Astronomy 7939: Mathematical Methods for Modern Astrophysics

Lecture Location: Web (Zoom link available on Canvas)

Lecture Times: Tuesdays 3:00PM-3:55PM (period 8), Thursdays 3:00PM-4:55PM (periods 8 & 9)

Instructor: Professor Zachary Slepian,

Office: Zoom/Bryant 302, (352) 294–1851

Office Hours: Fridays 4 PM - 5 PM ET, and by appointment

Contact Information: zslepian@ufl.edu

Course Website: Canvas/E-Learning

Course Recording: Generally, I am planning to record our meetings for any students who cannot attend. Below is UF policy on recording:

Our class sessions may be audio-visually recorded for students in the class to refer back and for enrolled students who are unable to attend live. Students who participate with their camera engaged or utilize a profile image are agreeing to have their video or image recorded. If you are unwilling to consent to have your profile or video image recorded, be sure to keep your camera off and do not use a profile image. Likewise, students who un-mute during class and participate orally are agreeing to have their voice recorded. If you are not willing to consent to have your voice recorded during class, you will need to keep your mute button activated and communicate exclusively using the "chat" feature, which allows students to type questions and comments live. The chat will not be recorded or shared. As in all courses, unauthorized recording and unauthorized sharing of recorded materials by students or any other party is prohibited.

Textbook: You must purchase the required text "Mathematical Methods for Physicists" (7th ed.) by Arfken, Weber, and Harris. Other references may be used for supplemental information throughout the course, such as Ivezic et al. "Statistics, Data Mining, and Machine Learning in Astronomy" and Press et al. "Numerical Methods." It is my recommendation to purchase these texts as they are wonderful references to have and often useful.

Brief Description: A survey of mathematical methods of use in modern astronomy and of their numerical implementation and use. The class will be roughly 1/3 conceptual, 1/3 applications, and 1/3 discussion of coding/numerical implementation.

Student Learning Outcomes:

- Students demonstrate competence in the terminology, concepts, methodologies and theories used within the discipline.

- Students communicate knowledge, ideas, and reasoning clearly and effectively in written or oral forms appropriate to the discipline.

- Students analyze information carefully and logically from multiple perspectives, using discipline-specific methods, and develop reasoned solutions to problems.

Course Learning Objectives:

- To provide students with a broad overview of math methods used in modern astronomy. This will be accomplished through lectures and weekly reading assignments and problem sets, as well as group projects.

- To teach students how to choose among the tools available in an informed way, and know how to locate in standard resources (both texts and code libraries) the appropriate math for a given problem and navigate putting it into practice and efficiently using it numerically, e.g. in *python.*

- To give students practice and comfort in the mathematical manipulations needed to use these tools effectively in a variety of astronomy problems and contexts.

Detailed Description of the Graded Course Structure:

Homework: Problem sets will be assigned throughout the semester on a roughly weekly basis. The assignment with the lowest grade will be dropped. Late homework will be penalized 10% per day but this penalty will not be applied if you have made an arrangement with the instructor to submit late, or if there are extenuating circumstances related even indirectly to the ongoing Covid pandemic.

Projects: There will be two small-group projects; details will be given early in the semester.

Extra Credit: A handout and discussion to explain the extra credit options will be provided early in the semester. All guidelines including due dates will be provided in the handout.

Course Grade Summary Breakdown: Each of the components of class described above will be assigned the following weights to determine your final score:

- Projects: 30% • Class Participation: 20% • Homework: 50%
- Grading Scale: (https://catalog.ufl.edu/ugrad/current/regulations/info/grades.aspx)

Score	**Grade**	**Score**	**Grade**	**Score**	**Grade**
90% – 100%	A	77% – 79%	B−	64% – 66%	D+
87% – 89%	A−	74% – 76%	C+	60% – 63%	D
84% – 86%	B+	70% – 73%	C	57% – 59%	D−
80% – 83%	B	67% – 69%	C−	Less than 56%	E

Class/University Policies:

Please put your phones and, unless you are taking notes, your laptops away during class: no Facebook, Twitter, texting, etc.

Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the disability Resource Center by visiting disability.ufl.edu/students/get-started. It is important for students to share their accommodation letter with their instructor and discuss their access needs, as early as possible in the semester. Classroom accommodations can only be provided after appropriate verification.

Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/.

Responsible citizenship among college students includes honesty and integrity in classwork; regard for the rights of others; and respect for local, state, and federal laws as well as campus standards. Students are responsible for understanding the standards of the "Code of Student Conduct" and the Student Handbook. From the Academic Honesty Guidelines and Student Conduct Code in the University of Florida Undergraduate Catalog: "Academic Honesty: The university requires all members of its community to be honest in all endeavors. A fundamental principle is that the whole process of learning and pursuit of knowledge are diminished by cheating, plagiarism, and other acts of academic dishonesty. In addition, every dishonest act in the academic environment affects other students adversely, from the skewing of the grading curve to giving unfair advantage for honors or for professional or graduate school admission. Therefore, the university will take severe action against dishonest students. Similarly, measures will be taken against faculty, staff, and administrators who practice dishonest or demeaning behavior." Any student caught cheating will be referred to the Honor Code Chancellor.

