This is a *graduate-level* course on physical cosmology.
This course covers our current evidence for dark matter, the evidence for the accelerated expansion of the universe, the physics of the early universe (including the theoretical implications of primordial gravitational waves and the prospects for measuring them), neutrinos and light relics, the physics of the Cosmic Microwave Background anisotropies, structure formation, gravitational lensing, and likelihood analysis.

Prerequisites: prior knowledge of General Relativity will be helpful for this course.

Course information:

Meeting Time: Tuesdays and Thursdays, 10:30 am - 11:45 am

Meeting Location: Lyman 425

Contact information:

Professor: Cora Dvorkin

Email: cdvorkin@g.harvard.edu

Office hours: Tuesdays, 2-3 pm (via zoom)

Teaching Fellow: Chandrika Chandrashekar

Email: cchandrashekar@g.harvard.edu

Office hours: Thursdays, 5:15-6:15 pm (Jefferson 357)

Sections: Thursdays, 4:15-5:15 PM (Lyman 330)

Notes for this course:

Prof. Dvorkin's lecture notes will be uploaded to the Canvas site before each class.

Bibliography:

There is no required textbook for this course, but here are a few suggestions:

- "Cosmology" (S. Weinberg).
- "Modern Cosmology" (S. Dodelson). One copy of this book is on reserve at the Cabot library. There are other two at the Wolbach library.
- "Cosmological Physics" (J. Peacock).
- "Cosmological Inflation and Large-Scale Structure" (A. Liddle and D. Lyth).
- "The primordial density perturbation" (A. Liddle and D. Lyth).
- "Physical Foundations of Cosmology" (S. Mukhanov).
- "A Course in Cosmology: From Theory to Practice" (D. Huterer).

The link to almost all of the books above can be found here.

Problem Sets:

There will be weekly problem sets.
You are encouraged to collaborate on the homework sets, but you must write them up individually. After discussions, make sure that you can work through the problems yourself and ensure that any answers you submit for evaluation are the result of your own efforts. You must list the names of the students with whom you worked on the problem sets. Additionally, you must cite any books, articles, websites, lectures, etc that have helped you with your work.

Final Project:

There will be a final project (due on the last day of classes). I will assign a list of suggested final project topics near the beginning of the course. Given that there are no exams, the final project is a very important part of the course, and I encourage you to start early.

Grading:

Grades will consist of 50% homework and 50% the final project.

Outline of the course:

Lectures 1 and 2: Introduction to Friedmann-Robertson-Walker Cosmology -- January 23, 25

Lecture 3: Einstein equations -- January 30

Lectures 4 and 5: Cosmic history (focusing on Big Bang nucleosynthesis and recombination) -- Feb 1 and 6

Lectures 6, 7, 8, and 9: Inflation -- Feb 8, 13, 15, 20

Lectures 10, 11, and 12: Cosmic Microwave Background anisotropies -- Feb 22, 27, 29

Lecture 13: Evidence for dark matter -- March 5

Lecture 14: Discovery of the accelerated expansion of the universe -- March 7

--- Spring break ---

Lecture 15: Baryon Acoustic Oscillations -- March 19

Lectures 16 and 17: Structure formation -- March 21, 26

Lecture 18: CMB Polarization (including gravitational waves) -- March 28

Lecture 19: Gravitational lensing -- April 2

Lectures 20, 21, and 22: Likelihood analysis -- April 4, 9, 11

Lecture 23: Special topics (students will vote from a list of suggested topics). Topics in the past have included: neutrinos, primordial non-Gaussianities, 21-cm cosmology, primordial CMB B-modes and foregrounds. -- April 16

Final project presentations: Presentations will be 10 minutes each, and everyone is required to ask at least one question. -- April 18

Final Projects:

For the final project, you may work with another student (or by yourself).

Possible projects are listed below. You are encouraged to come up with your own project idea, but you first have to discuss it with Prof. Dvorkin.

Project 1: Write a Markov-Chain Monte-Carlo likelihood analysis algorithm and implement it on a cosmological/astrophysical data set (it could be the CMB, a supernovae data set, or any other data set that you would like to analyze). The output should be the probability distribution function of the cosmological parameters included in the model used.

Project 2: Write a Mukhanov-Sasaki code that takes as input any inflationary potential, and gives as output the initial curvature power spectrum.

Project 3: Write a Boltzmann solver that includes the different species in the universe, and has as an output the CMB power spectrum. (you can ignore neutrinos in this project).

Project 4: Implement a Fisher forecast analysis on any extension of the LCDM scenario (e.g., a non-cosmological constant dark energy scenario, non cold dark matter components, non-Gaussian primordial fluctuations, extra relativistic degrees of freedom, etc).

Project 5: Run a Markov-Chain Monte-Carlo likelihood analysis on any extension of the LCDM cosmological scenario (for this purpose, you can modify publicly available Boltzmann solvers, such as COSMOMC or MontePython).

Project 6: Your new idea (previously discussed with Prof. Dvorkin).