

Astronomy 376C: Cosmology

Unique Number 48030

Fall 2022

Class Meeting Times: TuTh 09:30-11:00am

Course Mode: Face-to-Face (PMA 15.216B)

Instructor: Prof. Mike Boylan-Kolchin (he/him/his)

Office: PMA 16.324

Teaching Assistant: Junehyoung Jeon (he/him/his)

Course Overview and Objectives

AST 376C is an introduction to Cosmology at a level suitable for Astronomy or Physics Majors. Cosmology is the study of the content of our Universe, where it came from, and how it evolves over time. This course covers basics of our understanding of the formation and evolution of structure in the Universe from the Big Bang to the present day. Cosmology is an exciting and still-changing discipline. In this course, you will:

- gain mathematical understanding of equations explaining the evolution of the Universe
- develop physical intuition the Universe, its contents, and its evolution over cosmic time
- learn about dark matter, dark energy, the intersection of astronomy and particle physics, and the expanding Universe, among other topics.

Some of the items covered (e.g., dark matter and dark energy) are not fully understood; by the end of this course, you will understand why we think that the matter and energy in the Universe are dominated by completely unfamiliar substances, as well as some of the outstanding questions in Cosmology today.

The class is intended for Physics and Astronomy majors, as well as those with a strong technical background in Physics and Astronomy. The course will assume a good working knowledge of calculus and Newtonian dynamics, as well as familiarity with differential equations. If you have concerns about the level of physics or math in the course, please contact me. All necessary astronomical terms and concepts will be introduced.

How Will I Succeed in this Course?

I have confidence that every single person in this course can learn the material and earn a good grade, provided you engage with the material deeply. I believe that the two most important components of success in this class are:

- **Understand the fundamental equations and their implications:** while much of the material can seem complicated, the underlying equations that govern the Universe's contents and its evolution can provide clarity. Understanding the basic equations of cosmology and their implications will help keep you grounded.
- **Be truthful with yourself about what you understand:** it's OK to be confused about a topic, an equation, or a concept! And it's definitely OK to ask questions, even if you're afraid they might be too simple! R. Feynman famously said "The first principle is that you must not fool yourself, and you are the easiest person to fool," and I think this is true in learning, too. It is easy to convince yourself that you understand something; it's important to be sure that you really do understand it.

Course Flags

This course carries the Quantitative Reasoning flag. Quantitative Reasoning courses are designed to equip you with skills that are necessary for understanding the types of quantitative arguments you will regularly encounter in your adult and professional life. You should therefore expect a substantial portion of your grade to come from your use of quantitative skills to analyze real-world – or real-Universe – problems.

Course Website and Email

The course website will be hosted on Canvas (<http://canvas.utexas.edu>). **Make sure that you are able to access and receive emails through Canvas.** Email is recognized as an official mode of university correspondence; you are responsible for reading your email for university and course-related information & announcements.

Course Textbook (required)

Introduction to Cosmology (Second Edition), B. Ryden (Cambridge University Press, 2017).

Please be sure to get the second edition, not the first edition. The book is available at the Co-op and at amazon.com (to purchase or rent), among other places.

There are many additional texts on cosmology and resources on the web that are useful for cosmology. One of the best at approximately the level of this course is *An Introduction to Modern Cosmology* (third edition), A. Liddle. Feel free to contact me if you are interested in more advanced or more specialized books.

In addition to the textbook, I will provide pdf notes that reinforce concepts from the text from my perspective.

Course Expectations

- **Attendance and Engagement:** Course attendance is crucial for understanding the complex material we will be covering. Additionally, we will be doing group exercises in class. These exercises are important for building your understanding and intuition about difficult problems. I always welcome questions about the course material during class (or at office hours).

Absences for illness, religious observances, participation in University activities at the request of University authorities, and compelling circumstances beyond the student's control are excused under University policy. Please inform the instructor *in advance* of any absences or schedule conflicts for religious observances.

- **Preparation:** This course covers fascinating but conceptually challenging concepts. Please preview the relevant section(s) of the book prior to class and read through it thoroughly after class. The amount of reading is typically small, but the gain in understanding is likely to be large. I will often provide notes that supplement this reading and that will be used as the basis for some of our discussions in class; please read these carefully and critically as well.

Prerequisites: Physics 301 & 303L; or 301 & 316; or 303K & 303L; or 303K & 316.

- **Assignments:** It is fine to discuss problems and concepts with your classmates – trying to explain something to someone else is a good way to see how well you understand it! We will also engage in group discussions in class. **However, it is crucial to remember that all graded assignments, including homeworks and examinations, must consist of your own thoughts in your own words.** Please also see the statement on academic integrity below.

