Syllabus for ASTRON 3785: Cosmology
University of Pittsburgh, Fall 2025

Schedule and Instructor. Astronomy/Physics 3785 will meet Mondays and Wednesdays, 1:30 to 2:45, Allen Hall 100. The instructor is Professor Arthur Kosowsky, Department of Physics and Astronomy. My office is Allen Hall 315. Email is the most efficient way to get in touch: kosowsky@pitt.edu. I will hold office hours after class, 2:45 to 4 on Wednesdays, and I am happy to meet with students at other times by appointment.

Prerequisites This course has no formal prerequisites. Cosmology draws on a wide range of topics in physics and astronomy, and you are expected to have an undergraduate-level familiarity with all of the basic areas of physics.

Overview. The course will cover the observational basis for the standard model of cosmology; basic properties of cosmological expanding spacetime including distance measures and redshifts; the thermal history of the universe including relic populations of dark matter, baryons, neutrinos, and nuclei; the cosmic microwave background radiation and its temperature and polarization anisotropies; linear growth of density perturbations; precision determination of the standard cosmological model; and near-future sources of data relevant to cosmology. We will conclude with an overview of possible departures from the standard model, and the outstanding physics questions that the standard cosmology leaves unanswered at the present time which include the nature of dark matter and dark energy at late times and the physics establishing the observed initial conditions of the universe at early times.

Over the past 30 years, cosmology has rapidly progressed, due to the enormous increase in data, particularly from the cosmic microwave background and from large galaxy surveys. This class will always keep centered the relevant data which support and constrain our model of the universe, and what types of data may in principle be available in the future.

Textbook. The textbook for the course is Cosmology by Daniel Baumann (Cambridge University Press, 2022). While there are now many textbooks on cosmology at a graduate level, this one is particularly outstanding for its clarity, its balance of topics, and its timeliness. I recommend purchasing this book for the course. It is around $70 new. It was published in 2022; you may be able to find used copies for cheaper. You can also download Baumann's cosmology lecture notes on which this book is based at http://cosmology.amsterdam/education/cosmology/. They are not as complete or polished as the book, and a few topics are clarified or corrected in the book, particularly in the structure formation chapters.

Other notable recent textbooks at a similar level include Modern Cosmology by Scott Dodelson and Fabian Schmidt (3rd edition, Academic Press 2025) and A Course in Cosmology by Dragan Huterer (Cambridge Press, 2023). Older classic textbooks include The Early Universe by Michael Turner and Edward Kolb (CRC Press, 1989) (still the standard for basic results and detailed calculations about cosmic thermodynamic processes; barely anything useful about perturbations and structure formation) and Principles of Physical Cosmology by P.J.E. Peebles (Princeton Press, 1993) (lots of deep and useful results but not always easy to understand). Textbooks at a lower level, aimed at undergraduates, include An Introduction to Modern Cosmology by Andrew Liddle (3rd edition, Wiley, 2015) and Introduction to Cosmology by Barbara Ryden (2nd edition, Cambridge Press, 2016).

I will also attempt to provide guidance to current review articles about specific topics that we cover.

Web Site. This class has a Canvas web site, where all course materials, problem sets, class images, and this syllabus will be posted. Log in at http://canvas.pitt.edu.

Homework and Exams. The class will have a number of problem sets – I will aim for two every three weeks, for a total of 8 or 9 during the semester. The problems on these assignments will relate directly to current issues in cosmology, and hopefully will feel relevant, not simply deriving equations. I will attempt to guide you through a certain topic with a set of related questions, including physical aspects of the problem, computational and theoretical results, and measurements of related observables.

I also plan a take-home final exam, which will involve a similar analysis to one of the assignment problems, but focussed on a current unsolved issue in cosmology.

Outline of Topics

Following each topic is the number of class meetings I plan to devote to it. The listed classes total 28, including the 2 classes during finals week. Depending on class interests, we may add and subtract topics.

Overview. Current data and observations; basic elements of the standard cosmological model. (1)

Basic properties of a homogeneous and isotropic universe. Newtonian derivation of the Friedmann equation for scale factor evolution. The expanding universe and the horizon scale. (1)

Thermodynamic Properties of matter, radiation, dark energy. Thermal history of the universe, energy scales. (1)

Cosmography. Distance measures, redshifts, age. Standard candles (Type-1a supernovae), standard sirens (binary gravitational wave sources), standard rulers (baryon acoustic oscillations), and standard clocks (stellar ages). (1)

Particle processes in an expanding universe. The Boltzmann equation. Freezeout of interactions: dark matter relic abundance. (2)

Nucleosynthesis of the light nuclei. (1)

Microwave background spectrum evolution: spectral distortions. (1)

Neutral hydrogen spin temperature and 21-cm emission. (1)

Linear perturbations. Decomposition into components, gauge freedom. Gaussian random initial conditions. (1)

Basic physics of the microwave background. Recombination and diffusion damping. (1) Sachs-Wolfe effect, Doppler effect, Integrated Sachs-Wolfe effect. (1)

Microwave background power spectrum. Dependence on standard model parameters. (1)

Microwave background polarization. Mechanism of generation, velocity coupling. E/B decomposition. (1)

Sources of B-mode polarization. Primordial gravitational waves. (1)

Growth of linear density perturbations. The matter power spectrum. Baryon acoustic oscillations. Neutrino cosmology. (3)

Gravitational lensing. Weak lensing, microwave background lensing. Probe of mass content, structure growth. Limits on neutrino masses. (3)

Sunyaev-Zeldovich effect. Basic physics. Probe of cluster abundances. Probe of peculiar velocities. (2)

Inflation. Observational motivation. Physical mechanism, phenomenology of horizon evolution. Generation of scalar perturbations, gaussian random statistics. Tensor perturbations. Inflation observables. (3)

Outstanding issues for the standard model. What is dark matter? What is dark energy? What is the mechanism of baryogenesis? What drives inflation, or does a viable alternative exist? Microwave background anomalies and cosmic variance. (2)