The Origin and Emergence of Structure in the Universe

This course is meant to build upon the Bachelor level "Introduction to Cosmology" and the Master level "Essentials". However, neither of those courses is a firm requirement for this course. In addition, this course and the Physical Cosmology course typically alternate from semester to semester and are meant to be complementary to one another. Finally, there are additional special topics courses in related areas that are taught by non-faculty. You are welcome to take one or to take all of these. One can obtain credit for all of them.

The goal of this course is to provide an overview of current research efforts in studies of the emergence of the structure in the Universe. Key elements of this research include studies of the nature of the evolution of density perturbations and the formation of collapsed halos within an expanding Universe. Instrumentation developments over the past two decades have allowed observational probes of the seeds of these structures in the cosmic microwave background and the direct and indirect detection of these structures out to redshifts close to the epoch of reionization. We will discuss each of the resulting studies in some detail, building up a broad overview of the current state of the field and the physical underpinnings of these different observations. We will seek to underscore the key remaining questions, especially those that raise challenges to our current understanding of the Universe.

This course covers the following topics:

Review of Homogeneous Cosmology

> This is a general overview of Friedman cosmology that reviews the underpinnings of our current physical worldview. We focus on connecting observables in an expanding universe to the underlying cosmological model.

Evolution of the Comic Density Field

> This is a discussion of the linear evolution of density perturbations in an expanding universe. We discuss also the statistical properties of density fields, introducing the power spectrum and correlation function of the density perturbations.

The Cosmic Microwave Background

> We discuss measurements of the variations in the temperature and polarization of the cosmic microwave background, providing connections between the observations and the underlying physical processes that are being probed. We review the core results from WMAP and Planck as well as the ground based missions SPT and ACT that have established a standard cosmological model within which structure formation studies now proceed.

Formation of halos in an expanding Universe

> We discuss the collapse of a dark matter and baryonic density fluctuation into a halo and then present the expected and observed structure of halos, the mass function of collapsed halos and the connections to the growth of structure and the linear power spectrum of density perturbations.

Reionization and the Formation of the First Objects

> The Universe remains neutral after recombination while overdense regions collapse due to gravitational instability. These first collapsed objects form stars, galaxies and supermassive black holes, driving ionizing radiation fields that reionize the Universe. Probes of this process are important for clarifying the populations that first emerged and measuring the cosmological parameters at this epoch intermediate between the

recombination epoch probed by CMB and the late time dynamics probed by local structures.

Constraints on the epoch of reionization (EOR) using neutral hydrogen observations

We will discuss the use of the neutral hydrogen 21cm line to probe the redshifts over which the Universe is ionized by the radiation from the first objects that form. We will discuss how the spatial distribution of the neutral hydrogen at these early epochs can provide insights into the sources of the reioinization.

High Redshift Quasars and their Supermassive Black Holes

We discuss the current observational constraints on high redshift quasars and the masses of the central black holes powering their emission. We explore whether the apparent supermassive black holes at these high redshifts pose a challenge to our understanding of structure formation.

Texts:

Cosmological Physics, John A. Peacock, Cambridge University Press, 1999.

Cosmological Inflation and Large-Scale Structure, Andrew Liddle and David Lyth, Cambridge University Press, 2000.

Modern Cosmology, Scott Dodelson, Academic Press, 2003.

Einführung in die Extragalaktische Astronomie und Kosmologie, Peter Schneider, Springer 2008.

The Cosmic Microwave Background, Ruth Durrer, Cambridge University Press, 2008.

Dark Energy: Theory and Observations, Luca Amendola and Shinji Tsujikawa, Cambridge University Press, 2010.

Several journal articles will be added as supplementary material.

Grading:

Grades will come from the final exams supplemented by extra points obtained through the homeworks. It is expected that students attend and participate in all lectures and tutorials.

Ten homeworks will be discussed and the answers presented by the students in tutorials. These homeworks will typically consist of three to four problems that can be solved given the material covered in the previous lectures. In the tutorials, students will present the solutions, and these will be discussed in detail with the tutor. Solutions will be posted on the website after the tutorials for the week are finished. The first homework will be handed out next week and the first week of tutorials will be the week of November 3. Through performance in the presentation of the answers over the semester, each student will receive between 0 and 2 grade boosts, where a single grade boost is, for example, from a 1.7 to a 1.3.

A final exam at the end of the course will cover a broader range of questions with a mix of problems similar to those in the tutorial as well as short answer questions taken from the material in the lectures and problem sets. We will select a date for this final exam in the first part of the reading period (February 12 – 16). The final exam will be in-class (presence).

Location and Time:

Lecture: 12:00 PM-13:30 PM Friday, Lecturer Prof. Joe Mohr.

Tutorial: 1.5 hours every week, starting the week of the Nov 3.
We will seek to set up tutorials that each have about 5 students.
Tutors are Dr. Sebastian Bocquet and Dr. Chris Davies

Lectures and tutorials will be held in person.

Contact:

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