Grading

You will receive the grade you earn in this course. **There will be no extra credit awarded during or after the semester**, so please be sure to put in the effort during the semester to earn the grade you want. Your grade will be based on the following components:

- *Homework* (assigned approximately once every two weeks): 40%.
On the due date, homework should be handed in at the beginning of the class; it will be considered late by the end of class. Late homework will be accepted for a week after the due-date and will be subjected to a penalty of up to 30%. **Your lowest homework grade will be dropped.**

If you have a valid emergency that prevents you from making a homework deadline, you should make all reasonable efforts to contact me **before** the due date; a self-signed note is sufficient provided that it contains a statement that (1) the information is true and correct and (2) you are aware that providing false information is prohibited under the Code of Student Conduct. If, for any reason, the University is officially closed on the day of the due date, the due date will be moved to the next lecture.
- *In-class Quizzes*: 40%
There will be (roughly) weekly unannounced in-class quizzes. These will take ~ 10 minutes and are designed to reinforce important concepts in the class, as there is substantial research that frequent, small-stakes evaluations are highly beneficial in long-term mastery of a subject (see [Make it Stick: The Science of Successful Learning](#) by P. Brown et al. for more details). **Your two lowest quiz grades will be dropped.** If you must be absent for an extended period or miss more than 2 quizzes, please arrange to discuss this with me.
- *Final project*: 20%
In place of a final exam, you will submit a project related to a topic of active research in cosmology. You will be evaluated based on your demonstrated knowledge of the topic's history, current status, and future prospects. The project will be due on the last day of classes (December 5).

Your grade will be computed as follows: the average grade you receive in each of the components listed above will be weighted by the percentage listed above and then rounded to the nearest 1 decimal place. Your final grade will be given by the following scale:

93 – 100: A
90 – 92.9: A-
87 – 89.9: B+
83 – 86.9: B
80 – 82.9: B-
77 – 79.9: C+
73 – 76.9: C
70 – 72.9: C-
67 – 69.9: D+
63 – 66.9: D
60 – 62.9: D-

Class Policies

- *Respect for others is vital.* I am: invested in the educational experience of each student in the class, respectful of individual differences, encouraging of creativity, available to discuss material and assignments; thorough in evaluating assignments; and rigorous yet supportive in maintaining high standards for performance. As a student, you are expected to work individually and with others, to create an atmosphere that is safe, valuing of one another, and open to diverse perspectives. Everyone is expected to show courtesy, civility, and respect for one another. Comments or postings that degrade or ridicule another, whether based on individual or cultural differences, are unacceptable.
- My official responsibilities as a professor occasionally require me to participate in external events. I will do my best to ensure these events do not conflict with class time; if I do have to miss any instructional time, another PhD UT astronomer will lead the class.
- **Sharing of Course Materials is Prohibited:** No materials used in this class, including, but not limited to, lecture hand-outs, videos, assessments (quizzes, exams, papers, projects, homework assignments), in-class materials, review sheets, and additional problem sets, may be shared online or with anyone outside of the class unless you have my explicit, written permission. Unauthorized sharing of materials promotes cheating. It is a violation of the University's Student Honor Code and an act of academic dishonesty. I am well aware of the sites used for sharing materials, and any materials found online that are associated with you, or any suspected unauthorized sharing of materials, will be reported to Student Conduct and Academic Integrity in the Office of the Dean of Students. These reports can result in sanctions, including failure in the course.
- **Class Recordings:** *In general, classes will not be recorded.* However, as we have all seen over the past 2 years, unforeseen circumstances can arise that will require either synchronous or asynchronous virtual components. In that case, any class recordings are reserved only for students in this class for educational purposes and are protected under FERPA. *The recordings should not be shared outside the class in any form.* Violation of this restriction by a student could lead to Student Misconduct proceedings.
- **Religious Holidays:** According to UT Austin policy, you must notify the professor of a pending absence at least fourteen days prior to the date of observance of a religious holy day. If you must miss a class, an examination, a work assignment, or a project in order to observe a religious holy day, you will be given an opportunity to complete the missed work within a reasonable time after the absence.

COVID-19 Update

The COVID-19 pandemic is **not** over. Wearing a mask indoors is strongly encouraged, as masks efficiently reduce the spread of COVID-19. If you are experiencing any symptoms of illness, please obtain a COVID-19 test (free of charge) at one of the many locations you can pick them up across campus and test before coming to class (see protect.utexas.edu for more information on where to get them). If you test positive, please do not come to class; instead, obtain a notification from [Student Emergency Services \(SES\)](#) and contact me via email (you do *not* need to reveal protected details about your health status). I encourage everyone to proactively test for COVID-19 throughout the semester at least once a week. If you are looking for ideas and strategies to help you feel more comfortable participating in our class, please explore the resources available here: <https://onestop.utexas.edu/keep-learning/>

Personal Pronouns

Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with differences of race, culture, religion, politics, sexual orientation, gender, gender variance, and nationalities. Class rosters are provided to the instructor with the students legal name, unless they have added a “preferred name” with the Gender and Sexuality Center (<http://diversity.utexas.edu/genderandsexuality/publications-and-resources/>). I will gladly honor your request to address you by a name that is different from what appears on the official roster, and by the gender pronouns you use. Please advise me of any changes early in the semester so that I may make appropriate updates to my records. For instructions on how to add your pronouns to Canvas, visit <https://utexas.instructure.com/courses/633028/pages/profile-pronouns>.

