LUND UNIVERSITY
Faculty of Science

SYLLABUS

Date 2016-06-29

Reg. Nr. U 2016/475

Syllabus for the course Dark Matter; Distribution, origin, detection and production, NAFY015

Swedish title: Mörk materia; Fördelning, ursprung, detektering och produktion

The course syllabus was confirmed by the Faculty board for graduate studies 12 October 2016. The course is in the third cycle and amounts to 3 credits.
The course syllabus is formally approved in Swedish. This is a translation.

Learning outcomes
The course is given by leading researchers in the field. The student shall get an overview of our knowledge about Dark Matter, from astronomy, astroparticle physics and particle physics. On completion of the course, participants shall be able to:

- describe the different observations, at different scales, that show the existence of Dark Matter
- describe how Dark Matter is distributed from the largest scale to the galaxy scale
- explain the influence of Dark Matter on the structure formation in the early Universe
- describe possible ways to detect and create Dark Matter
- explain different candidates for Dark Matter, and which properties are allowed and disallowed based on observations and experiments
- compute Dark Matter relic abundances
- estimate astrophysical Dark Matter detection through its annihilation or decay into standard model particles
- compute the velocity distribution of dark matter particles on Earth and estimate the magnitude of the expected annual modulation of the rate in direct dark matter detection
- compute the kinematics of elastic and inelastic scattering of dark matter particles with target nuclei
- estimate scattering cross sections in different dark matter models
- explain why some couplings and kinematic features of dark matter models favour a dark matter signal in some direct detection targets and disfavour it in others
- describe the basics of halo-dependent and halo-independent methods of direct dark matter detection data analysis
- properly combine limits from different types of dark matter searches (direct, indirect and at colliders.

Course content
Observables, measurement and timescales in astronomy. Classical evidences for Dark Matter: galaxy clusters and the virial theorem, rotation curves. What Dark Matter is not. Cosmology primer: Homogeneous Universe; FLRW metric; Friedmann equation; the “Lambda Cold Dark Matter” (LCDM) standard cosmological model.

Inhomogeneous Universe. Numerical simulations of structure formation in LCDM.
Evidence for Dark Matter from the Cosmic Microwave Background (CMB) and Large Scale Structure. The “bullet cluster” and evidence for particle Dark Matter.
The Lyman-alpha forest and the temperature of Dark Matter. Near-field cosmology and “small scale puzzles” in LCDM. Including the effect of “baryons” (stars and gas) in the models.
Beyond LCDM: Self-interacting and warm Dark Matter, alternative gravity models.
Future probes of Dark Matter: Gravitational lensing, stellar stream bumps.
Possible Dark Matter production mechanisms: Freeze-out; freeze-in; particle decays; gravitational production; misalignment mechanism; spontaneous symmetry breaking and asymmetric Dark Matter.
Axions: The theoretical motivation, phenomenology and present constraints. Production of axions.
Indirect Dark Matter searches: Introduction to Dark Matter detection; gamma rays; neutrinos, antimatter (antiprotons and positrons).
Direct Dark Matter searches: What we know and do not know about the dark matter and possible candidates. Dark matter particles as the earliest relics from the Big Bang. Direct dark matter detection. Worldwide efforts. The expected rate in direct detection experiments (detector response, cross section and halo model) and their uncertainties. The local distribution of dark matter in our galaxy. Expected annual modulation of the direct detection rate. Past hints of dark matter in direct detection experiments. Halo-dependent and halo-independent direct detection data analysis.
Search strategies at the Large Hadron Collider. Introduction to search strategies at the LHC. Complete and simplified dark matter models and their searches at the LHC.
Complementarity of dark matter searches

Teaching

The course is given during one week followed by another week of individual problem solving. The daily layout of the first week is three hours of lectures and four hours of individual problem solving. The teachers are continually accessible for discussions and supervision. At the end of the first week, problems corresponding to one week of work are distributed.

Assessment

The assessment is based on distributed problem solving exercises.

Grading scale

Possible grades are Passed or Failed. A pass grade requires approved solutions to all problems and distributed exercises

Language of instruction

The course if given in English

Entry requirements

Admitted to third cycle studies in Physics, with master in physics, astrophysics or engineer in engineering physics.