UNIVERSITÀ DELLA CALABRIA
DIPARTIMENTO DI FISICA

Master's Degree Course in Physics

"Manifesto degli studi"
Study plan

Academic year
2023-2024

Approved by the Unified Council of the Degrees in Physics on 06/03/2023
and by the Council of the Physics Department on 14/03/2023

Denominazione del Corso di Studio Magistrale	**Fisica**
Denominazione in inglese del Corso di Studio Magistrale	**Physics**
Anno Accademico	**2023/2024**
Classe di Corso di Studio	**LM-17 Fisica**
Dipartimento	**Fisica**
Coordinatore del Corso di Studio	**Prof. Alessandro Papa**
Sito web	https://fisica.unical.it/didattica/

Annex 1- Official study plan for full-time students (2023/2024)

Astrophysics, Geophysics and Plasma Physics (216)

Year	Semester	Teaching	Attività formativa	Ambito	SSD	ECTS lect.	ECTS exerc.	ECTS lab.	ECTS
1	I	Scientific data acquisition and processing	Caratterizzante	Sperimentale e applicativo	FIS/07	4	-	2	**6**
		Advanced computer science for physics	Altre attività formative	Abilità informatiche e telematiche	INF/01	1	2	-	**3**
		Machine learning for physics	Altre attività formative	Abilità informatiche e telematiche	FIS/02	0	3	-	**3**
		Advanced mathematical methods for physics	Affine o integrativa		MAT/07	4	2	-	**6**
		Physics of complex systems	Caratterizzante	Teorico e dei fondamenti della fisica	FIS/02	5	1	-	**6**
		Fundamental processes in astrophysics	Caratterizzante	Microfisico e della struttura della materia	FIS/03	5	1	-	**6**
	II	Astrophysics laboratory	Caratterizzante	Astrofisico, geofisico e spaziale	FIS/05	3	-	3	**6**
		Space physics	Caratterizzante	Astrofisico, geofisico e spaziale	FIS/06	4	2	-	**6**
		Nuclear and particle physics	Caratterizzante	Sperimentale e applicativo	FIS/01	5	1	-	**6**
		Bonds, molecules, phases and phase transitions	Affine o integrativa		CHIM/02	4	2	-	**6**
		Elective course	Altre attività formative	A scelta dello studente					**6**
2	I	Solar physics and Sun-Earth connection	Caratterizzante	Astrofisico, geofisico e spaziale	FIS/06	4	2	-	**6**
		Advanced computational physics	Caratterizzante	Microfisico e della struttura della materia	FIS/03	5	1	-	**6**
		Plasma astrophysics	Caratterizzante	Astrofisico, geofisico e spaziale	FIS/05	5	1	-	**6**
		Elective course	Altre attività formative	A scelta dello studente					**6**
	II	Thesis	Altre attività formative						**36**
ECTS Total									**120**

Physics of the Atmosphere, Meteorology and Climatology (220)

Year	Semester	Teaching	Attività formativa	Ambito	SSD	ECTS lect.	ECTS exerc.	ECTS lab.	ECTS
1	I	Scientific data acquisition and processing	Caratterizzante	Sperimentale e applicativo	FIS/07	4	-	2	**6**
		Advanced computer science for physics	Altre attività formative	Abilità informatiche e telematiche	INF/01	1	2	-	**3**
		Machine learning for physics	Altre attività formative	Abilità informatiche e telematiche	FIS/02	0	3	-	**3**
		Advanced mathematical methods for physics	Affine o integrativa		MAT/07	4	2	-	**6**
		Advanced quantum mechanics	Caratterizzante	Teorico e dei fondamenti della fisica	FIS/02	4	2	-	**6**
		Chaotic behavior of geophysical flows	Caratterizzante	Astrofisico, geofisico e spaziale	FIS/06	5	1	-	**6**
	II	Geophysics laboratory	Caratterizzante	Sperimentale e applicativo	FIS/01	3	-	3	**6**
		Dynamics of the atmosphere	Caratterizzante	Astrofisico, geofisico e spaziale	FIS/06	5	1	-	**6**
		Nuclear and particle physics	Caratterizzante	Sperimentale e applicativo	FIS/01	5	1	-	**6**
		Bonds, molecules, phases and phase transitions	Affine o integrativa		CHIM/02	4	2	-	**6**
		Elective course	Altre attività formative	A scelta dello studente					**6**
2	I	Space weather	Caratterizzante	Astrofisico, geofisico e spaziale	FIS/06	4	2	-	**6**
		Synoptic and mesoscale meteorology	Caratterizzante	Astrofisico, geofisico e spaziale	FIS/06	5	1	-	**6**
		Fundamental processes in astrophysics	Caratterizzante	Microfisico e della struttura della materia	FIS/03	5	1	-	**6**
		Elective course	Altre attività formative	A scelta dello studente					**6**
	II	Thesis	Altre attività formative						**36**
ECTS Total									**120**

