Astronomy 660: Galaxies and Cosmology
San Diego State University
Spring 2011

Lecture times and locations: T/Th 3:30 – 4:45 PM, Rm. GMCS-305 (Geology-Mathematics-Computer Sciences building).

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Office Hours: Fridays, 12:00 – 2:00 PM, and by appointment
Website: http://sciences.sdsu.edu/~leonard/astro660
Required course text: *An Introduction to Modern Astrophysics*, **second edition**, by Bradley Carroll & Dale Ostlie.
Recommended texts: *Introduction to Cosmology* (first edition), by Barbara Ryden.
Galaxies in the Universe (second edition), by Sparke & Gallagher.

Course Description

Astronomy 660. Galaxies and Cosmology

Here we consider the universe on the grandest of scales, focusing on cosmology (extragalactic distance scale, Hubble expansion, Newtonian and relativistic cosmology, early universe and cosmic microwave background) and galaxies (morphology, contents, photometric properties). A particular emphasis will be placed on how (very) recent observations are being used to constrain cosmological models.

Student Learning Objectives

Upon completing this course, you should be able to:

- Construct an argument based on astronomical evidence that the universe has evolved from a hot, dense state;
- Present the currently favored scientific theory for what the ultimate fate of our universe will be, and outline the astronomical observations upon which it is based;
- Discuss the major morphological and kinematic similarities and differences among spiral, elliptical, and irregular galaxies;
- Describe the astronomical observations that compel astronomers to believe in the existence of dark matter and dark energy;
- Describe at least three major areas in extragalactic astrophysics in which our astronomical knowledge is known to be incomplete.

Course Schedule[1]

Week 1 (January 18 → January 24): *A Beginning*

Topics covered – Edwin Hubble's discovery; course introduction; Assumed background knowledge — the Astronomy 660 Toolkit: Newton's laws, using Newton's formulation of Kepler's Third Law to measure mass, Virial theorem, Trigonometric parallax, Magnitudes, Flux and Luminosity, Distance modulus, light: wave nature, blackbody radiation (Planck's function, radiation pressure and density), introduction to spectroscopy, UBV filters and color index, relativistic Doppler shift (redshift and blueshift), $E = mc^2$, spectral lines and Kirchoff's Laws, Photons, Bohr atomic model and hydrogen's spectral lines; The Expansion of the Universe and the true meaning of cosmological redshift; Hubble constant; the Cosmological Principle.

→ Note: The first class is on Thursday, January 20.

Week 2 (January 25 → January 31): *Cosmology Made Simple: A Newtonian Approach*

Topics covered – Hubble time; cosmic scale factor; Newtonian formulation of a pressureless, dust-filled universe; dynamics of a Newtonian universe; lookback time; the Friedmann, fluid, and acceleration equations.

Week 3 (February 1 → February 7): *The Big Bang*

Topics covered – The fluid equation and the equation of state; the generalized equations of cosmology; deceleration parameter; competing cosmological models, c. 1950: The Big Bang vs. Steady State; the Big Bang wins: Discovery of the CMB.

→ Last day to drop classes: 11:59 PM Tuesday, Feb. 1.
→ Last day to add classes: 11:59 PM Thursday, Feb. 3.

Week 4 (February 8 → February 14): *The Evolving Universe*

Topics covered – The Cosmological Principle upheld: Sunyaev-Zel'dovich Effect; first law of thermodynamics; review of quantum mechanics: spin states, bosons, fermions, anti-particles, neutrinos; review of statistical mechanics: Bose-Einstein statistics, Fermi-Dirac statistics, degrees of freedom, Boltzmann and Saha equations; key moments in cosmic history; expansion history of universe; concordance cosmology.

Week 5 (February 15 → February 21): *A General Relativity Primer*

Topics covered – Big Bang nucleosynthesis; origin of the CMB and the surface of last scattering; general theory of relativity and the curvature of spacetime; proper time; coordinate distance vs. proper distance.

Week 6 (February 22 → February 28): *Relativistic Cosmology*

Topics covered – Spacetime interval; metric for flat spacetime; curved spacetime *outside* of a mass concentration: the Schwarzschild metric; proper time and distance; Friedmann equation with curvature; curved spacetime *inside* a dust-filled universe: The Robertson-Walker metric; Einstein's biggest blunder: The Cosmological Constant and dark energy; model universes on the $\Omega_m - \Omega_\Lambda$ plane.

Week 7 (March 1 → March 7): *The Cosmological Constant*

Topics covered – Age of universe with cosmological constant; particle horizon; cosmological redshift derived; distances in an expanding universe; maximum visible age.

[1] All dates subject to changes announced in class. Please consult each week's *Weekly Handout* for the specific textbook and *Course Reader* readings assigned each week.

