**Announcements**

- **Reading Quiz due *TONIGHT* at 11:55 PM!** The on-line reading quiz (“Quiz 10”), based on material from your reading for last week, is due tonight, Tuesday, December 1, by 11:55 PM. After that time, the reading quiz will no longer be available, and no late assignments will be accepted for any reason. Full solutions will be posted 10 minutes after the quiz is due at the textbook web-site (and shortly thereafter at the course web-page as well).

- **Final exam in two weeks.** As stated in the course syllabus (printed in the Course Reader), the final examination in this course will take place at the following times and locations:
  
  **Section 6 (11 AM class):** Tuesday, December 15, 10:30 AM → 12:30 PM, Room PA-216 (normal lecture room).

  **Section 8 (2 PM class):** Tuesday, December 15, 1:00 PM → 3:00 PM, Room NE-060 (normal lecture room).

  Details about the nature of the final exam are given in the Course Reader in the document in the “Exam Preparation Material” section entitled “Final Exam Review Guide”, and will be discussed next week in class. Do note the following:

  1. The final exam must be taken at the scheduled time, and no makeup (or early) exams will be given.

  2. *The final examination is cumulative*, and will cover the entire course’s content with equal emphasis (roughly; there will be a slight emphasis given to the content since the second midterm – i.e., the last 6 lectures).

  3. As with the midterm exams, you will again be permitted to bring an official “cheat sheet” to the final exam.

- **Guest lecturer this week!** As mentioned in last week’s handout, this week’s class lectures will be delivered by Mr. Alex Burke. You are probably familiar with Alex already, since he is one of our Teaching Associates this semester. I think you will find his lectures to be extremely interesting, as they will cover a fascinating and important topic in astronomy: Galaxies. Alex will be covering exactly the same slides from the Course Reader that I would have covered, had I been here to deliver the lectures myself, so pay close attention!

- **Office hours changed on Friday, December 4.** This week, my Friday office hours will be held from 4:00 PM - 5:00 PM (instead of the usual 12:00 - 2:00 PM).

**Reading Guide and Homework Assignment**

*(On-Line Reading Quiz #11 Due: Friday, December 11, 11:55 PM)*

Note: This is the final reading assignment of the course, and covers all of the material to be presented during the final two weeks of class. Since it goes beyond what we shall cover this week alone, the full reading assignment is formally due until the last day of class, next Thursday, December 10. I am giving you the full remainder of the readings now since I want you to know what you will be responsible for on the final exam well in advance. It is strongly advised that you complete this reading by the last day of class. So, onto the readings:

This week we move outwards to discuss how astronomers measure distances to far away objects in the Universe, concluding with a discussion of galaxies. Then, we conclude the course by finally tackling the really BIG questions, and they concern the study of cosmology: Did the Universe have a beginning? Will it come to an end? What is it doing right now? These readings present to you the scientific answers to these questions. Note that I am having you (again) read some sections slightly out of order in the text, since it better reflects the way the material was presented in lecture; you may, of course, read the text in any order that you like – just be sure to read it!
1. **Text — Chapter 10, Section 10.1: Fundamental Units of Distance.**

   This first section covers what should be familiar territory by this point in the course: the definitions of common distances used in astronomy, such as the light-second, and the astronomical unit. It also discusses some of the techniques used to measure distances in the Solar System.

2. **Text — Chapter 10, Section 10.2: Surveying the Stars.**

   This section moves outward from our Solar System, and discusses how distances to the nearest stars are measured through the quantitative relation between the *parallax* of a nearby star and its *distance* from us:

   \[ D = \frac{1}{p} \]

   where \( D \) is the distance in parsecs (1 parsec = 3.26 light years), and \( p \) is the *parallax* of the star, defined to be one-half the angle that a star shifts when seen from opposite sides of Earth’s orbit, in arcseconds. You should be able to work with this equation to derive distances when given measured parallaxes (and vice-versa).

