AST 7939: Physical Cosmology

Z. Slepian

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E-mail: `zslepian@ufl.edu`
Office Hours: M 10-11:00 am/also after class
Office: Bryant Space Science Center 302

Web: **www.still-working-on-it**
Class Hours: MWF 3-3.50 PM
Classroom: Bryant Space Science Center 3

Course Description

This course is intended to prepare a student to do research at the cutting edge of cosmology by outlining the conceptual underpinnings, important historical advances, dominant areas of current interest in this discipline. The course will also give students experience with the mathematical and numerical methods, algorithms, and high-performance computing that have become core to modern cosmological research. The hope is that the tools learned in this course will also be of use to students working in disciplines outside of cosmology, be they other areas of astrophysics or even beyond that, big data.

Course Philosophy

Science is empirical, so part of learning a branch of science is learning information. We will be doing some of that—there are core equations, numbers, and facts that are necessary to enable you to understand current research in cosmology. But more than that, I want this class to teach you how to *think* cosmologically—both in terms of big picture, and in terms of looking for symmetries in problem solving and having an intuition for how the mathematical and numerical tools interplay with that. In short, a goal of the course is to hone your physicist jiu-jitsu skills.

Required/Useful Materials & Resources

- Owning P.J.E. Peebles' "Physical Cosmology" (1980) as well as T. Padmanabhan's "Large-Scale Structure" (1993) would be useful; both should be available used for modest prices in softcover. I will also have one copy of each available for students upon request in the department.
- S. Weinberg's "Cosmology" (2008) as well as S. Dodelson's "Modern Cosmology" (2003) and E. Kolb & M. Turner's "The Early Universe" (1990) are also useful references though

not required. A more introductory reference is B. Ryden's "Introduction to Cosmology" (2002). A useful reference on General Relativity is J. Hartle's "Gravity: An Introduction to Einstein's General Relativity."

- There are a number of excellent cosmology lecture note sets available online. D. Baumann's general notes at http://cosmology.amsterdam/education/cosmology/, notes on primordial cosmology at https://arxiv.org/abs/1807.03098, and notes on inflation at https://arxiv.org/abs/0907.5424 are worth consulting, as are D. Tong's notes (more introductory) at http://www.damtp.cam.ac.uk/user/tong/cosmo.html. C. Hirata's notes at http://www.tapir.caltech.edu/~chirata/ph217/index.html are also useful though often more technically detailed than we will require in this course. Hirata's notes on General Relativity are also useful (http://www.tapir.caltech.edu/~chirata/ph236/) though far more detailed than what we will directly require for the course. M. Kamionkowski's lecture notes are also worth reading (http://kamion.pha.jhu.edu/Ay127/home.html).

- A working PYTHON installation as well as ability to run a terminal and a basic editing program for coding will be useful in the course. MATHEMATICA may be useful but is not required.

- The integral and mathematical function compilation "Table of Integrals, Series, and Products" by I.S. Gradshteyn & I.M. Ryzhik may also be of use during the course; I will make one available upon request and students may likely obtain modestly-priced copies used as well. This is a useful standard resource in the field and gaining familiarity with it will be desirable. An undergraduate-level textbook on linear algebra and on ordinary differential equations will also be good to have on hand; I leave students the choice of which they prefer. A copy of W. Press, S. Teukolsky, W. Vetterling, and B. Flannery's "Numerical Recipes" may also be useful; I will make a copy available upon request as well.

- Stack Overflow is a good resource for coding questions.

- adsabs.harvard.edu is a good resource for finding papers and tracing forward and backwards citation webs.

Course Objectives

Successful students will:

1. Be comfortable with the key physical concepts underpinning cosmology.

2. Be able to read research papers in the discipline with understanding and frame critical questions about them.

3. Be able to use basic numerical methods and algorithms to execute computations and data analysis.

4. Be comfortable with the mathematical techniques important in modern cosmology.

5. Have a broad conceptual outline of the different areas within cosmology and their interrelationships.

Course Structure

Class Structure

There are two lecture periods per week; each period will be split into two halves. One half will generally cover mathematical or numerical techniques essential for cosmology; the other half will generally cover the physics.

