Announcements

- **Reminder**: The first problem set collection (incorporating problems assigned last week as well as this week) will take place next Tuesday, January 29, at the start of class.

Reading Guide

This week we really begin our study of galaxies, having completed the lightning-quick tour of general course background material last week. Much of the reading for this week concerns more background material that will be essential to our study of galaxies, but is assumed prior knowledge for this course and so may not be extensively discussed in class. So, be sure to read it carefully! Following this, we begin our discussion of galaxies with a study of their morphology and then brief consideration of the galaxy we know best, the Milky Way.

1. **Text – Chapter 7, Section 7.3 (partial): Eclipsing, Spectroscopic Binaries.**
   Just read the (important) subsection that begins on p. 187, entitled “The Mass Function and the Mass-Luminosity Relation”, and study the associated Figure 7.7.

2. **Text – Chapter 8, Section 8.2: The Hertzsprung-Russell Diagram.**
   This should be a review for you of the famous H-R diagram; if not, read closely! The key points are on p. 219 – 224. Although not discussed in class, the MK luminosity classification, on p. 225, and the associated definition of spectroscopic parallax, is also handy to be familiar with.

   These sections cover a wide array of topics. For section 9.2, while the whole section contains useful information (and thus it is all assigned), be sure to carefully review especially the material on pages 240 – 244, on mean free path and optical depth; this will turn out to be important both for our study of galaxies as well as, later, cosmology (e.g., the early universe). For §9.3, focus on p. 251 – 254, down to (but, not including) the subsection on limb darkening. Note especially on p. 253 the statement: “Looking into a star at any angle, we always look back to an optical depth of about $\tau_\lambda = 2/3$”. This will be important in one of the homework problems assigned, below. Finally, in §9.5, just read the first subsection on Equivalent Widths.

4. **Text – Chapter 12, Section 12.3 (partial): Pre-Main-Sequence Evolution.**
   Main key concept of import here is that of HII regions, described on p. 431 – 432.

5. **Text – Chapter 13, Section 13.3 (partial): Stellar Clusters.**
   Just familiarize yourself with the reading on p. 474 – 475, on Population I, II, and III stars, and globular and open clusters. The technique of spectroscopic parallax to estimate distances is again described (this time in the context of clusters) on p. 475.

6. **Text – Chapter 15, Section 15.2: The Classification of Supernovae.**
   Supernovae will turn out to be of such fundamental importance to both our study of galaxies (e.g., dispersing metals into the ISM) as well as cosmology (e.g., as brilliant distance indicators), that a working knowledge of the different types is good to have. Don’t split hairs over the details of the various subtypes, but do remember: Type Ia arise from exploding white dwarfs whereas all other types are believed to result from the core collapse and subsequent envelope ejection of massive stars.

7. **Text – Chapter 25, Section 25.1: The Hubble Sequence.**
   Ah. Finally a section on galaxies! This section opens with a recounting of the Great Shapley-Curtis Debate. Though not covered in class, it is historically important and serves to underscore the degree
of disagreement there was in the community prior to Hubble’s discovery of the extragalactic nature of Andromeda. Next, the book goes through (in somewhat more detail) what we covered in class this week concerning the naming (classification) of galaxies. There is a lot of detail given here; the most important bits were covered in class.

8. Optional Reading: From Sparke & Gallagher, Galaxies in the Universe, §1.3: Other Galaxies.

This section provides more detail on the morphological classification scheme for galaxies. Note that section 1.3.1, on Galaxy Photometry, goes into more detail than we covered in class, or is covered by your text.


Before proceeding onward with our study of other galaxies, we first dip back into a quick study of our own Galaxy, the Milky Way, since much of the terminology developed in these sections will be used again when discussing external galaxies. As with all of this “background” material, we shall tread rather lightly on it, picking up only those pieces essential to our study of external galaxies.

