“Cosmology and Astroparticle Physics”

Course contents

1. Elements of General Relativity and Particle Physics (1 lecture)
   1.1. Geometry, Particles and Symmetries
   1.2. Einstein equations and Λ-term
   1.3. Standard Model of Particle Physics and Beyond

2. Homogeneous Isotropic Universe (1 lecture)
   2.1. Friedmann–Lemaitre–Robertson–Walker Metric
   2.2. Redshift. Hubble Law
   2.3. Gas of free particles in expanding Universe

3. Dynamics of Cosmological Expansion (2 lectures)
   3.1. Friedmann equation
   3.2. Sample cosmological solutions
      - Non-relativistic matter
      - Relativistic matter
      - Vacuum
      - General barotropic equation of state
   3.3. Solutions with Recollapse

4. The Standard Cosmological Model: ΛCDM (3 lectures)
   4.1. Composition of the present Universe. Dark Matter and Dark Energy
   4.2. General properties of Cosmological evolution
   4.3. Radiation Domination and Matter Domination Epochs
   4.4. Present Age of the Universe and Horizon Size
   4.5. Brightness-Redshift relation for distant standard candles
   4.6. Theory versus cosmological observations

5. Thermodynamics of Expanding Universe (1 lecture)
   5.1. Densities of bosons and fermions in cosmological plasma
   5.2. Entropy generation. Baryon-to-Photon ratio

6. Recombination (2 lectures)
   6.1. Recombination temperature.
   6.2. Photon last scattering
   6.3. Horizon at recombination.

7. Relic Neutrinos (1 lecture)
   7.1. Neutrino Freeze-Out in the Early Universe
   7.2. Cosmological bound on neutrino mass
   7.3. Sterile neutrino

8. Big Bang Nucleosynthesis (1 lecture)
   8.1. Neutron Freeze-Out. Neutron-to-proton ratio
   8.2. Kinetics of Nucleosythesis
   8.3. Theory versus observations

9. Dark Matter: formation, evolution and consequences (2 lectures)
   9.1. Cold, Hot and Warm Dark Matter
   9.2. Freeze-Out of heavy relic
   9.3. Weakly Interacting Massive Particles (WIMPs)
   9.4. Dark Matter candidates in Particle Physics:
      - Neutralino
      - Sneutrino
      - Gravitino
      - Axions
      - Other superheavy relic particles
   9.5. Theory versus observations: direct and indirect detection measurements

10. Phase transitions in the Early Universe (1 lecture)
   10.1. Order of phase transitions
   10.2. Effective potential in one-loop approximation
   10.3. Infrared problem

11. Generation of the Baryon and Lepton Asymmetries (1 lecture)
   11.1. Necessary conditions for Baryogenesis
   11.2. Baryon and Lepton number violation in particle interactions
   11.3. Leptogenesis

12. Inflationary Epoch (1 lecture)
   12.1. Chaotic Inflation
   12.2. Large-Scale Structure of expanding Universe
   12.3. Temperature and density fluctuations in the Cosmic Microwave Background

13. Particle Physics of Cosmic Rays and their sources (3 lectures)
    13.1. The spectrum and composition of the cosmic rays
    13.2. Ultra-High Energy Cosmic Rays and neutrino astrophysics
    13.3. Point sources of gamma-rays. Gamma-ray bursts.
    13.4. Atmospheric neutrinos: neutrino oscillations
    13.5. Neutron stars and pulsars
    13.6. Black Holes and Hawking radiation
    13.7. Observational implications

14. *Topological defects and Solitons in the Universe
    14.1. Production of topological defects in the Early Universe
    14.2. The monopole problem
    14.3. Variety of topological defects: Cosmic Strings, Domain Walls, Textures and Q-balls