ASTR 704/504: Cosmology
MWF 10:10-11:00, Phillips Hall 220

Instructor: Dr. Adrienne Erickcek
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Office Hours: Wednesdays 11am – 1pm, Thursdays 5pm – 6pm, or by appointment

ASTR 504 Prerequisites: ASTR 301, PHYS 301
ASTR 504 Corequisite: PHYS 321

Course Description:
This course is intended for graduate students and advanced undergraduate students and will provide them with an overview of modern cosmology. Starting from the basic principles of general relativity, we will develop models of our expanding spacetime and connect its expansion to the contents of the Universe. We will then follow the evolution of the Universe from its fiery origins to the synthesis of the light elements and the emission of the cosmic microwave background. Finally, we will trace the evolution of cosmological structures from the production of density fluctuations during inflation to the formation of bound halos. This course draws from several sub-fields of physics, including gravitational physics, classical field theory, and quantum mechanics. The course will emphasize quantitative problem solving and will equip students with the background knowledge required to interpret and participate in modern cosmological research. To demonstrate this competency, the students will work in teams to investigate an outstanding cosmological problem and will prepare written summaries and an oral presentation of its current status.

Course Goals:
1. To obtain a working knowledge of general relativity as it pertains to expanding spacetime and the evolution of cosmological perturbations.
2. To understand how astronomical observations allow us to trace the evolution of the Universe from the hot Big Bang to the current dark-energy dominated era.
3. To understand the inflation paradigm for the origin of our Universe: its motivations, its predictions, and the observations that will further test it in the future.
4. To obtain the quantitative skills required for cosmological computations.
5. To interpret the primary literature that communicates progress at the frontier of cosmological research.

Course Resources:
Required Text: Modern Cosmology, Scott Dodelson, Academic Press, 2003. (Dod.)
Optional Texts (on reserve in Undergraduate Library): The Early Universe, Edward W. Kolb and Michael S. Turner, Westview Press, 1990. (K&T); Cosmology: The Origin and Evolution of Cosmic Structure, Peter Coles and Francesco Lucchin, Wiley & Sons Ltd, 2002. (C&L); Spacetime and Geometry, Sean Carroll, Addison Wesley, 2004 (Car.)

Journal articles available online:
Liddle, Parsons and Barrow. *Phys. Rev. D* 50, 7222 (1994) (LPB)
Bertshinger "Cosmological Dynamics" astro-ph/9503125 (Bert)

Course Requirements:

1. Completion of 10 problem sets.
2. An individual written report (5 pages) and an oral team presentation (10 minutes) that summarizes the status of a current outstanding cosmological problem by drawing on at least three different published journal articles and presenting worked derivations of key results.
3. Participation in the in-class problem-solving sessions that will be incorporated into several lectures. The participation grade will be based on solutions shared with the class.

Grades:

Problem Sets	45%
Midterm	15%
Final	20%
Research Summary	15%
Class participation	5%

Course Policies: Collaboration on problem sets is encouraged, but each student must submit an independently prepared solution set. Unless prior arrangements have been made or there is a university-excused absence, late problem sets will be accepted until the Monday following their due date, but will receive a 20% penalty. Students will have the opportunity to correct and resubmit two problem sets. The take-home midterm is open-book and open-notes (and open-internet), but must be completed without any aid from another human. You must submit the take-home midterm with the signed pledge, "On my honor, I have neither given nor received unauthorized aid on this assignment." The final exam will be closed book, but the students may refer to notes that they personally prepare on a letter-sized sheet of paper.

ASTR 704/504 Distinction: The problem sets will include challenge questions that are required for 704 students and optional for 504 students. ASTR 504 students who complete these questions will receive extra credit. The two courses will also have different midterm exams.

