Syllabus ASTR610

Class Purpose

Astronomy is an observational science – few experiments are possible, and theory serves more to explain than to predict new phenomena. As a result, it is important for everyone involved in gathering and interpreting data to understand something about the instruments which filter our view of the Universe. In this course, we cover the basic principles of instrumentation and the associated techniques involved in recovering data from distant objects. We will discuss physical limits on ideal instruments and some of the real imperfections that can lead to real systematic effects. The goal of this course is to understand instrumentation as a coherent whole, differing only in details from one part of the spectrum to another. We will draw heavily on examples from the radio through optical wavelengths to illustrate the basic principles of instrumentation, but we will also discuss other parts of the spectrum (UV, X-ray, and gamma-ray) to show how technical details differ in these regions. This course also includes a review of basic statistics applied to signal and data analysis.

Expectations

My expectation is that the students will conduct themselves as graduate students. This means putting electronic distractions to the side during the lectures, following the lecture material, following and reading references after lectures, and in general demonstrating curiosity. Assignments are individual, and should be completed by students independently. That does not mean that students should not be talking to each other about what they are doing (on the contrary, your objective should be to learn!), but it means that each one should arrive at the solutions through their own thought process and understanding (otherwise you are not learning!). I expect students will be curious enough to go above and beyond what I ask in the homeworks, rather than just following my script. Instead of worrying about the grade, worry about exploring and learning and the grade will come with that!

Class Meetings

The class meets in room 0201 of the Atlantic Building from on Tuesdays and Thursdays 12:30-1:45 pm. When I travel we will reschedule at a mutually agreeable time. Classes will consist primarily of intensive lectures and, I hope, equally intensive questions and discussions as we move through the course material.

Office Hours

Questions about lecture and problem sets or other topics are strongly encouraged. Given everyone's varied schedules, we will do this by appointment or by random encounter. Please come ask questions early as they emerge. The hour or two before class on the days problem sets are due seem to be popular times for questions, but are difficult for me as I prepare for the lecture. My email, phone, and office number are at the top of this page.

Grading

There will be regular homework assignments that will count for 40% of the course grade. You should anticipate spending a considerable amount of time on the assignments – this is, of course, where you will learn the most. A number of the homework assignments involve computer programming. As part of the coursework, I require use of a higher-level language such as MATLAB, Python, or R because of their extensive data manipulation and display capabilities. There will be two exams: a mid-term exam which counts for 25% of the course grade and a final exam that counts for 35%. Both examinations count as Major Grading Events as defined by the university. A good number of the problems on these exams will be in the format of the Qualifying Examination for the Department of Astronomy. As is usual for graduate classes, I expect that most students will receive an A or B.

Attendance

Since we are not following a textbook for this class, attendance and careful note taking is essential. If you must miss a class, please arrange to get notes from one of your classmates and plan to come talk with me about points you find unclear. If you know you will be away for university-related travel or religious holidays, please let me know as soon as possible (technically, within the first two weeks of the semester) so we can arrange alternate scheduling of homeworks or exams. This same timeframe holds for students who need accommodation for documented disabilities.

Useful texts and references

There are no required texts for this class. We cover too much ground at too many levels for one text to suffice, and purchasing an entire set of texts would be financially ruinous. Here is a list of my favorite reference books for this class. You may wish to build you library with one or two of them, depending on your interests.

Bracewell: The Fourier Transform and its Applications, 3rd Edition.

This wonderful book covers both theory and applications of the Fourier transform.

James, A Student's Guide to Fourier Transforms With Applications in Physics and Engineering

A very nice introduction to Fourier transforms and their uses. Paperback: cheap!

Hecht, Optics

A particularly clearly written optics book with considerable information on modern and classical optics.

Born and Wolf, Principles of Optics

Advanced topics in diffraction and other optical theory, optical interferometers.

Schroeder: Astronomical Optics

This book covers astronomical optical systems, telescopes, and spectrometers in considerable technical detail.

Thompson, Moran, Swenson: Interferometry and Synthesis in Radio Astronomy

Detailed discussions of radio interferometers at a fundamental but advanced level. An indispensable reference for practitioners.

Rohlfs & Wilson: Tools of Radio Astronomy

This book covers instrumentation and techniques from the radio astronomical perspective, as well as discussing radiation mechanisms and radio astronomy in general.

Rieke: Detection of Radiation
Covers the detection of radiation from radio to gamma rays.
Howell: Handbook of CCD Astronomy
CCD operation, data processing, and instruments.
Ross: Introduction to Probability and Statistics for Engineers and Scientists
Very clear exposition of classical elementary statistics at the upper-division undergraduate level.
Dalgaard: Introductory Statistics with R
Clear introduction to statistics common for data analysis and the R language. Most of the examples are geared toward the biological sciences, where R is very popular, but the basics are the same for all sciences.
Lupton: Statistics in Theory and Practice
Intermediate-level statistics book that covers more advanced topics in data analysis with astronomical examples.
Seidelmann: Explanatory Supplement to the Astronomical Almanac
A fundamental reference for fundamental observers – coordinate systems and transformations, time systems, precession, etc.

The aspirational plan for lectures follows

1	Jan 25	Introduction. Detection of radiation principles.
2	Jan 27	Direct and heterodyne detection.
3	Feb 1	Semiconductor properties. Noise sources.
4	Feb 3	Calibration of CCD frames.
5	Feb 8	Coherent detection. A deeper look into heterodyne basics.
6	Feb 10	Coherent detection. The noise equation and basic measurements.
7	Feb 15	Coherent detection. Basics of radio telescopes.
8	Feb 17	Conventions and units of radio telescopes.
9	Feb 22	Statistics. Basic distributions.
10	Feb 24	Hypothesis testing and confidence limits.
11	Mar 1	Errors in parameter estimation.
12	Mar 3	Geometrical optics. Basic equations and lenses.
13	Mar 8	Mirrors. Stops and pupils. Fermat's principle. Basic telescopes.
14	Mar 10	Aberrations. Zernike polynomials. Transfer functions.
	Mar 15	MIDTERM
15	Mar 17	Fourier transforms. Aliasing. Filtering and windowing.
	Mar 22	SPRING BREAK
	Mar 24	SPRING BREAK
16	Mar 29	Physical optics. Diffraction.
17	Mar 31	Two slit diffraction. Gratings and the grating equation.
18	Apr 5	Grating spectrograph.
19	Apr 7	Fabry-Perot spectrometer.
20	Apr 12	Fourier Transform spectrometer.

21	Apr 14	Interferometry basics.
22	Apr 19	The two-element interferometer. Response and image filtering.
23	Apr 21	Radio interferometer basic design and response.
24	Apr 26	Deconvolution. Closure phases and self-calibration.
25	Apr 28	Machine Learning basics. Regression and classification.
26	May 3	Neighbors and decision trees.
27	May 5	Classification and evaluation. Over and under fitting.
28	May 10	Review.
	May 17	FINAL