Astro 16 – Astrophysics: Stars, ISM, and Galaxies
Fall 2019
Profs. David Cohen and Jesse Rivera

Syllabus

This semester-long course is a survey of central topics in astrophysics, with an emphasis on stars, but also covering the interstellar medium (ISM) out of which stars are formed, and galaxies (including our own Milky Way) – large organized systems in which stars live their lives. We will introduce and/or review the underlying physics concepts (and mathematical techniques) necessary to understand the properties and functioning of stars, the interstellar medium, and galaxies. These include gravity, mechanics, thermal physics, and radiation (light) and matter (atomic physics), with a little bit of gas dynamics, statistical mechanics, and nuclear physics, too. We'll derive some key physical equations. Basic calculus will sometimes be used. We'll do a few integrals and solve a couple of simple differential equations by integrating them. The occasional derivative will need to be computed. We will have you (and teach you how to) plot and do some numerical analysis of some astrophysically important functions. Most important will be working to develop a sense of the correspondence between the math, the visualization and the physical world of forces, matter, and energy.

Much of our study will be from a theoretical point of view (e.g. how do stars 'work'?) but a significant amount will be observational (e.g. how do we determine the properties of stars?).

We will all work hard to ensure that the class does not revolve around memorization of isolated facts, but rather involves developing integrated understanding of concepts (that then can be applied to different situations, systems, and problems). This will give students a bigger-picture view of stars and their lives from formation to death, cycling material through the galactic interstellar medium, producing heavy elements as well as light as a byproduct of their efforts to prevent gravitational collapse. It will also demonstrate how interesting physics concepts students have learned – or are learning – in other classes can be applied to real-world (if cosmic) systems, often in combination with each other.

Classes will include a fair amount of lecture (perhaps half of any given class time, but often the lecture topics will be chosen based on student input and discussion with the class), but also some discussion and in-class student work. Students will be expected to read about – and think about – the material for a given day's class *ahead of time*, and sometimes to do a pre-class problem or two, based on that reading and/or ask questions and request topics for in-class discussion via an online questionnaire prior to class. Class itself will be for asking and answering questions and delving deeper into material that students will already be thinking about.

We will use a combination of textbooks and online resources and this year we are not requiring you to buy any textbooks. In previous years we've used the quite good textbook, "Foundations of Astrophysics" by Barbara Ryden and Bradley Peterson, lightly supplemented by other material. But this year, we're going to try using just a few chapters of that book, plus some material from Marc Kutner's "Astronomy: A Physical Perspective" and some other texts, too. Those two textbooks, plus some others, will be on reserve at Cornell. Just ask for them at the front desk. (They can't leave the library, though.) We will scan the textbook reading for you ahead of time, though we really – really! – encourage you to at least occasionally use the physical books in the library, because there are intangible benefits to using the actual book, including serendipitous discovery, higher resolution, the existence of the index and table of contents and supporting material elsewhere in the same book. If you think you will go on to study more astrophysics, we recommend buying your own copy of Ryden and Peterson to keep. You'll be glad to be able to refer to it when you take other courses and seminars.

Each class will have an assignment document that introduces the new material and provides guidance for thinking about the reading.

We will use Moodle as the primary way to organize our resources, assignments, work, discussion forums, online polls/questionnaires, lab information, and everything else. We will also have a relatively static class website – resources we use repeatedly (but not copyrighted readings!) and basic course information will be there. The URL is https://astro.swarthmore.edu/astro16/ and it will be updated periodically. But Moodle is the place to check to see what's going on in our next class, what you should be working on, what the next homework is, etc.

We will have a homework assignment roughly once per week. (A subset of the homework problems will be graded, and students will be expected to look over the solutions to all the problems and make sure they can do all the problems, even the ones that aren't graded. There will be opportunities in class to discuss problems – and their solutions – from the previous week's homework.)

We will have about six nighttime lab meetings (on Tuesday nights) roughly every other week, on a pre-determined schedule (but at this moment – version 1 of this syllabus – we don't quite have the lab night schedule set yet; it will be posted below in an updated version of this document). Please leave Tuesday nights from 8pm to 11pm free. We will use the 24-inch telescope in the Peter van de Kamp Observatory on the roof of the science center for these labs, but, because the telescope is computer controlled, quite automated, and (knock on wood) operating relatively smoothly, we will not be spending that much time actually in the observatory. Much more of our lab effort will be put into working with the data we've taken at the telescope, but on our computers and often during the daytime. SC 187 is our nominal lab room, and there are computers in there with the necessary software, but students will benefit from (and enjoy) being able to work with their telescope data on their own computers. We'll give you information about the software during the first week of class; please let us know if you don't have easy access to a computer running windows or the Mac OS. We have computers you can use outside of class and lab time.

