October 2, 2019

Syllabus for Cosmology I, ASTR 310
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Scope, goals and format

The subject matter will address a range and depth of knowledge of cosmology appropriate for graduate students in any subfield of astronomy or astrophysics. It will include a survey of the history of the subject in the context of physics and astrophysics, the current state of the art, and important outstanding questions and future opportunities. The goal is to become conversant with the subject: we will cover what every Ph.D. in astrophysics should know about cosmology. A listing is given below of the standard canon.

Students will gain experience in reading and critical analysis of scientific papers, participation in critical discussion, and oral presentation. Assignments will be in long-form written format, and help build experience in clear and precise scientific writing.

The course will be taught in a seminar format. We will meet on Monday and Wednesday from 1:30-2:50 in ERC 583.

Reading and assignments

Readings will be selected from research papers and review articles.

A useful textbook for the course is ``Cosmology" by Steven Weinberg (Oxford, 2008), available for free as an e-book from the university library. It provides a backbone of rigorous theory and a useful entry into the entire literature of the subject up to about 2007.

Another excellent useful reference is "Cosmological Physics" by John Peacock (Cambridge, 1999), which is on library reserve. It is more readable (and less formal) than Weinberg, although it is not as up to date.

We will also rely on an excellent set of lecture note slides from Wayne Hu's cosmology course. This site also includes useful problem sets with exercises:

http://background.uchicago.edu/~whu/Courses/ast321_17.html

These will be supplemented by a combination of other articles to provide additional detail on how measurements are made and what the most important current results are.

Student assignments will include analysis and summaries of papers, explanations of important theoretical results, and critical summaries of the main experimental techniques and results. Each student will also be assigned a different topic for a course project, which will include a written paper and a class presentation.

Topics by week

To help plan, here is a preliminary summary timeline for the course. Details are subject to change.

October 2

Overview of the subject
Co-development of cosmology and fundamental physics in the 20th century
Overview of LambdaCDM concordance cosmology
Summary review of main assumptions, theoretical elements and supporting measurements
Specific mapping of measurements onto theoretical elements and timeline of cosmic history
Preview of outstanding issues for 21st century research

Reading:
White article: https://arxiv.org/abs/0704.2291
Kolb article: https://arxiv.org/abs/0708.1199

review of big bang cosmology,
http://pdg.lbl.gov/2019/reviews/rpp2018-rev-bbang-cosmology.pdf

We will also preview current issues likely to arise at the ``Cosmic Controversies'' conference starting this Saturday at the Gleacher center downtown, **October 5-8**:

https://voices.uchicago.edu/cosmiccontroversies/

Please plan to attend as much of the conference as you can; we are told that students can register for free if you help Aimee at the registration desk.

October 7, 9

October 7: ``Cosmic Controversies'' conference this day instead of class

October 9: review of conference: new results, status of the subject, start FRW cosmology

Also in class on October 9: discussion of student projects and presentation topics

Reading:
Weinberg chapters 1 and 2
Hu slides on FRW cosmology:
http://background.uchicago.edu/~whu/Courses/Ast321_11/ast321_1.pdf

a review of the distance scale:

https://www.annualreviews.org/doi/pdf/10.1146/annurev-astro-082708-101829

while this is not a review article, there is some introductory material in here:

https://iopscience.iop.org/article/10.3847/1538-4357/ab2f73/pdf

And here is a short article that gives an overview of the tension:

https://arxiv.org/ftp/arxiv/papers/1706/1706.02739.pdf (archive version)

(From *Nature Astronomy* **volume 1**, Article number: 0121 (2017))

First assignment (written version due **October 15**, based on our October 9 discussion):

1. Write a summary essay about one of the questions addressed by the "Cosmic Controversies" conference. Include a brief review of the state of the art of the question.
2. Write a short paragraph on three topics that you would be interested in for your project. These will be used to assign topics on October 21.

October 14, 16

Discussion of essay topics and project topics October 14, anticipating assignment due October 15. Propose/discuss final topics October 16.

Continue reviewing Hu's notes on cosmic expansion and FRW universes.

Overview of the contents of the universe, and expansion history.

October 21, 23

October 21: finalize project and presentation topic
October 23: title and date assignments
Second assignment (due **October 30**): Submit a two-page executive summary and abstract of the talk and the project you will present later in the quarter. Include a list of initial primary reference sources. Details of the assignment are provided on Canvas.

