MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Physics Department

Physics 8.286: The Early Universe — Sunday, August 30, 2020
Prof. Alan Guth

COURSE INFORMATION

INSTRUCTOR: Alan H. Guth, Room 6-322, Ext. 3-6265, guth@ctp.mit.edu.

TEACHING ASSISTANT: Bruno Scheihing, bscheihi@mit.edu.

LECTURE HOURS: Mondays and Wednesdays, 11:05 a.m. – 12:25 p.m. A Zoom Meeting ID will we emailed to all class members. If you have not received it by 6 pm Tuesday 9/1/20, please send email to Alan Guth. The lectures will be recorded, and the recordings will be available to the world through the course website, https://web.mit.edu/8.286/www.

REQUIRED TEXTBOOKS:

Introduction to Cosmology, Second Edition (Cambridge University Press, 2016), by Barbara Ryden.

The First Three Minutes, 2nd paper edition (Basic Books, 1993), by Steven Weinberg.

RECOMMENDED BOOKS:

An Introduction to Modern Cosmology, 2nd Edition (Wiley, 2003), by Andrew Liddle.

The Inflationary Universe (Perseus Books, 1997), by Alan H. Guth. This was written as a popular-level book, and therefore has no equations. It does not, however, shy away from trying to explain the relevant principles of physics and their logical connections. It attempts a kind of story-telling flavor, describing the history of twentieth century cosmology, and also the story of my own involvement in cosmology. The course will in no way follow this book, but you might like it.

LECTURE NOTES AND OTHER READING:

There is no textbook that I know of that is really appropriate for the intended content of this course, although Barbara Ryden's book, **Introduction to Cosmology**, comes much closer than any book I have seen previously. Steven Weinberg's **The First Three Minutes** is a superbly written book which gives an excellent description of cosmology in general, and the synthesis of the light chemical elements in particular. But it does not describe the mathematical details. It has a mathematical appendix, but the description there is very sketchy. We will try to fill in some of the mathematics behind Weinberg's descriptions in class.

The bulk of the course, however, will be based on lecture notes that will be posted periodically on the course website. The material in these lecture notes will be essential for doing the problem sets and quizzes, and will form the backbone of the course. (Incidentally, David Kaiser and I are currently working on an undergraduate textbook on cosmology, which will be largely based on these lecture notes.)

For the first part of the course (classical cosmology), the lectures and the associated lecture notes will describe the subject at a level of detail that is much more mathematical than Weinberg's book, and a little beyond the level of Ryden's book. For the second part of the course (modern particle physics and its recent impact on cosmology), we will rely mostly on the lecture notes, although Ryden does have a good chapter on inflation. You will also be asked to read several articles from *Scientific American* or similar publications.

CLASS FORMAT:

Teaching fully online is certainly a new experience for me. I will be treating it as something of an experiment, and the class will benefit a lot from feedback from you.

In particular, we can choose between more or less normal lectures, or we can use a "flipped classroom" format. By normal lectures, I mean that I would try to explain the material from scratch, and you would be encouraged to interrupt with questions whenever anything was unclear, or whenever you wanted to learn something that I didn't say. I would plan to use slides to replace the blackboard, and I would post the slides before the lecture, so that you could follow along and look back when you want. [Another option would be for me to write on a tablet as a blackboard replacement, but then you would be limited to seeing one (fairly small) screenful at a time, and there would be no advance copy.]

The "flipped classroom" approach would involve asking you to view the lectures from the 2013 version of this course that are available through OCW (OpenCourseWare). We would then use the class time for discussion. I would answer questions from you, discuss specific points that seem particularly subtle, and maybe discuss some of the homework problems. (There will in any case be office hours, by both Bruno Scheihing and me, for the discussion of the problem sets.)

I expect to try both of these formats, and then we can discuss which format works best. The first two classes will be in lecture format, and will consist mostly of an overview of inflationary cosmology. They will be based on a lecture that I have been giving at various places around the world, under the title "Inflationary Cosmology: Do We Live in a Multiverse?". After this overview, we will start from the beginning to lay out the physics of the early universe.

GRADING:

In recent years the grade has been based 75% on quizzes and 25% on the problem sets, but this fall, aiming to make it a bit more relaxed, the grade will be only 66% quizzes, and 34% problem sets. However, if your grade would turn out better under the old system, then that's the grade you will be given. The tentative dates for the quizzes will be

1) Wednesday, September 30, 2020 (7 preceding classes)
2) Wednesday, October 28, 2020 (7 classes since first quiz)
3) Wednesday, December 2, 2020 (6 classes since second quiz)

We will use these dates unless I hear from you about significant conflicts. (If the conflicts involve only a few students, then alternate dates can be arranged for those students.) You will be asked to time your work on the quiz at 85 consecutive minutes, and then to scan or take a cell-phone photo of your pages and upload them. To allow for time zones around the world, the quiz will be available for 24 hours starting at the normal class time. The quiz will be closed-book, with no use of internet or calculators, but I will be providing extensive formula sheets (available in advance).