For this particular section, begin by reading the introductory paragraph on p. 881, and the first subsection Distance to the Galactic Center very carefully, since it sets the stage for all that is to come. The second subsection, The Structure of the Thin and Thick Disks is useful, especially to get a good sense of what scale height means. The third subsection, The Age-Metallicity Relation, is very important, so read it thoroughly, and be sure you understand the definition of metallicity. The fourth subsection, Age Estimates of the Thin and Thick Disks is useful, just to wrap up the study of these different disk populations. The fifth subsection, Mass-to-Light Ratios presents a very important concept for our study of galaxies; read thoroughly. We’ll likely be covering the remainder of §24.2 next week.

Homework Questions: Due Tuesday, January 29

The following questions represent the second part of the first homework set, which you will turn in at the start of class on Tuesday, January 29. Note that the problem numbering scheme continues from last week (and will continue throughout the semester!)

Please answer the following questions as completely as possible. In the case of numerical problems, please indicate your final answer by circling it. Partial credit for incorrect answers will only be given if work is clearly shown.

12. (15 points total). Point your WEB browser to:

http://corelli.sdsu.edu/courses/astro660_spring2013/galaxy.flm

and download the 2-column ASCII flux spectrum of a galaxy observed as part of the Sloan Digital Sky Survey (http://www.sdss.org/). Note that in this file, the first column is wavelengths in Å, and the second column is flux (at each observed wavelength) in $10^{-17} \text{ erg cm}^{-2} \text{s}^{-1} \text{Å}^{-1}$.

(a) (5 points). Determine the approximate redshift of the galaxy. Hint: Use whatever plotting program you have at your disposal to plot the spectrum, and note that the strongest emission line is Hα.

(b) (5 points). Write a very short computer program to remove the redshift from this galaxy’s spectrum so that you can, in the next part of this problem, plot the galaxy’s spectrum with “rest wavelength” along the x-axis. You may use whatever computer programming language you like (e.g., FORTRAN, c++, IDL, etc.; you may not simply use a software program that already exists, such as IRAF). Ideally, your program should be a general-purpose deredshifting program capable of taking an inputed spectrum, removing its redshift (allowing for the possibility of blueshifted or redshifted initial spectra), and returning the new “rest” wavelength scale for the spectrum. Hand in a printout of your computer code for this part of the problem.
(c) (5 points). Run this galaxy’s spectrum through the program that you wrote for part (b), and then plot the de-redshifted galaxy spectrum using whatever plotting program you like. Verify that the Hα and Hβ emission lines land in the correct location and label them on your plot. For this part of the problem, simply hand in your annotated plot.

13. (5 points) Text, problem 9.7. *Hint:* What optical depth represents the *average* level in an atmosphere from which photons can escape?

14. (5 points) The density of stars in the Galactic midplane belonging to the “thin disk” population at the radial distance of the Sun from the center of the Milky Way is \(\sim 6 \times 10^{-4}\) stars pc\(^{-3}\). Calculate the distance above or below the Galactic midplane (at the radial distance of the Sun) at which the number density of thin disk stars is expected to have dropped to \(\sim 2.22 \times 10^{-4}\) stars pc\(^{-3}\).

15. (5 points) A star is measured to have \([\text{Fe/H}] = -2.0\). If the Sun has \(\left(\frac{N_{\text{Fe}}}{N_{\text{H}}}\right) = 3 \times 10^{-5}\), where \(N_{\text{Fe}}\) and \(N_{\text{H}}\) equal the number of iron and hydrogen atoms, respectively, then how many H atoms are there for each Fe atom in the star? What does \(\left(\frac{N_{\text{Fe}}}{N_{\text{H}}}\right)\) equal for the star? Is this star considered to be metal-rich or metal-poor? (Be sure to directly answer all 3 questions!)

16. (30 points total) For this problem, you will calculate the metallicity of an HII region by measuring relative line strengths in its spectrum.

Point your WEB browser to:

http://corelli.sdsu.edu/courses/astro660/spring2013/HII.fla

and download the 2-column ASCII flux spectrum of an HII region observed as part of the recent study by Galyam & Leonard (2009, Nature, 458, 865) discussed in class. Note that in this file, the first column is wavelength, in Å, and the second column is flux (at each observed wavelength) in erg cm\(^{-2}\) s\(^{-1}\) Å\(^{-1}\).