Academic Dishonesty

University of Texas Honor Code: The core values of The University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility. Each member of the university is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community. Students who violate University rules on scholastic dishonesty are subject to disciplinary penalties, including the possibility of failure in the course and/or dismissal from the University. Standards for Academic Integrity are posted at <http://deanofstudents.utexas.edu/sjs/acint.student.php>

Plagiarism: As a research university, The University of Texas at Austin takes plagiarism very seriously. Do not risk getting involved in a plagiarism infraction – the consequences simply are not worth it. Always cite your sources, and when in doubt, consult a professor or librarian. You may also read more about plagiarism at the Student Judicial Services website: http://www.utexas.edu/cola/cwgs/_files/pdf-4/ai2012.pdf

Accessible/Compliant Statement

If you are a student with a disability, or think you may have a disability, and need accommodations please contact Disability and Access (D&A). You may refer to D&A's website for contact and more information: <http://diversity.utexas.edu/disability/>. If you are already registered with D&A, please deliver your Accommodation Letter to me as early as possible in the semester so we can discuss your approved accommodations.

Accessible, Inclusive, and Compliant Statement

The university is committed to creating an accessible and inclusive learning environment consistent with university policy and federal and state law. Please let me know if you experience any barriers to learning so I can work with you to ensure you have equal opportunity to participate fully in this course. If you are a student with a disability, or think you may have a disability, and need accommodations please contact Disabilities and Access (D&A) <http://diversity.utexas.edu/disability/>. If you are already registered with D&A, please deliver your Accommodation Letter to me as early as possible in the semester so we can discuss your approved accommodations and needs in this course.

University Deadlines

Please see <http://registrar.utexas.edu/calendars/22-23> for relevant University deadlines (including drop deadlines)

Behavior Concerns Advice Line (BCAL)

The Behavior Concerns Advice Line is a service that provides The University of Texas at Austin's faculty, students, and staff an opportunity to discuss their concerns about another individual's behavior. This service is a partnership among the Office of the Dean of Students, the Counseling & Mental Health Center, the Employee Assistance Program, & The University of Texas Police Department. If you have concerns about the safety or behavior of fellow students, TAs, or Professors, call BCAL at 512-232-5050.

Title IX Reporting

Title IX is a federal law that protects against sex and gender based discrimination, sexual harassment, sexual assault, sexual misconduct, dating/domestic violence and stalking at federally funded educational institutions. UT Austin is committed to fostering a learning and working environment free from discrimination in all its forms. When sexual misconduct occurs in our community, the university can: (1) Intervene to prevent harmful behavior from continuing or escalating; (2) Provide support and remedies to students and employees who have experienced harm or have become involved in a Title IX investigation; (3) Investigate and discipline violations of the university's relevant policies.

Faculty members and certain staff members are considered "Responsible Employees" or Mandatory Reporters, which means that they are required to report violations of Title IX to the Title IX Coordinator. **I am a Responsible Employee and must report any Title IX related incidents that are disclosed in writing, discussion, or one-on-one. Before talking with me, or with any faculty or staff member about a Title IX related incident, be sure to ask whether they are a responsible employee.** By state law, any responsible employee who does not report any Title IX related incidents that are disclosed to them must be fired from the University (and can be charged with a criminal offense – Class B or Class A Misdemeanor).

If you want to speak with someone for support or remedies without making an official report to the university, email advocate@austin.utexas.edu For more information about reporting options and resources, visit <http://titleix.utexas.edu> or contact the Title IX Office at titleix@austin.utexas.edu.

Preliminary Course Outline

Note: changes to this schedule may be made at my discretion and if circumstances require. It is your responsibility to note these changes when announced (although I will do my best to ensure that you receive the changes with as much advanced notice as possible). The readings for later in the semester will be updated during the course based on progress to that point.

Dates	Topics
Aug 23, 25	Astronomy units, cosmological principles, observational cosmology's basis <i>(reading: Ryden, chapters 1 & 2.1-2.3; notes1.pdf & notes2.pdf)</i>
Aug 30, Sept 1	Redshift, Hubble's law, and cosmological expansion; coordinate systems <i>(reading: Ryden, chapters 2.3 & 4.2-4.4; notes2.pdf & notes3.pdf)</i>
Sept 6, 8	Basic equations of cosmology; FRW models <i>(reading: Ryden, chapters 4.2-4.4; notes4.pdf)</i>
Sept 13, 15	Geometry and metrics; distances <i>(reading: Ryden, chapter 3.2, 3.4, 3.5, 6.2, 6.3; notes5.pdf)</i>
Sept 20, 22	Distances; multiple component universes; the Λ CDM model <i>(reading: Ryden, chapter 5; notes6.pdf)</i>
Sept 27, 29	Hot big bang: timeline of the first three minutes
Oct 4, 6	Big bang nucleosynthesis (BBN)
Oct 11, 13	The Cosmic Microwave Background & Baryon Acoustic Oscillations
Oct 18, 20	Cosmological structure formation
Oct 25, 27	Spherical collapse & dark matter halos
Nov 1, 3	Dark matter & dark energy
Nov 8, 10	Galaxy formation
Nov 15, 17	Cosmological inflation;
	Thanksgiving Break: Nov. 22, 24
Nov 29 - Dec 1:	Outstanding issues and future directions; final project