Syllabus for ASTRON 113: Introduction to Astronomy
University of Pittsburgh, Spring 2015

Schedule and Instructor. Astronomy/Physics 113 will meet Tuesdays and Thursdays, 1:00 to 2:15, Thaw Hall 11. The instructor is Professor Arthur Kosowsky, Department of Physics and Astronomy. My office is Allen Hall 315 (in the front door, two rights, door on the left). My campus phone is 624-9571, but email is the most efficient way to get in touch: kosowsky@pitt.edu. I will hold regular office hours on Monday and Tuesday 11AM to noon. If you cannot make either of these times, I can meet other times by arrangement. The course grader will be Brian Flores, blf40@pitt.edu.

Prerequisites The stated prerequisites for this class are basic math, including trigonometry, and elementary physics. In practice, you are expected to have a clear understanding of basic physical concepts such as force, energy, momentum, angular momentum, electric and magnetic fields, and temperature. Also, you need to be comfortable doing basic mathematical reasoning, including algebra and geometry. Some knowledge of basic calculus may be helpful, although the assigned work in the class will not require it.

This class is designed to be the beginning class in a sequence of astronomy classes leading to a physics and astronomy major. As such, the course material and problem sets are intended to be suitably challenging for potential future majors. If you are intending to major in a field outside of the natural sciences and are looking for a natural sciences distribution requirement at the level of a popular science book or science journalism, you should consider taking Astronomy 0087, 0088, or 0089 instead.

Honors Section Students in the class with adequate background can register for the Honors section of this course. It will meet one extra time per week, and cover additional material and more in-depth calculations than in the regular course. Students in this section should be comfortable with calculus. The Honors section requires some additional work, and may require modified exams covering the additional material covered in the Honors recitation. Students can earn an additional course credit for taking the Honors section. The extra recitation will be scheduled during the first week of class. If you are unsure about your preparation or background, please talk to the instructor.

Overview. This class is designed to introduce students to the study of astronomy and astrophysics, and lay a foundation for taking the more advanced astrophysics classes offered by the Department of Physics and Astronomy. *Astronomy* is the science devoted to observations of the sky, while *astrophysics* is the branch of physics concerned with explaining astronomical observations in terms of physical principles. Despite its title, this class will not be devoted primarily to astronomy; while we will discuss numerous astronomical observations, we will spend much of the class on astrophysics: attempting to understand a range of observations in terms of basic physics.

Astronomy and astrophysics are very broad fields, and it is impossible to give a comprehensive overview, or even cover all of what many astronomers would consider "basic" knowledge, in a single semester. In selecting material for this class, I have been guided by a few basic considerations: (1) trying to provide conceptual coherence to the material we cover; (2) selecting topics from a range of astrophysical systems, ranging from planets to cosmology; (3) covering some of the most interesting recent developments in the field. Much of this class will be focused on the major theme of *gravity* and how it shapes the universe we observe. Manyof the topics will be some variation on how the force of gravity affects the motions of objects we can observe, and the conclusions we can draw from these observations. Specific topics will include the motions of planets in the sky, Kepler's Laws of planetary motion, Newton's Law of Gravity, supermassive black holes, planets around other stars, tidal forces and tidal streams of stars, parallax and distances, dark matter in spiral galaxies, gravitational lensing, the expansion of the universe, dark energy, black holes, and gravitational waves. We will also cover some basic aspects of stars, including hydrostatic equilibrium, energy source, stellar evolution, and helioseismology. Included will be a few basics of observational astronomy, including telescope resolution, the electromagnetic spectrum and spectroscopy, as needed to understand the astrophysics topics in class.