Prof. Eric Jensen will be running the labs, but we – Profs. Rivera and Cohen – will be helping out, too.

Some of the nighttime lab sessions will be used to learn material about observational astronomy that's needed for laboratory/telescope work: basic optics, cameras and detectors, statistics and signal-to-noise considerations for observation planning and data analysis. Rather than incorporate this material (some of which will involve textbook reading) into the class itself, we are going to incorporate it into the nighttime lab sessions. So, some of our lab meetings will have their own reading assignments prior to the lab meetings, and will involve discussion and work related to that material, not necessarily making observations with the telescope. This will also make it possible for us to deal with the uncertainty in the weather (we can't use the telescope when it's cloudy).

Partly to accommodate students working on telescope data during the daytime, we will have extended office hours on a regular basis and much of the work students will do with data can be done outside of the nighttime lab sessions, but still with some guidance from the course and lab instructors.

Astro 16 has two Science Associates – students who have taken Astro 16 themselves and who will be in class and at nighttime help-sessions (probably on Sunday nights) and may be available at times to help you outside of class, too, especially with computation and with lab data analysis.

We will have two exams during the semester and a final exam, but much of a students grade will be based on homework and other pre-class and in-class work and participation. We will refine our grading criteria/rubric after the semester starts, but the breakdown will be roughly: Homework, pre-class problems, and lab work (at least 50%), with two midterms (25% total) and a final exam (about 25%) composing the remainder.

We will accept homework up to 24 hours late and assess a 10% penalty; or up to 48 hours late with a 20% penalty. No permission needs to be asked; no excuses need to be given. If you have a true emergency, please get in touch with as soon as possible. We will do whatever we can to accommodate you. Students will not be allowed to make up missed labs or exams. Please let us know if we seem unaware of religious holidays and observance that might prevent a student from handing in an assignment on time. We will be glad to accommodate religious observance and will try to anticipate upcoming holidays.

If you believe you need accommodations for a disability or a chronic medical condition, please contact Student Disability Services (Parrish 113W, 123W) via e-mail at studentdisabilityservices@swarthmore.edu to arrange an appointment to discuss your needs. As appropriate, the office will issue students with documented disabilities or medical conditions a formal Accommodations Letter.

Since accommodations require early planning and are not retroactive, please contact Student Disability Services as soon as possible. For details about the accommodations process, visit the Student Disability Services website. You are also welcome to contact us, Prof. Cohen or Prof. Rivera, privately to discuss your academic needs. However, all disability-related accommodations must be arranged, in advance, through Student Disability Services.

Schedule
v.1 (31 August 2019), this first version has broad subject areas, and future versions will have readings and resources, lab meetings, exams, and more. This document will be periodically updated throughout the semester.

week 1:

Properties of the Sun and scale of the local universe
angular measure
gravity, mechanics, uniform circular motion
brief historical context of modern astronomy (Greeks, Kepler, Newton)
Kepler's laws

week 2:

more gravity and orbits
parallax
inverse square law
electromagnetic spectrum, light as wave and as photon
Doppler shift
spectroscopy, Kirchoff's laws

week 3:

atomic processes, more spectroscopy
spectral line profiles
Maxwell-Boltzmann
LTE, Saha, Boltzmann, Planck

week 4:

pure absorption radiation transport, optical depth
solid angle
review, wrap-up, discussion

week 5:

stellar spectra (Eddington-Barbier)
magnitudes, colors, extinction and reddening
star properties: radii, temperatures

week 6:

binary stars (and exoplanets)
fall break

week 7:

hydrostatic equilibrium
stellar atmospheres
spectral types
luminosity classes
Hertzsprung-Russell diagram

week 8:

stellar structure equations
energy sources and nuclear fusion
modeling and test of stellar structure

week 9:

finishing up stellar structure
evidence for dust and gas in the ISM
absorption line diagnostics
H II regions
thermal balance

week 10:

star formation
begin post-main-sequence evolution

week 11:
(just one class meeting – Thanksgiving)

degeneracy pressure, white dwarfs

week 12:

massive star evolution, including supernovae
neutron stars

week 13:
three class meetings (one makeup from Thanksgiving)

Milky Way morphology
stellar populations
rotation curve and dark matter
central black hole
external galaxies
galaxy clusters
Hubble law