Week 8 (March 8 → March 14): *Observational Cosmology*

Topics covered – How distances are actually measured in astronomy: Parallax, Cepheids, and Type Ia supernovae; luminosity distance; redshift-magnitude relation.

Week 9 (March 15 → March 21): *The Surprise of the Century: The Accelerating Universe*

Topics covered – The very latest supernova results; understanding the supernova result: statistics review/error analysis; constraining the equation of state parameter w; dark energy.

Week 10 (March 22 → March 28): *The Very Early Universe*

Topics covered – Angular diameter distance; examining the CMB; the very early universe and inflation: Unification and spontaneous symmetry breaking, problems with the standard theory of the big bang, inflation, the false vacuum, the CMB and the decoupling of matter and radiation.

Week 11 (March 29 → April 4): *Matter at Rest*

Topics covered – Sitting on the beach.

→ Note: No class on March 29 or March 31 — it's Spring Break!

Week 12 (April 5 → April 11): *The Cosmic Microwave Background*

Topics covered – Acoustic oscillations and damping; cosmic harmonics and acoustic oscillations; fine-tuning our understanding of cosmic harmonics; implications of the angular power spectrum peaks. Background material for study of galaxies: H-R diagram, stellar mass-luminosity relation, metallicity, interstellar dust and extinction; H II regions; 21-cm radiation of hydrogen.

Week 13 (April 12 → April 18): *Introduction to Stars and Galaxies*

Topics covered – Metallicity (Z) and Population I, II, and III stars; globular clusters; the Hubble sequence.

→ **Midterm Exam taken in class on Tuesday, April 12.**

Week 14 (April 19 → April 25): *The Milky Way and Spiral Galaxies*

Topics covered – Brief overview of Milky Way contents and morphology: age-metallicity relation, mass-to-light ratio, Galactic bulge, disk, and Stellar halo, globular clusters, rotation curve and evidence for dark matter, the Galactic Center, evidence for a supermassive black hole; $r^{1/4}$ law; Spiral galaxies: Morphology, rotation curves, Tully-Fisher relation, mass-to-light ratios, metallicity gradients, supermassive black holes and their relation to other observables.

Week 15 (April 26 → May 2): *The Nature of Galaxies*

Topics covered – Globular clusters, introduction to density-wave theory, X-ray luminosity, abundance of dust, K-correction. Elliptical galaxies: Morphological classes, dust and gas content, metallicity, surface brightness profiles, kinematics of stellar population (Faber-Jackson relation; fundamental plane, rotation parameter).

Week 16 (May 3 → May 9): *Elliptical Galaxies*

Topics covered – Malquist bias; elliptical galaxies: morphology-density relation, correlations with diskiness/boxiness; galaxy luminosity function; galaxy evolution.

Week 17 (May 10 → May 17): *Large-Scale Stucture of the Universe*

Topics covered – Galaxy clustering; observed large-scale structure.

→ Note: The last class is Tuesday, May 10.

→ Final Exam: Tuesday, May 17 1:00 PM → 3:00 PM, Room GMCS-305 (normal lecture room).

Note: The "final exam" in this course will consist of final oral presentations, and will take place during the time scheduled for the final exam.

→ Final Project written report due by Thursday, May 19, 5:00 PM.

Assignments and Course Grades

Course grades will be based on the following scale:

Grade	Percentage
A	93.00 – 100%
A-	90.00 – 92.99%
B+	85.00 – 89.99%
B	75.00 – 84.99%
B-	70.00 – 74.99%
C+	65.00 – 69.99%
C	55.00 – 64.99%
C-	50.00 – 54.99%
D+	45.00 – 49.99%
D	35.00 – 44.99%
D-	30.00 – 34.99%
F	$< 29.99\%$

The final course grade will be determined based on your work in the following areas:

- *Homework assignments*: 20%. There will be ~ 6 homework assignments (consisting of problems and, occasionally, essays) due throughout the term, roughly every two weeks. Late homeworks will not be accepted under any circumstances *except* if you are observing for the prior two nights before the homework due date, in which case it will be due the day following your final observing night. You must contact me ahead of time to make arrangements for this. Otherwise, it is your responsibility to turn in your homework *before* the start of class on the day it is due.

- *Midterm Examination*: 45%. There will be one midterm exam, which will take place in class on Tuesday April 12.

- *Final Project*: 35%. The final project will consist of two parts: An oral presentation (to be given during the final examination time for the course: Tuesday, May 17 1:00 PM $\rightarrow$ 3:00 PM, and a written report, to be turned in no later than 5 PM on Thursday, May 19. Details about the nature of the final project will be given several weeks into the term.

  Please note that no late assignments will be accepted (other than as provided above), or make-up exams given. The final presentation must be given at the scheduled time. There will be no "extra credit" projects given. Finally, no form of cheating will be tolerated, and will result in automatic failure in the course and additional disciplinary action by the University.

