MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Physics Department

Physics 8.286: The Early Universe — November 22, 2009
Prof. Alan Guth

SUGGESTED TOPICS FOR EXTRA CREDIT PAPER

The Paper: If you are interested, you may write an extra-credit paper on any topic related to cosmology, which will be due on Fri, December 4, the last day of the next-to-last week of classes. Under MIT rules, this is the last possible due date for this sort of assignment:

> Optional assignments between December 4 and the last scheduled class period in the subject should be for self-study and may not be used toward part of the grade in a subject, even for extra points or as substitutes for earlier assignments.
>
> — http://web.mit.edu/faculty/teaching/termend.html#ugnofinal

It should be roughly four pages in length. Depending on the quality of the paper, you will receive up to 3 extra credit points, which will be added to your final overall average for the course.

I expect these essays to be more or less at the *Scientific American* level, and below I have listed a number of *Scientific American* articles that you might use as starting points. You should include a (short) bibliography of your sources. (I would expect you to have at least 3 sources, but this might vary depending on the topic. I find that the Wikipedia is often very useful, but of course it should not be your only source.)

I am also including some books in the suggested references below. If you wish, you can write a book review of any of these books or any other book related to cosmology that you might choose. (For a book review you do not need a bibliography. The book you are reviewing is enough.) Of course the recommended books can also be used as sources of information for papers on specific topics.

The history of cosmology is very interesting, so historically based papers will also be welcome.

I would recommend that you let me know in advance (by email) what you plan to write about, in case I have any additional suggestions for references or angles. But this is not required.

When you submit the paper, we strongly prefer submission by email, preferably in postscript, PDF, or MS Word. Please email your submission to both Leo Stein (leostein@mit.edu) and me (guth@ctp.mit.edu).

Suggested Topics:

1) The Cosmic Microwave Background: Physics and/or summary of observational results.

Possible reference: The Cosmic Symphony, **Scientific American**, February 2004; by Wayne Hu and Martin White; 10 page(s). (New observations of the cosmic microwave background radiation show that the early universe resounded with harmonious oscillations.)

2) The Cosmic Microwave Background: specific experiments. You can choose any one (or perhaps several if you want) of the following experiments:

   a) COBE (Cosmic Background Explorer, the first CMB satellite mission, launched 1990)

   b) WMAP (Wilkinson Microwave Anisotropy Probe, the current CMB satellite mission, launched 2001)

   c) Planck (the next CMB satellite mission, launched May 14, 2009)

   d) Balloon experiments: for example, BOOMERANG (at the South Pole)

3) Dark matter

4) The accelerating universe and dark energy

   Possible reference: A Cosmic Conundrum, by Lawrence M. Krauss and Michael S. Turner, **Scientific American,** September 2004.

5) String theory

   Possible reference: **The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory,** by Brian Greene (book, 2000).

   Possible reference: **The Fabric of the Cosmos: Space, Time, and the Texture of Reality,** by Brian Greene (book, 2005).

6) The critics of string theory — what are their arguments, how valid are they?

   Possible reference: **The Trouble with Physics: the Rise of String Theory, the Fall of a Science, Land What Comes Next,** by Lee Smolin (book, 2006).

   Possible reference: **Not Even Wrong: The Failure of String Theory And the Search for Unity in Physical Law,** by Peter Woit (book, 2006).

7) The string theory landscape

   Possible reference: The String Theory Landscape, by Raphael Bousso and Joseph Polchinski, **Scientific American,** September 2004.

   Possible reference: **The Cosmic Landscape: String Theory and the Illusion of Intelligent Design,** by Leonard Susskind (book, 2007).

   Possible reference: **Many Worlds in One: The Search for Other Universes,** by Alexander Vilenkin (book, 2006).

Possible reference: The Great Cosmic Roller-Coaster Ride, by Cliff Burgess and Fernando Quevedo, **Scientific American,** November 2007.

8) Eternal inflation

Possible reference: The Self-Reproducing Inflationary Universe, **Scientific American,** November 1994; by Andrei Linde; 8 page(s). (Recent versions of the inflationary scenario describe the universe as a self-generating fractal that sprouts other inflationary universes.)

9) Parallel universes

Possible reference: Parallel Universes, **Scientific American,** May 2003, by Max Tegmark; 12 page(s). (Not just a staple of science fiction, other universes are a direct implication of cosmological observations.)

10) The Measure Problem: The definition of probabilities in an eternally inflating multiverse

Unfortunately, I don't know of any **Scientific American** level descriptions of this topic. Technical references include:

A.H. Guth, "Eternal inflation and its implications," J. Phys. A **40**, 6811 (2007) [arXiv:hep-th/0702178].

