Astronomy 382D: Astronomical Data Analysis

Fall 2023

Course Information

Unique Course Number: 48385
Meeting times: M/W 9:30-11:00 am
Classroom: PMA 15.216B
Course website: Canvas (canvas.utexas.edu)

Contact Information

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Office hours: M/W 11am-12 pm

Course Description

Interpreting astronomical observations begins with analyzing data. From optimally extracting a stellar spectrum to constraining cosmological models, data analysis lies at the heart of all aspects of astronomy. The goal of this course is to provide a practical guide to analyzing astronomical data. Topics will include applied probability theory, parameter estimation, Bayesian statistics, maximum likelihood methods, model fitting, and Markov chain Monte Carlo sampling. Students will work with a variety of real astronomical datasets to develop experience and skills for research. Requires graduate standing or consent of the instructor.

Course-Level Learning Objectives:

The primary aim of this course is to establish a strong foundation of knowledge and techniques used to interpret datasets that are common in astronomy. After taking this course, you will be able to:

- Quantify how astronomical events are related in the framework of joint, marginal, and conditional probabilities.
- Solve counting problems related to random draws using combinatorics.
- Summarize the properties of common probability distributions encountered in astronomy.
- Explain the limiting relationships among families of probability distributions and appropriate problems for their use.
- Establish whether two quantities are related to each other and how to quantify any correlation.
- Assess how, when, and under what conditions to address questions using Bayesian statistics.
- Construct likelihood functions for a wide range of data encountered in astronomy.
- Quantify the degree of certainty that a model parameter lies within a given interval.
- Select which among multiple models is justified by the data.

- Determine whether systematic errors may be present in your data, and decide how to deal with them.
- Write a program to sample from parameter posterior distributions given a dataset, an underlying model, and previous parameter constraints.

Prerequisites: Graduate standing or consent from instructor. Students are expected to be proficient in a programming language of their choice (e.g., Python, IDL) to plot data, graph functions, and carry out other computational tasks. Students should also have a strong grasp of calculus and mathematical modeling.

Textbooks and Materials

- **Required**: We will use *Data Analysis for Scientists and Engineers* by Edward L. Robinson (Princeton University Press, 2016) as the primary reference for this course.
- Textbook readings will be supplemented with journal articles and review papers. Access to major scientific journals in astronomy is required. These are available online when accessing the Astrophysical Data System or publishers' websites through UT. PDFs of these publications will also be posted to Canvas.
- Laptop and familiarity with a programming language to create plots and carry out computational exercises in class. I recommend Python 3 for this, although any language of your choice is fine. Please contact me if you have questions or if you don't have a laptop readily available.

Below are additional references that may be helpful if you would like supplementary material:
- Sivia, *Data Analysis: A Bayesian Tutorial* (2nd ed.), 2006
- Wall & Jenkins, *Practical Statistics for Astronomers* (2nd ed.), 2012
- Ivezic, Connolly, VanderPlas, Gray, *Statistics, Data Mining, & Machine Learning in Astronomy* (Updated ed.), 2019
- Press, Teukolsky, Vetterling, Flannery, *Numerical Recipes* (3rd ed.), 2007
- Feigelson & Babu, *Modern Statistical Methods for Astronomy*, 2012
- Gelman, Carlin, Stern, Dunson, Vehtari, & Rubin, *Bayesian Data Analysis* (3rd ed.), 2013
- Hilbe, de Souza, & Ishida, *Bayesian Models for Astrophysical Data*, 2017

Course Requirements

This course is organized following evidence-based teaching practices that are designed to improve student understanding as well as long-term retention of the material. Students are expected to read the textbook chapters and journal articles ahead of class following the course schedule listed in Canvas. An outline of topics we will cover is included at the bottom of this syllabus. (These may be subject to modifications throughout the semester). Selected topics will then be reinforced through lectures, discussions in class, and assignments. **Active, engaged participation from students is extremely important!**

This class will consist of lectures, exercises, and guided activities. Learning assessments will be made through homework, take-home programming projects, and short in-class presentations.

Homework: Homework assignments will be made available at least two weeks before they are due. There will be two assignments during the semester. Each assignment will count for 20% of the final grade, or 40% altogether.