Statement Regarding Face-to-Face Interactions and Covid

This course is designated 80-99% online. For the 1% non-online component, as well as for any meetings outside of class (e.g. if office hours are held in person) any meetings will adhere to the following guidelines.

In response to COVID-19, the following policies and requirements are in place to maintain your learning environment and to enhance the safety of our in-classroom interactions.

- You are required to wear approved face coverings at all times during class (if in the classroom) and within buildings. Following and enforcing these policies and requirements are all of our responsibility. Failure to do so will lead to a report to the Office of Student Conduct and Conflict Resolution.

- This course has been assigned a physical classroom with enough capacity to maintain physical distancing (6 feet between individuals) requirements. Please utilize designated seats and maintain appropriate spacing between students. Please do not move desks or stations.
- Sanitizing supplies are available in the classroom if you wish to wipe down your desks prior to sitting down and at the end of the class.
- Follow your instructor's guidance on how to enter and exit the classroom. Practice physical distancing to the extent possible when entering and exiting the classroom.
- If you are experiencing COVID-19 symptoms (Click here for guidance from the CDC on symptoms of coronavirus), please use the UF Health screening system and follow the instructions on whether you are able to attend class. Click here for UF Health guidance on what to do if you have been exposed to or are experiencing Covid-19 symptoms.
- Course materials will be provided to you with an excused absence, and you will be given a reasonable amount of time to make up work. Find more information in the university attendance policies.

Tentative Class Schedule by Week

(week 1 = week starting Monday, January 11th, but please note class is Tuesday/Thursday each week).

Each week is noted below the listing of sections in Arfken Weber Harris that will be covered that week (numbering corresponds to AWH 7th ed.)

Topics may evolve slightly based on student interest, as is appropriate for a graduate class.

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1. Mathematical Preliminaries
-1.3. binomial theorem
-1.8. complex numbers
-1.9. derivatives and extrema
-1.10. evaluation of integrals
-1.11. Dirac Delta function
Week 1
**finding derivatives and extrema with Mathematica, with sympy*
**finding integrals with Mathematica*
**numerical integration methods: python. e.g. trapezoid, Romberg; concepts: adaptive step-size, order of the error*
**Using Gradshteyn and Ryzhik as your friend.*
**how do we get a Delta function in python?*
**how do we work with them in Mathematica?*
**Plotting in the complex plane with Mathematica and python.*
**analytic integration methods: let's build our cheat sheet.*

2. Matrices
-combine 2.1. and 2.2.
5.2. Gram-Schmidt Orthogonalization
6.2 Matrix Eigenvalue problems
Week 2
**matrix manipulations with python*
**decompositions such as QR, LU, SVD, approximate inversion/ issues of numerical inversion.*
**condition number*
**numerical linear algebra*

23. Probability and Statistics
Week 3 and 4
*Here, we will use AWH as a jumping off point but also use the Ivezic. I put this early, even though it is later in AWH, because I think it's important and interesting and want us to get to it early in the semester.
Topics will include:
-Fisher matrix, confidence intervals

-fitting a line with x and y errors, comparison of methods
-in case of upper and lower limits and incomplete data
-Gaussian mixtures
-k-nearest neighbor, other clustering algorithms
-Bayesian statistics

3. Vectors
-3.1. Basic review
-3.2. Vectors in 3D space
-3.3. Coordinate transformations
-3.4. Rotations
-3.8. Integral Theorems
3.10. Curvilinear Coordinates
Week 5
**transformations and rotations in python*
**integral theorems as they appear in E&M, plasma physics, stellar structure*

7. ODEs
-7.2. First-order equations
-7.3. Constant coefficients
-7.4. Second-order linear ODEs
-7.5. Series solution
-7.6. Other solutions
-7.7. Forced ODEs
-7.8. Nonlinear ODEs
Weeks 6/7
**solving with Mathematica, with python.*
**how do common solution methods work? Euler, Runge-Kutta, spectral methods.*

9. PDEs
-not too much detail on this, just one lecture, pointing out where it is, what are the 3 most important things to know
-9.4. separation of variables
-9.5. Laplace and Poisson equations

-9.6. Wave equation
Week 7

**examples*

**numerical solution; Courant condition, spectral methods, hydro sims; R-H jump conditions.*

10. Green's Functions
10.1. 1-D problems
Week 8

11. Complex Variables
-11.1. Intro
-11.3, 4, 5—Integrals, Laurent expansion
-11.7. Residues
-11.8. Definite Integrals
Week 8

**could add: Mobius transformations*

12. Further topics
-12.1. Orthogonal Polynomials
-12.6. Asymptotic series [could cut]
-12.7. Steepest Descents [could cut]
Week 9

**accessing these in Mathematica, in python. Plotting.*

13.3. Beta function
15. Legendre Functions
18.5. Hypergeometric functions
Week 10

**accessing in Mathematica, in python.*

14. Bessel functions
Week 11

**accessing in Mathematica, in python.*

**how to think about integration of them, resonance.*

16.2. Angular momentum coupling
-include more advanced resources: Varshalovich+, Yutsis, Rose.
<u>*Week 12*</u>

**how to access in Mathematica, python, sympy.*
**how these are actually computed? Storage algorithms (?)*

19./20. Fourier series & Transforms
<u>*Week 13 and 14*</u>

**let's implement in python, and access in python.*