“Matter Genesis in the Early Universe”

DESCRIPTION:

This course will introduce motivated scenarios for the genesis of matter in the early universe. In particular, it will present motivated scenarios for the production of dark matter, which makes 85% of the matter content in our universe and it is still of unknown origin and composition. All phenomena described here take place before the time of Big Bang Nucleosynthesis, and we have no direct information about the energy budget of the universe as such early times.

In the first part of the course, particle production will always take place in a universe whose energy content is dominated by a radiation bath. This is the extrapolation of the snapshot that we get by studying the abundances of primordial light nuclei. The focus will be on three motivated dark matter candidate: WIMPs, FIMPs and Axions. For each case, we will investigate how these particles are produced in the early universe as well as their potential experimental signatures today.

In the second part of the course, we will study phenomena of particle production in a background that is different from a thermal bath. We will focus our attention on two specific cases: production during inflation, and during the early stages of reheating (when the field responsible for inflation is decaying but it is still dominating the energy budget of the universe). We will study both perturbative, and nonperturbative mechanisms of production in these contexts. Attention will be devoted both to the analytical computations of these processes, and to the associated phenomenological signatures (including the generation of gravitational waves of frequencies detectable at experiments such as LIGO/Virgo and LISA)

TIMETABLE:

Weakly Interacting Massive Particles (WIMPs) (4 hours)
- thermal freeze-out
- WIMP models
- direct searches
- indirect searches
- collider searches

Feebly Interacting Massive Particles (FIMPs) (2 hours)
- freeze-in production in the early universe
- FIMP models
- experimental signatures of freeze-in

Axion Dark Matter (6 hours)
- the strong CP problem
- cold axions production via misalignment
- cold axions production via topological defects
- hot axions production and signatures in the Cosmic Microwave Background
- experimental searches for axions

Perturbative particle production during reheating (3 hours)
- expansion of the universe at reheating beyond the instantaneous inflaton decay approximation
- Particle production during reheating from operators of various dimensions

Non-perturbative production during reheating (3 hours)

- Analytical methods: parametric resonance, tachyonic preheating, rescattering
- Numerical methods: brief review of lattice simulations of reheating, and the long road toward thermalisation

Particle production during inflation (6 hours)
- Isolated instances of particle production (features in the spectrum of the primordial scalar perturbations)
- Continuous particle production and QFT realisations of warm inflation
- Gauge field amplification in axion inflation: computational aspects
- Gauge field amplification in axion inflation: observational aspects, with a focus on gravitational waves observable at interferometer scales