from galaxy spectra, astronomers use Lick indices. Lick indices are equivalent width (EW) measurements of a particular index band. The wavelength bands used to determine the continuum are defined as well for each index. On the following pages you can find the index and continuum bands needed to measure all Lick indices: http://astro.wsu.edu/worthey/html/system.html.

b. [12 points] Measure Mgb in all spectra and plot its EW as a function of age for the 3 different metallicities.

c. [12 points] As is clear from the figure made in b, one absorption line is not enough to break the degeneracy between metallicity and the age of the stellar population. Therefore, astronomers use a Balmer line in combination with a metal line. Measure the Hβ line and plot Hβ vs. Mgb for the generated populations. Connect points of equal age and metallicity and indicate the ages and metallicities in the grid. Why use the combination of a metal and a Balmer line? What can you conclude from this figure?

d. [12 points] Stellar population models take into account mass loss due to stellar winds and supernova explosions, and gas is returned to the ISM. However, the metallicity in the models is usually fixed, and the returned enriched gas does not influence the metallicity of future generations of stars. This is okay for a simple stellar population, but for a more extended star formation history this is usually not the case. Assume that a galaxy forms its stars over three star-formation episodes (assume delta functions, i.e., SSPs), in which the same number of stars are being formed. During the first burst, the gas has a metallicity of $\log Z/Z_\odot = -0.5$. During the second burst, one Gyr later, the gas-phase metallicity is solar. During the 3rd burst at 2 Gyrs the gas-phase metallicity is $\log Z/Z_\odot = +0.5$. Measure Mgb over a range of ages, and plot its evolution in comparison to a an SSP with solar metallicity. How do the two curves compare?

e. [2 points] In real-life galaxies the number of successive star formation episodes does not necessarily scale with the final metallicity. Explain why.

Note, problem 1: In class we discussed that the relation between Mg and the total metallicity depends on the relative enrichment of core-collapse vs. Type Ia supernovae. Nonetheless, in problem 1 we assumed that magnesium is a proxy for metallicity, as the used SPS models assumes a fixed chemical abundance pattern.

Problem 2: The closed box model [26 points]

In class we derived the closed box chemical evolution model and found that the gas-phase metallicity evolves as $Z(t) = -y \ln (f_{gas}(t))$, with y the yield defined as the ratio of the mass in metals returned to the ISM to that of the total mass that stays enclosed. This model assumes that the initial metallicity is $Z(0) = 0$, that long-lived stars are locked up forever, and that short-lived stars - who are responsible for the enrichment - immediately return their metals after they are formed.

a. [6 points] Assume that a galaxy has a constant SFR, a constant yield of $0.5Z_{\odot}$, and that gas fraction is 30% at 13 Gyr. Plot the evolution $Z(Z_{\odot})$ vs t (Gyr).

b. [10 points] Plot the metallicity distribution (*dn/dZ)* of the stars at 13 Gyr. What is the average stellar metallicity at this time? What is the fraction of stars at 13 Gyr that has a metallicity less than $0.25\ Z_{\odot}$? In our solar neighborhood the yield is indeed about $0.5Z_{\odot}$, and the gas fraction is about 30%. However, the fraction of stars with less than $0.25\ Z_{\odot}$ is about 2%. How can you explain this difference?

c. [10 points] Instead of a constant SFR, consider an exponential declining SFR ($\propto \exp[-t/\tau]$) with the same yield and a timescale of τ=11 Gyr. How does the gas-phase metallicity evolve in this case? How does the stellar metallicity distribution look like at 13 Gyr compared to a constant SFR. What does this comparison tell us?

Problem 3: Dark matter halos [24 points]

Download the files z0.halos, z2.halos, and z4.halos, uploaded to bCourses. These files, provided by former UCB postdoctoral fellow Robert Feldmann, contain the properties of dark matter halos at 3 different redshifts (z=0, z=2, and z=4) in a box of 15 Mpc/h (co-moving) on a side.

a. [8 points] Plot the dark matter halos mass function ($\log \phi$ [Mpc^{-3} dex^{-1}] vs $\log M_{vir}$ [$M_{\odot}$]) for the three redshifts in the same figure. What can you conclude from the figure?

b. [8 points] Take the stellar mass function of all galaxies at z=2 by Tomczak et al. (2014) and plot them in the same figure as the mass function of the dark matter halos at the same redshift. What can you conclude from this figure?

c. [8 points] The provided dark matter halo simulation has a limited box size and poorly samples the high mass end. To trace the function to higher masses, assume the dark matter halo mass function is a power law and extrapolate the function to much larger dark matter halo masses. Now assume that every halo hosts a galaxy and match the two mass functions at the same number density. Plot the ratio of stellar to halo mass as a function of stellar mass. What can you learn from this figure?