(a) (5 points) In a manner similar to what you did in Problem 12 for the galaxy spectrum (i.e., you wrote a computer program to do this!), determine the redshift of the spectrum, remove the redshift from the spectrum, replot it, and label the following narrow emission lines: [OII]\(\lambda\lambda 3726/3729\) (unresolved in this spectrum, the doublet appears as a single line), [NII]\(\lambda 6548\), [NII]\(\lambda 6584\), Hβ, and Hα.

(b) (15 points) Calculate the metallicity of this HII region, expressed as \(\log(O/H) + 12\). For this part, you may assume that the reddening to the HII region is \(A_V = 0\) mag. To calculate the metallicity:

- Download and read through Kewley & Dopita 2002, ApJS (Astrophysical Journal Supplement Series), 142, 35, to determine the best way to estimate metallicity for this HII region, given the available lines. (Note that this and all papers referred to in this course can be downloaded from the NASA ADS website: http://adsabs.harvard.edu/bib.abs.html .)
- Measure the fluxes of the appropriate emission lines, and report your answers in erg cm\(^{-2}\) s\(^{-1}\). You may just manually add up the flux for each line, or use a more sophisticated algorithm, e.g., IRAF or IDL. *Hints:* To measure the strength of an emission line manually:
  - Determine the “continuum” level of the spectrum at each emission line of interest. The continuum is the flux value that underlies the emission lines – that is, it’s what the spectrum would likely have looked like in the absence of the emission lines. You can estimate this value by considering the spectral regions immediately around the emission line. Note that the spectrum does not have great signal-to-noise ratio, and so you’ll have to make the best estimate that you can.
  - Add up the flux under each emission line of interest. To do this, take the measured flux value in each “wavelength bin”, subtract the continuum value, and multiply the result by the width of the bin (each bin should be roughly 2 Å). Do this for all bins across the emission line, and add up all the values together. The resulting number is the total flux in the emission line, in units of erg cm\(^{-2}\) s\(^{-1}\).
• Derive the appropriate flux ratio needed to determine the metallicity of the HII region, and then determine the metallicity (expressed as \( \log(O/H) + 12 \)) using the appropriate relation from Kewley & Dopita (2002), showing all steps in your process.
• Compare your value with the solar value of \( \log(O/H) + 12 = 8.66 \). Is the gas in this galaxy near the supernova more metal rich than the Sun?

c) (10 points) Redo the calculation of part (b), but now assume that \( A_V = 1.0 \) mag to the HII region, and correct for the effects of the interstellar reddening. \textit{Hint:} To do this, you will need to estimate the amount of the flux that has been \textit{removed} from the light due to the effects of interstellar dust absorption (i.e., extinction). This amount, of course, is wavelength dependent, and thus will change the line ratio that you derived in part (b), which was used to determine the metallicity. What \( A_V = 1.0 \) mag” is telling you is that there is one magnitude of extinction at the “effective wavelength” of the V band, which is \( \lambda_V \approx 5500 \) Å. Naturally, wavelengths to the blue of this will have a greater extinction, and those to the red will have less extinction. Your job here is to figure out how the flux ratio for the lines of interest calculated earlier change due to the effects of interstellar reddening (i.e., more blue light is removed, compared with red light), and then how this change affects the metallicity determination. To do this, you may find the following website useful:

http://dogwood.physics.mcmaster.ca/Acurve.html

This website enables you to calculate the extinction at any wavelength \( (A_{\lambda}) \), given the extinction in the V band \( (A_V) \). You may assume that \( R_V = 3.1 \) (known as the extinction coefficient). Note that wavelengths are entered in microns at this website.

17. (10 points). Suppose the mass-to-light ratio of the stellar content of the disk of a spiral galaxy is found to be \( M/L \approx 2 \) \( M_\odot/L_\odot \). Assuming that the majority of the stars in the disk are main-sequence stars \( > 0.5 \) \( M_\odot \), for which the normal mass-luminosity relation applies, what is the “typical” mass of a star responsible for the light coming from this disk (i.e., \( < M > \))?