Nuclear and Subnuclear Physics (219)

Year	Semester	Teaching	Attività formativa	Ambito	SSD	ECTS lect.	ECTS exerc.	ECTS lab.	ECTS
1	I	Scientific data acquisition and processing	Caratterizzante	Sperimentale e applicativo	FIS/07	4	-	2	**6**
		Advanced computer science for physics	Altre attività formative	Abilità informatiche e telematiche	INF/01	1	2	-	**3**
		Machine learning for physics	Altre attività formative	Abilità informatiche e telematiche	FIS/02	0	3	-	**3**
		Advanced mathematical methods for physics	Affine o integrativa		MAT/07	4	2	-	**6**
		Advanced quantum mechanics	Caratterizzante	Teorico e dei fondamenti della fisica	FIS/02	4	2	-	**6**
		Fundamental processes in astrophysics	Caratterizzante	Microfisico e della struttura della materia	FIS/03	5	1	-	**6**
	II	Nuclear and particle physics laboratory I	Caratterizzante	Sperimentale e applicativo	FIS/01	2	-	4	**6**
		Quantum field theory I	Caratterizzante	Teorico e dei fondamenti della fisica	FIS/02	4	2	-	**6**
		Nuclear and particle physics	Caratterizzante	Sperimentale e applicativo	FIS/01	5	1	-	**6**
		Bonds, molecules, phases and phase transitions	Affine o integrativa		CHIM/02	4	2	-	**6**
		Elective course	Altre attività formative	A scelta dello studente					**6**
2	I	Quantum field theory II	Caratterizzante	Teorico e dei fondamenti della fisica	FIS/02	4	2	-	**6**
		Particle physics phenomenology I	Caratterizzante	Sperimentale e applicativo	FIS/01	5	1	-	**6**
		Particle physics phenomenology II	Caratterizzante	Sperimentale e applicativo	FIS/01	5	1	-	**6**
		Elective course	Altre attività formative	A scelta dello studente					**6**
	II	Thesis	Altre attività formative						**36**
ECTS Total									**120**

Matter Physics (217)

Year	Semester	Teaching	Attività formativa	Ambito	SSD	ECTS lect.	ECTS exerc.	ECTS lab.	ECTS
1	I	Scientific data acquisition and processing	Caratterizzante	Sperimentale e applicativo	FIS/07	4	-	2	**6**
		Advanced computer science for physics	Altre attività formative	Abilità informatiche e telematiche	INF/01	1	2	-	**3**
		Machine learning for physics	Altre attività formative	Abilità informatiche e telematiche	FIS/02	0	3	-	**3**
		Advanced mathematical methods for physics	Affine o integrativa		MAT/07	4	2	-	**6**
		Advanced quantum mechanics	Caratterizzante	Teorico e dei fondamenti della fisica	FIS/02	4	2	-	**6**
		One of the following: -Solid state physics -Biophysics	Caratterizzante	Sperimentale e applicativo	FIS/07	5 4	1 2	- -	**6**
	II	*One of the following:* -Biophysics laboratory -Condensed matter physics laboratory -Theoretical condensed matter physics	Caratterizzante	Microfisico e della struttura della materia	FIS/03	3 3 4	- - 2	3 3 -	**6**
		One of the following: -Surface physics -Physical methods in bio-medicine	Caratterizzante	Sperimentale e applicativo	FIS/01 FIS/07	4	2	-	**6**
		Nuclear and particle physics	Caratterizzante	Sperimentale e applicativo	FIS/01	5	1	-	**6**
		Bonds, molecules, phases and phase transitions	Affine o integrativa		CHIM/02	4	2	-	**6**
		Elective course	Altre attività formative	A scelta dello studente					**6**
2	I	*One of the following:* -Physics of complex systems -Statistical mechanics	Caratterizzante	Teorico e dei fondamenti della fisica	FIS/02	5 4	1 2	- -	**6**

