The course syllabus

“Cosmology and Astroparticle Physics”

7.5 ECTS credits

(English reduced version)

- **General information**

- This course is offered as one of the theoretical physics courses at the Faculty of Science. The course is an elective one at the advanced level of the Master of Science and PhD degrees with a specialization in physics. It is given in English.

- **Learning Goals**

- The course aims to give students the basic knowledge on theoretical concepts of the Particle Astrophysics and the Universe evolution with a focus on a deep interconnection between cosmology and particle physics. The course intends to cover the major aspects of the Hot Big Bang theory and the Standard Cosmological Model at the forefront of theoretical and experimental high energy astroparticle physics.

- *Knowledge and Understanding*

After completed course, the student should be able to

- explain the dynamics of cosmological expansion in the framework of Standard Cosmological Model, identify basic stages of the Universe evolution, their characteristics.

- describe the properties and composition of the modern Universe, the basic features and dynamics of baryon matter, dark matter and dark energy.

- describe the connection between cosmology and high energy particle physics, and relate their properties to each other, in examples covered by the course content.

Skills and Abilities

After completed course, the student should be able to

- derive evolution equations of the Universe and cosmological solutions relevant for the course contents.

- calculate properties of the Universe, such as age, horizon size, temperature and entropy density, at specified times during its evolution, assuming realistic conditions.

- derive particle abundances (e.g. neutrino, WIMPs, baryons) and mass bounds based on properties of particle interactions in the hot cosmological plasma in a particular cosmological evolution scenario and current astrophysical data relevant for the course contents.

- *Examples of problems that students should be able to solve after the course:*

- Find the bounds on maximum size and lifetime of the closed Universe assuming that dark energy instantaneously switches off right after the present epoch.

- Estimate the temperature and age of the Universe at the time when neutron burning terminates. What would be the residual neutron abundance if other reactions were negligible?

  - **Course content**

- Homogeneous Isotropic Universe: the Hubble law, the Friedmann–Lemaitre–Robertson–Walker Metric, and the behavior of gases of stable non-interacting particles in the realistic case of expanding homogeneous isotropic Universe.

- Dynamics of Cosmological Expansion: the Friedmann equation, with solutions in a few distinct cases, *e.g.,* non-relativistic matter, relativistic matter, vacuum, and general barotropic equation of state and solutions with Recollapse.

- The Standard Cosmological Model: the composition of the present Universe. Dark Matter and Dark Energy, and how these affect the Cosmological evolution. Universe age and horizon size. Brightness-Redshift relation for distant standard candles.

- Recombination epoch and its influence on Cosmic Microwave Background properties.

- Relic Neutrinos: neutrino evolution and Freeze-Out in the hot cosmological plasma. Cosmological bounds on neutrino mass.

- Big Bang Nucleosynthesis: kinetic theory of the Nucleosynthesis, the neutron-to-proton ratio and the primordial light elements abundance.

- Dark Matter: properties of Cold, Hot and Warm Dark Matter models. Formation of the Dark Matter abundance during Freeze-Out of Weakly Interacting Massive Particles. Dark Matter properties of candidates known from Particle Physics. Indirect and direct detection measurements.

- Generation of the Baryon and Lepton Asymmetries: necessary conditions for the Baryogenesis. Baryon and lepton number violation in particle interactions.

- Inflationary Epoch: basics of the Chaotic Inflation theory. Large-Scale Structure formation at the latest stages of expansion. Influence on temperature and density fluctuations in the Cosmic Microwave Background.

- Particle Physics of Cosmic Rays and their sources: spectrum and composition of the cosmic rays, observational implications and techniques. Astrophysical sources of the Ultra-High Energy Cosmic Rays. Properties of galactic and extra-galactic gamma-ray bursts.

- **Teaching and Assessment**

- Teaching consists of lectures and problem solving sessions. Assessment is composed of written assignments and oral theory exam. For students, who fail the exam, there is a possibility to retake the exam soon afterwards. The grades for the course are “pass with distinction”, “pass” or “fail”. To pass the course students must pass the oral examination and written assignments. The final grade is determined by weighing the results of the different parts of the examination.

- **Prerequisites**

- The prior knowledge of the Particle Physics (an introductory course in Particle Physics or equivalent) is required. The prior knowledge of the General Relativity is recommended.

- **Literature**

- The course is mainly based on the book “Introduction to the Theory of the Early Universe: Hot Big Bang Theory” by D. Gorbunov and V. Rubakov, World Scientific 2011. Additional material on topics which are not covered in this book or related to the present-day theoretical and experimental results will be handed-in prior the corresponding lectures during the course.