A. Pillepich
Block Course: Cosmology
With an emphasis on Structure Formation
Heidelberg University SS2020

Overview
Lecturer: Annalisa Pillepich (MPIA)
Tutor: Diego Sotillo (MPIA)
Term: Summer semester, 2020
Dates: September 9 - 18 2020
Times: Daily from 10:00 - 16:00 (morning lectures 10:00-13:00 + exercises 14:15-16:00)
Location: Philos.-weg 12, seminar room R106
Requirements for credits for PhD students: 80% attendance and 60% of exercises
Requirements for credits for Master students: 80% attendance, 60% of exercises, exam
Exam: tentatively 2 hours written exam (about 1-2 weeks after the course)
Practicalities with exercises: Exercise classes will be held in the afternoon. They will be a mix of analytical and numerical problems. Students are invited to bring their laptop (or contact the lecturer if this is not possible) and to be ready to execute exercises, solve numerical equations, and make plots with Python, Matlab, IDL, or Mathematica. Solutions will be hand in to me and Diego via email.

Contents
The lecture is an introduction to cosmology for Master and PhD students with an emphasis on structure formation. The lecture and exercise class will be held in English.

The lecture covers the basic principles and properties of the standard cosmological model. We will review the observational findings and theoretical arguments that support it and mention alternatives that are currently considered. We will make use of concepts from Newtonian gravity, General Relativity and some basic astronomy. Topics will include:

- The initial conditions of the Universe: elements of Inflation
- The cosmic microwave background
- The homogeneous Universe and its time evolution
- The thermal and ionization history of the Universe
- Cold dark matter and its "observational" evidences
- Dark energy and its "observational" evidences
- Beyond homogeneity: linear theory and the growth of perturbations
- Beyond homogeneity: beyond linear theory, gravitational collapse
- Beyond homogeneity: power spectra, bispectra and other descriptors of the spatial distribution of matter
- The hierarchical growth of structures: (cold) dark matter haloes and the large-scale structure

- Fundamentals of galaxy formation
- Fundamentals of cosmological simulations: N-body and hydrodynamical sims
- From observations of the cosmic microwave background to the values of the cosmological parameters
- From observations of the large-scale structures to the values of the cosmological parameters

Actual Sections:

1. The observed Universe
    a. The visible Universe: galaxies, clusters, …
    b. Arguments for DarkMatter
    c. Arguments for Dark Energy
    d. The Cosmic Microwave Background
    e. The Standard Cosmological Model in a nutshell

2. The large-scale Universe, i.e. the homogenous Universe
    a. Building a Cosmological Model
    b. The Cosmological Principle
    c. Matter Contents of the Universe
    d.The Friedman-Roberston-Walker metric
    e.The dynamical equations of the Universe
    f. Observations in a FRW Universe: scales, horizons, redshifts, distance measures, age,…

3. Structure formation, i.e. the inhomogenous Universe
    g. Linear growth of perturbations: perturbation theory and structure formation, Jeans length,…
    h. Bound structures: spherical-collapse model, structures of DM haloes, Zeldovich theory, …
    i. N-body simulations
    j. Statistics of the linear density fluctuations: Gaussian random fields, P(k), \xi(r) …
    k. Statistics of the large-scale structure: halo statistics, halo/galaxy bias, LSS topology, …

4. The early Universe
    a. The thermal history of the Universe: adiabatic evolution,T-t relation
    b. Primordial Nucleosynthesis
    c. Recombination & Photon decoupling
    d. CMB: energy content, origin, anisotropies
    e. Elements of Inflation
    f. Gaussian and non Gaussian random fields

5. The late Universe
    a. The accelerated expansion and Arguments for a Lambda/Dark Energy
    b. Types of Dark Matter
    c. The baryonic fluid
    d. Fundamentals of galaxy formation
    e. Hydrodynamical galaxy simulations

f. Galaxy Clusters
g. The ionization history of the Universe

6. The measured Universe
   a. Observations in FRW worlds
   b. Arguments for Dark Energy
   c. Cosmology-dependent observables
   d. Present and future cosmological surveys
   e. Current constraints on cosmological parameters
   f. From observations of the large-scale structures to the cosmological parameters
   g. From observations of the CMB to the values of the cosmological parameters
   h. Fisher Matrix Formalism and predictions for Precision Cosmology

7. Summary: The standard cosmological model as of 2020

Suggested reading and acknowledgments

M. Bartelmann, Cosmology, Lecture notes, Heidelberg University (online)
L. Amendola, Lecture notes: Cosmology, Heidelberg University (online)
C. Porciani, Cosmology, Lecture notes, ETH Zurich (not online)
M. Maturi, Cosmology, Lecture notes, Heidelberg University (online)
P. Schneider, Extragalactic Astronomy and Cosmology, Springer
A. Liddle, An Introduction to Modern Cosmology, Wiley

Lecture Plans (tentative):

Wed 2020/09/9	Introduction to the Course + The observed Universe
Thu 2020/09/10	The large-scale Universe
Fri 2020/09/11	Structure formation (I)
Mon 2020/09/14	Structure formation (II)
Tue 2020/09/15	The early Universe (I)
Wed 2020/09/16	The early Universe
Thu 2020/09/17	The late Universe
Fri 2020/09/18	The measured Universe

Exam (tentative): oral 30min/person, on dates to be determined