Astrophysical Sciences 303: Observing and Modeling the Universe

Fall 2010
Lectures: T & Th 3:00-4:20, 145 Peyton

The goal of this course is to introduce students to the techniques that astrophysicists use to model and observe the universe. The course is oriented to astrophysics majors, although the techniques students will learn will be of use for any of the natural sciences. This course will prepare students in research methods that will be used in their independent research (junior papers and senior theses). Topics will include methods of observational astronomy, instruments and telescopes, statistical modeling of data and numerical techniques. The course will introduce students to IDL, a high level computer language used for modeling and for data analysis.

Professors:
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Teaching Assistant:
Tim Brandt (017 Peyton Hall, x8-????, tbrandt@astro.princeton.edu)

We will not have formal office hours; students should feel free to drop by our offices when we have the doors open, or make appointments by sending us e-mail.

There will be no midterm or final exam. Grades will be based on problem sets (60%; we'll have eight assignments), class participation/discussion (15%), and a 15-minute final presentation (25%) to be given by each student on a topic to be chosen by the student in consultation with the professors. The homeworks will include both standard problem sets, and detailed computer exercises; for the latter, we will ask that your computer code be turned in as well. People are encouraged to help each other on the homeworks and the computer codes, but you should write your codes separately, and the writeups of the homeworks and computer codes should be your own. We will probably also set up informal times to meet to help you get started on the problem sets (which will be challenging!).

The final presentations will take place during reading period; we will arrange the times for those later in the semester.

Prerequisites:

Math 103,104 or their equivalent are required. We recommend that Math 200-level courses be taken concurrently. If you haven't taken linear algebra yet, we urge you to be sure to talk to us if/when unfamilar notation or concepts come up.
Physics 103,104, or 105,106 are required.
Astrophysics 204 is recommended but not required.

Textbooks:

We have two required textbooks:

- Hale Bradt: *Astronomy Methods: A Physical Approach to Astronomical Observations* (Cambridge: 2004) This book, as its title implies, emphasizes observational techniques, and will be particularly useful in discussions of telescopes and detectors. It is quite pedagogical, but at times doesn't go quite to the depth that we will require.
- Press et al.: *Numerical Recipes (in Fortran, C, or Pascal): The Art of Scientific Computing, Second or Third Edition* (Cambridge). This is a standard reference (which you can get for the language you are most familiar with), and is a wonderful source of information about statistics, mathematical physics, and numerical methods of all sorts. Every physical scientist should have a copy on their shelves. It is not meant to be read sequentially, and it covers topics thoroughly, from elementary concepts, to the most advanced numerical techniques.

Also on reserve (on the reserve shelf in the Grand Central Meeting Room in Peyton Hall):

- Robert Lupton: *Statistics in Theory and Practice* (Princeton: 1993). This is a terse but complete summary of statistics for mathematically sophisticated physical scientists. Amazingly comprehensive in well under 200 pages.
- Philip Bevington and D. Keith Robinson: *Data Reduction and Error Analysis for the Physical Sciences* (McGraw-Hill: 2002). Somewhat less sophisticated and comprehensive than Lupton's book, but at times easier to follow.
- Wall and Jenkins: *Practical Statistics for Astronomers* (Cambridge: 2003) This covers much of the same territory as Lupton's book, with more astronomical examples, somewhat less mathematical sophistication, and more pedagogy (i.e., more words!).
- Acton: *Numerical Methods that Work* (Mathematical Association of America: 1997) This book covers similar material to Numerical Recipes.
- Howell: *Handbook of CCD Astronomy, 2nd Edition* (Cambridge: 2006) A summary of the use of CCDs in astronomy, at a level appropriate for this course.
- Rieke: *Detection of Light: From the Ultraviolet to Submillimeter* (Cambridge: 2002) A more advanced book describing the physics of light detection, including CCDs, photodiodes, heterodyne receivers, and much more. Strong emphasis on the relevant solid-state physics.