Programming projects: There will be two programming assignments in this course. These will be made available at least two weeks before they are due. Students will be required to submit not only their results, but also a printed copy of the code they wrote. Each assignment will count for 20% of the final grade, or 40% altogether.

You are welcome to code in any programming language of your choice. For an introduction to Python, I recommend the free textbook *Python for Astronomers: An Introduction to Scientific Computing* by Pasha and Agostino (https://prappleizer.github.io/textbook.pdf). Interactive tutorials can be found here: https://prappleizer.github.io.

In-Class Participation and Short Presentations: This class will be structured with a combination of shorter lectures as well as interactive lessons and activities. These in-class exercises are an important part of the course, so **attendance and active participation is very important**. The interactive material and discussions are intended to reinforce the concepts in the class and assist you in completing your homework assignments.

Twice during the semester students will be given assignments that involve searching the astronomical literature, reproducing the analysis of a paper, and presenting a short (~5-7 min) summary of the results to the class. Details about each assignment will be given at least two weeks before the presentation date.

Presentations and a written summary of the associated work will make up 20% of your total grade.

There will be no tests or final exam for this course.

Course Policies

Communication:

- The course webpage on the Canvas system will be updated with announcements, supplementary resources, and deadlines. It is your responsibility to check Canvas daily. I recommend setting up email alerts to be notified when I send messages or post assignments. You may also wish to download the mobile app.

- It is also your responsibility to keep track to the administrative deadlines related to the course, for example add/drop dates and Pass/Fail credit deadlines.

- Email is recognized as an official mode of university correspondence. You are responsible for reading your email for both university and course-related information. Please check your email daily.

- All questions related to this course should be directed through Canvas. Please consult this syllabus for answers first!

Courtesy and use of electronics:

- **You are expected to arrive to class on time.** Out of consideration to me and your fellow students, please do not leave class early unless you have talked to me in advance.

- Phone use, social media, and texting during lecture or activities is not permitted. Please make sure your phones are silenced before class begins.

Travel:

- As part of my duties as faculty, I may be required to travel during the semester. I will do my best to minimize the impact of this travel and maintain communication while away. When I am gone, I will either cancel class for that day or another UT astronomer will lead the class in my place.

Syllabus Changes:

- I reserve the right to make changes to the syllabus and class schedule, if necessary. If any changes are made they will be announced through Canvas and new versions will be uploaded.

COVID-19:

- If you are experiencing any symptoms of COVID-19, please follow university guidelines here: https://healthyhorns.utexas.edu/coronavirus_exposure_action_chart.html, including getting tested. If you test positive, you should isolate yourself at home. Behavior Concerns and COVID-19 Advice Line (BCCAL) can assist you with isolation options, class absence notification or other support and if you find out that you have a positive test for COVID-19.
- If you are experiencing any symptoms of COVID-19 ***do not come to class in person***. If you are well enough to attend via zoom, this option may be possible. Please contact me to discuss arrangements and accommodations.

Policy on Deadlines

Missing Homework or Programming Project: **Late homework and projects will not be accepted.** If you do not complete an assignment for emergency reasons, contact me by email within three days of the due date of the assignment. In some situations, late assignments may be

accepted at my discretion, but documentation will generally be required. I encourage you to start your homework and programming assignments early.

Missing Presentations: If an emergency or personal event occurs which causes you to miss one of the presentations you are signed up for, you must arrange to switch with someone else and notify me at least 2 days beforehand. If the emergency occurs within 2 days of the presentation and you contact me **prior** to the start of class, I will work with you to schedule a time to make it up. Documentation will generally be required. *If this emergency is COVID-related, I will be very flexible about making up missing work.*

Emergencies and University Closings: If an emergency occurs (for example, a death in the family or hospitalization) that influences your performance in the class, you must contact me as soon as possible and provide documentation within one week. I will work with you to schedule a new deadline for homework and projects you missed.

