Course Syllabus

ASTR 21100

Winter 2020

Computational Techniques in Astrophysics

Classes: Wed, Fri 13:30-14:50, KPTC 309

Lab session: Mon 13:30-14:50, KPTC 309

Instructor: Andrey Kravtsov

Contact info: office=ERC 415, email = kravtsov@uchicago.edu

Office hours: Tue, 10:30-11:30am, modifications will be announced; on certain weeks additional office hours may be announced.

Teaching assistants: Dimitrios Tanoglidis (dtanoglidis@uchicago.edu)
Georgios Zacharegkas (gzacharegkas@uchicago.edu)

Feedback options: we welcome regular feedback on any aspect of the course from you throughout the course, which you can provide via the feedback option in short weekly assignments (see below), e-mail to instructor or TAs, e-mail or personal meeting with A&A Academic Affairs Coordinator Julia Brazas (julia@uchicago.edu), or anonymously using instructor's mailbox in the NE corner of the 4th floor of the ERC building.

Summary

Notable dates: Friday, Feb 14 – no class (college break), **Wed, Feb 19** – I will be away, format and subject of the class will be announced later. **Friday, March 13** – no class (College reading period). **Monday, March 16** – 1:30-3pm meet to present final projects (tentative).

Course description: the purpose of this course is to introduce computational, statistical, and machine learning methods and algorithms most frequently used in modern astronomy research. The Python programming language will be used almost exclusively due to its near platform independence and widespread usage in astronomy, with heavy emphasis on vectorized computations via the numpy, scipy, and astropy libraries and other elements of high-performance computing with Python.

Class format: in Wed and Fri classes we will pose and consider typical problems encountered in astrophysics research. Computational approaches and numerical algorithms will be introduced and discussed as part of the solutions to these problems. Please, be prepared to actively participate in the discussions and to work in groups to discuss approaches to obtain solutions and their implementations. To be able to play with the code and do quick experiments in class, please bring your laptop with sufficient battery charge to class starting on Jan 9. Your laptop should have a Python and Jupyter notebooks, as well as numpy, scipy, and astropy installed.

We will also ask you to consider and implement certain problems to reinforce your learning and understanding in homework assignments and projects. As discussed in more detail below, assignments will be of two types: 1) short weekly assignments containing conceptual questions about material we covered that do not require coding and computation, which will also provide you an opportunity to provide regular feedback on the material we cover and class format, and 2) larger practical assignments and projects, with an option to design your own project related to your research.

You will work on these assignments in groups and on your own and will have an opportunity for us to review your work and receive feedback during Monday lab, instructor office hours on Tuesday, or after class.

Exams: there will be no exams in this course. However, during the finals week, instead of the final exam, we will have a session for group presentations of the final project.

Grades: Assignments of type 1 will contribute 20% of your grade, assignments of type 2 will contribute 80%. No curve will be used to assign the final grades.

Honor code: during group discussions you will discuss approaches to do a particular exercise or calculation, and work together on code implementation. *Collaborative* work on implementation of the code and debugging is welcome and encouraged, provided that you actively participate in this work and contribute meaningfully. Unless specified otherwise, we expect you to then personally carry out calculations, obtain your own results and plots, and present your own reasoning, answers, and discussion of results, which you will submit as your individual assignment.

By the end of this course you should:

- ❏ Become comfortable with designing and implementing numerical algorithms for your research tasks or for independent checks of library routines, realizing that you can often implement a better routine for your task than a library one. We hope that after this course you will view such tasks as an interesting intellectual challenge and as an integral and indispensable part of scientific enterprise.
- ❏ Be able to make publication-quality plots and produce data visualizations in 1d, 2d, and 3d, such as line plots, scatter plots with and without uncertainties, histograms, contour plots, etc.
- ❏ Be able to research for relevant methods and evaluate optimal numerical approaches for computational tasks that are commonly encountered in astronomical research.
- ❏ Be able to write efficient Python programs using good coding style and documentation and employing the numpy, scipy, and astropy libraries.
- ❏ Have a working understanding of truncation and roundoff errors affecting results of numerical computations and be able to recognize when each type of error is dominant and why
- ❏ Be able to present your results to an audience, answer questions, and explain the reasons for your specific choice of approach, numerical methods and ways to present results.
- ❏ Be able to critically assess computation results, choices of how to present them, and choice of specific methods used presented by your colleagues.
- ❏ Have a basic understanding of the best methods to use for

  > function approximation (interpolation and least squares regression) in 1D and in multiple dimensions using basis expansion of functions, including polynomials, splines, trigonometric series and Fourier transformations, and wavelet expansions.

  > numerical integration and differentiation.

  > reconstruction of functions from a finite number of discrete samples in 1D and multiple dimensions.

  > filtering and smoothing noisy data.

  > generating random samples of functions in 1d and multiple dimensions.

  > finding minima and maxima of functions (optimization).

  > basic statistical analyses, Bayesian model parameter inference, and model comparisons.

  > solving systems of ordinary differential equations.

  > applying machine learning techniques for data analysis, such as classification, regression, etc.

Details

What we expect from you:

- Your commitment to actively engage in learning material and related discussions during class and while working on assignments. We expect a commitment of about 5-7 hours per week for reading and working on assignments and projects, in addition to class and lab time for this class (i.e., ~10 hours total per week).
- Timely submission of results of your work on assignments and projects. This will allow us to provide timely and meaningful feedback to you.
- If you have significant prior knowledge of specific material covered in class, we expect that you share it and help your classmates in group discussions and work in a friendly and collaborative manner. If you feel that specific material covered in class or in assignments is too basic for you, choose a more difficult option, or, if such an option is not provided, ask for it.
- If you feel that your prior knowledge is not sufficient to understand the material being covered or practical exercises in assignments and projects, actively seek help, information, and pointers to background materials from your classmates, TAs, and instructor.
- That you treat your classmates and instructor respectfully by listening when other people are speaking and by communicating with everyone politely and respectfully.That you work collaboratively with your classmates during group work on assignments and projects. At the same time, I expect you to follow the expectations laid out for individual work in the “Honor code” section above and in the general College’s honor code.

