Homework 2: Integrated Spectra of Star Clusters

In this homework you will examine spectra that correspond to the ages and metallicities of the star clusters you met in Project 1. Spectra contain much more information about a stars temperature and composition than the colors you used in Project 1. However, in this project, rather than having spectra of hundreds of stars in each cluster, you have just a single spectra that combines the light of all the stars (an "integrated spectrum"). Your goal is to try identifying the spectra that corresponds to each cluster. This will require some thinking and sleuthing!

The properties of the five clusters are:

Cluster	Project 1 Number	Age	[Fe/H]	Spectra Letter (A-E)?
NGC 2516	3	100 Myr	0.0	
NGC 2420	4	1.1 Gyr	0.0	
NGC 2682/M67	1	4 Gyr	0.0	
NGC 6397	2	13 Gyr	-0.7*	
NGC 6838/M71	5	13 Gyr	-2.0	

* for simplicity I made the corresponding spectrum solar metallicity ([Fe/H]=0.0) for NGC 6397.

The Spectra:
A plot of the UV/optical spectrum of all of the clusters is shown on the next page. These spectra are not actual data of the clusters. Instead, I've used models of stellar spectra of a population of stars with the same age and metallicity as the clusters. The models were created by Gustavo Bruzual & Stéphane Charlot using a process called *spectral synthesis*:

1. To determine the temperatures and luminosities of stars in the population, they use the Padova isochrones, the same ones we used in Project 1.
2. They assume a mass spectrum of stars (an "initial mass function" aka IMF) to populate the isochrones with stars at a range of masses. We will learn more about the IMF later in class.
3. They determine the spectra for each star from a library of stellar spectra (STELIB; Le Borgne et al. 2003).
4. They add together all the spectra in proportion to a stars luminosity.

This is equivalent to blurring out the light of a star cluster with a known age and metallicity and sending it through a spectrograph. These models are known as *single* or *simple stellar population* (SSP) models. In general, the light of the brightest stars will dominate these spectra.

Your Tools:
Your goal is to unlock some of the information contained in the spectra and understand how they corresponds to the CMDs of the clusters from Project 1. The spectra of the five clusters is shown in the attached figure. The clusters have again been anonymized as clusters A-E. These spectra are also available in data files in the directory: ~`aseth/astro301/hw2/cluster_*.dat`. These files have two columns, wavelength and flux. Note that there is no overall luminosity information available from these spectra (this is typically true with spectra!); the fluxes have been normalized by dividing by the median flux.

The most obvious property of the cluster spectra is the color, or overall slope of the cluster's light. But there are more subtle differences between the spectra – the strengths of the many absorption lines varies in a way that can be used to estimate the temperature and metallicity of a stars' spectra. Section 8.1 of Carroll & Ostlie contains information both on how these lines are formed and the strengths of lines as a function of spectral type. Particularly useful are Table 8.1 and Figures 8.2-8.5. Also recall the correspondence between color and spectral type available at:
`http://www.stsci.edu/~inr/intrins.html`

Questions:

1. On the top spectrum (Cluster E) of the attached figure label the Hydrogen Balmer absorption lines: Hα (6563Å), Hβ (4861Å), Hγ (4340Å), Hδ (4102Å) and Hϵ (3970Å). Describe how these lines are generated in the atmosphere of a star and why the Hδ line is at shorter wavelengths than Hα.

2. On the bottom spectrum label some prominent metal lines: Ca II (3934Å="Ca K", 3968Å="Ca H"), Ca I (4227Å), Fe I (4383Å and 4405Å), Mg I (5167Å, 5173Å, and 5183Å="the Mg Triplet"), Na I (5890Å and 5896Å="Na D"). What is the difference in origin between the Ca I and Ca II lines?

3. From the attached figure you should immediately be able to identify the youngest cluster, corresponding to Cluster 3 in Project 1.
   (A) Identify this clusters spectrum, and briefly describe how you were able to identify it.
   (B) What spectral type of star does this spectrum resemble? Explain why in terms of the CMD of the cluster.
   (C) Why are the metal lines in this cluster weak?

4. Of the remaining four spectrum, one is clearly not like the others.
   (A) What cluster does this spectrum correspond to? How do you know?
   (B) Why are the metal lines in this cluster weak?

5. The remaining three spectra all look qualitatively similar.
   (A) Why is this? Use your knowledge of the cluster's color-magnitude diagrams to explain this.
   (B) Explain why the bluer part of the spectrum is a better place to see differences between these clusters.

6. You'll need to turn to more quantitative measures to match the remaining three spectra. So measure the depths of the following four absorption lines for *all five clusters*: Ca K (3934Å), Hβ (4861Å), Mg I (5183Å), Na I (5890Å). To make this measurement use your IDL plotting skills to plot just the region right around the line of interest (remembering the `XRANGE, YRANGE,` and `YSTYLE` keywords). You could also write a program to do this automatically! Then make two measurements: (1) measure the flux in the deepest point in the line, (2) measure the flux in the non-absorbed "stellar continuum" adjacent to the line. Then calculate the line depth: (1 - [flux(absorption)/flux(continuum)]). Make a table of these values for all five clusters.

7. Based on these linestrengths and the material in C&O, match the remaining three spectra to their associated clusters. Explain your choices in detail!