Thermal history and CMB, early Universe, nucleosynthesis, dark matter candidates

Hu notes on thermal history:

http://background.uchicago.edu/~whu/Courses/Ast321_11/ast321_2.pdf

Background: Weinberg chapters 3 and 4

review article on cosmic nucleosynthesis and abundances:
http://pdg.lbl.gov/2019/reviews/rpp2018-rev-bbang-nucleosynthesis.pdf

review article on dark matter: http://pdg.lbl.gov/2019/reviews/rpp2018-rev-dark-matter.pdf

October 28, 30

Review of homogeneous processes and history (recombination, thermalization, BBN, baryogenesis)

homogeneous inflation: horizon and flatness problems, scalar field evolution, slow roll

scale-invariant perturbations, tilt, gravitational waves

Hu notes on inflation: http://background.uchicago.edu/~whu/Courses/Ast321_11/ast321_4.pdf

Background: Weinberg chapters 4 and 10

review article on inflation: http://pdg.lbl.gov/2019/reviews/rpp2018-rev-inflation.pdf

November 4, 6

Review of evolution of physical components and effects: influences on relic perturbations

Linear perturbations, transform space, transfer functions and anisotropies

Hu notes on inhomogeneties:

http://background.uchicago.edu/~whu/Courses/Ast321_11/ast321_3.pdf

Hu notes on transfer function, CMB and LSS:

http://background.uchicago.edu/~whu/Courses/Ast321_11/ast321_5.pdf

Background: Weinberg chapters 5, 6, 7

CMB review: http://pdg.lbl.gov/2019/reviews/rpp2018-rev-cosmic-microwave-background.pdft

Theory review by Ned Wright: https://arxiv.org/abs/astro-ph/0305591

WMAP and Planck papers

Formation of galaxies and large scale structure

Hu notes on spherical collapse and halo model:
http://background.uchicago.edu/~whu/Courses/Ast321_11/ast321_7.pdf

November 11

precision tests of concordance cosmology, measurement of parameters

Hu CMB tutorial: http://background.uchicago.edu/~whu/intermediate/intermediate.html

Background: Weinberg chapter 8

review of cosmological parameters:

http://pdg.lbl.gov/2019/reviews/rpp2018-rev-cosmological-parameters.pdf

Dark energy, dark radiation, etc.

review of the dark energy problem:

http://pdg.lbl.gov/2019/reviews/rpp2018-rev-dark-energy.pdf

November 13: 2 student presentations

November 18, 20
4 student presentations

November 25
2 student presentations

December 2, 4

4 final student project presentations

Projects

After the first two weeks, we will decide on a project topic for each student. The project will consist of writing a critical scholarly review paper about a subject, and a 30 +10 presentation during the last weeks of class.

students may select from the following suggestions, or propose their own.

Examples of suggested topics:

Survey a historical episode in relativistic cosmological theory. Some examples: Should we add Lemaitre's name to FRW, or to the Hubble constant? How did attitudes change over time to the cosmological constant? What was the role played by the Steady State advocates?

Analyze the detailed approaches taken by the two teams that discovered cosmic acceleration by supernovae. Describe how the discovery unfolded as data improved.

Review the history surrounding the discovery of the CMB. Are there lessons useful for practicing science today?

Describe the measurements by satellites of CMB spectrum and anisotropy: COBE, WMAP, and Planck. What were the main breakthroughs?

Review observational techniques in a subfield related to cosmology and evaluate the obstacles to increased precision. For example, consider the ways we measure the deuterium and/or helium abundance, and what is needed to connect those measurements to a primordial value.

Review an episode where a significant faction of experts were very wrong about something, and changed their mind when data got better. (For example: large scale galaxy flows, gamma ray bursts).

Review the current tension between Hubble constants measured directly by local means, and indirectly via a cosmological model and precision measurements of CMB and cosmic structure.

Review the potential and challenges of some as-yet-unproven technique, e.g. 21 cm intensity mapping, or cosmography with standard sirens.

Update the cases made by White and Kolb in 2007 about ``Fundamentalism''. Are the ``two cultures'' closer or farther apart? Does it matter? Has scientific progress changed the situation, for example with regard to Dark Energy?

Survey the international scene in future space cosmology projects, especially cooperation and competition among space programs in the US, Europe, and China. This will include OIR telescopes, gravitational waves, microwave background missions, etc.

Review the history and current status of the subject of “quantum cosmology”. This includes things like the Hawking-Hartle “no boundary” hypothesis, various “landscape” models, “multiverses”, measure theory and anthropic arguments, etc.

References

astrophysical constants: http://pdg.lbl.gov/2019/reviews/rpp2018-rev-astrophysical-constants.pdf

physical constants: http://pdg.lbl.gov/2019/reviews/rpp2018-rev-phys-constants.pdf

Core course syllabus

from the department's website:

Cosmology I Syllabus (from Autumn Quarter 2017)

The FLRW metric, observables
FLRW solutions for useful special cases
Cosmological parameters
Realistic universes
Jeans instability, growth of structure
Correlation functions, matter power spectrum
Harrison-Zeldovich results
Non-linear regime, halo models
BBN basics, equilibrium equations, freeze-out conditions
Inventory of particles, equilibrium conditions
Recombination
Pre-recombination dynamics, acoustic modes
Last scattering surface, damping
CMB overview, CMB power spectra, inflation