Observational Astronomy **First Name:**________________
Lab: I-4FS **Last Name:**________________

Spectra and colors of stars and galaxies

Today we will examine the colors, the "spectra", and the velocities of stars. Most of the stars we will look at are *much* fainter than you can see with your eye — however, they are very similar physically to those you are familiar with, just further away in our Galaxy. We will also take a look at a handful of galaxies, and try to understand how the stellar content of the galaxies affects their images and spectra.

Below is a spectrum of the Sun, in black, and a blackbody spectrum at T=5777 Kelvin in green. Notice how the peaks coincide: this indicates that the temperature of the sun is close to a temperature of T=5777 Kelvin, and notice the features in the sun spectrum: absorption and emission from various elements, while the blackbody spectrum is smooth.

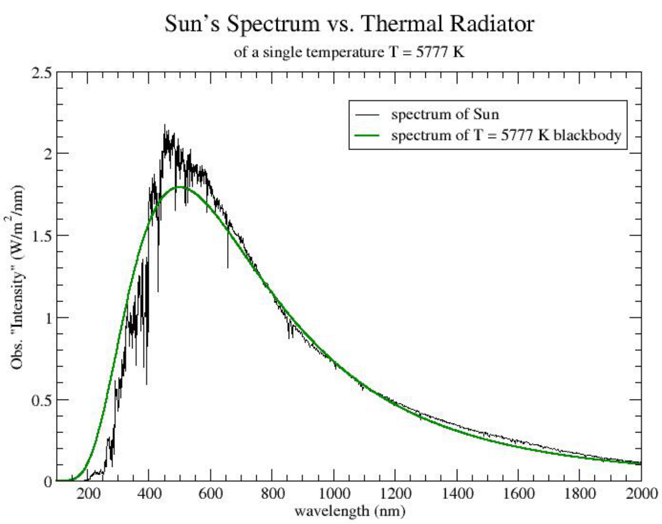


Figure 1: A screenshot of the Agent Exoplanet website with Qatar 1b dataset.

To begin the exercise, open a Mozilla Firefox browser on your computer to the URL `http://mirror.sdss3.org`. (Not Internet Explorer, which has some issues with looking at this site). This site gives you access to a set of real astronomical data released in January 2011 by a team of astronomers (including us at NYU). In the menu, go to "Spectra" and under that "Bulk Search."

1. Colors of stars

Enter the right ascensions and declinations listed below into the bulk search form. When you submit the search, it should return a table of rows. Each row corresponds to a star, and by hitting "Plot" in the appropriate row you can look at the image and the spectrum of the star.

R.A. (deg)	Dec (deg)	Type	$\lambda_{\rm peak}$ (Ang.)	T (K)	H&K?	Balmer?
228.06551	6.865659					
16.437201	-10.7071					
17.848558	16.327376					
151.95765	34.369592					
47.249486	38.01783					
64.948151	5.261293					
146.77222	62.631055					

First consider just the colors of the stars in the image on the bottom left.
Note that these images, in addition to being far deeper than what you can see with your eye, exhibit somewhat more color contrast as well.
Under the "Type" column, rank the list above from bluest to reddest according to the image that you see. Use the labels O, B, A, F, G, K, M from bluest to reddest.
The bluer of the stars are the hotter ones, and usually the more massive and younger stars as well.

2. Relationship of colors to the spectrum

Now consider the "spectrum" shown on each plot. The curve shown is the amount of light emitted from each wavelength, from blue (short) wavelengths on the left to red (long) wavelengths on the right. The unit of length here is the Angstrom, which is 10^{-10} meters. Your eye is sensitive to light between about 4000 and 7000 Angstroms.
For a perfect "blackbody" spectrum, the temperature of a star would be related to its peak wavelength of emission by the simple formula: $\lambda_{\rm peak} T \approx 3$ mm Kelvin. Although stars are not perfect blackbodies, there is still an approximate relationship between the color and the temperature.
Look at each spectrum and estimate the peak wavelength. If the spectrum continues to increase past the left or right edge of the spectrum, indicate the maximum or minimum possible wavelength.
Use the peak wavelength to deduce the temperature (or the minimum or maximum temperature where appropriate). Notice that the temperature is closely related to the color classification in the first section. This temperature is the effective temperature at the surface of the star — for all these stars the temperatures in their centers where nuclear fusion is occurring is much hotter!

3. Features in the spectra

There are a number of clear absorption features (called "lines") in the spectra, seen as deep troughs at particular wavelengths. There are many sets of lines associated with a number of different absorption features, but we'll be interested today in just two sets of them: the calcium H and K lines, and the hydrogen Balmer lines.
The calcium H and K lines are near the left edge of these spectra, at around 3933 Angstroms (K) and 3969 (H) Angstroms. They are produced by trace amounts of calcium (gaseous calcium!) in the outer atmospheres of the stars. Look for these in the spectra and mark the

table above according to whether each star has visible H & K. Which star has the strongest calcium features?
The Balmer lines are features due to hydrogen in the outer atmosphere. There is a large set of them: Hα at 6563 Angstroms, Hβ at 4861 Angstroms, Hγ at 4341 Angstroms, Hδ at 4102 Angstroms, Hϵ at 3970 Angstroms, etc. Note in the above table which stars have these, and which star has the strongest features.
There is always hydrogen in stellar atmospheres, but it has to be at the right temperature to produce deep hydrogen lines. Using the table above, guess what that temperature is.

