Announcements

• Welcome to Astronomy 660: Galaxies and Cosmology! This handout is much like the ones that you will receive every Monday throughout the course. On them, you will always find current class Announcements and the weekly Reading Guide and Homework Questions. In addition to this handout, a separate handout will also typically be given out that contains a subset of the Powerpoint slides that will be shown during the week’s (or class’) lectures.

• Purchase a copy of the text book. As stated in the course syllabus, the required text for this course is An Introduction to Modern Galactic Astrophysics and Cosmology, second edition, by Bradley Carroll & Dale Ostlie. Note that first edition copies of this text are no good, as there have been very substantial changes made for the second edition. The book is on sale at the SDSU Bookstore for $118.40 (new) and $91.42 (used; used copies are fine!). (If you own – or wish to purchase – a copy of the larger “Big Orange Book” by Carroll & Ostlie (An Introduction to Modern Astrophysics), that is OK, but you’ll have to make sure you’re doing the correct reading assignments and problems that are being assigned, since all page numbers and chapters will refer to the smaller book.)

• Consider purchasing the “recommended” texts. In addition to the required text, there are two books that are recommended:

  – Introduction to Cosmology, by Barbara Ryden ($77.49 new, $59.80 used)
  – Galaxies in the Universe: An Introduction, by Linda S. Sparke and John S. Gallagher III ($76.99 new, $59.40 used)

Throughout the course, I will be recommending that certain sections of these books be read, to augment the required text readings.

Reading Guide

This week, we begin with a reading assignment that should largely consist of review material for you, and is thus not being covered in lecture. It is essential that this material be thoroughly understood prior to embarking on the rest of the course, so read the material carefully! You may find it helpful to have the Astronomy 660 Toolkit handout handy as you read through these sections, since it highlights the most important material covered, and (roughly) follows the order of the readings given below.

All text readings refer to the text: An Introduction to Modern Galactic Astrophysics and Cosmology, second edition, by Bradley Carroll & Dale Ostlie.

1. **Text – Chapter 2, Section 2.1: Elliptical Orbits.** This section provides a review of Kepler’s 3 Laws of planetary motion, of which the most important is #3, since Newton’s reformulation of it provides the means by which astronomers still determine the masses of objects’ that are in orbits. The other laws are useful since they provided the means by which Isaac Newton was able to test his force laws and, especially, his law of universal gravitation. The end of the section, on ellipses, is worthwhile to glance at, but we shall not be using the equations in this course.

2. **Text – Chapter 2, Section 2.2: Newtonian Mechanics.** Read this entire section thoroughly, as it provides the entire Newtonian framework within which we shall be studying gravity for much of the rest of the course (i.e., until we hit Einstein’s Theory of General Relativity). The derivations are succinct, and should be understandable to you.

3. **Text – Chapter 2, Section 2.3: Kepler’s Laws Derived.** Only parts of this section are really vital to have thoroughly under your belt for this course. The first parts of the section, on reduced mass and angular momentum, should be familiar to you from classical mechanics, and are worth a look but will not be used much in the rest of the course. The first major concept worthy of focused effort
comes at the bottom of p. 49, where you are reminded that the total energy of a binary orbit is exactly one-half the time-averaged potential energy of the system – an idea critical to understanding the virial theorem, which will prove to be a very important concept for our study of galaxies. Finally, Newton’s version of Kepler’s Third Law, derived on p. 50 and discussed on p. 51, is very important; as the text says: “The importance to astronomy of Newton’s form of Kepler’s third law cannot be overstated.” A very true statement, indeed.

4. **Text – Chapter 2, Section 2.4: The Virial Theorem.** Focus here mainly on the results of the Virial theorem, and not so much on its derivation. The main thing to recognize is that the Virial theorem will crop up again later in the course when we are trying to estimate masses of structures (centers of spiral galaxies, elliptical galaxies) through the analysis of the average velocities of stars.

5. **Text – Chapter 3, Section 3.1: Stellar Parallax.** Establishing the distance scale for the universe will be a key part of the course, and it all begins with trigonometric parallax. Key point: parallax is by far the best distance measure that we have. Its limitation, of course, is that at present it can only be applied very nearby. This should change, however, in the coming decades, as its use will be expanded to include nearby galaxies.

6. **Text – Chapter 3, Section 3.2: The Magnitude Scale.** Yup, it seems every astronomy course starts with a discussion of magnitudes. Why? Because they’re quite confusing, but essential to understand in order to interpret observations, and observational cosmology is no different. Of all of the equations in this section, by far the most important to tuck away for later is Eq. 3.6, which defines the distance modulus. Remember, distance modulus is the quantity that is actually measured by astronomers for standard candles. This point will be key when we come to discuss the use of standard candles (e.g., Type Ia supernovae) to determine cosmological parameters.