		Linear and non-linear spectroscopies	Caratterizzante	Sperimentale e applicativo	FIS/07	4	1	1	**6**
		Fundamental processes in astrophysics	Caratterizzante	Microfisico e della struttura della materia	FIS/03	5	1	-	**6**
		Elective course	Altre attività formative	A scelta dello studente					**6**
	II	Thesis	Altre attività formative						**36**
ECTS Total									**120**

Physics and Technology of Materials (218)

Year	Semester	Teaching	Attività formativa	Ambito	SSD	ECTS lect.	ECTS exerc.	ECTS lab.	ECTS
1	I	Scientific data acquisition and processing	Caratterizzante	Sperimentale e applicativo	FIS/07	4	-	2	**6**
		Advanced computer science for physics	Altre attività formative	Abilità informatiche e telematiche	INF/01	1	2	-	**3**
		Machine learning for physics	Altre attività formative	Abilità informatiche e telematiche	FIS/02	0	3	-	**3**
		Advanced mathematical methods for physics	Affine o integrativa		MAT/07	4	2	-	**6**
		Advanced quantum mechanics	Caratterizzante	Teorico e dei fondamenti della fisica	FIS/02	4	2	-	**6**
		One of the following: -Solid state physics -Soft matter physics	Caratterizzante	Sperimentale e applicativo	FIS/07	5 4	1 1	- 1	**6**
	II	*One of the following:* -Biophysics laboratory - Condensed matter physics laboratory	Caratterizzante	Microfisico e della struttura della materia	FIS/03	3 3	- -	3 3	**6**
		Surface physics	Caratterizzante	Sperimentale e applicativo	FIS/01	4	2	-	**6**
		Optics and photonics	Caratterizzante	Microfisico e della struttura della materia	FIS/03	4	-	2	**6**
		Bonds, molecules, phases and phase transitions	Affine o integrativa		CHIM/02	4	2	-	**6**
		Elective course	Altre attività formative	A scelta dello studente					**6**
2	I	Microscopy	Caratterizzante	Microfisico e della struttura della materia	FIS/03	4	-	2	**6**
		Linear and non-linear spectroscopies	Caratterizzante	Sperimentale e applicativo	FIS/07	4	1	1	**6**
		Molecular spectroscopy	Caratterizzante	Sperimentale e applicativo	FIS/07	4	-	2	**6**
		Elective course	Altre attività formative	A scelta dello studente					**6**
	II	Thesis	Altre attività formative						**36**
ECTS Total									**120**

Suggested Elective Courses

Year	Semester	Teaching	Attività formativa	Ambito	SSD	ECTS lect.	ECTS exerc.	ECTS lab.	ECTS
2	I	Computational biophysics	Altre attività formative	A scelta dello studente	FIS/07	4	2	-	**6**
1	II	Cosmology	Altre attività formative	A scelta dello studente	FIS/05	3	3	-	**6**
2	I	High-energy astrophysics	Altre attività formative	A scelta dello studente	FIS/05	4	2	-	**6**
2	I	Mathematics education	Altre attività formative	A scelta dello studente	MAT/04	4	-	2	**6**
2	I	Mesophases and metastructures	Altre attività formative	A scelta dello studente	FIS/03	4	-	2	**6**
2	I	Nuclear and particle physics laboratory II	Altre attività formative	A scelta dello studente	FIS/01	3	-	3	**6**
1	II	Physics education	Altre attività formative	A scelta dello studente	FIS/08	5	1	-	**6**