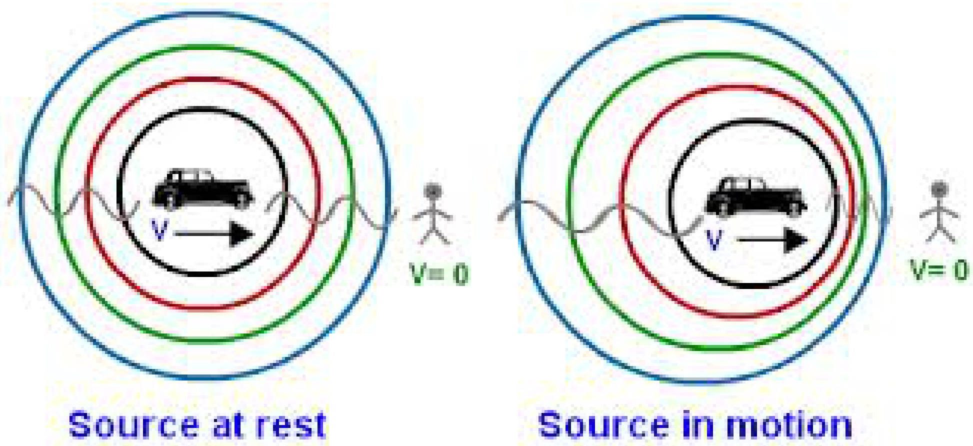
Which type(s) of stars have neither H & K lines nor Balmer lines?

4. Doppler shifts in galaxies

Now we will look at a handful of galaxies. As you probably know, galaxies are distant analogs to the Milky Way, and consist of conglomerations of 10s of billions of stars. This fact will be evident when we look at their spectra. Search for the following spectra in the "bulk search" window (but keep your results window for the stars open for comparison).

R.A. (deg)	Dec (deg)	Type	$\frac{\text{Young}}{\text{Old}}$	K-line (A)	Hδ (A)	Velocity (km/s)
153.4605	38.764896					
140.03594	8.1503628					
35.170815	1.0521941					
185.7200	6.6798709					
173.41101	4.1961732					

You will notice for some galaxy there are large "spikes," which we call "emission lines." The light at these wavelengths is not coming from the stars, but instead from gas in HII regions within the galaxy — their presence is usually a sign of ongoing star-formation in the galaxy (though certain lines indicate the presence of a black hole at the center of the galaxy). Note that the most prominent set of lines are Balmer *emission* lines!
Look for the H and K lines of calcium and the Balmer lines for each spectrum. Because Balmer emission makes it hard to see the lines, you will have to search for Balmer emission in the Hδ line to see it in the cases where it is there. List above the location in the spectrum of the K line and the Hδ line in cases where you see them.
These galaxies are moving quickly away from us. Remember that light travels at a finite speed. Just like the sound of a sirene is affected by the relative motion of the sirene, the source, and us, the listener, the motion of celestial objects away from us modifies the frequency of the light emission. When an ambulance drives toward us the sound will be higher pitched: higher frrequencies/lower wavelengths. When the ambulance moves away the frequency decreases/wavelength get larger. This is a purely geometric effect: look at the figure in the next page to visualize it. Similarly, these galaxies are receding from us due to



the expansion of the universe, and the light they emit will appear at a larger wavelenth than it was emitted at: it will be "reddened". We call this "cosmological redshift". so you will notice that the wavelengths of these lines are *redshifted* from their positions in the stellar spectra, which are almost at rest with respect to us. This Doppler shift is related to the velocity by the equation:

$$\frac{\lambda_{\rm obs}}{\lambda_{\rm rest}} = 1 + \frac{v}{c} \tag{1}$$

where $c = 299792$ km/s is the speed of light. Use this equation to deduce the velocities of recession for the galaxies above, and list it in the table.

5. Colors of galaxies

Compare the spectra of the galaxies to the spectra of the stars. Write down which type of star each galaxies spectrum is most similar to. The bluest stars are the shortest-lived, and the reddest stars are the longest lived — based on this fact write down whether each galaxy is young or old (consider O, B and A stars "young" and any cooler star to be "old"). To put these "ages" in perspective, A stars live for a billion years!

Look at the colors in the images of the galaxies — you should be able to notice that the "younger" galaxies are in general bluer than the "older" galaxies.

Look up the galaxy at RA = 215.08136 and Dec = 3.9327125. Click on the image on the bottom left to get a larger view. In general, where does the star-formation in the three big galaxies you see seem to be occurring? Nearer their centers or further out?

6. How faint are these stars and galaxies?

The images and spectra you looked at in this lab are MUCH fainter than visible with the human eye — they were obtained with a 2.5m telescope. To get a sense, enter the coordinates of the star Castor into the image search section of the page: RA = 113.65, Dec = 31.888. Castor is about as bright as Polaris. You will need to increase the search radius till you find something. Then look at the image. Do you see what is happening, and why you had to increase the search radius? (Remember that one must be jentle with one's telescopes and

cameras: something too bright will leave a permanent mark on the camera).
Lastly, open the wikipedia page for Castor, and click the link in the top right to wikisky (where it says Coordinates). Zoom out till you see both Castor (alpha-Gem) and Pollux (beta-Gem). Roll over the objects to see their names and their apparent magnitude. Notice that alpha and beta Gem have similar apparent magnitudes, but different colors. Use the menu on the top left where it says DSS, and select SDSS III as your survey. Notice the different colors of alpha and beta Gem. Based on the color you see, predict which should be brighter in X ray, and in Infrared light, and explain why. PLEASE ATTEMPT TO MAKE A PREDICTION BEFORE YOU GO ON! To assure you will, you will not have points taken away if your prediction is wrong.

Which should be brighter in Xray? Why?

Which should be brighter in IR light?

Now switch, using the same menu, to the X-ray sky survey, RASS3, and the infrared survey IRAS, and scroll over objects to identify them (notice the positions on the maps are quite accurate! take care you do not confuse sources.) Does what you see agree with your predictions?