# Astrophysical Sciences 303: Observing and Modeling the Universe

Fall 2016
Lectures: Mondays and Wednesdays 3:00-4:20, Jadwin A07

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.

**Professors:**
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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 seven or eight assignments, due roughly every week and a half), class participation/discussion (15%), and a final project (25%). 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!). The final project will be a mock observing proposal to use the James Webb Space Telescope to tackle a pressing problem in astrophysics today. We will hold a mock telescope allocation committee meeting during reading week to peer-review the proposals.

You all have (or soon will 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 2.7.8, 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 unfamilar notation or concepts come up.
Physics 103,104, or 105,106 are required.
Astrophysics 204 is recommended but not required.
Some experience with computer programming is recommended but not required.

**Textbooks:**

We have two required textbooks (also available on reserve at Lewis Library). We will assign reading, but will not follow the books closely. The two books are:

- 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 note that this book is available on-line for free: `http://proquest.safaribooksonline.com/9780691151687`.

We also have a recommended textbook, especially for those students who are not familiar with the Python programming language:

- Kinder and Nelson 2015, *A Student's Guide to Python for Physical Modeling*

Also on reserve (on the reserve shelves in the Lewis Library):

- 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.

- 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.

- Sivia and Skilling, *Data Analysis: A Bayesian Tutorial* (Oxford University Press: 2006) A particularly clear view of statistical issues.

- 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.

- Rieke: *Measuring the Universe: A Multiwavelength Perspective* (Cambridge: 2012).

- 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.

- 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.

- Condon and Ransom, *Essential Radio Astronomy* (Princeton University Press, 2016), a comprensive overview of the subject.

- 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/`.

- 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 the standard textbook for AST 204.

- Bradley Carroll and Dale Ostlie: *An Introduction to Modern Astrophysics, second edition* (Addison-Wesley: 2006). At roughly the same level as Ryden and Peterson, but encyclopedic in its scope and length.

- Frank Shu: *The Physical Universe: An Introduction to Astronomy* (University Science Books: 1981) Somewhat dated (Michael bought it as an undergraduate!), 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` .
Homework assignments and useful links can be found there. We will *not* use blackboard for this course.

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. Lectures on the dates in blue will be given by Michael, and those in red will be given by Jenny.

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| September 14, 19 | **Observing the Universe**<br>The electromagnetic spectrum; emission mechanisms in different wavebands.<br>Read: Bradt Chapters 1 and 2; Ivezić Chapter 1 and Appendix A |
| September 21, 26 | **Measuring Brightness**<br>The Earth's atmosphere. Brightness of the night sky.<br>Measurements of brightness in astronomy.<br>Read: Bradt, Chapter 8, Section 11.2<br>*Homework 1 due September 26* |
| September 28, October 3 | **Astrometry, Time, and Astronomical Distances**<br>Read: Bradt Chapters 3, 4, 9 |
| October 5, 10 | **Statistics, Distributions, and Measurement Errors**<br>Central Limit Theorem. Poisson Process.<br>Read: Ivezić, Chapter 3<br>*Homework 2 due October 5* |
| October 12, 17 | **Model-Fitting and Likelihoods**<br>$\chi^2$, linear fits, confidence intervals<br>Read: Ivezić, Chapters 4, 8<br>*Homework 3 due October 17* |
| October 19, 24, 26 | **Telescopes and Optics**<br>Focal ratios. Diffraction limits.<br>Astronomical seeing and the concept of a PSF.<br>Read: Bradt, Chapter 5 |
| Week of October 31 | **Fall Break!** |
| November 7, 9 | **Fourier Transforms in Astronomy, PSFs**<br>The Fast Fourier Transform<br>Read: Ivezić, Chapter 10<br>*Homework 4 due November 7* |
| November 14 | **Optical Aberrations and Adaptive Optics**<br>Read: Bradt, Section 5.5<br>*Homework 5 due November 16* |
| November 16 | **X-ray and Gamma-Ray Astronomy**<br>Read: Bradt, Chapter 6.4 |
| November 21 | **Optical Detectors and Imagers**<br>Read: Brandt, Chapter 6.3 |
| November 28 | **Detection of Gravitational Waves**<br>Read: Brandt, Chapter 12.4<br>*JWST proposal outline/abstract due November 28* |
| November 30 | **Measurements of Spectra**<br>*Homework 6 due November 30* |
| December 5, 7 | **IR and Radio Astronomy**<br>Coherent vs. incoherent detectors<br>Telescope Arrays and Aperture Synthesis<br>Read: Bradt, Chapter 7 |

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| December 12, 14 | **The Sloan Digital Sky Survey and the Future** |
| | The Large Synoptic Survey Telescope and other future facilities<br>*JWST proposal due December 14* |
| January 9, 11 | Mock telescope allocation committee meeting for |
| (Reading period) | peer review of final projects |
| *Homework 7 due January 17 (Dean's Date)* | Turn into Michael's mailbox |
| *No final exam!* | |
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