There will be 9 problem sets during the term, with one due at the last class (Wednesday, December 9), and all the others due at 5:00 pm Boston time on Fridays. The first problem set will be due on Friday, September 11, 2020. This fall (unlike recent years) the lowest problem set grade will be dropped. But you should feel strongly encouraged to do all the problem sets, and I will try to make this convenient by being very generous with extensions. If you find that you are having an unusually busy week and cannot fit in the 8.286 problem set, I'm okay with giving you an extension — just send an email describing the situation, and ask me.

SPECIAL RELATIVITY:

I think that many of you have studied some special relativity, but special relativity is not a prerequisite for this course. For the benefit of those who have not studied special relativity, the basic results are summarized in Lecture Notes 1. You will be expected to understand and occasionally use these statements, but we will not discuss how they are derived. A full treatment of special relativity is available in 8.033 (Relativity) or 8.20 (Introduction to Special Relativity, during IAP). For those who are interested in self-studying this subject, a few references are mentioned in Lecture Notes 1. I would be happy to talk to you outside of class about any aspects of relativity. There will be a few more results from special relativity that will be needed as the course progresses ($E = mc^2$, for example!), and I will try to point them out and summarize them carefully as we go along.

COURSE OUTLINE:

1. Doppler Effect (and a little Special Relativity)
2. Kinematics of Newtonian Cosmology
3. Dynamics of Newtonian Cosmology
4. Introduction to Non-Euclidean Spaces
5. Black-Body Radiation and the Early History of the Universe
6. The Accelerating Universe and the Cosmological Constant
7. Big-Bang Nucleosynthesis
8. Problems of the Conventional (Non-Inflationary) Hot Big Bang Model
9. Grand Unified Theories and the Magnetic Monopole Problem
10. The Inflationary Universe Model
11. Primordial Density Fluctuations and the Cosmic Microwave Background
12. Eternal Inflation and the Multiverse

HOMEWORK POLICY:

In this course I regard the problem sets primarily as an educational experience, rather than a mechanism of evaluation. I have allocated 34% of the grade to problem sets in order to encourage you to do them, and to make life easier for students who find it difficult to do well on quizzes. You should feel free to work on these problems in groups, and I would strongly encourage you to do so. With the right mix of students, the homework can be more fun and more illuminating. I would recommend that, before the group meeting, you at least think carefully about how you would solve each of the problems, but a group meeting can be very helpful in thrashing out the details and in rooting out misconceptions. I will soon be setting up a Class Contact webpage to help you make contact with each other.

However, it is important pedagogically that each student write up the solution independently. The simple copying of a friend's paper is not the kind of effort that the grading is intended to encourage. Using 8.286 solutions that have been circulated in previous years is strictly off limits. Using other sources, such as other textbooks or web documents, is considered perfectly okay, as long as you write up the solution in your own words.

A homework problem which appears to be copied from another student, from a solution circulated in a previous term, or copied more or less verbatim from some other source (without rewriting in your own words) will be given a reduced grade, possibly a zero. Except in blatant cases, however, students will be given a warning the first time this happens, and will be given an opportunity to redo the relevant solutions. Since the homework is intended primarily for learning, and not evaluation, there is nothing that you can do on the homework — in this course — that will lead to an interview with the Committee on Discipline. I say this because I want to strongly encourage you to work in groups on the homework, and I don't want you to feel that there are any hidden dangers. (Remember, however, that you should not assume that this policy holds in other classes; different professors have different points of view on these issues.)

MORE ADVANCED READING:

There are some excellent graduate-level textbooks on cosmology that some of you might want to look at. These books are well beyond the level of this course, but I mention them in case any of you become interested in pursuing some topic at a more advanced level. The first two are written from the astrophysical point of view, while the last five describe the early universe more from the particle physicists' slant:

Cosmological Physics (Cambridge University Press, 1999), by John A. Peacock.

Principles of Physical Cosmology (Princeton University Press, 1993), by P.J.E. Peebles.

Cosmology (Oxford University Press, 2008), by Steven Weinberg.

Modern Cosmology (Academic Press, 2003), by Scott Dodelson.

Physical Foundations of Cosmology (Cambridge University Press, 2005), by Viatcheslav Mukhanov.

The Early Universe (Addison-Wesley, 1990), by Edward W. Kolb and Michael S. Turner.

Particle Physics and Inflationary Cosmology (Harwood Academic publishers, 1990), by Andrei Linde.

THE COURSE WEBSITE:

https://web.mit.edu/8.286/www

All course information will be posted at the URL above. Problem set and quiz submission, and grade postings, will be at a different URL, to be announced shortly.