Class	Topics	Reading	Assignments Due
Week 1: January 5	**Introduction**		
Wed.	Intro and overview of observations	Dod 1	
Fri.	Hubble's Law and metrics		
Week 2: January 12	**General relativity in cosmology**		
Mon.	GR overview and FRW metrics	Dod 2.1	
Wed.	Tensor manipulations		
Fri.	Connections and geodesics	Car 3.1-3.5	
Week 3: January 19	**The Expanding Universe**		
Wed.	Geodesics and Curvature	Car 8.1-8.3	
Fri.	Friedmann & Density evolution	Dod 2.3-2.4	PS #1: GR
Week 4: January 26	**Thermodynamics**		
Mon.	Cosmic Inventory and history of the Universe	Dod. 2.2	

Wed.	Cosmological distances	Dod. 2.3	
Fri.	Distribution functions	K&T 3.3-3.4	PS #2: FRW and Expansion
Week 5: February 2	**Thermodynamics**		
Mon.	Energy density, units, gstar	Dod 2.3-2.5	
Wed.	Entropy, temperature evolution, and Boltzmann Eq.	Dod. 3.1, K&T 5.1-5.2	
Fri.	Characteristics of the early universe, freeze-out idea	Dod. 3.4,	PS #3: Distances and Inventory
Week 6: February 9	**Freeze-out and BBN**		
Mon.	Dark matter freeze-out	Dod 3.2 K&T 4	
Wed.	Proton-neutron freeze-out, Helium production		
Fri.	Helium production and BBN observations		PS #4: Thermo and Freeze-out
Week 7: February 16	**CMB & Inflation Motivation**		
Mon.	Saha equation and CMB observations	Dod. 3.3	
Wed.	Horizon and flatness problems; Motivation for inflation	Dod. 6.2	
Fri.	Scalar field theory		PS #5: CMB and BBN
Week 8: February 23	**Inflation**		
Mon.	Slow roll models of inflation	Dod. 6.3, LPB I-III	
Wed.	Duration of inflation, metric perts		
Fri.	Decomposition of metric and gauges	Dod. 5, Bert 4	MIDTERM DUE
Week 9: March 2	**Inflationary perturbations**		
Mon.	Scalar Perturbations	Dod. 5	
Wed.	Classical inflationary perturbations	Dod. 6.5	
Fri.	Quantizing scalar perturbations and the inflationary power spect.	Dod. 6.6	PS #6: Inflation/ Metric Perts
Week 10: March 16	**Inflation observed**		
Mon.	Tensor perturbations from inflation, including power spect.	Dod. 6.4	
Wed.	Inflationary observations, potential perts, Einstein Eqs.	Dod. 5	
Fri.	Boltzmann equations I	Dod. 4	PS #7: Inflationary Perturbations

Week 11: March 23	**Evolution of Perturbations**		
Mon.	Boltzmann equations II	Dod. 4	
Wed.	Boltzmann equations III		
Fri.	Initial conditions and transfer function	Dod. 6.1,7.1-7.2	PS #8: Boltzmann Equations
Week 12: March 30	**CMB Anisotropies**		
Mon.	Matter power spectrum and growth function	Dod 7.3-7.6	
Wed.	CMB Angular Power spectrum, The Sachs-Wolfe plateau	Dod 8.5.2,8,2	
Fri.	Good Friday		
Week 13: April 6	**The CMB and the Halo Model**		
Mon.	CMB acoustic oscillations	Dod 8.3	
Wed.	The CMB power spectrum	Dod 8.4-8.7	
Fri.	CMB Polarization	C&L 13.3, 14.1	PS #9: Evolution of Perturbations
Week 14: April 13	**Probes of Nonlinear Structure**		
Mon.	CMB Exercises and Baryon Acoustic Oscillations		
Wed.	Top-hat collapse, Press-Schechter formalism	C&L 14.5 Dod. 9.5	
Fri.	Halo model: virial theorem, virial mass and virial radius, NFW profiles, scalings		PS #10: CMB Anisotropies
Week 15: April 20	**Models and Tests of Dark Energy**		
Mon.	Student Presentations		
Wed.	Student Presentations		Written research summaries
Fri.	Dark Energy Models and Observables		Resubmitted problem sets
April 27: 8 AM	FINAL EXAM		FINAL EXAM