7. **Text – Chapter 3, Section 3.3: The Wave Nature of Light.** Eq. 3.10 is the main thing you want to remind yourself of from this section, as well as Table 3.1, which shows you the various wavelength regions of the electromagnetic spectrum. The material on the Poynting vector is less important for our purposes, as are the specific formulae for radiation pressure (but do know that radiation can exert a pressure!) We’ll be much more interested in the equation for blackbody radiation pressure in §3.5, so be sure to refresh yourself on it.

8. **Text – Chapter 3, Section 3.4: Blackbody Radiation.** Everything in this section is crucial to have under your belt. The early universe was filled with thermal radiation, whose properties we shall study in depth.

9. **Text – Chapter 3, Section 3.5: The Quantization of Energy.** The key bits of this section to remind yourself about are the fact that the blackbody function is perfectly described by applying the laws of quantum mechanics, and is given by the Planck function (Eq. 3.22; we shall not be using this specific equation all that much, but do know that it exists). Also critical, of course, is the introduction of $h$, Planck’s constant, which sets the stage for understanding the particle properties of light (i.e., photons). Don’t worry so much about the discussion of monochromatic luminosity and flux; focus in on the final results of that discussion that occur on p. 89, specifically, the total energy density and radiation pressure of blackbody radiation.

10. **Text – Chapter 3, Section 3.6: The Color Index.** Yes, more fun with magnitudes. Here you want to come away with the basic fact that astronomers often use the color index as a proxy for temperature: Generally, the lower the color index, the hotter the object. Since stars (and other objects) are not perfect blackbodies, however, there is not always a neat 1-to-1 correspondence between color index and temperature; however, the color index is the quantity actually measured by astronomers and so is very important to understand. And, stars are, in fact, quite good blackbodies (as are stellar explosions – i.e., supernovae – at early times after the explosion). Don’t worry too much about the details of bolometric corrections and sensitivity functions, but do have a working understanding of what these things are.
11. **Text – Chapter 4, Section 4.3: Time and Space in Special Relativity.** You have hopefully met special relativity in a genuine physics course before; in this class (as with much of this physics intro.), we concern ourselves mainly with the results of the theory, and less with its formal derivation. In the end, we shall really be mainly concerned with the relativistic Doppler Effect (described on p. 111 – 113), and so that is the crucial piece of this section to get under your belt. However, to understand the surrounding discussion, it is necessary that you grasp Eq. 4.27, the time dilation equation. Once that is understood, skip over to p. 111, and read the section on “Relativistic Doppler Shift”. The most important equations are the definition of the redshift parameter (Eq. 4.34), as well as Eq. 4.37, which tells how observed and emitted time durations are affected by relative motion. Example 4.3.2 at the bottom of p. 113 is useful to look through, as it will introduce you to the concept of “cosmological redshift”, a topic to be described in great detail later on. You may skip the last two subsections of this section (on relativistic velocity transformation and synchrotron radiation). Note that if you want a really good introduction to special relativity, I highly recommend the physics text by Arthur Beiser, *Concepts of Modern Physics*; Chapter 1 of this book gives the best introduction to special relativity that I know of.

12. **Text – Chapter 4, Section 4.4: Relativistic Momentum and Energy.**

Well, you obviously will need to know $E_{\text{rest}} = mc^2$ for this class, so here it is. In this section, equations 4.46, 4.47, and 4.48 are the most important ones, and the discussion leading up to them on pages 117 and 118 should help to physically motivate them. You need not spend time (re)learning the derivation of relativistic momentum presented on p. 119 – 121; again, here we are just concerned with the results.

13. **Text – Chapter 5, Section 5.1: Spectral Lines.**

Read pages 126 – 129, on Kirchoff’s Laws and stellar spectra (and the interpretation of Doppler shifts). Of the spectral lines given in Table 5.1, by far the most important one to memorize is that of H$_\alpha$, for which $\lambda_0 = 6563$ Å; coming in close second are the Ca II K and H lines at 3934 Å and 3969 Å, respectively. You may skip the subsection on spectrographs that concludes this section.

14. **Text – Chapter 5, Section 5.2: Photons.** The particle nature of light is described, along with the experiments that led to its discovery. Equation 5.5 is the key point to take away:

$$E = \frac{hc}{\lambda}$$

Note the useful unit combination $hc = 12,400$ eV Å.