Master's Degree in Physics

Brief description of teaching units

Teaching Unit	**ADVANCED COMPUTATIONAL PHYSICS**
SSD	**FIS/03**
ECTS	**6**
Learning outcomes	The teaching unit of **Advanced computational physics** aims at providing the student with the knowledge of the fundamentals for the numerical study of partial differential equations encountered in physics, and the ability to quantitatively solve problems in which these equations are used. At the end of the course the student will be able to obtain a numerical solution for the main types of equations and boundary conditions. EXPECTED LEARNING OUTCOMES Knowledge and understanding: basic principles and advanced methodology for the numerical solution of partial differential equations Ability to apply knowledge and understanding: apply the basic and advanced principles of numerical methods to obtain a solution in numerical form problems typical of physics. Independent judgment: ability to independently identify the numerical scheme most appropriate for each problem, even when the boundary conditions vary. Communication skills: ability to describe the advantages and disadvantages of each numerical approach to the study of the equations of physics. Learning skills: understanding the importance of using the correct numerical scheme.
Prerequisities	None

Teaching unit	**ADVANCED COMPUTER SCIENCE FOR PHYSICS**
SSD	**INF/01**
ECTS	**3**
Learning outcomes	The teaching unit of **Advanced computer science for physics** aims at providing students with the ability to analyze problems, design algorithms for their solutions, and implement them in Python 3. EXPECTED LEARNING OUTCOMES Knowledge and understanding: - Principles of computer programming - Structured programming in Python - Object Oriented Programming in Python

	- Advanced data manipulation Ability to apply knowledge and understanding - Design and write algorithms in Python - ability to perform defined technical tasks, such as mathematical, algorithmic, and computational modeling - ability to use computational tools to solve theoretical and applied problems - ability to work in groups and independently, making appropriate use of acquired mathematical, computational, and computer skills. Soft Skills: through the study of topics proposed in the course and the development of lab exercises, it is expected that students develop teamworking ability and creativity. Independent judgment: - Analyzing and solving problems - Abiliy to find alternative and/or innovative solutions Communication skills: ability to discuss, both in oral and written form, algorithmic, and computational methods and ideas. Learning skills: - acquisition of appropriate computational and computer skills - knowledge of specific programming languages and software (especially Python and development tools).
Prerequisites	None

Teaching Unit	**ADVANCED MATHEMATICAL METHODS FOR PHYSICS**
SSD	**MAT/07**
ECTS	**6**
Learning outcomes	The teaching unit of **Advanced mathematical methods for physics** aims at making the student familiar with the fundamentals of the general theory of groups, with the theory of matrix Lie groups and matrix Lie algebras and with the general theory of representations. She/He will be able to describe the finite dimensional representations of the Lorentz group and the Lie algebra of the Poincaré group. Finally she/he will be familiar with the most important partial differential equations of mathematical-physics. EXPECTED LEARNING RESULTS Knowledge and understanding: She/He will be able to the conceptual effectiveness of a systematic knowledge of the mathematical theory of Lie groups in modern physics. That characterizes the physico-mathematical approach which will be a guide during the course. Moreover, she/he will

	be able to use Green's method for solving partial differential equations relevant to physics. Independent judgment: to be aware of the usefulness of the concept of group in physics, as well as of the use of partial differential equations to describe space-time evolution processes. Communication skills: to be concise but precise and rigorous at the same time. To be able to communicate deep physical problems in the right mathematical formalism. To be able to communicate how concrete the abstract formulation of a physical problem can be. Learning skills: critical thinking, ability to think of the foundational aspects of physics, attention to detail.
Prerequisities	None

