Physics 608 Cosmology

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Dr. Tad Pryor 302W Serin Physics Lab 445-5462
pryor@physics.rutgers.edu

Overview: Cosmology is the study of the origin and evolution of the Universe. As such, it is a big topic, employing a wide range of physics, both theoretical and experimental. Cosmology has deep ties both to astrophysics, as many cosmologically important observations of celestial objects must be interpreted through the prism of astrophysics, and to fundamental physics, since the form our Universe displays is determined by gravitation, particle physics, nuclear physics, and thermodynamics. These various physical processes have come together into a simple "concordance (or standard) model" of cosmology which predicts a wide and rich array of observable phenomena.

This is an exciting time in cosmology. Technological advances over the past decade have made possible an array of observations which strongly constrains the properties of the Universe. The discovery that the expansion of the Universe is accelerating presents a great challenge to high-energy physicists to explain the source and nature of the mysterious "dark energy" which is likely driving this expansion. The Sloan Digital Sky Survey has observed more than a quarter of the sky, detecting nearly 200 million celestial objects and measuring spectra of more than 675,000 galaxies, 90,000 quasars, and 185,000 stars. Wide-coverage gravitational lensing surveys are probing the distribution of mass in the Universe. And last, but not least, measurements of the Cosmic Microwave Background, notably the first-year results from the WMAP satellite, have yielded values for cosmological parameters with an accuracy of several percent. After spending decades in what cynics called "an attempt to measure two numbers" (the Hubble constant the the deacceleration constant), we are now in the age of "precision cosmology".

The current job of cosmologists is to determine if the deluge of observational data are consistent with the standard cosmological model. While the bulk of the data appears nicely consistent with the model, a few possible trouble spots exist. This class will attempt to highlight the quality of the current match between data and observation, and the extent to which the model is internally consistent.

Another theme of the class will be the use of cosmology as a tool for probing fundamental physics and astrophysics. As cosmology becomes better constrained, the basic model of the Universe can be used as a platform from which to explore the impacts of various particle physics ideas on the early Universe. On the other end, the basic cosmological model provides the simple initial conditions from which quasars, galaxies, and other complex astrophysical systems arose.

Lectures: Monday and Wednesday, 4th period (1:40 - 3:00 PM for classes on Busch Campus), SEC 212.

Home page: http://www.physics.rutgers.edu/grad/608/

Text: *Cosmological Physics*, J. A. Peacock, 1999, Cambridge University Press. This book is very ambitious in its scope, which is both the book's strength and disadvantage. Peacock spends hundreds of pages discussing all aspects of physics which conceivably impact cosmology (including, for example, quantum field theory), space which would have better been used to cover some cosmology topics in more depth. The book is somewhat uneven, with certain excellent sections (especially large-scale structure) and others which are less successful.

Potentially useful references are:

Gravitation and Cosmology, S. Weinberg, 1973. One of the first modern cosmology textbooks and still a classic in many respects. The field has progressed hugely in the intervening 30 years, but much of the basic material is presented in an elegant and clear manner.

The Early Universe, E. W. Kolb & M. S. Turner, 1990, Westview Press. This book is a basic source for much of the fundamental-physics side of cosmology, such as thermal history, particle dark matter, phase transitions and inflation. But it has only cursory coverage of any issue in structure formation, including the microwave background, large-scale galaxy distributions, Lyman-alpha forests, gravitational lensing, or galaxy formation, which together encompass the great majority of current active research.

Modern Cosmology, S. Dodelson, 2003, Academic Press. A recent book with a focus on the microwave background.

Cosmology: The Origin and Evolution of Cosmic Structure, 2nd edition, P. Coles & F. Lucchin, 2002, Wiley. A good all-around cosmology textbook.

Physical Cosmology, P. J. E. Peebles, 1993, Princeton University Press. It contains a great wealth of information, some of which can be found nowhere else. But the book's coherence length is only a few pages; this lack of organization makes the book a rough ride for most students (and the index is not overly detailed).

Structure Formation in the Universe, T. Padmanabhan, 1993, Cambridge Univ. Press. Is heavily weighted towards large-scale structure and is quite mathematical.

Cosmology and Astrophysics Through Problems, T. Padmanabhan, 1996, Cambridge Univ. Press. Contains quite a bit of cosmological material in problem-solution format.