Approximation Techniques. Astrophysics is often not a high-precision science. Unlike, for example, particle physics or condensed matter physics, we do not have the ability to perform repeated experiments on astrophysical systems; we must simply observe what nature has provided and draw the conclusions we can. In addition, astrophysical systems are often complex, with a range of physical effects and complicated spatial arrangements. Most systems can be explained qualitatively using basic principles, but we often do not have enough information to understand individual systems to very high precision (with a few notable exceptions, like the microwave background temperature fluctuations or the oscillations of the sun). One important aspect of this class will be learning techniques for obtaining approximate answers and explaining general features of data, rather than performing mathematically exact calculations. This is well-suited to an astrophysics class because it is a good match to the subject matter. More importantly, this is the way that physicists and astronomers think about actual problems. If you can explain the general features of a system with reasonable quantitative accuracy using a few basic physical principles, then you have a true understanding of the system, even if you cannot perform a theoretical calculation which reproduces the data to very high precision. This approach has the additional advantage that it does not require advanced mathematical knowledge. While calculus will be helpful for understanding many topics in class, you will not be required to do any calculus in problems or exams, and in fact most mathematics in the class will be basic algebra and geometry. This does *not* mean that the class will be easy! We will study a range of sophisticated astrophysics; obtaining only approximate answers instead of exact ones frees us to think about the science rather than getting hung up on mathematical details.

In practical terms, we will practice making "order-of-magnitude" estimates for most of the systems we study. (Technically, this means that you get the answer correct to within a factor of ten.) The way we do this is via techniques like dimensional analysis, scaling relations, analogies, and common sense. You must understand basic physics principles like energy and momentum in order to apply them to astrophysical systems! Using these basic principles, plus general arguments, we will figure out approximations to explain many observations. In this class, I usually will not care if your answer is off by a factor of two; you don't need more than one significant figure in your numerical answers. So it is fine if you say that $\pi \approx 3$ and $\pi^2 \approx 10$, for example. We will do many examples of approximate calculations in class, so you will have a lot of practice. One of your goals should be to develop a feel for when answers seem right and when they are not. Sometimes the approximations we use may not give the right answer, but if your answer is off by many orders of magnitude I expect you to notice this.

Class lectures will be presented using chalk and blackboard, supplemented by projected images. Please be prepared to take notes – no powerpoint files will be used or posted, because powerpoint makes for boring classes. Some relevant documents or notes from the instructor may be posted on the course web site (see below). Please don't hesitate to ask questions during class – if you don't understand something, it's a good bet that many other people in the class don't understand also.

Class Goals. The main goals of this class are: (1) Understand basic principles of physics and their application to astrophysical systems; (2) Become skilled at estimation, including dimensional analysis, order-of-magnitude estimates, and scaling arguments; (3) Learn about numerous recent advances in astrophysics, one of the most dynamic of all current scientific endeavors. The main goals of this class are *not*: (1) Memorize a lot of stuff; (2) Learn complicated equations and techniques for solving them. If you become a physics and astronomy major, you will have plenty of practice in other classes with learning complicated equations and techniques for solving them; on the other hand, very few other classes will focus to such an extent on approximation, which is a vital skill in any branch of quantitative science. Whatever your major, you will also probably have to memorize more things than you would like. My rationale for not making memorization a high priority is that it takes time and energy which would better be spent on the other educational goals in the class, and that in this age with virtually unlimited factual resources literally at our fingertips, memorization is much less important than it was in times past.

Textbook. Unfortunately, no available textbook is well-matched to the approach, level, and range of topics of this class, so no textbook is required. An excellent book which covers similar material at a somewhat more advanced level is Principles of Astrophysics by Charles R. Keeton (Springer, 2014). The Pitt library has e-book copies available. Astrophysics in a Nutshell by Dan Maoz (Princeton Press, 2007) is also an excellent, concise textbook which uses more math (extensive calculus) and physics than the current course will. Please make at least one friend in class with whom you can share notes if you miss class. Images shown in class, along with web links and other supplemental material, will be posted. Several textbooks which may be useful will be put on reserve in the Engineering Library on the first floor of Benedum Hall.

Web Site. This class has a Blackboard web site, where all course materials, problem sets, class images, and this syllabus will be posted. Log in at http://courseweb.pitt.edu.

Homework, Tests and Grades. The graded work in the class will consist of around 10 weekly problem sets, one in-class, open-book midterm exam, and an in-class, open-book comprehensive final exam. The total problem set grade will count for one-half of the course grade, the two exams each for one-quarter of the course grade. The lowest one of the problem set scores will be dropped in computing the total problem set grade.

