Syllabus for Bayesian Astrostatistics
AST 5731 / STAT 5731

Course Description: Modern astrophysics research relies on sophisticated statistical methods to interpret and analyze the large amount of data characteristic of new experiments. This course will introduce Bayesian methods for interpreting and analyzing large data sets from astrophysical experiments. These methods will be demonstrated using astrophysics real-world data sets, and a focus on modern statistical softwares such as R and python. The course will assume familiarity with basic concepts in astrophysics, but it will include brief reviews as needed to demonstrate the use of modern data analysis techniques.

For graduate students in Physics and Astrophysics programs, this course will provide a systematic introduction to some of the most modern data analysis techniques used in astrophysics today. For graduate students with traditional data science backgrounds (Computer Science, Statistics, Engineering), this course will provide immersion into domain-specific data analysis problems with numerous examples of fundamental problem-specific challenges in applying the modern data analysis techniques.

Students and Scheduling: For graduate students in Physics, Astronomy, Statistics, Computer Science, Data Science, and Engineering departments. Advanced undergraduates may register with instructor permission.

This course is a part of the new NSF training program *Data Science in Multimessenger Astrophysics* and of the proposed graduate (M.S. and Ph.D.) minor degree in *Data Science in Astrophysics*. It will be offered in the Fall semester, beginning in Fall 2020. The course will be cross-listed between AST and STAT, and it is expected to be taught by faculty from both departments.

Number of credits and contact hours: 4 credits with 4 contact hours (3 lecture, 1 lab).

Prerequisites: Multivariable calculus (e.g. MATH 2263) and linear algebra (e.g. MATH 2243); or instructor consent. Suggested–statistical methods at the level of AST 4031, AST 5031, STAT 3021, or STAT 5021; or familiarity with astrophysics topics such as star formation and evolution, galaxies and clusters, composition and expansion of the universe, gravitational wave sources and waveforms, and high-energy astrophysics.

Course Readings:
Primary Textbook: *Bayesian Models for Astrophysical Data: Using R, JAGS, Python, and Stan* by J. M. Hilbe, R. S. de Souza, and E. O. Ishida

Supplemental Reading:
Modern Statistical Methods for Astronomy with R Applications by E. D. Feigelson
Practical Statistics for Astronomers by J. V. Wall and C. R. Jenkins
Data Analysis: A Bayesian Tutorial by D. S. Sivia

A First Course in Bayesian Statistical Methods by P. D. Hoff
Statistical Rethinking: A Bayesian Course with Examples in R and Stan by R. McElreath

Software: R and Python will be emphasized throughout as will modern methods, such as R Markdown and Github, for ensuring reproducibility of results.

Tentative Schedule:

Week	Topic
	Introduction to Bayesian Methods
1-2	Probability: Probability functions, random variables, joint, marginal, and conditional distributions, Bayes rule, Monte Carlo methods for sampling. Introduction to R and Python.
2-3	Bayesian Statistics: likelihood, priors (conjugate, empirical, improper, Jeffreys), posterior, prior influence, Bayes factors, role of sample size. Astronomical databases, and case study.
4-6	Linear Regression: Ordinary least squares and maximum likelihood, fitting, interpretation, model selection Bayesian regression, fitting, interpretation, model selection, measurement error, penalized regression (lasso, ridge), credible intervals, astronomy case study
	Generalized Linear Models
7-8	Bayesian Non-Gaussian Continuous Response Models: Lognormal, Gamma, and Beta regression models fitting, interpretation, model selection, astronomy case studies
9-11	Bayesian Discrete Response Models: Binomial, Poisson, Negative Binomial, and zero-inflated models fitting, interpretation, model selection, astronomy case studies
	Hierarchical Models
12	Bayesian Gaussian hierarchical models fitting, interpretation, model selection, astronomy case studies
13	Bayesian Binomial hierarchical models fitting, interpretation, model selection, astronomy case studies
14	Bayesian Poisson hierarchical models fitting, interpretation, model selection, astronomy case studies
15	Bayesian Negative Binomial hierarchical models fitting, interpretation, model selection, astronomy case studies