Grading

This class will not be graded on a curve unless I decide to do so after the course has ended. Final grades will be assigned based on the following breakdown:

Homework (40%)
Programming projects (40%)
Presentations and associated work (20%)

	93.00% ≤ ***A*** ≤ 100%	90.00% ≤ ***A-*** <93.00%
87.00% ≤ ***B***+ < 90.00%	83.00% ≤ ***B*** < 87.00%	80.00% ≤ ***B-*** < 83.00%
77.00% ≤ ***C***+ < 80.00%	73.00% ≤ ***C*** < 77.00%	70.00% ≤ ***C-*** < 73.00%
67.00% ≤ ***D***+ < 70.00%	63.00% ≤ ***D*** < 67.00%	60.00% ≤ ***D-*** < 63.00%
	F < 60%	

Academic Dishonesty

The University of Texas Honor Code: The core values of The University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility. Each member of the university is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community. Students who violate University rules on scholastic dishonesty are subject to disciplinary penalties, including the possibility of failure in the course and/or dismissal from the University. Standards for Academic Integrity are posted at http://deanofstudents.utexas.edu/conduct/index.php

Plagiarism: The University of Texas at Austin takes plagiarism very seriously. **This applies to programming projects as well as homework questions.** You may read more about plagiarism at the Student Judicial Services website: http://deanofstudents.utexas.edu/conduct/academicintegrity.php

The minimum penalty for cheating is receiving a zero on the assignment. I reserve the right to seek a penalty I deem appropriate for the given case of academic dishonesty, including failing the class and being reported to Student Judicial Services. For more information, read in the General Information Catalog about scholastic dishonesty.

Students with Disabilities

Please notify me of any modification/adaptation you may require to accommodate a disability-related need. The University of Texas at Austin provides upon request appropriate academic accommodations for qualified students with disabilities. For more information, contact Services for Students with Disabilities (SSD) at (512) 0471-6259 (voice) or (512) 232-2937 (video phone) or http://diversity.utexas.edu/disability/. If you request academic accommodation for a disability, please provide appropriate documentation from the SSD Office at the beginning of the semester.

Mental Health Services

Graduate life can be challenging and stressful. Diminished mental health, including significant stress, mood changes, excessive worry, or problems with eating and/or sleeping can interfere with optimal academic performance. Similarly, problems with relationships, family worries, loss, or a personal struggle or crisis can also contribute to decreased academic performance.

UT Austin's Counseling and Mental Heath Center (https://cmhc.utexas.edu; 512-471-3515) provides mental health services to support the academic success of students. This includes counseling services, wellness workshops, free and confidential therapy groups, and general information. I encourage you to browse their website and actively seek support if you're experiencing any of these difficulties.

Harassment and Assault

Harassment of any sort will not be tolerated in this classroom or related workspaces. Title IX makes it clear that violence and harassment based on sex and gender are Civil Rights violations subject to the same kinds of accountability and the same kinds of support applied to offenses against other protected categories such as race, national origin, etc. If you or someone you know has been harassed or assaulted, you can find the appropriate resources through the University Title IX Coordinator (512-232-3992), UT Austin Campus Police (512-471-4441), the Student

Ombuds Services (which can provide *confidential* advice, resources and help; 512-471-3825), and the UT Counseling and Mental Health Center (512-471-3515).

Diversity, Equity, and Inclusion

Astronomy belongs to ***all*** people, independent of race, religion (or lack thereof), gender, gender identity, gender expression, or sexual orientation. Incidents of discrimination, assault, harassment, threats, intimidation, profiling, or coercion based on membership or perceived membership will not be tolerated.

Students with Children

I recognize the difficulty of being a student with children. If you have children, or other family commitments, please come see me to discuss any modifications of the course policies which will maximize your success in this course.

*Anticipated Course Schedule**

Week	Topics	Data Analysis**
Week 1	Course overview	
Weeks 2-4	Probability and Combinatorics	Chapter 1.1, 1.2, 2.1
Weeks 5-6	Characterizing Probability Distributions	Chapter 1.3
Weeks 6-7	Common Distributions	Chapter 2.2-2.7, 1.4
Weeks 9-10	Measurements and Sampling	Chapter 4.1-4.5, 3.1, 3.2
Week 11	Bayesian Statistics	Chapter 7
Week 12	Maximum Likelihood and Model Fitting	Chapter 5
Weeks 13-14	Markov Chain Monte Carlo	Chapter 3.5

** Subject to minor changes*
*** Data Analysis for Scientists and Engineers, Edward L. Robinson, 2016, Princeton University Press*