First Principles of Cosmology, E. V. Linder, 1997, Prentice Hall. Is a nice, concise undergraduate-level overview of some major areas of cosmology, with an emphasis on nucleosynthesis, the microwave background, and large-scale structure.

Introduction to Cosmology, B. Ryden, 2003, Addison Wesley. A good, up-to-date undergraduate cosmology text. Includes material on the accelerating universe.

Cosmology, the Science of the Universe, 2nd edition, E. Harrison, 2000, Cambridge University Press. The author is the Harrison of the Harrison-Zel'dovich power spectrum.

The book was written as a textbook for the author's discussion seminar about cosmology offered to non-science majors at Amherst College. The book has little mathematical content, but is conceptually quite deep; cosmologists at any level of experience and sophistication can get something out of it.

Office hours: I generally do not set up specific office hours for a graduate course, but feel free to contact me by email or phone or to set up a time to drop by my office. I am generally in my office roughly 9:30 AM – 5:00 PM every weekday. I am also available to answer questions after class.

Homework and Grades: Your grade will be based on about five problems sets (50%) and a term paper (50%). The problems will be due approximately every two weeks. Please let me know in advance if you will not be able to turn in a particular problem set by the due date.

The term paper should constitute a *critical assessment* of the recent literature on a topic and not simply a summary of one or two papers. You will also make a 20-minute presentation to the rest of the class during the last two weeks of the semester. I will hand out more details on the paper shortly.

Students with Disabilities: If you have a disability, you are urged to speak to the course supervisor early in the semester to make the necessary arrangements to support a successful learning experience. Students with disabilities should consult the department webpage: http://www.physics.rutgers.edu/ugrad/disabilities.html.

Outline of Topics:
Below are fourteen general topics that I hope to cover (plus an initial overview), representing a broad survey of the present state of cosmology and currently hot research areas. The class schedule will cover approximately one of these topics per week.

1. General overview: the "big picture". A synopsis of the current standard cosmological model and the main sources of data which support and test it.
2. Homogeneous and isotropic spacetimes. The form of the Friedman-Robertson-Walker metric. Distance measures. Horizons. Nontrivial topology and tests.
3. The expansion of the Universe. The Friedman equation for the evolution of the scale factor. Standard rulers and standard candles; classical cosmological tests. Cosmic age. Observations of cosmic acceleration. The cosmological constant problem.
4. The thermal history of the Universe. Matter content; equations of state. Kinetic theory. Thermal equilibrium. Distortions of the photon blackbody spectrum. Phase transitions. Relic particles.
5. Primordial nucleosynthesis. Initial conditions. Interaction network and rate equations. Time scales. Relic nuclear abundances. Current observations: Lyman-alpha deuterium lines, old stellar lithium content. Limits on the baryon-photon ratio. Constraints on the expansion rate.

6. Recombination. Atomic processes. Departures from equilibrium. Width of last scattering surface. Relic ionization.

7. Phase transitions. Physics of false vacuum. QCD and electroweak phase transitions. Inflationary and ekpyrotic models.

8. Cosmological perturbations. Gauge issues. Baryonic perturbations, Jeans mass. Oscillatory solutions. Dark matter perturbations. Evolution of primordial acoustic oscillations.

9. Primary microwave background fluctuations. Sachs-Wolfe effect. Doppler and intrinsic effects. Diffusion damping. Generic features of the power spectrum. Physical parameters. Polarization. Tensor modes and inflation. Initial conditions. Gaussianity. Experimental results.

10. Growth of structure. Gravitational instability. Linear transfer function. Nonlinear transfer function. Large-scale density and velocity fields. Redshift surveys, particularly 2dF and Sloan. Biasing. Peculiar velocity surveys. Observational considerations.

11. The first objects. High-redshift quasars. Reionization. The Lyman-alpha forest as a probe of structure.

12. Properties of galaxies. Spiral galaxy rotation curves. Observed regularities. Elliptical galaxies. Stellar populations. Central black holes. Merger models, merger trees. Numerical simulations and modeling.

13. Dark matter. Cold and hot. Particle physics candidates. Potential difficulties. Possible modifications. Experimental searches. Local distributions.

14. Gravitational lensing. Lensing formalism: lens plane, magnification, shear, caustics. Strong lensing and mass distribution. Weak lensing. Weak lensing surveys. Microlensing.

15. Secondary microwave background fluctuations. Sunyaev-Zel'dovich effect. Gravitational lensing. Experimental prospects.