OBSERVATIONS, DATA ANALYSIS, & STATISTICS: ASTR-5550

This document presents topical guidelines for instructors of one of the five APS core graduate courses. It is provided as a reference to support instructors in their syllabus preparation, and to assist the APS Examinations Committee in their review of those syllabi. Following each set of primary/recommended topics (in black), we list suggested optional topics (in *violet*) and example applications to APS research fields (in green) suitable for student projects, scientific coding, or homework exercises. It is anticipated that instructors focus at least two-thirds of class time on the primary course topics, with the remaining time spent on optional topics or other related topics of the instructor's choosing. Instructors are encouraged to draw upon a range of examples from astrophysics, planetary science, and solar/space physics to illustrate the core material. The current version of these guidelines was adopted by the AY20-21 and AY21-22 Graduate Curriculum and Concerns Committees (GCCC). Future changes/updates will be made regularly; alternately, changes can be proposed to the GCCC.

Probability

Definitions of terms; random variables
Probability density functions, with common examples (Gaussian, Poisson)
Expectation values and moments
Conditional probability and Bayes' theorem
Central limit theorem

Statistics

Construction of statistical estimators
Distributions of common statistics
Confidence intervals, error propagation, changes of variables (analytic & numeric)
Covariance and correlations
Hypothesis testing

Data Modeling and Parameter Estimation

Maximum likelihood approaches; chi-squared minimization
Evaluating likelihoods/posteriors across a parameter grid; error estimation
Linear parameters & analytic likelihood/posterior maximization (weighted linear least squares)
Nonlinear parameters & numerical methods (e.g., Levenberg-Marquardt, scipy.optimize)
Sampling from parameter probability distributions with MCMC methods
Application: fitting same data with grid search, linear least-squares, L-M, & MCMC methods

Observations: Imaging Theory

Geometric optics
Physical optics; diffraction theory
Image formation
Interferometry and aperture synthesis

Noise and Signal Processing

Shot noise
Sky subtraction
Review of applied Fourier transforms
Nyquist-Shannon sampling theorem
Filtering in the time or frequency domain
Confusion limit in crowded imaging
Application: simulating observed data with various noise sources
Application: Fourier applications & extensions: wavelet transforms; Lomb-Scargle

Detectors and Data Analysis

Practical CCD imaging & photometry (basic data reduction; error propagation)
Multiwavelength data gathering and analysis methods: e.g.,

- *radio techniques: antenna theory; brightness temperatures*
- *X-ray techniques: photon counting*
- *Techniques for in situ measurement of particles and fields*

Application: reduce & analyze real data for any of the above techniques

Spectroscopy

Basic principles of optical spectroscopy
Spectral resolution, bandwidth, noise sources
Backgrounds as a function of wavelength
Designs: diffraction gratings, Fourier transform spectrometers, heterodyne receivers
Application: fitting & analyzing absorption/emission line data