ASTR 452 (Spring 2019)

Astrophysics II: Galaxies and Cosmology
Tues & Thurs, 2:30-3:45 pm, HBH 453

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Course Description: This course is an introduction to modern cosmology and aspects of galaxies. On the cosmological front, you will learn about the standard cosmological model: inflation followed by a radiation, a dark-matter and finally a cosmological constant dominated universe. You will learn about (1) the interplay between the contents of the universe and its space-time dynamics, (2) about how different particle species emerge from the thermal soup after the big bang and (3) the evolution of structure in our universe: from tiny quantum fluctuations during our universe's infancy to correlated distribution of galaxies we see in the sky today. In the 4th quarter of the course we will discuss galaxies in more detail including our own host galaxy. We will emphasize the kinematics and dynamics of galaxies, as well as important scaling relations between observables. Throughout the course, we will emphasize the the interplay between different areas of physics in an astrophysical/cosmological setting and how our current theoretical understanding of galaxies and cosmology is firmly rooted in observations.

Learning Objectives:
By the end of the course, you (the student) should be able to to do the following:

- Describe and calculate the dynamics of the homogeneous universe, understand how the dynamics relates to its contents as well as observational probes of these dynamics.
- Be familiar with the thermal history of our universe and be able to calculate how different species of particles emerge from the thermal soup in the early universe.
- Calculate the evolution of density perturbations and gravitational waves in our universe; from initial conditions during inflation to the present day and understand corresponding observations.
- Understand galactic kinematics and dynamics, and be familiar with scaling relations between different observables of galaxies and galaxy clusters.
- Make order of magnitude estimates, apply concepts from many different areas of physics and perform detailed calculations of astrophysical/cosmological observables with an understanding of the approximations involved.

Prerequisites: A good base in electromagnetism, classical mechanics, statistical mechanics, special relativity, quantum mechanics, and of course prior exposure to astrophysics in general will be helpful. I will introduce relevant ideas as needed for (aspects of) general relativity, familiarity with GR will make your life easier. I will assume familiarity with systems of ordinary differential equations, multivariable calculus, Fourier analysis and linear algebra. Formally, for undergraduate students at Rice the prerequisites include (ASTR 350 OR ASTR 360) and (PHYS 301 and PHYS 302). If you do not have these requirements, please contact me and we can see if you can still take the course.

Class Website: All course materials including problem sets, links to relevant websites, supplementary material, class updates and announcements will be posted on the ASTR 452 Canvas page. It is your responsibility to check Canvas regularly for the most recent information concerning the class.

Main Text(s):

- *Class Notes*: My hand written notes for the class will be provided after each class.
- *Modern Classical Physics (chapter 28: Cosmology)* by Thorne and Blandford: This chapter is terse, but excellent for getting a short, insightful dose of modern cosmology. The rest of the book is an excellent reference for all things classical; including optics, fluids, plasmas, elasticity, relativity and statistical physics!
- *Cosmology Lecture Notes* by Baumann (U. of Amsterdam): We will partly follow Baumann's notes for the cosmology part of this course. They will provide slightly more technical detail than the lecture notes. These notes will be available on Canvas.
- *Extragalactic Astronomy and Cosmology* by Peter Schneider: We will use parts of this book for the last quarter of the course. It has a good balance of relevant observational details along with the theory. It is also a gentler, less mathematical treatment for the cosmology part of the course.

The text books are recommended, but not required for you to buy.

Additional Resources:

- *Cosmology* by Steven Weinberg: If you want rigor, this is the place to go to. It has most of the interesting things you can do "by hand" in cosmology. It might not be easy on the first reading but I recommend referring to it.
- *Physical Cosmology* by Mukhanov: I like the treatment of hydrodynamical perturbations in this book. It also has some more advanced topics relevant for the very early universe.
- *Spacetime and Geometry: An Introduction to General Relativity* by Carroll. This is an excellent textbook for GR at the graduate level.
- *Physical Cosmology* by Scott Dodelson: This is a detailed, graduate level text. It is particularly good in its detailed treatment of the cosmic microwave background.
- *An Introduction to Modern Astrophysics* by Carroll & Ostlie. Less advanced than the course, but comprehensive.

Exams and Problem Sets:
Problem sets every 1 - 2 weeks
2 Oral Exams (a Midterm and a Final). If the number of students is large (> 8), we will have a take home or an in-class (with limited notes) midterm/final.

Grading Policies: Homeworks will account for 50% of the grade and the two exams will account 25% each of the total grade. Late homeworks are annoying. For unexcused tardiness, there will be a 20% reduction/per day in credit, with no credit 2 days after the homework is due. If illness or other circumstances beyond your control lead to a delay in submission, please contact me as soon as possible (before the deadline, and after in exceptional circumstances). The final grade for the course will include some discretion based on class participation/interactions etc. Attendance is highly recommended.

Collaboration and Help: For a better understanding of the material you are strongly encouraged to talk to other students, postdocs and faculty (including me!). For the problem sets, you should work on each problem independently first (≥ 1 hr). When needed, get help about the general idea of how to do the problem but not the details of the entire calculation. If you collaborate/get help from others, they should be acknowledged in the problem sets along with details of what you collaborated/got help on. The write-up should always be done independently. Do not look up solutions online or from previous years. The Honor Code applies. You can review Rice's Honor Council documentation online at: honor.rice.edu/index.cfm

Special Needs: If you have a documented disability that requires special consideration for this class then please contact the me as soon as possible to discuss your needs. Students with disabilities should also contact the Disability Support Services Office in the Ley Student Center (dss.rice.edu).

Note: I reserve the right to change the contents and policies in this syllabus during the semester to suit the needs of the class.

Tentative Course Outline: The weekly/daily coverage might change depending on progress of the class.

Week	Content
Week 1	• 1. Introduction to our Cosmos & Spacetime Geometry • 2. A Primer on Calculus on Curved Spaces
Week 2	• 3. The Geodesic Equation and its Cosmological Applications • 4. Homogeneous Spacetime Dynamics – Conservation Equations
Week 3	• 5. Homogeneous Spacetime Dynamics – Einstein Equations • 6. Distances in Cosmology & Horizons + Inflation
Week 4	• 7. Inflation & Reheating + Overview of Thermal History of Our Universe • 8. Review of Equilibrium Statistical Mechanics with Application to $e + e-$ Annihilation and Neutrino Freezout
Week 5	• 9. Beyond Equilibrium – the Boltzman Equation • 10. Recombination
Week 6	• 11. Big Bang Nucleosynthesis + Review • 12. Introduction to Cosmological Perturbation Theory
Week 7	• 13. Conservation and Einstein Equations • 14. Single and Multicomponent Equations - Examples
Week 8	• 15. Types of Perturbations and Initial Conditions • 16. Evolution of Perturbations
Week 9	• 17. Matter Power Spectrum • 18. Statistical Measures of Matter Inhomogeneities + Nonlinear Structure Formation
Week 10	• 19. Statistical Measures of Anisotropy – Application to Cosmic Microwave Background (CMB) Anisotropies • 20. Quantum Fluctuations during Inflation $\longrightarrow$ CMB $\longrightarrow$ Galaxies.
Week 11	• 21. Kinematics & Contents of Galaxies • 22. Galactic Rotation Curves + Our Galactic Center
Week 12	• 23. The World of Galaxies and Galaxy Clusters • 24. Dynamical Friction + Relaxation Time Scales
Week 13	• 25. Scaling Relations • 26. Black Holes and Galaxies
Week 14	• 27. Gravitational Waves • 28. Summary and Future Outlook