Teaching Unit	**ADVANCED QUANTUM MECHANICS**
SSD	**FIS/02**
ECTS	**6**
Learning outcomes	The teaching unit of **Advanced quantum mechanics** aims at deepening the concepts and methods of quantum physics, already introduced in the three-year course, also introducing the relativistic wave equations, the quantization of the electromagnetic field and matter fields in the non-relativistic regime. EXPECTED LEARNING OUTCOMES Knowledge and Understanding: principles underlying the advanced formulation of non-relativistic quantum mechanics and of relativistic wave mechanics. A critical understanding of the limits of applicability of the semiclassical and of the non-relativistic descriptions of the interaction between matter and radiation, and of the limits of the relativistic extension of wave mechanics. Knowledge of the basic methodology of second quantization and of the concept of elementary excitation of a field. Understanding the necessity and the meaning of renormalization. Applying Knowledge and Understanding: ability to apply the acquired knowledge to provide a quantitative description of (and to solve simple problems related to) basic physical phenomena of radiation matter interaction and of many-body physics (e.g., emission, absorption and photon scattering processes, dynamical properties of fermion and boson gases, either free or on a lattice). Ability to perform elementary manipulation of the Dirac matrices to solve problems of relativistic wave mechanics. Soft skills: problem solving, in particular through the quantum formalism. Development of a critical attitude towards the modeling of physical phenomena. Ability to acquire new knowledge in the realm of quantum physics and to discuss it in a suitable and technically-correct language.

Prerequisities	None

Teaching Unit	**ASTROPHYSICS LABORATORY**
SSD	**FIS/05**
ECTS	**6**
Learning outcomes	The teaching unit of **Astrophysics laboratory** aims at providing the student with the basic knowledge of the collection and processing of astronomical and geophysical data, both from the ground and from space, and the ability to extract the physical parameters from the said data. At the end of the course the student will be able to elaborate and critically evaluate the meaning of the collected data. EXPECTED LEARNING OUTCOMES Knowledge and understanding: basic principles and methodology of observations and measurements in astrophysics and geophysics. Ability to apply knowledge and understanding: applying the basic principles of the astrophysics and geophysics laboratory to extract the physical parameters from the measurements. Independent judgment: ability to independently extract fundamental information from astrophysical and geophysical data, both from the ground and from space. Communication skills: ability to describe the phenomenology that corresponds to the adopted observations. Learning skills: ability to understand the importance of selecting the best instrumentation to observe a given astrophysical or geophysical phenomenon.
Prerequisities	None

Teaching Unit	**BIOPHYSICS**
SSD	**FIS/07**
ECTS	**6**
Learning outcomes	The teaching unit of **Biophysics** aims at providing the students with a description of the physical properties of biological matter, with emphasis to the main components of cell membranes and to lipid-protein interaction. EXPECTED LEARNING OUTCOMES Knowledge and understanding: ability to understand the physical mechanisms underlying molecular processes in cell membranes; knowledge of the principles of optical and magnetic spectroscopic techniques for the study of biomembranes.

	Ability to apply knowledge and understanding: capability to interpret complex biological phenomena from a physical viewpoint; capability to apply the most appropriate experimental techniques for the physical and molecular characterization of biosystems; capability to write in a coherent and logical way a scientific report. Independent judgement: ability to autonomously identify the main physical processes involved in the structure-dynamic-function in biosystems. Communication skills: ability to clearly and logically explain the phenomena occurring in biosystems; ability to team work with classmates. Learning skills: ability to autonomously deepen themes and topics treated during the course; ability to self-orient in the bibliographic research and update.
Prerequisities	None