S. Winitzki, "Predictions in eternal inflation," Lect. Notes Phys. **738**, 157 (2008) [arXiv:gr-qc/0612164].

A. Linde, "Inflationary Cosmology," Lect. Notes Phys. **738**, 1 (2008) [arXiv:0705.0164 [hep-th]].

A. De Simone, A.H. Guth, A. Linde, M, Noorbala, M.P. Salem, and A. Vilenkin, "Boltzmann brains and the scale-factor cutoff measure of the multiverse," arXiv:0808.3778 [hep-th].

11) Particle physics and symmetry

Possible reference: **Symmetry and the Beautiful Universe,** by Leon M. Lederman, Christopher T. Hill (book, 2004).

12) Extra dimensions

Possible reference: **Warped Passages : Unraveling the Mysteries of the Universe's Hidden Dimensions,** by Lisa Randall (book, 2005).

Possible reference: **Hiding in the Mirror : The Mysterious Allure of Extra Dimensions, from Plato to String Theory and Beyond,** by Lawrence M. Krauss (book, 2005)

Possible reference: The Universe's Unseen Dimensions, by Nima Arkani-Hamed, Savas Dimopoulos, and Georgi Dvali, **Scientific American,** August 2000.

13) The universe from a computational point of view

    Possible reference: **Programming the Universe : A Quantum Computer Scientist Takes On the Cosmos,** by Seth Lloyd (book, 2006).

14) Black holes

    Possible reference: **Black Holes and Time Warps: Einstein's Outrageous Legacy,** by Kip S. Thorne (book, 1995).

15) The black hole information paradox

    Possible reference: Black Holes and the Information Paradox, by Leonard Susskind, **Scientific American**, April 1997.

16) Gravity Probe B: a satellite experiment to test frame dragging in general relativity. Currently in orbit.

17) The Sloan Digital Sky Survey: a mammoth, particle physics style collaboration of several hundred astronomers, undertaking the task of surveying about one quarter of the sky at optical wavelengths.

18) General relativity and time travel

    Possible reference: There is an excellent chapter on time travel in the Kip Thorne book cited above.

    Possible reference: Negative Energy, Wormholes and Warp Drive, **Scientific American,** January 2000; by Lawrence Ford and Thomas Roman; 8 page(s). (The construction of wormholes and warp drive would require a very unusual form of energy. Unfortunately, the same laws of physics that allow the existence of this "negative energy" also appear to limit its behavior.)

    Possible reference: How to Build a Time Machine, **Scientific American,** September 2002; by Paul Davies; 6 page(s). (It wouldn't be easy, but it might be possible.) (Comment by AHG: The previous parenthetical remark comes from **Scientific American.** I would recommend not counting on it, although nobody has ever proven that the laws of physics forbid the possibility of time machines. Davies also wrote a book with the same title.)

19) Veneziano's "pre-big bang" approach to cosmology

    Possible reference: The Myth of the Beginning of Time, **Scientific American,** May 2004; by Gabriele Veneziano; 10 page(s). (String theory suggests that the big bang was not the origin of the universe but simply the outcome of a preexisting state.) (Comment by AHG: Veneziano is responsible for the Veneziano model of particle scattering, a theory that set off a chain of evolution that led to modern string theory. He is a former MIT faculty member. This version of cosmology is a minority report at present, but Veneziano is certainly a very solid theoretical physicist.)

20) The Ekpyrotic cyclic model of Paul Steinhardt and Neil Turok

    Possible reference: **Endless Universe: Beyond the Big Bang,** by Paul J. Steinhardt and Neil Turok (book, 2007).

21) History: Albert Einstein and Alexander Friedmann: why was Einstein so slow to accept the possibility of an evolving universe?

22) History: the discovery of the cosmic microwave background.

23) History: big bang nucleosynthesis, perhaps going back to George Gamow, Ralph Alpher, and Robert Herman.

24) Magnetic monopoles

    Possible reference: Superheavy Magnetic Monopoles, by Richard A. Carrigan, Jr. and W. Peter Trower, **Scientific American**, April 1982 (In the **Particle Physics in the Cosmos** review book, on the recommended book list for this course. It's long out of print, but Amazon.com still has listings for used copies.)

25) Grand unified theories

    Possible reference: A Unified Theory of Elementary Particles and Forces, by Howard Georgi, **Scientific American,** April 1981. (In the **Particle Physics in the Cosmos** review book.)

    Possible reference: The Decay of the Proton, by Steven Weinberg, **Scientific American,** June 1981. (In the **Particle Physics in the Cosmos** review book.)

26) The matter-antimatter asymmetry of the universe

    Possible reference: The Cosmic Asymmetry between Matter and Antimatter, by Frank Wilczek, **Scientific American,** Dec 1980. (In the **Particle Physics in the Cosmos** review book.)

27) Possible book review: **A Briefer History of Time,** by Stephen Hawking and Leonard Mlodinow (2005).

28) Possible book review: **The State of the Universe: A Primer in Modern Cosmology,** by Pedro Ferreira (2007).

29) Possible book review: **The Infinite Cosmos: Questions from the Frontiers of Cosmology,** by Joseph Silk (2006).