Syllabus for ASTRON 1122: The Solar System and Extrasolar Planets
University of Pittsburgh, Fall 2014

Schedule and Instructor. Astronomy/Physics 1122 will meet Tuesdays and Thursdays, 11:00 to 12:15, Thaw Hall 210. The instructor is Professor Arthur Kosowsky, Department of Physics and Astronomy. My office is Allen Hall 315 (floor 3, opposite side from elevator on the right, second door from the end). 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 at 11AM to noon and Tuesday at 10 AM to 11 AM. If you cannot make either of these times, I can meet other times by arrangement.

Prerequisites This class is intended primarily for astronomy and physics majors, and other students with equivalent preparation. A good working knowledge of calculus will be assumed, and we may solve some simple differential equations. Also assumed is a working familiarity with concepts from first-year physics (forces, momentum, energy, temperature, pressure, density). We may use some concepts from atomic and molecular physics but the class will not assume previous knowledge of these areas.

Overview. Planets have been observed and mythologized since ancient times. Predicting the motions of the visible planets (Mercury, Venus, Mars, Jupiter, Saturn) with respect to the stars led to the Ptolemaic system of astronomy, with the Earth at the center of the universe and planets following epicyclic orbits, which held sway for 1400 years. Precise planetary position measurements drove the development of modern astronomy until the invention of the telescope in the early 1600's. Tycho Brahe's 30 years worth of precision planetary position measurements led to the abandonment of the Ptolemaic astronomy in favor of Johannes Kepler's laws of planetary motion. These in turn were a central driver in the development of Newton's Laws of Motion and Law of Gravitation by 1687, which still today form the foundation of physics.

Uranus was discovered by William Herschel in 1781 through telescopic observations. Increasingly precise planetary orbital measurements through the 19th century led to the prediction of another planet Neptune by Urbain le Verrier and John Couch Adams in 1846, via its gravitational effects on the other planets. Neptune was discovered at the predicted position by Francois Arrago in 1846. This discovery was a sensational demonstration of the expanding abilities of astronomy, and the power of Newton's Laws to describe our universe.

In the 1970's and 1980's, a series of spacecraft visited Venus, Mars, Jupiter, Saturn, and Uranus, providing dramatic images of their surfaces, cloud features, moons, and rings. The images led to a number of interesting conclusions for how the planets formed and evolved, including the presence of volcanos, cratering from impacts, and erosion patterns. By the late 1990's, digital sky imaging and automated computer processing led to the discovery of several minor planets orbiting in the vicinity of Pluto, including Eris, Sedna, and Quaoar; these caused the "demotion" of Pluto from a planet to a minor planet by the International Astronomical Union.

Planets around other stars have been observed with various techniques since the 1990's, and we now know of several thousand stars which have at least one detected orbiting planet. Timeless questions which were purely the purview of speculation – are there other worlds, and if so, are they inhabited? – are now coming into the realm of scientific observation. The study of so-called "exoplanets" around other stars has in the past decade exploded into one of the most active and vibrant fields of modern astronomy.

This course will cover the physical properties of planets and their environments: orbital properties, interactions with the parent star, atmospheric temperature and chemical composition, formation and orbital migration. These issues will be addressed using basic principles of physics (and maybe a bit of chemistry as needed). We will consider in some detail the various methods for detecting planets orbiting other stars, and look at patterns in the most current data about planet populations.The most interesting question related to planets is whether they might harbor life, and this is a question addressable using scientific reasoning. We will consider how the physical properties of planets affect their ability to support life, and what future observational techniques might allow us to determine observationally whether a given planet around a distant star supports life.

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) Give a definition of a planet, and understand the various issues making this definition problematic. (2) Obtain a working knowledge of physical processes which shape the properties of planets, including gravity, radiation, and thermodynamics, and construct quantitative estimates of planet properties using these basic physics principles. (3) Explain current techniques for finding planets around other stars, understand statistical properties of these planets, and draw conclusions from this data about the process of planet formation. (4) Give arguments for universal properties of living organisms, and be able to connect hospitable environments for life with the physical properties of planets and stars. (5) Understand the capabilities and physical limitations of proposed experiments to image planets around other stars.

Textbook and Online Resources. The textbook is *Exrasolar Planets and Astrobiology* by Caleb A. Scharf (University Science Books, 2009). This book gives a nice overview of planets with a focus on the general topic of astrobiology, the study of life outside of the Earth. (Of course, we have not discovered any such life, but astrobiology studies the ingredients necessary for life, and the possible environments in which life might evolve.) The book is at a fairly easy level to read. Our course will focus somewhat more on the physics shaping planets and affecting exobiology than the textbook. Also, we will cover the material in the book in a different order, but most chapters of the book are reasonably independent of the others. I also encourage you to make use of many available on-line resources. Wikipedia has excellent entries on most topics covered in this course. Exoplanets.org is a web site devoted to the current status of knowledge about planets orbiting other stars.

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 12 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%.

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. It is a good place to find help from your peers.

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. Some talks are also given by faculty and graduate students from Pitt. 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. A link to the weekly schedule of talks is available at the department web site.

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 (August 25) What is a planet? A brief history of planets, the invention of astronomy and physics, the Pluto debate, and the modern frontiers of astronomy. Planetary orbits. Kepler's and Newton's Laws.

Week 2 (September 1) Gravitational effects in the solar system. Solar system stability. Tidal forces and effects. Sphericity.

Week 3 (September 8) Reading: Scharf, Chapter 8, Sections 8.1 to 8.4. Asteroids, comets, and minor planets. The Kuiper Belt and the Oort cloud. Impacts.

Week 4 (September 15) Stars, stellar types and evolution histories. Planet temperatures and evolution.

Week 5 (September 22) Reading: Scharf, Chapter 6, Sections 6.1 to 6.6. Planet atmospheres. Atmospheric evaporation. Atmosphere thermodynamics, greenhouse effect.

Week 6 (September 29) Reading: Scharf, Chapter 4, sections 4.1 and 4.2. Detection techniques for extrasolar planets: reflex velocities, transits, gravitational lensing, astrometry.

Week 7 (October 6) Reading: Exoplanets.org. Statistics of extrasolar planetary systems. Planet masses, distances. Correlations with stellar types. Selection effects. MIDTERM EXAM in class, Thursday October 9.

Week 8 (October 13) Reading: Scharf, Chapter 3. Current theories about formation of planetary systems. Planet migration. NO CLASS Tuesday, October 14 (Monday schedule due to Fall Break day.)

Week 9 (October 20) Reading: Scharf, Chapter 2. Star formation and protoplanetary disks. Accretion of planets. Bombardment history of solar system objects.

Week 10 (October 27) Reading: Scharf, Chapters 5 and 9. What is life? Necessary physical conditions for the development of life. Habitable zones.

Week 11 (November 3) Reading: Scharf, Chapter 7. Chemistry of life. Dust and prebiotic molecule formation.

Week 12 (November 10) Reading: Scharf, Chapter 6, sections 6.7 to 6.10. Biomarkers. What can we observe that indicates life?

Week 13 (November 17) Intelligent life. The Fermi paradox: are we alone? Search for Extraterrestrial Intelligence. The Drake equation.

Week 13.5 (November 24) Tuesday: Catch-up day. Thanksgiving recess: Wednesday to Friday.

Week 14 (December 1) Reading: Scharf, Chapter 4, Section 4.3. Future technology for direct imaging of planets around other stars. Spectroscopy of exoplanet atmospheres.

Finals Week (December 9) FINAL EXAM: Wednesday, December 10, 10–11:50 AM.