Teaching Unit	**BIOPHYSICS LABORATORY**
SSD	**FIS/03**
ECTS	**6**
Learning outcomes	The teaching unit of **Biophysics laboratory** aims at providing the students with a description of the physico-chemical principles that drive the formation of lipid/protein complexes, the self-assembly of lipid aggregates (i.e., model systems of cell membranes) and of the spectroscopic techniques commonly used to study structural, dynamic and molecular properties of membrane model systems. EXPECTED LEARNING OUTCOMES Knowledge and understanding: knowledge of the physical principles of the spectroscopic techniques for membrane studies; ability to prepare differing phospholipid mesophases, protein samples and lipid/protein complexes; capability to carry out spectroscopic experiments for the biophysical characterization of biosystems. Ability to apply knowledge and understanding: capability to use the results obtained from experiments to understand functioning of biosystems; capability to write in a coherent and logical manner a scientific report. Independent judgement: ability to autonomously and independently characterize biosystems by using spectroscopic techniques; ability to select the most appropriate experimental technique to investigate biosystems. Communication skills: ability to clearly and logically describe the phenomena occurring during the self-assembly of lipid aggregates and the physical principles of spectroscopic methods for the study of biosystems; ability to team working with classmates.

	Learning skills: ability to autonomously strengthen and deepen themes and topics related to membrane biophysics; ability to design experiments for the biophysical characterization of biosystems; ability to self-orient in the bibliographic literature and update.
Prerequisities	None

Teaching Unit	**BONDS, MOLECULES, PHASES AND PHASE TRANSITIONS**
SSD	**CHIM/02**
ECTS	**6**
Learning outcomes	The teaching unit of **Bonds, molecules, phases and phase transitions** aims at discussing the commonly used models for describing chemical bonds, providing students with the skills to correlate the type of binding to physical properties, including phase transitions. EXPECTED LEARNING OUTCOMES Knowledge and understanding: understanding the concept of chemical bonding based on the quantum description of electrons. Understanding the thermodynamics of phase transitions and knowing about their description in terms of mean field/phenomenological models. Ability to apply knowledge and understanding: ability to apply models of atomic and molecular orbitals to the description of simple molecules and compounds. Independent judgment: ability to evaluate autonomously the usefulness of the different models of chemical bonding. Ability to evaluate the relationship among the symmetries of phases, the order parameters, the phenomenological free energies and the features of phase transitions. Communication skills: ability to describe the salient aspects of molecular structure and the theory of chemical bonds. Learning ability: ability to learn about physical properties also in terms of the type (covalent, ionic, hydrogen and metal) of bonds characterizing a substance.
Prerequisities	None

Teaching Unit	**CHAOTIC BEHAVIOR OF GEOPHYSICAL FLOWS**
SSD	**FIS/06**
ECTS	**6**
Learning outcomes	The teaching unit of **Chaotic behavior of geophysical flows** proposes to describe the concepts of complexity and chaos, which now play an important role in geophysics. Non-linear phenomena are described in various contexts of geophysics, and their interpretative models are discussed. The course includes three laboratory experiences concerning

	the transition to chaos in mechanical, fluid-dynamic and electrical systems. EXPECTED LEARNING OUTCOMES Knowledge and understanding: understanding of the concepts underlying the theoretical description of the Physics of complexity and acquisition of the physical models that allow the interpretation of chaotic phenomena in complex systems of geophysical nature. Ability to apply knowledge and understanding: ability to apply the fundamental models of non-linear physics to the interpretation of complex and / or chaotic phenomena; ability to solve simple problems concerning non-integrable systems. Independent judgment: ability to evaluate the consequences of the non-linear behavior of simple physical systems. Communication skills: ability to describe the salient qualitative and quantitative aspects of phenomenology and basic theoretical modeling of complex, non-linear and chaotic systems.
Prerequisities	None

Teaching Unit	**COMPUTATIONAL BIOPHYSICS**
SSD	**FIS/07**
ECTS	**6**
Learning outcomes	The teaching unit of **Computational biophysics** aims at providing students with the basic knowledge for modeling biological systems through the use of numerical simulation methods. The student is introduced to molecular dynamics modeling and simulation techniques. At the end of the course the student will be able to: understand the concepts of statistical mechanics and the physical mechanisms that allow to describe the interactions between biological macromolecules, know and use the numerical analysis methodologies employed in this specific field of research. EXPECTED LEARNING OUTCOMES Knowledge and understanding: ability to model complex problems in the field of biophysics using the appropriate physical-statistical and computational methodologies. Ability to apply knowledge and understanding: ability to use the acquired knowledge to reproduce the functioning mechanisms of biological systems and improve their understanding in terms of physical properties. Independent judgment: experience in recognizing the strengths and limitations of computer simulations and evaluating the circumstances in

	which a numerical technique can help in determining an interpretative physical model. Communication skills: ability to describe the interactions between biological macromolecules and the most common simulation techniques. Learning skills: ability to model and simulate interactions between biological macromolecules starting from physical and statistical concepts on the interactions involved in these systems.
Prerequisities	None