3. **On-line tutorial:** On the “Tutorial: Chapter 10” section of the textbook website, look at the *Astronomy Exercise* called “Parallax II”. We looked at this one in class, and it provides a nice demonstration of just how parallax is used to determine the distances of nearby stars.

4. **Text — Chapter 10, Section 10.3.1: Standard Bulbs Revisited.**

   This section reviews the already-introduced topic of *standard candles* or, as your book prefers, *standard bulbs*. The power of standard bulbs for determining distances is vital to establishing the distance scale in astronomy, and the most accurate class of objects that can be used as standard bulbs in the nearby universe is the so-called Cepheid star. The complete details of these interesting stars are given in the next four subsections of the book (i.e., §10.3.2 → §10.3.5), which are not being assigned. As discussed in class, we are skipping over these details. Here’s what you need to know about Cepheids:

   **Cepheid star:** A type of supergiant star that is up to 10,000 times more luminous than the Sun. In 1910, Henrietta Leavitt determined that Cepheids could be used as standard candles. It was Edwin Hubble who, in 1924, used Cepheids to determine the distance to the Andromeda nebula, and found it to be very far away — about 1 million light years (a bit shorter than today’s best estimate of 2 million light years, but nonetheless very far!). Cepheids have now been used to measure distances out to about 100 million light years.

5. **Text — Chapter 17, Sections 17.1 and 17.2: The Great Nebula Debate and Types of Galaxies.**

   Start by reading the introduction on page 383 as well as the caption to the picture of the *Hubble Deep Field* on page 382. Section 17.1 opens the chapter by recounting the “Great Nebula Debate”, and how it was resolved by Edwin Hubble’s discovery that the spiral nebulae are, in fact, large stellar systems separate from our Milky Way Galaxy (itself a large spiral galaxy). §17.2 walks you through the different *types* of galaxies. Focus attention on the *differences* among the three basic types.

6. **On-line tutorial:** On the “Tutorial: Chapter 17” section of the textbook website, look at the *Active Figure* called “Galaxy Types”. This is a nice interactive applet that allows you to explore the differences among elliptical, spiral, and barred-spiral galaxies. Notice in particular how a spiral galaxy *rotates*, whereas the stellar motions in an elliptical galaxy are much more randomized.

7. **Text — Chapter 16, Section 16.3: The Mass of the Galaxy.**

   Read here about the discovery of *dark matter*, both in our Galaxy (the Milky Way) as well as throughout the Universe. Notice, in particular, that it is the use of Newton’s version of Kepler’s Third Law that provides the main evidence for the existence of dark matter in the Milky Way. The end of §16.3.2 goes into a bit more detail on the possibilities for dark matter than we did in class, but the bottom line is, as of now, we don’t know what it is and a number of seemingly “likely” candidates have been shown to be incorrect. Any ideas?
8. On-line tutorial: On the “Tutorial: Chapter 2” section of the textbook website, look again at the Astronomy Exercise called “Orbital Motion”, and simply do the following: Adjust the mass of the Sun so that it is 0.5 \( M_{\text{Sun}} \). Notice how slowly the planet orbits it. Then, increase the Sun’s mass so that it is 2.0 \( M_{\text{Sun}} \). Look how Earth’s orbital velocity speeds up! Conclusion: The greater the mass interior to an orbit, the faster that orbit will be. This concept is crucial to an understanding of how dark matter is detected in galaxies.

9. **Text — Chapter 17, Section 17.3.1: Masses of Galaxies.** Read here about how the masses of galaxies are derived by analyzing the spectra of objects (stars) or material (interstellar gas) in the galaxies. Note that dark matter is inferred to exist in both spiral and elliptical galaxies.

10. **Text — Chapter 16, Section 16.4: The Center of the Galaxy.**

    Here you take a somewhat more detailed journey to the center of the Milky Way galaxy than was presented in class, and read about all of the evidence that a “supermassive” black hole exists in the very center of the Milky Way. Pay particular attention to the fact that it is the orbits of stars very close to the center that provides the main “proof” for the existence of a black hole in the galaxy’s center, and recall our class discussion on this subject.

