ASTR513: Statistical and Computational Methods in Astrophysics

Fall 2020; 3 credits

Tuesday - Thursday 2:00-3:15 pm

Instructor: Dimitrios Psaltis; SO N324, 621-7859

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Course Description.— This course will cover two distinct but closely related tools heavily used in astrophysics. The first part will introduce basic computational methods for solving physical problems. The course will cover methods related to the solution of linear and non-linear equations, the numerical integration of arbitrary functions, and the solution of ordinary differential equations. For this course we will use the UNIX operating system, the C programming language, and the Python framework.

No previous experience with any of these is required.

In the second part, we will review the foundations of modern statistical methods (frequentist and Bayesian) that are used in current research problems in (astro)physics, with emphasis on big-data science. In particular, we will review various mathematical aspects of frequentist and Bayesian inference methods, non-linear regressions methods, modeling of data, Monte Carlo techniques, error estimation, and model selection. Our focus will be on the application of statistical methods, without sacrificing rigor and detail.

Course Objectives— During this course students will learn to write basic scientific algorithms to solve integrals and differential equations frequently encountered in astrophysics. Then they will learn about statistical description of data. They will implement Bayesian and Frequentist methods and apply them to topics of current interest, as well as explore computational techniques for statistical inference such as Markov-Chain Monte Carlo methods. Applications will include (but not be limited to) comparing stochastic (e.g., turbulent hydrodynamic) models to noisy data, time- and frequency-domain analysis (power spectra, wavelets, etc), density estimation (e.g., luminosity and mass functions), and high-dimensional parameter estimation.

Learning Outcomes— Upon completing this course, student should be able to
1. Write basic computer programs to solve physical problems including integrals and differential equations;
2. Understand the foundations of modern statistical methods (Frequentist and Bayesian);
3. Develop and implement their own statistical tools;
4. Apply statistical methods to a wide variety of projects in their research.

Prerequisites.— The only prerequisite for this class is a competent use of a computer language.

Course Website.— Course material including handouts and notes will be posted on the D2L course website. You can find the syllabus, the schedule for the term (including any changes or updates to the schedule), handouts, and information about papers there.

Meeting Times.— The class will meet Tuesdays and Thursdays at 2:00-3:15pm via Zoom. As this is a lab class, our synchronous meetings will give us the opportunity to learn from and assist each other with coding and implementation challenges.

Textbooks.— Lectures notes, in the form of a typed draft, will be available on the class web page.

Suggested texts:

- The C Programming Language by Kernighan & Ritchie (2nd edition) is an excellent introductory book to programming in C.
- Numerical Recipes in C by Press, Teukolsky, Vettering, & Flannery (2nd edition) has been the standard reference in the field for many years and offers an in depth presentation of all the topics that we will cover (and many more). A free, online version of the book is available at http://numerical.recipes/oldverswitcher.html
- Pattern Recognition and Machine Learning by Bishop. A free online version of this book is available.

The University of Arizona offers a number of introductory classes in statistics and you're encouraged to visit the websites of these classes and use their resources. In particular, visit the web site for MATH363, Introduction to Statistical Methods

http://math.arizona.edu/~jwatkins/math363f15.htm

offered in the Fall of 2015, for slides and audio from the class, as well as a free introductory textbook on statistics.

- **Assignments – Staying Current**

You are required to complete the following two types of assignments within their due dates in order stay current and finish the course. Each assignment type will help you improve different types of skills that you will need in your careers.

(i) Homework: this will require solving detailed, quantitative problems that will involve analytic calculations, simple numerical calculations, statistical inferences, etc. I will assign 6 sets of homework, about once every two weeks. The due dates for the homework will be on Wednesdays, at 5pm.

For each student, I will drop the set with the lowest grade, and the 5 best sets will count for 10% of the grade each, for a total of 50%.

(ii) Project: Details on the project, which you will work on in groups, will be announced later in the semester. The project will count for a total of 50%.

There will be no midterm or final exams. There will be no credit for late assignments, unless there are special circumstances (see below).

A total score of 90% will guarantee an A. The final distribution of scores will determine the exact grade breakdown.

- **Policies**

Attendance.— Class attendance is optional. Please join the class only if you find it useful. However, if you do come to class, please give your full attention and participate in the discussion.

All holidays or special events observed by organized religions will be honored for those students who show affiliation with that particular religion,

Absences.— If you feel sick, or may have been in contact with someone who is infectious, stay home. Except for seeking medical care, avoid contact with others and do not travel.

Please let me know if you will not be able to attend because of health reasons.

Campus Health is testing for COVID-19. Please call (520) 621-9202 before you visit in person.

Visit the UArizona COVID-19 page for regular updates.

Absences (or difficulty turning in assignments on time) that are pre-approved by the UA Dean of Students (or Dean's designee) will be honored.

There will be make up assignments or special arrangements with a well documented valid excuse.

Life challenges.— If you are experiencing unexpected barriers to your success in your courses, please note the Dean of Students Office is a central support resource for all students and may be helpful. The Dean of Students Office can be reached at 520-621-2057 or mailto:DOS-deanofstudents@email.arizona.edu.

Physical and mental-health challenges.— If you are facing physical or mental health challenges this semester, please note that Campus Health provides quality medical and mental health care. For medical appointments, call (520-621-9202. For After Hours care, call (520) 570-7898. For the Counseling & Psych Services (CAPS) 24/7 hotline, call (520) 621-3334.

Academic Integrity.— Cheating or any other form of unethical or threatening behavior will not be tolerated. You can find more information on these issues in the following two web sites of the university:
`http://deanofstudents.arizona.edu/policies-and-codes/code-academic-integrity`
`http://policy.arizona.edu/education-and-student-affairs/threatening-behavior-students`

Accessibility and Accommodations.— At the University of Arizona we strive to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability or pregnancy, you are welcome to let me know so that we can discuss options. You are also encouraged to contact Disability Resources (520) 621-3268 to explore reasonable accommodation. Please be aware that the accessible table and chairs in this room should remain available for students who find that standard classroom seating is not usable.

Incompletes.— Incompletes will only be given if a student has satisfactorily completed the majority of the work in the class and has a valid reason, such as medical, for not completing the remainder of the course. Students must make arrangements with the instructor in order to receive an incomplete.

Other than grade and absence policies, the information contained in this syllabus may be subject to change with reasonable advance notice.