What you can expect from instructor and TAs:

- We are here to share what we know and help you learn. We will do our best to facilitate learning by being open to and available to answer questions.
- We will answer the question “Why should I care about this?” about anything we cover in this course. This means that we will be ready to

explain to you why a particular method we are discussing is important and how it is used in astronomical research.

- ❏ We will provide ways for you to give us specific feedback and suggestions about material and the format of the class nearly every week in the minor assignment questionnaire (“type 1” assignments, see below). You are also welcome to provide feedback by email to a TA or instructor, or anonymously by putting a note in the instructor’s mailbox in the NE corner of the 4th floor of the ERC building. We will make our best effort to respond to feedback and incorporate suggestions promptly.
- ❏ We will clearly communicate expectations for acceptable coursework, deadline, and will grade assignments fairly and promptly. We will try our best to provide meaningful feedback for your work, if your assignment is submitted by the deadline.
- ❏ We will provide several opportunities for you to ask specific questions and receive guidance on your practical exercises and projects before they are due (Monday lab, during office hours and in class).
- ❏ We will be receptive to reasonable collective requests for assignment modification if valid reasons are specified.

Assignments: this is a heavily practice-based class and there will be regular assignments that will be of two flavors:

1) every Wednesday you will get a relatively small assignment consisting of a few conceptual questions related to the material covered in the last couple of classes, which will be due on Thursday by 9pm. These assignments will not require coding and computation. However, depending on how well you internalized material and concepts covered in class, you may find it useful to review the Jupyter notebooks used in class (or follow suggested reading). These assignments should take less than an hour to complete (roughly). The purpose of these assignments is to make sure that you understand key concepts of the discussed material and to allow us to identify common misconceptions. If such misconceptions become apparent, they will be addressed in the subsequent classes. As part of these assignments you will also have a chance to provide comments and suggestions about class format and material.

2) Some of the weeks on Friday you will be assigned exercises or mini-projects that will require coding (usually implementing of algorithms we discuss), computation, and analyses. Part of the Friday class then will be dedicated to review and group discussion of the assignment and subsequent Monday lab and office hours will be used for questions and working through the assignment. Depending on the scope and difficulty

of the assignment, it will be due either on the following Wednesday after class or later. Some assignments will be in the form of small projects. For these, you will need to work in small groups and present results both in the form of codes and Jupyter notebook summarizing computations and plots, and in an in-class group presentation (using Jupyter notebook or slides).

The exercises will have points associated with them, which will count towards the total point count for the entire assignment. Multiple options of different difficulty will be available in most cases. You are also encouraged to design your own exercises/projects, perhaps related to your current research or something you want to explore provided that it is related to the methods we are covering in the particular assignment. If you decide to go this route, contact me with the formulation of your exercise idea by the end of Friday's class after assignment is distributed.

The total score for an assignment or project will reflect its scope and difficulty. Grading will be based on how fully an exercise is completed with partial points given for partly completed exercise. The contribution of different assignments to your final grade will be weighted by the total number of points of each assignment.

Coding style and good practices: we will discuss good coding style and practices in class (see here for useful guidelines). We will also make our best effort to illustrate what we consider to be good coding style in the example codes that we distribute to you. We expect you to attempt to follow good coding practices and may evaluate your code style as part of the overall assignment evaluation.

Using lab sessions and office hours to aid your work on assignments and projects: in addition to regular lectures on Wednesday and Friday, we will have a lab session on Monday at 1:30-2:20pm. Attending this session is not required, but encouraged. These labs are a great opportunity to clear up conceptual difficulties or implementation issues that arise while working on the larger "type 2" assignments. However, we strongly suggest that you make a significant effort on these assignments prior to the start of lab: ideally you should have already reviewed the background material, designed a preliminary approach, and attempted to start coding before the lab. If you start the assignment in lab, our ability to aid in your work will be much more limited. In addition to the Monday lab session, the instructor will also be available to answer questions during office hours on Tuesday and after class on Wednesday and Friday.

Deadlines. Each assignment will have a specified deadline. Short assignments of type 1, will have a hard deadline because your answers are needed in time to inform the preparation of the next class. *A hard deadline will not be enforced for assignments of type 2 and no points will be taken off for late submission*s, but we can guarantee to provide full feedback for your work only if it is submitted by the deadline and can provide our version of assignment solutions to you only after your work is submitted.

Submitting Assignments. Unless specified otherwise, assignments for this course should be submitted via class site on Canvas. Before submitting assignments that involve coding, make sure that the code runs. In particular, for a Jupyter notebook before submission, select Kernel Restart and then Run All. Make sure that all of the notebook cells in your notebook have executed without errors and produced the desired output. *We will be very limited in our ability to grade parts of the assignment in which code does not run.*

Reading materials: there is no required textbook, relevant material will be distributed and/or presented in class in Jupyter notebooks. Check the class website on Github for the general list of useful materials.

Code repository where Jupyter notebooks used in class, codes, assignments, and most data files will be deposited (note that you can sign up for an educational/student github account, if you don't have one, but you can also simply access repository via browser): https://github.com/a-kravtsov/a211w20

Slack workspace: https://a211w20.slack.com/

The Slack workspace will be used for communications between you and instructor and TAs outside classes and during group work in classes.