You are encouraged to discuss homework problems with fellow students. You must prepare the homework solutions on your own, however. If you get answers to problems from your classmates but do not understand the material, it will be evident in your exam scores. The problems will (hopefully) span a range of difficulty; don't get discouraged if you can't always solve every part of every problem. Make use of office hours: both class scores and understanding tend to be substantially greater for students who take advantage of office hours.

Exams will be open book: You may use your class notes and your own problem set solutions and other course material. Several general reference books will also be provided at the exam. Arrangements for make-up exams must be arranged with the instructor *in advance* of any exam for which you have a schedule conflict. Acceptable excuses include being out of town for a verified university-related reason. Family reunions, ski trips, visiting friends, or hangovers are not acceptable excuses. If you miss an exam due to illness, be prepared to have a signed letter from your doctor or from the university health service.

The class will be graded on a curve with a minimum straight scale. The cutoff for an A in the class will be at most 90% or more of the total possible points, but may be lower than this depending on the distribution of scores. Likewise, the cutoff for a B will be at most 80%, for a C at most 70%, and for a passing grade at most 60%.

Observing Trip. A class trip to beautiful and historic Allegheny Observatory, located in Pittsburgh's Riverview Park on the north side, will be arranged one evening during the semester. Transportation will be provided at no expense. Be sure to come look at the sky through one of the Observatory's large telescopes. A date will be arranged during the semester for an evening with the fewest conflicts.

Department of Physics and Astronomy. The Department wants you to feel welcome. If you are interested in the possibility of becoming a physics and astronomy major, please talk to me about it. The department has a donut and coffee hour every Wednesday at 4 PM in 211 Thaw. Come meet faculty and students. The department's undergraduate center is in Allen Hall 104; you can often find physics majors there studying and socializing.

Astronomy Seminars. The University of Pittsburgh astronomy group hosts seminars on current topics of interest in astronomy and astrophysics on alternate Fridays at noon. Pizza is available, or bring your lunch. Most days, a speaker from another institution will talk about their current research. The seminars will address the latest work on many topics covered in class. They are aimed at the level of first-year graduate students, but 113 students are welcome to give them a try and should be able to get the general idea of many talks. Everyone is encouraged to come hear about current research in astrophysics from scientists doing it. Also, you may be interested to attend the weekly Physics and Astronomy Colloquium, held either at Pitt in 102 Thaw Hall or at Carnegie-Mellon, 7500 Wean Hall, Mondays at 4:30 with cookies and coffee before.

Students with Disabilities. If you have a disability, please speak to the course instructor early in the semester to make any necessary arrangements to support a successful learning experience, and provide documentation through your disabilities coordinator.

Outline of Topics

Week 1 (January 5) Review of basic physical quantities and their dimensions. Fundamental physical constants. Sample applications of dimensional analysis. Order-of-magnitude estimation, scaling relations.

Week 2 (January 12) Kinematics. Newton's Law of Gravity, orbits of planets and satellites. Gravitational potential energy.

Week 3 (January 19) Extrasolar planets. Detection methods. Kepler satellite results.

Week 4 (January 26) Dynamics of the galactic center: stellar orbits, mass of the central object. Telescope resolution, atmospheric seeing.

Week 5 (February 2) Virial theorem. Dark matter in galaxy clusters and dwarf galaxies.

Week 6 (February 9) Gravitational lensing: strong lensing, weak lensing, microlensing.

Week 7 (February 16) Tidal forces, corotation, tidal streams. Midterm Exam.

Week 8 (February 23) Radiation properties, flux. blackbody emission, atomic emission and absorption

Week 9 (March 2) The sun and stars. Stellar energy source, radiation propagation, stellar structure. SPRING BREAK: Week of March 9.

Week 10 (March 16) Stellar evolution. Stellar end states.

Week 11 (March 23) The expanding universe. Olber's paradox. Age, expansion; standard candles; dark energy.

Week 12 (March 30) Cosmic microwave background physics. Spectrum, temperature variations.

Week 13 (April 6) Galaxies and growth of structure.

Week 14 (April 13) History of the Universe.

Finals Week (April 20) Final Exam: to be scheduled.