11. **Text — Chapter 18, Section 18.3.1: Observational Evidence for Black Holes.**

    Read here about the evidence for supermassive black holes lurking at the centers of nearly all galaxies, not just the Milky Way! And especially, note again that the main evidence comes from studying the orbital properties (i.e., Newton’s version of Kepler’s Third Law strikes again) of stuff (stars, gas, dust, etc.) located very close to the centers of these other galaxies.

12. **Text — Chapter 17, Sections 17.4.1 and 17.4.2: The Extragalactic Distance Scale: Variable Stars and Standard Bulbs.**

    These sections continue the discussion of how distances are measured in the universe by recapping the use of Cepheid stars (which we did not discuss in detail, other than to say they can be used as standard candles), and then moving on to discuss the use of Type Ia supernovae as standard candles (or ‘bulbs’). Type Ia supernovae have turned out to be astronomers’ most precise distance indicator at very large distances – distances well beyond where Cepheid stars can be used.

13. **Text — Chapter 17, Section 17.5: The Expanding Universe.**

    Read here about how the observations of Hubble, Humason, and Slipher led to Hubble’s discovery of the expanding universe. Really make sure that you understand just how Hubble’s original velocity-distance relationship, as shown in Figure 17.18, leads naturally to the conclusion that our Universe has been expanding since a primeval explosion occurred at a specific point in time in the past.

14. On-line tutorial: On the “Tutorial: Chapter 17” section of the textbook website, look at the Active Figure called “Raisin Bread”, to solidify the analogy between the expanding universe and a loaf of rising raisin bread in your mind. We looked at this figure in class; be sure to read the summary in the “Intro” section, after playing with the active figure a bit.

15. **Text — Chapter 19, Section 19.3.1: The Cosmological Principle.**

    Read this brief section on the cosmological principle: the assumption that, on large scales, the universe at any given time is the same everywhere; that is, it is isotropic and homogeneous.

16. **Course Reader — Required Reading: An Expanding Universe, Measuring the Expected Deceleration, and The Future of the Universe.** (See the Course Reader’s Table of Contents for exact page numbers.)

    We conclude our reading for the course with excerpts from the final pages of the popular astronomy textbook by Jay Pasachoff and Alex Filippenko, *The Cosmos: Astronomy in the New Millennium*. This text gives an excellent presentation of the latest results in cosmology, and is somewhat more up-to-date than our course textbook.
The first reading, *An Expanding Universe*, is essentially a recap of material presented by your textbook, which you read earlier in this assignment. The last two sections, *Measuring the Expected Deceleration*, and *The Future of the Universe*, concern the ultimate fate of our Universe, and are essentially what will be covered by the final lecture in the course, on Thursday, December 10.

→ Optional Astronomy Podcast, from Astronomycast.com: Episode 5: *The Big Bang and Cosmic Microwave Background*, available at http://www.astronomycast.com/, as well as through iTunes. Nicely presented, and goes beyond what we considered in class to include a discussion of the Cosmic Microwave Background, which is additional evidence for the Big Bang cosmology.

17. **On-line reading quiz (Due: 11:55 PM, Friday, December 11):** Take the final reading quiz of the semester by clicking on the “Quiz 11” assignment at the on-line textbook web-site. The Reading Quiz will become available to you at 12:05 AM, Wednesday, December 2. **It consists of only *1* question**, which is an essay of a rather philosophical nature. You will receive full credit (i.e., 100%) for any answer that you give, but you must take the quiz to get your 100%! You must complete this on-line quiz by 11:55 PM Friday, December 11 (note the extension to a Friday due date to give you a little extra time to think about the question). You need only take the quiz once, as you are guaranteed a 100% the first time!

(A supernova graces the cover of Time Magazine, in 1987.)