Syllabus Ay130: Introduction to Cosmology

- **Course Information**

  Course number: Astronomy 130

  Course title: Introduction to cosmology

  Term: Fall 2024

  Times: Monday and Wednesday, 1:30 - 2:45 pm

  Location: Science Center 300H

- **Contact Information**

  - Instructor: Xingang Chen
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  - Teaching Fellow: TBD
    Email address: TBD
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    Office hours: TBD

  Students are encouraged to use these sessions to complete the course materials with help from the TF and peers.

  Additional resource for course-related communications (especially questions visible to everyone) is the Slack workspace, accessible from the course menu on Canvas.

- **Course Objective**

  This course covers the evolution of the Universe from shortly after the Big Bang (13.7 billion years ago) to the formation of galaxies like the one we live in. We even contemplate how the Universe will look in the distant future. This enormous span of time sounds like a lot to pack in one semester, but we are aided by the fact that as you go back to early times in the Universe, things are simpler. With straightforward physics we can describe how spacetime expands, how the primordial fireball cools down and becomes transparent to photons, how the light nuclei (H, He, Li, Be) form, and how gravitational instability amplifies tiny density fluctuations so that they grow into the large structures (e.g. clusters of galaxies) we see today. The study of these things is physical cosmology, and has led us to the startling conclusion that most of the matter in the Universe is not made of the stuff we are (we call it dark matter), and most of the energy density in the Universe is not even matter at all (we call it dark energy).

  The study of physical cosmology raises many other fundamental questions, including:

- What is spacetime, how do we know it is expanding, and what does that even mean?
- What is the precise mathematical description of this expansion, and what does it tell us about gravity?
- How can we derive cosmological parameters (age of the Universe, etc.) from the cosmic microwave background? How are such observations done?
- What is the content of our Universe?
- What is dark matter? How can we learn about its particle nature in the lab? In space?
- What is dark energy? What is the nature of dark energy?
- What is the evolutionary history of our Universe? And what is the fate of our Universe?
- Where do the "primordial" elements (H, He, Li, Be) come from?
- What is inflation, and what problems does it solve?
- How does the large-scale structure (galaxy clusters, etc.) form? Why does it look like it does?

By exploring such questions, we will see how the Big Bang model unifies so many disparate observational facts into a coherent picture, while also raising profound new questions for both astrophysics and particle physics.

- **Prerequisites**

  A college-level course in mechanics satisfied by Physics 15a, Physics16, or Physical Sciences 12a. A course on calculus is required (e.g. Math 1b). General Relativity is not required.

- **Textbooks**

  There is no specific required textbook for this course. Taking notes during the lectures should be sufficient. On the other hand, having a reference book on such a subject does help a lot. I recommend any of the following textbooks. I will describe the specialty of each book below, and you may decide which one suits you the best. My lectures will be closer to the first one.

  - Introduction to Cosmology, Barbara S. Ryden (2nd edition). ISBN 978-1-107-15483-4. This is an excellent introductory book for undergraduates. General relativity, although forms the backbone of the subject of cosmology, is very lightly introduced in this book and is not required to understand the contents of the book.
  - An Introduction to Modern Cosmology, A. Liddle. This book is written at the same level of the first book, which sometime provides complimentary details and explanations to the same topics. It is a useful exercise to learn similar materials by consulting different books with complementary points of view.

- Principles of Physical Cosmology, P. J. E. Peebles. This is a classic book used in some graduate cosmology classes, which nicely covers nearly all subjects of cosmology. It goes much beyond what is required for Ay130, but if you want a more thorough discussion, it is a good reference.
- Modern Cosmology, S. Dodelson and F. Schmidt (2nd edition) This is also a graduate-level book, going much further than the requirements of this course. The latest edition includes additions on recent developments in the field (like nonlinear growth of structure and numerical analysis techniques).

- **Course Outline**

Sessions	Contents
1	Introduction
2	General relativity 1
3	General relativity 2
4	Cosmic dynamics
5	Model universes 1
6	Model universes 2
7	Measuring parameters 1
8	Measuring parameters 2
9	Matter and Radiation
10	Dark matter 1
11	Dark matter 2
12	Dark energy
13	Midterm Exam
14	Cosmic Microwave Background 1
15	Cosmic Microwave Background 2
16	Big Bang Nucleosynthesis 1
17	Big Bang Nucleosynthesis 2
18	Inhomogeneous Universe
19	Structure Formation
20	Gravitational Instability 1
21	Gravitational Instability 2
22	Stars and Galaxies 1
23	Stars and Galaxies 2
24	Cosmic Inflation 1
25	Cosmic Inflation 2

- **Course and Grading Policy**
  - Homeworks (50%)

    Homework is the most important practice after lectures. Students should try to solve the homework problems as independently and carefully as possible. Collaboration and discussions with classmates, TFs and the instructor on homework is encouraged, but you must ensure that anything submitted is the result of your own work and reflects your own approach to the topic, after the discussions. See Collaboration Policies for more details.
  - Midterm exam (20%)

    The midterm exam will be closed-book in-class exam. Two pages of "cheat sheets" are allowed to write down whatever materials that might help to remind you about the contents of the lectures. Calculators (or equivalent laptop programs) are allowed.
  - Final exam (20%)

    The final exam will be take-home open-book course projects, which deal with more physical, hence more interesting and intensive, problems. Students are expected to work independently; collaboration and consultation is not allowed. Date and deadline will be announced in class.
  - Participation (10%)

    Students are expected to attend all lectures except for special reasons. Questions and discussions are encouraged during and after the lectures. Office hours and problem sessions are another opportunity for such interactions.

- **Academic Integrity and Collaboration Policies**

  Any material submitted to meet course requirements – homework assignments, papers, projects, examinations – is expected to be a student's own work. Collaboration on studying and on homework assignments is encouraged, but you must ensure that anything submitted is the result of your own work and reflects your own approach to the topic. If unsure, ask the instructor or TFs. Students must make note of any collaborators, and any resources employed apart from the course textbooks and lecture notes when submitting work. This includes discussions with other students, websites, and other books and course notes.

  All members of the Harvard College community are expected to abide by the Harvard College Honor Code, which states:

  Members of the Harvard College community commit themselves to producing academic work of integrity – that is, work that adheres to the scholarly and intellectual standards of accurate attribution of sources, appropriate collection and use of data, and transparent acknowledgement of the contribution of others to their ideas, discoveries, interpretations, and conclusions. Cheating on exams or problem sets, plagiarizing or misrepresenting the ideas or language of someone else as ones own, falsifying data, or any other instance of academic dishonesty violates the standards of our community, as well as the standards of the wider world of learning and affairs.

- **Policy on course material distribution**

  Please refrain from distributing any of the course materials outside this class, both to specific individuals and through untargeted channels. This includes the homework assignments, exams, their solutions, and lecture notes.

  Your cooperation is greatly appreciated and contributes to a fair and enriching learning environment for all current and future students.