Astrophysical Sciences 303: Observing and Modeling the Universe

Fall 2014
Lectures: T & Th 3:00-4:20, 33 Peyton

This course will 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 Python, a high level computer language used extensively in astronomy for modeling and for data analysis.

Professor:
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Teaching Assistant:
Lile Wang (032 Peyton Hall, 734-834-3936, lilew@princeton.edu)

We will not have formal office hours; students should feel free to drop by our offices when we have our 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, due roughly every week and a half), class participation/discussion (15%), and a final paper (25%), due on Dean’s Date, on a topic to be chosen by the student in consultation with Professor Strauss. The homeworks will include both standard analytic problems, 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 also set up informal times to meet to help you get started on the problem sets (which will be challenging!).

You all have accounts on the astronomy department computer system, and are encouraged to do your computer exercises there. But python can also be installed on a laptop, if you prefer. We are using python/ipython version 2.7.3, together with modules including numPy, SciPy, and matplotlib.
**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 unfamiliar notation or concepts come up. Physics 103,104, or 105,106 are required. Astrophysics 204 is recommended but not required. Some experience with programming 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.

- Ivezić et al.: *Statistics, Data Mining, and Machine Learning in Astronomy* (2014: Princeton). This book, written by a former Peyton Hall resident, covers many of the course topics in statistics and programming that we will need in this course. While it goes into far more depth on some subjects than we will need, it covers the basics very well. It also serves as a useful introduction to Python; see Appendix A.

Also on reserve (on the reserve shelves in the Grand Central Meeting Room in Peyton Hall and in the Lewis Library):


- Press et al: *Numerical Recipes: The Art of Scientific Computing, Third Edition* (Cambridge). This is a standard reference, and is a wonderful source of information about statistics, mathematical physics, and numerical methods of all sorts. It covers topics thoroughly, from elementary concepts, to the most advanced numerical techniques. This book used to be recommended for this course; Ivezić et al is in fact a better match to our needs.

- 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!).
• Feigelson and Babu: *Modern Statistical Methods for Astronomy* (Cambridge: 2012). Covers a broad range of statistical techniques, but doesn’t always give the mathematical background about where these techniques come from.

• Acton: *Numerical Methods that Work* (Mathematical Association of America: 1997) This book covers similar material to Numerical Recipes.


• 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.


• Lena et al, *Observational Astrophysics* (Springer-Verlag: 2012). This is an advanced textbook, which covers many of the topics we will discuss in this course.

• Kitchin: *Astrophysical Techniques* (Sixth edition, Taylor & Francis, 2013). 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.


• 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/](http://dlmf.nist.gov/).

• There are several links to Python primers from the course web site. Those who haven’t taken AST 204 or its equivalent will also find it useful to look at any of the standard introductory calculus-based astronomy texts, such as:

• Barbara Ryden and Brad Peterson: *Foundations of Astrophysics*, (Addison-Wesley: 2010). This is at a similar level to Carroll and Ostlie, but is far shorter, and thus more accessible.

• Frank Shu: *The Physical Universe: An Introduction to Astronomy* (University Science Books: 1981) Somewhat dated (I bought it as an undergraduate!), but beautifully written, with a very strong emphasis on the basic physical principles.

The course home page is:
Homework assignments and useful links can be found there.

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.
<table>
<thead>
<tr>
<th>Date</th>
<th>Lecture Title</th>
<th>Details</th>
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<tbody>
<tr>
<td>September 11, 16</td>
<td>Observing the Universe</td>
<td>The electromagnetic spectrum; emission mechanisms in different wavebands. Read: Bradt Chapters 1 and 2; Ivezić Chapter 1 and Appendix A</td>
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<tr>
<td>September 18, 23</td>
<td>Measuring Brightness</td>
<td>The Earth’s atmosphere. Brightness of the night sky. Measurements of brightness in astronomy. Read: Bradt, Chapter 8, Section 11.2 Homework 1 due September 23</td>
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<tr>
<td>September 25, 30</td>
<td>Astrometry, Time, and Astronomical Distances</td>
<td>Read: Bradt Chapters 3, 4, 9</td>
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<tr>
<td>October 2, 7</td>
<td>Statistics, Distributions, and Measurement Errors</td>
<td>Central Limit Theorem. Poisson Process. Read: Ivezić, Chapter 3 Homework 2 due October 2</td>
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<tr>
<td>October 9, 14</td>
<td>Model-Fitting and Likelihoods</td>
<td>$\chi^2$, linear fits, confidence intervals Read: Ivezić, Chapters 4, 8 Homework 3 due October 16</td>
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<tr>
<td>October 16, 21, 23</td>
<td>Telescopes and Optics</td>
<td>Focal ratios. Diffraction limits. Astronomical seeing and the concept of a PSF. Read: Bradt, Chapter 5</td>
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<td>Week of October 27</td>
<td>Fall Break!</td>
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<td>November 4</td>
<td>X-ray and Gamma-Ray Astronomy</td>
<td>Read: Bradt, Chapter 6 Homework 4 due November 4</td>
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<td>November 6, 11</td>
<td>Optical Aberrations and Adaptive Optics</td>
<td>Read: Bradt, Section 5.5</td>
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<td>November 13</td>
<td>Next Generation of Large Telescopes (Mike Bolte)</td>
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<td>November 18, 20</td>
<td>Advanced Topics in Statistics</td>
<td>Covariances, non-linear $\chi^2$, hypothesis testing Bayesian vs. Frequentist statistics Read: Ivezić, Chapters 4, 5, 8</td>
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<td>November 25</td>
<td>Fourier Transforms in Astronomy</td>
<td>The Fast Fourier Transform Read: Ivezić, Chapter 10 Homework 6 due November 25</td>
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<td>December 2, 4</td>
<td>IR and Radio Astronomy</td>
<td>Coherent vs. incoherent detectors Telescope Arrays and Aperture Synthesis Read: Bradt, Chapter 7</td>
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<td>December 9, 11</td>
<td>CCDs and Spectrographs</td>
<td>The Sloan Digital Sky Survey The Large Synoptic Survey Telescope and other future facilities Homework 7 due December 11</td>
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<td>Final paper due January 13 (Dean’s Date)</td>
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