Teaching Unit	**CONDENSED MATTER PHYSICS LABORATORY**
SSD	**FIS/03**
ECTS	**6**
Learning outcomes	The teaching unit of **Condensed matter physics laboratory** aims at providing the student with the knowledge of a good number of experimental techniques for the preparation and study of materials. The course aims at presenting and testing the main investigation methods at the microscopic and nanoscopic level of the morphological-crystallographic and spectroscopic properties of matter both in volume and on the surface. EXPECTED LEARNING OUTCOMES Knowledge and understanding: ability to understand the physical mechanisms underlying the main experimental techniques designed to prepare and characterize innovative materials. Ability to apply knowledge and understanding: ability to use the knowledge acquired to use advanced instrumentation for the preparation and characterization of materials. Independent judgment: the ability to autonomously identify the most appropriate preparation and measurement techniques for investigating the physical properties of materials. Communication skills: ability to describe the advanced techniques used in the physics of the subject. Learning skills: ability to interpret experimental results in light of the acquired notions of advanced electromagnetism and optics.
Prerequisities	None

Teaching unit	**COSMOLOGY**
SSD	**FIS/05**
ECTS	**6**
Learning outcomes	The teaching unit of **Cosmology** aims at providing the student with a good knowledge, understanding and awareness of the main phenomena of

	modern cosmology, and the ability to apply the basic principles of relativistic gravity, inflationary scenario, density perturbations, as well as knowledge on dark matter and cosmic microwave background, to obtain a description of the main models of the universe. At the end of the course the student will be able to interpret the observational evidence of the standard model of cosmology, to describe in quantitative terms the universe, and communicate the main properties of the latter. EXPECTED LEARNING OUTCOMES Knowledge and understanding: understanding of the basic principles and methodologies of modern cosmology, knowledge of the main models of the universe, understanding of the assumptions and of the constraints coming from observational data. Ability to apply knowledge and understanding: apply the basic principles of relativistic gravity, as well as knowledge on dark matter, to obtain a description of the main models of the universe and to solve problems on the evolution of the universe. Independent judgment: ability to autonomously extract fundamental information on the structure of the universe from astronomical and cosmological observations. Communication skills: ability to describe the phenomenology underlying the dynamics of the expanding universe from the early times to nowadays. Learning skills: ability to understand the importance of physical phenomena that shape the universe's evolution and discuss in a critical way the constraints coming from observational data.
Prerequisites	None

Teaching Unit	**DYNAMICS OF THE ATMOSPHERE**
SSD	**FIS/06**
ECTS	**6**
Learnieng outcomes	The teaching unit of **Dynamics of the atmosphere** aims at providing the student with a deep knowledge, understanding and awareness of the main phenomena that take place in the atmosphere of the Earth and in the oceans. EXPECTED LEARNING OUTCOMES Knowledge and understanding: acquisition of adequate basic knowledge of the main phenomena that take place in the atmosphere of the Earth and in the oceans; acquisition of the tools that are necessary to solve both theoretical and practical problems in the research work on atmospheric phenomena; ability to read and understand texts, including advanced ones, and research articles in English.