Assessments

- There will be 10 problem sets, a midterm exam, a final exam, and a term project. Class participation will also count towards the final grade.
- Each problem set should be submitted using the standardized Latex template I will provide. This is to ensure easy legibility during grading as well as to solidify students' Latex skills, essential in any area of astronomy. I ask that students submit problem sets both in printed hard copy at the beginning of class and by email to be received before the start of the class during which the problem set is due. This is to ensure that I always have access to the problem sets for quick grading but also can easily provide hand-written feedback to students on the hard copy.
- The midterm and final will be in class. They will not comprise a substantial portion of the grade but will serve as important checkpoints both for the students and the instructor as to how well the material is being understood.
- The term project will be an opportunity for students to either write a review paper and thereby explore a topic we touch on in the class in greater detail, as well as hone their writing skills, or an opportunity for students to undertake a small-scale research project by applying some of the methods learned in class to a dataset or numerical computation. Either option will be presented in draft form before final submission to offer students the opportunity for detailed feedback and improvement.

Grading Policy

I reserve the right to curve the scale dependent on overall class scores at the end of the semester. Any curve will go in the direction of benefiting students' final letter grades.

- **40%** will stem from problem sets.
- **25%** will stem from the midterm and final exams.
- **10%** will stem from in-class participation.
- **25%** will stem from the term project.

Course Policies

During Class

Laptops and celluar phones—I respectfully ask that students do not use laptops during class save for if we are programming together in class. The class will not entail much text, though some equations will be presented on the board, and I believe that laptops would therefore not be useful tools for note-taking, but offer substantial potential to distract. Of course if a student requires a laptop to mitigate a documented disability that is fine, but I would ask that the student communicate this issue to me through the appropriate channels. I would also ask that students refrain from using cellular phones during class; again, this offers much opportunity for distraction.

Attendance Policy

I would ask that students attend every class and arrive on time. Of course sometimes absences are unavoidable but if possible, I would ask that a student alert me to an absence before it occurs. I would also ask that the student seek out the notes from that class session from a colleague afterwards. I do not intend to post notes online because I think doing so makes it more tempting to skip class. I would also ask that if a student has an absence from class to which they have not alerted me in advance, they contact me afterwards to let me know what the issue was (subject of course to respect for students' privacy) and if I can take any action to keep them on track in the class. The core of the class is lecture, and I want lectures to be useful for everyone. If the lectures feel less than useful, I ask that students let me know what could be improved before reaching the point that being absent seems a good solution.

Policies on Late Assignments

I will not accept late assignments barring extraordinary circumstances. Accepting late assignments would complicate timely posting of solutions to assignments and create additional organizational overhead for me. As one goes to the post-doc and faculty level, astronomy is a challenging discipline especially as regards obtaining grant funding, and funding agencies are rarely lenient about accepting late submissions. Practice in preparing materials on time and to a high standard is therefore one of the research and professional skills that I hope this course will inculcate and strengthen. I of course understand that situations can arise where it is not possible to submit an assignment on time (e.g. a family emergency or a medical issue), and I would simply ask students to alert me if such a situation does arise and we will find a solution.

Collaboration & Exam/Term Project Policies

Collaboration on problem sets is encouraged: your peers are the most valuable resource to grow with and learn from, and practicing collaborative science is a key skill this course will strengthen. However, students must write up their work independently. This is to make sure that each individual student comes away with a solid understanding of the course material, and that if that is not happening, I am aware of it early and can strengthen the course to address this.

The midterm and final exams will be in class and not collaborative: they must be completed individually with no reference to other students or any outside materials. For the midterm, a 1 page hand-written study sheet may be used; for the final, a 2 page study sheet may be used. These sheets must be written by hand by the student and must be legible without use of any aids (e.g. magnification). I will collect them at the end of each exam for review when grading the exam.

The term project must also be executed independently although I encourage students to share drafts or equivalent with each other for constructive criticism. However each final submission must be the sole product of the student submitting it.

Academic Integrity and Honesty

UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code." On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (**https://www.dso.ufl.edu/sccr/process/student-conduct- honor-code/**) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

Accommodations for Disabilities

Students with disabilities requesting accommodations should first register with the Disability Resource Center (352-392-8565, **https://www.dso.ufl.edu/drc/**) by providing appropriate documentation. Once registered, students will receive an accommodation letter which must be presented to the instructor when requesting accommodation. Students with disabilities should follow this procedure as early as possible in the semester.