- Kitchin: *Astrophysical Techniques* (Fifth edition, Taylor & Francis, 2009). Detailed discussions of detectors in astronomy, similar in scope to the book by Bradt, but somewhat more advanced. Quite complete, but occasionally hard to follow.

- Birney et al, *Observational Astronomy* (Cambridge: 2005). Similar to Bradt et al, but not as deep.

- Cox: *Astrophysical Quantities* A useful reference work listing, in encyclopedic fashion, large quantities of astrophysical facts. Useful as a reference, but less useful as a textbook to learn from.

- Olver et al: *NIST Handbook of Mathematical Functions.* A comprehensive compilation of the properties of every mathematical function you ever heard of (and many that you haven't). Also see the accompanying website at `http://dlmf.nist.gov/`.

- Bowman: *An Introduction to Programming with IDL: Interactive Data Language.*

- Kling: *An IDL Primer*

- There are also several links to IDL primers from the course web site.

  Those who haven't taken AST 204 or its equivalent will also find it it useful to look at any of the standard introductory calculus-based astronomy texts, such as:

- Bradley Carroll and Dale Ostlie: *An Introduction to Modern Astrophysics* (Addison-Wesley: 1996) (or its second edition). This is the standard textbook for AST 204, encyclopedic in its scope and length.

- Frank Shu: *The Physical Universe: An Introduction to Astronomy* (University Science Books: 1981) Somewhat dated, but beautifully written, with a very strong emphasis on the basic physical principles.

The course home page is:
`http://www.astro.princeton.edu/~strauss/ast303` .

The syllabus can be found on the following page. It is approximate, and will almost certainly change as the course progresses. We will keep it up to date on the course web page. The first half of the course (observational astronomy, statistical methods) will be taught almost entirely by Michael Strauss, and the second half (more statistics, numerical methods) will be taught almost entirely by David Spergel.

September 16, 21	Strauss	**Observing the Universe** The electromagnetic spectrum and the atmosphere. Read Bradt Chapters 1 and 2
September 23, 28	Strauss	**Observing the Universe** Astronomical measurements: imaging, spectroscopy, and astrometry Astronomical coordinates, and motions on the sky Astronomical measurements of time and distance Read: Bradt, Chapters 3 and 4.
September 30, October 5	Strauss	**Telescopes and Optics** Basic Optics. Telescope design. Read: Bradt Chapters 5, 7
October 7, 12	Strauss	**Astronomical Instruments** Read: Bradt Chapters 5, 7
October 14, 19	Strauss	**Detectors for photons; non-photon astronomy** CCDs, Detectors for UV and X-ray Detection of radio waves Read: Bradt: Chapters 6, 12
October 21, 26	Strauss, Spergel	**Astronomical Statistics** Measurement errors and astronomy. Fitting models to data. Poisson statistics. Introduction to numerical methods. Read: Numerical Recipes Chapter 14 & 15 Lupton Chapters 2 & 3; Bradt Chapters 8 & 9
October 28	Hale Bradt (Guest)	**X-ray astronomy** History, methods of focussing and detection Read: Bradt, Chapters 5.3, 6.3
Week of November 1	**Fall Break!**	
November 9, 11	Strauss	**Advanced statistics** Likelihood Analysis, minimizing functions The central limit theorem
November 16, 18	Spergel	**Introduction to Numerical Methods** How to read Numerical Recipes When to do calculations numerically. Numerical integration methods Read: Numerical recipes Chapters 4, 12, 13
November 23, 30	Spergel	**Orbits and Orbit Integration** Numerical solution of differential equations Stable and unstable integrators Leapfrog and symplectic integration Read: Numerical Recipes Chapter 17
December 2, 7	Spergel	**Numerical Simulations** Goals, Methods, Testing Courant Condition; Solving Poisson Equation Tree Codes, Mesh Codes, and Parallel Computing
December 9, 14,16	Spergel	**Fluid Equations** Equations of fluid motion. Euler versus Lagrangian. Grid codes versus SPH. Boundary Conditions.