Final Grade Calculator Worksheet

To compute your final grade in the course:

Step 1: Write down all of your homework grades (percentage equivalents):

Step 2: Add the homework grades together and divide by the total number of homework assignments. Write down that number here:

Step 3: Take the number obtained in step 2, and multiply it by 0.2. Write that number down here, and put a box around it:

Step 4: Take your midterm exam percentage and multiply it by 0.45. Write the resulting number down here and put a box around it:

Step 5: Take your final project percentage and multiply it by 0.35. Write the resulting number down here and put a box around it:

Step 6: Add the boxed numbers from Steps 3, 4, and 5 together and write it here:

Step 7: Use the grade scale given on the previous page to calculate your final letter grade, and write it down here:

In all likelihood, this is your final grade for the course. In *exceptional* cases, I may *raise* your grade by up to one mark (e.g., C- to C; B+ to A-, etc.) based on such subjective criteria as my sense of your overall *enthusiasm* for the class and course material. This can be demonstrated in many ways, including "class participation" (note that giving the sense that you are an engaged listener is considered to be just as important as actively contributing to the discussion), attendance, coming to office hours, effort and dedication, and so forth. Note that I will never *lower* a grade that you have earned; your enthusiasm can only help you.

Strategy

And now, some time-tested tips for success in this class:

- **Stay on top of the reading**. The textbook contains the bulk of the material for which you are responsible in this course. Each Tuesday you will be given a "Reading Guide" as part of the weekly handout. Look the reading guides over carefully as you read the week's assignment; they will tell you exactly what parts of the assigned sections are crucial to understand. During certain parts of the course (especially at the beginning, when it is assumed that most of the material is review) the reading assignments will be quite hefty – don't get behind, especially if you have not seen some of the "review" material before!

- **Come to lecture**. Lectures are *based* on the text, but a conscious effort is made to present the material in a somewhat different manner from that given by the book. Often, in lecture I will concentrate on facilitating your qualitative *understanding of equations rather than their mathematical derivations*, since the text generally does a thorough job on that front (and what it doesn't do can be assigned in the problem sets). Everyone has a different preferred learning style; some find lectures the best way to learn the material, some find a textbook presentation most helpful, but everyone benefits from seeing the material presented more than one time and in multiple ways. By coming to lecture you will also see just what information is being emphasized – this is likely to be the same information that is stressed on your exams.

- **Get help**. Come to my office hours. Work together with friends in the class. There are lots of opportunities to get assistance on the course material – use them!

- **Study**. Don't wait until the last minute to prepare for the midterm. This course presents a large amount of information, and it can really "catch up to you" if you do not stay current with the readings.

- **Visit the course website, http://sciences.sdsu.edu/∼leonard/astro660**. There you will find all of the class handouts and assignments, in case you missed anything. All Powerpoint slides from the lectures are also posted there, usually within a day after the lecture is given.

Other Things

•**Contacting me.** Ordered from the *best* way to get in touch with me to absolute *worst* way to get in touch with me:

1. **Best way:** *Come to office hours.* This is absolutely the best way to get help from me in a one-on-one (or small group) setting. My office hours are a low-pressure environment, and you don't need to come even with specific questions in mind – if you just want to talk about the material in general or have me review some concepts with you that is fine.

2. **Good way:** *Send me email.* This is an effective way to contact me directly. I am very responsive to emails, often responding within minutes and almost always within 24 hours.

3. **OK way:** *Come up immediately after class.* If you have a very quick question (or need to let me know something) that can be dealt with in under a minute or so, coming up immediately after lecture can be effective. If it's more complicated, I may ask you to come back to my office to discuss.

4. **Poor way:** *Call my office.* This is not such a great way to get hold of me, as I am frequently out of the office, or, if I am meeting with other students at the time, I may not even answer the phone. Send email, and you'll likely get a better response.

5. **TERRIBLE way:** *Come up right before class.* Please do not try to talk with me immediately before class, either at my office or in the lecture room. This is absolutely the worst time to attempt to communicate with me. Before lecture I am likely busy getting the lecture material ready/Powerpoint working/etc. If it's a quick question, or you need to let me know something, speak with me right after class or, even better, during office hours or through email.

•**Class videos.** If you get to class a little early, on most days you will find a video playing, usually having something to do with the material to be presented in that day's lecture. *Getting to class early to watch these videos is completely optional*; they will never contain required material that is not also presented during the formal lecture and/or by the textbook. The official class will never begin before 3:30 PM. That said, many students in the past have found the videos to be a relaxing way to get introduced to the topics being discussed in the course, before class actually begins.

•**Asking questions.** Questions during lecture are encouraged – don't be afraid to put your hand up if something has confused you (and appears unlikely to be covered in the subsequent lecture). In particular, the first ten minutes or so of every Tuesday's class will be specifically set aside to answer any questions that you may have about the course or material.