Other Tidbits

Course Evaluation

Students are expected to provide feedback on the quality of instruction in this course by completing online evaluations at **https://evaluations.ufl.edu**. Evaluations are typically open during the last two or three weeks of the semester, but students will be given specific times when they are open. Summary results of these assessments are available to students at **https:// evaluations.ufl.edu/results/**.

Counseling and Wellness Center

Contact information for the Counseling and Wellness Center: **http://www.counseling.ufl.edu/ cwc/Default.aspx**, 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

Writing Studio

The writing studio is committed to helping University of Florida students meet their academic and professional goals by becoming better writers. Visit the writing studio online at **http:// writing.ufl.edu/writing-studio/** or in 302 Tigert Hall for one-on-one consultations and workshops.

Schedule and weekly topics

The schedule is intended to be accurate but may evolve as needed. Typically one bullet corresponds to one lecture, save for **Math** lines, which will if possible be integrated into other lectures.

Week 01, 08/19 - 08/23: Beginnings

- A Cosmologist's Overview
- Inflation: Part I (Friday)
- **Math**: Fourier Transforms
- Just 2 lectures this week since Monday was before classes began

Week 02, 08/26 - 08/30: Beginnings Continue

- Inflation II
- Reheating and Particle Creation
- Big Bang Nucleosynthesis
- **Math**: Fourier Transforms

Week 03, 09/02 - 09/06: First 380,000 Years

- Plasma Era & Baryon Acoustic Oscillations I
- Plasma Era & Baryon Acoustic Oscillations II
- Formation of the Cosmic Microwave Background (CMB)
- **Math**: Integration
- Monday September 2nd is a holiday

Week 04, 09/09 - 09/13: First 380,000 Years round 2

- CMB II: Temperature and Polarization Power Spectrum and Observational Results
- CMB III: Other cool stuff: Algorithms, Relativistic Species, Dark Matter & Magnetic Field Constraints, secondary CMB anisotropies: thermal and kinetic Sunyaev-Zel'dovich Effects, Lensing
- Dark Ages & Reionization
- **Math**: Ordinary Differential Equations

Week 05, 09/16 - 09/20: Structure Formation: Linear to Non-Linear

- Friedmann Equation and Linear Structure Formation
- Perturbation Theory
- Perturbation Theory II
- **Math**: Linear Algebra

Week 06, 09/23 - 09/27: ... to Galaxies

- Spherical Collapse and Formation of Halos
- Halo and Galaxy Biasing
- **Math**: Vectors and Tensors

Week 07, 09/30 - 10/04: Observables

- Redshift Space Distortions
- 2-Point Correlation Function, 3-Point Correlation Function, Power Spectrum, Bispectrum
- Clusters, Distance Probes, Weak Lensing
- Upcoming Surveys
- **Math:** Linear Algebra
- Friday October 4th is UF Homecoming

Week 08, 10/07 - 10/11: The Unknown Unknowns

- Dark Matter
- Simulations/High-Performance Computing
- Dark Energy

Week 09, 10/14 - 10/18:

- Modified Gravity
- Magnetic Fields and Magnetogenesis
- General Relativity I

Week 10, 10/21 - 10/25: ...

- General Relativity II: to the Friedmann Equations
- Gauge in Perturbation Theory
- Boltzmann Hierarchy: Neutrinos

Week 11, 10/28 - 11/01: ...

- Galaxies Used in Observational Cosmology: Luminous Red Galaxies, Emission Line Galaxies, X-Ray Clusters, Dwarf Galaxies
- Algorithms for Large-Scale Structure
- Modeling the power spectrum and bispectrum, including redshift-space distortions

Week 12, 11/04 - 11/08: ...

- We will be doing things for Weeks 12-15. But I am leaving it open now since the pace outlined in the first 3/4 of the course may be ambitious: I want flex time to be able to take longer on the items detailed in previous weeks. We will also spend some time for exams and reviewing, and we will also need time in class to discuss the class projects/term papers and present them.

Week 13, 11/11 - 11/15: ...

- ...
- Monday November 11th is a holiday

Week 14, 11/18 - 11/22: ...

- ...
- Wednesday to Friday November 27th-29th are holidays

Week 15, 11/25 - 11/29: ...

Week 16, 12/02 - 12/06: ...

- Last class is Wednesday December 4th; 5th and 6th are "Reading Days"
- We may have the final in class

Week 17, 12/09 - 12/13: **Exam Period** Technically begins Saturday December 7th