

Program of the **Dark Matter, Neutrinos and Underground Physics** course (6 CFU) – A.A. 2024/2025 (Prof. P. Belli)

Brief **historical overview** of fundamental interactions between particles, quantum mechanics, waves and particles, relativity, relativistic quantum field theories, fundamental fields, conservation laws, symmetries, and Outline of the Standard Model of elementary particles. Historical references.

Interactions of charged particles with the matter; radiation-matter interactions; cross sections; range; mean free path; cross section p-p. Nuclei fragmentation.

Formation of nuclei in the Universe; theoretical explanation of the cosmic rays abundances. **Primordial nucleosynthesis**. Short history of the early Universe. The n/p ratio. The first 200 s (three minutes). Light elements abundances and ${}^7\text{Li}$ problem. The formation of nuclei heavier than $A=7$. Nucleosynthesis in the stars. Thermonuclear fusion processes. Evolution of a star. Fusion cross sections; S-factor; Gamow factor and peak. The fusion reactions in the Sun. Subsequent stages of a star. The triple alpha process. The s-, r-, and p- processes. The last stages of a star. Degenerate stars. The Chandrasekhar mass. White dwarfs. Supernovae (SN) and their classification. Neutron stars. Pulsars. Black holes.

The **Dark Universe**. Astrophysical evidence of Dark Matter (DM). Rotational curves of spiral galaxies; cluster of galaxies; the bullet cluster. The standard Big Bang model. Overview of **Cosmology**. The Friedmann equations. The geometry of the Universe. The basis of the Big Bang model. The cosmic microwave background (CMB); the anisotropy of CMB; information on the geometry of the Universe; the Ω budget. The expansion of the Universe (Hubble law); Sn type IA as standard candles; the expansion is accelerating; dark energy. Gravitational probes. Nucleosynthesis. The abundance of light elements. The Baryonic acoustic oscillations (BAO). Concordance Λ CDM model. Hot, Warm and Cold non-baryonic dark matter. Hot DM and neutrinos. Dark Matter candidates. Decoupling of DM particles in the early Universe. Relic cold DM. Axions and axion searches. Strategies for DM detection. Indirect detection. Overview of experimental techniques. The direct detection. Processes of direct detection. The cases of elastic and inelastic interactions on nuclei. Halo models, parameters. Expected signals. Uncertainties in the evaluation. Arguments related to the experimental procedures. Low-background techniques. The model independent signature. Classification of the different experimental efforts. Status, experimental signals, and perspectives.

Neutrino Physics and neutrino astronomy. Astrophysical and terrestrial, natural, and home-made sources of neutrinos. Overview of neutrino history. Neutrino interactions; neutrino oscillations in vacuum and in matter (MSW effect). Majorana neutrinos. **Solar neutrinos**. Production of neutrinos in the Sun. Detection schemes. Experiments and interpretation. Confirmation of oscillation parameters from long-baseline reactor

antineutrinos. **Atmospheric neutrinos.** Detection methods and experimental results. Confirmation of oscillation parameters from long-baseline accelerator experiments. Disappearance of ν_μ ; appearance of ν_τ . PMNS mixing neutrino matrix. Measurement of θ_{13} and CP violation phase. Sterile neutrinos. **Geoneutrinos** and their detection. **Supernovae neutrinos.** SN1987A and detection of SN neutrinos. Perspectives and estimates. First detection of **high energy (extragalactic) neutrinos.** Anisotropy and power law. **Relic cosmological neutrinos** and estimates on neutrino masses. Measurements of neutrino masses from the end-point of β decay. Neutrino masses and Majorana neutrino in 2β decay experiments; Schechter-Valle theorem; expectations. 2β decay experiments, a classification and description of the experimental method. Some examples of techniques, experiments, and results.

The technical and experimental details of the **Underground Physics** will be discussed during the lectures.

Recommended readings.

- M. Spurio, *Particles and Astrophysics, a multi-messenger approach.* Springer. DOI 10.1007/978-3-319-08051-2
- D. Perkins, *Particle Astrophysics.* Oxford Master series in Particle Physics.
- J. Rich, *Fundamentals of Cosmology.* Springer. DOI 10.1007/978-3-642-02800-7
- J.L. Basdevant, J. Rich, M. Spiro, *Fundamentals in Nuclear Physics.* Springer. ISBN 0-387-01672-4
- M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018) and 2019 update.
- C. Grupen, *Astroparticle Physics.* Springer.
- S. Bilenky, *Introduction to the Physics of Massive and Mixed Neutrinos.* Springer DOI 10.1007/978-3-319-74802-3
- P. Blasi, *Acceleration of galactic cosmic rays.* Riv. Nuovo Cim. 42 (2019) 549.
- U. Sarkar, *Particle and Astroparticle Physics.* Taylor and Francis. ISBN-13: 978-1-58488-931-1
- K. Zuber, *Neutrino Physics.* CRC press. ISBN: 978-1-138-71889-0
- bibliography mentioned during lectures
- other references will be given upon request