C161: Relativistic Astrophysics and Cosmology

UC Berkeley, Spring 2016

Elements of general relativity. Physics of pulsars, cosmic rays, black holes. The cosmological distance scale, elementary cosmological models, properties of galaxies and quasars. The mass density and age of the universe. Evidence for dark matter and dark energy and concepts of the early universe and of galaxy formation. Reflections on astrophysics as a probe of the extrema of physics.

**Instructor**: Prof. Aaron Parsons (aparsons at berkeley)

**Office**: Campbell 455

**Office Hours:** M 4:00p – 4:30p Campbell 121

**GSI**: Max Genecov (mgenecov at berkeley)

**Office Hours**: W 11:30a – 12:30p Campbell 233

**TALC**: Tu 5:00p – 6:30p, Campbell 121

**GSI**: Morgan Presley (mpresley at berkeley)

**Office Hours**: Fri 1:30p – 2:30p Campbell 233

**TALC**: W 5:00p – 6:30p, Campbell 121

**Lectures**: Tu/Th 11:10a – 12:30p, Campbell 131a

**Web**: <https://casper.berkeley.edu/astrobaki/index.php/Relativistic_Astrophysics_and_Cosmology>

**BCourses**: <https://bcourses.berkeley.edu/courses/1412794>

**Main Text**: Andrew Liddle “An Introduction to Modern Cosmology” (2nd Edition, Wiley)

**Other Readings**:

* Peter Schneider "Extragalactic Astronomy and Cosmology" (complementary material to Liddle, covering astrophysical properties of galaxies, clusters and other important observational facts)
* Barbara Ryden "Introduction to Cosmology" (Addison Wesley; similar to Liddle)
* M. S. Longair "Galaxy Formation" (for those interested in graduate-level cosmology)
* Steven Weinberg "The First Three Minutes" (a popular account of the thermal history of the universe)
* Kip Thorne "Black Holes and Time Warps" (a beautifully written popular book on black holes and relativity)

**Grading**: 50% Problem Sets; 25% Exam; 25% Project/in-class presentation

**Guidelines for presentations:**

In-class presentations give you the opportunity to investigate a current research topic in cosmology, using the knowledge you have gained in class. Unlike standard physics courses, cosmology is a rapidly progressing subject filled with new results. These presentations help keep us up to date! You will get a taste of the excitement in cosmological research, and practice an important science skill: giving oral presentations.

Each talk (by a pair of students) is 15 minutes. The audience is your classmates, so pedagogy is important. Talk as if you were a professor recruiting your classmates to work on your topic. Focus on questions such as: Why is it important? How is it done? What have we learned? What to expect next? For topics discussed in class, spend only one slide reviewing theory and then jump into the observations and phenomenology. For other topics, balance theory and results. Within this framework, you have the freedom to design your talk. We will provide some references to get you started. You must explore beyond it, read a lot, learn a lot, and extract the essential points to present to the class. Have fun!

**Course Content**

1. **The Smooth Universe**
   1. The Cosmological Principle; Hubble parameter H; scale factor a [Ch 1,2]
   2. Friedmann equation; equation of state; radiation, matter, dark energy [Ch 3,4,5]
   3. Density parameter Omega; open, flat, closed cosmological models [Ch 6]
   4. Time evolution of H, Omega, and a [Ch 7]
   5. Rudiments of general relativity; the Robertson-Walker metric [Ch 8, A1]
   6. Basic kinematic properties: distance-redshift, time-redshift, age, angular sizes [A2]
2. **The Bright Side**
   1. The Planck mass; the ugliest number in physics
   2. Thermodynamics of Fermi and Bose gases in an expanding universe
   3. The longest 3 minutes of your life
   4. Big Bang Nucleosynthesis: helium, deuterium, lithium, baryon-to-photon ratio [Ch 12]
3. **The Dark Side**
   1. Evidence for dark matter [Ch 9]
   2. Evidence for dark energy
   3. Two dark matter problems: baryonic vs non-baryonic
   4. What can they be?
4. **The Lumpy Universe**
   1. Gravitational instability in a static universe
   2. Gravitational instability in an expanding universe
   3. Growth of cosmic structures
   4. Photon-baryon scattering physics; the cosmic microwave background [Ch 10, A5]
5. **The Baby Universe**
   1. Successes of the standard Big Bang model [Ch 11]
   2. Problems of the standard Big Bang model [Ch 13]
   3. How to fix it? Inflation
6. **Black Holes**
   1. Supermassive black holes at centers of galaxies
   2. Gravity waves: sources: binary black holes
   3. Gravity waves: detection
7. **Sample Topics** (student presentations)

* The Distance Ladder
* The Monopole Problem
* Cosmic Acceleration: Supernovae
* Astrophysical Tests of General Relativity
* General Relativity versus Modified Gravity
* Dark Matter: Strong Gravitational Lensing
* Dark Matter: Weak Gravitational Lensing
* Dark Matter: Weakly Interacting Massive Particles
* Dark Matter: Neutrinos
* Cosmic Microwave Background: Primary Anisotropy
* Cosmic Microwave Background: B-Mode Polarization
* Cosmic Microwave Background: Sunyaev-Zeldovich Effect
* Epoch of Reionization: Galaxy and Quasar Surveys
* Epoch of Reionization: 21cm Experiments
* Galaxy Surveys: Large-Scale Structure
* Galaxy Surveys: Baryon Acoustic Oscillations
* Cosmological Simulations: N-Body and Hydrodynamics
* Gravitational Waves: Astrophysical Sources
* Gravitational Waves: Detection Experiments
* Observing Supermassive Black Holes
* Multiverse Theory