15. **Text – Chapter 5, Section 5.3: The Bohr Model of the Atom.**

In this section, Carroll and Ostlie provide a rather standard physics-text introduction to the strange world of the quantum atom. They build on classical ideas about angular momentum and wave interference in an effort to explain the observed spectrum of the simplest atom, hydrogen. Unfortunately, the quantum atom is not based on classical ideas, and I believe that any “intuition” developed through such an approach is ultimately misleading. Thus, I feel the simplest way to attack the quantum atom is to simply accept what it predicts; “intuition” then follows. To this end, the most important reading in § 5.3 occurs on pages 134 and 135, and then pages 141, 142, and 143. Pages 136-140 discuss the Bohr atom, which ultimately provides a useful construction for visualizing the process of quantum transitions, but its semi-classical assumptions are, in fact, incorrect. Therefore, you may skim over this middle section; but do pause to remind yourself about what it means to ionize an atom, and also what is meant by the principal quantum number. Since hydrogen will turn out to be an extremely important element for our study, understanding how to use Equation (5.14) will also be useful. But do not worry about the semi-classical explanation of the Bohr atom found on pages 136 and 137. After reading this section, you should have a good mental image of quantum transitions, and a solid understanding of Kirchoff’s laws, as explained by quantum mechanics.

16. **Text – Chapter 13, Section 2: The Expansion of the Universe.**

This whole section is vital to the rest of the course; read carefully.
Homework Questions: Due Monday, February 9

The following questions represent the first homework set, which you will turn in at the start of class on Monday, February 9.

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. All problem numbers refer to the end of chapter questions from the text.

1. (5 points) In a far-away planetary system, planet ShiAnne is orbiting star Shimonee in a perfect circle, with an orbital velocity of 100 km/s. In this same system, Comet Alex, which is on a purely radial orbit, is rapidly approaching star Shimonee (i.e., it will ultimately crash into the star), and is now at the same distance from star Shimonee as planet ShiAnne is (but note that Comet Alex will not crash into planet ShiAnne or, in fact, be even remotely affected by its gravity). If one assumes that Comet Alex began its journey from very far away from star Shimonee, estimate the approximate velocity of comet Alex at the present time.

2. (5 points) Our Sun orbits the center of the Milky Way galaxy roughly once every 250 million years, and is believed to be about 8 kpc from the center. Use this information to estimate the total mass of the Milky Way interior to the Sun's orbit. Express your answer in terms of solar masses ($M_{\odot}$). (You will find the table of astronomical and physical constants on the inside cover of your text to be helpful!)

3. (5 points) Problem 3.2.

4. (10 points, 5 for part (a) and 5 for part (b)). Problem 3.3.

5. (14 points, 2 for each part). Problem 3.9. Hint: Expressing the answer for part (a) in terms of solar luminosity, $L_{\odot}$, will assist in solving part (b).

6. (10 points, 3 each for parts (a) and (c), and 4 for part (b)). Problem 3.15.

7. (5 points) In the observed spectrum of Barnard’s star, the Ha absorption line is observed to have a wavelength of 6560.34 Å. What is the radial velocity of Barnard’s star?

Problem Set continued on next page →
8. (6 points). The figure below shows the observed spectrum of a young supernova. From the identified locations of the H\textalpha{} and H\beta{} emission lines in the observed spectrum, estimate the redshift parameter of the supernova.

![Supernova Spectrum](image)

9. (10 points). “Type II-Plateau” supernovae have optical light-curves that are characterized by a quick rise to maximum, followed by an enduring “plateau” phase of nearly constant optical brightness. Let's assume (incorrectly, but OK for this problem) that the plateau phase of all Type II-Plateau supernovae intrinsically lasts exactly 100 days. Now, suppose that the optical “plateau” in the light curve of a very distant Type II-Plateau supernova is observed by an Earth-based astronomer to last for 150 days. Using this information, calculate the expected wavelength of the emission peak of the H\alpha{} line ($\lambda_{0} = 6563$ Å), in Angstroms, in the observed spectrum of this supernova.

10. (15 points total). Point your WEB browser to:
http://corelli.sdsu.edu/courses/astro660_spring2009/reading/reading1/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 $10^{-17}$ erg cm$^{-2}$ s$^{-1}$ 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 H\alpha{}.

(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.

11. (15 points total) A hydrogen atom, initially in the ground state, absorbs an ultraviolet photon of wavelength 973 Å.

(a) (3) What is the energy of this photon, in eV?

(b) (2) To what energy level, n, is the electron in the hydrogen atom excited (note: Due to roundoff, the energy you calculated in part (a) may not perfectly match an electronic transition in the hydrogen atom; for the purposes of this problem, let’s assume that if it is close (i.e., within 0.2 eV), then it is OK and the transition will occur!)?

(c) (5) Make an energy level diagram similar to Figure 5.7 (in the text) that shows the initial absorption and then all of the possible emission lines that may result as the electron cascades from this excited state back down to the ground state. Label the lines that belong to the Lyman, Balmer, and Paschen series (i.e., Hα, Lβ, etc.).

(d) (5) Calculate the wavelengths, in Å, for all of the possible emission lines that you identified in part (c).