	Ability to apply knowledge and understanding: ability to understand formulae and equations that characterize the study of atmospheric phenomena; ability in deriving and elaborating simple theoretical models; ability to solve, using either analytical or computing tools, the equations that characterize the description of atmospheric phenomena. Independent judgement: ability to construct and developing, thorough logical-mathematical arguments, simple models that allow the student an effective study of the atmospheric phenomena; ability to clearly state the limits and implications of the realized modelling and the range of validity of the obtained results. Communication skills: ability to communicate problems, ideas and solutions regarding atmospheric phenomena, either own or other authors' ones, both to a specialized or generic public, both in written and in oral form, in the own language or in the English language; ability to work in groups and autonomously, by using in an appropriate manner the physical-mathematical and computing abilities acquired during the course. Learning ability: ability to continue the studies in the field of atmospheric physics with a good degree of autonomy; ability to acquire a flexible mind and promptly be involved in working environments, by easily adapting to the study of new problems and acquiring specific skills.
Prerequisities	None

Teaching Unit	**FUNDAMENTAL PROCESSES IN ASTROPHYSICS**
SSD	**FIS/03**
ECTS	**6**
Learning outcomes	The teaching unit of **Fundamental processes in astrophysics** aims at the acquisition by the student of the ability to quantitatively describe some models, even numerical, of stellar structure, starting from the basic physical processes. EXPECTED LEARNING OUTCOMES Knowledge and understanding: phenomenology of energy production in stars, basic principles and quantitative aspects of star physics. Ability to apply knowledge and understanding: applying the description of basic physics to obtain information on the main physical phenomena of the stellar structure. Independent judgment: ability to independently extract fundamental information on the main physical aspects of stars of various types, starting from the basic equations of modern physics.

	Communication skills: ability to describe the phenomenology that underlies the structure and stellar evolution. Learning skills: understanding the description of star systems and the approximations used in the description of the system through basic physical processes.
Prerequisities	None

Teaching unit	**GEOPHYSICS LABORATORY**
SSD	**FIS/01**
ECTS	**6**
Learning outcomes	The teaching unit of **Geophysics laboratory** aims at providing the student with the knowledge of the most important aspects of solid earth geophysics, and in particular of instruments and methods for the study of ground motion. Remote sensing methods will also be covered. The course includes the use of instruments for data acquisition, methods of data analysis and interpretation of the results. EXPECTED LEARNING OUTCOMES Knowledge and understanding: understanding the main concepts and models of solid Earth geophysics, seismicity, and remote sensing. Ability to apply knowledge and understanding: ability to employ measuring instruments and perform data acquisition and analysis, in the contexts of seismic surveys and atmospheric monitoring. Independent judgment: ability to autonomously identify the most convenient methodologies for specific problems and to evaluate their effectiveness. Communication skills: development of the ability to communicate geophysical ideas, and discuss problems and applicative solutions concerning the topic of the course. Learning skills: understanding the multidisciplinary nature and aspects of Geophysics; understanding its impact in many contexts of great social interest (such as environmental monitoring, natural hazards, weather-marine phenomena).
Prerequisites	None

Teaching Unit	**HIGH-ENERGY ASTROPHYSICS**
SSD	**FIS/05**
ECTS	**6**
Learning outcomes	The teaching unit of **High-energy astrophysics** aims at forming the student with knowledges on physical processes, such as acceleration and transport of energetic particles, dynamics of shock waves in collisionless plasmas, radiative processes, in different astrophysical systems, such as

	the heliosphere, galaxies and extragalactic sources. Theory will be compared with observations in-situ (from spacecraft in the interplanetary medium) and from remote sensing (radio, X-ray, gamma emissions in supernova remnants, in galaxy clusters, from pulsars, and gamma ray bursts). A portion of the course will be dedicated to the observative properties of distant objects, such as magnetars, pulsars, gamma ray bursts, and sources of gravitational waves. At the end of the lectures, the student is supposed to be able to interpret in-situ and remote observations, as well as to describe quantitatively the physical processes at work in the objects studied, by using principles from classical physics and from general relativity. EXPECTED LEARNING OUTCOMES Knowledge and understanding: understanding the dynamics of charged particles in time dependent magnetic fields and in magnetic turbulence; knowledge of the main mechanisms of particle acceleration at collision less shock waves; understanding of in-situ and remote observations in light of the physical processes studied and of the radiative processes described during the lectures (such as synchrotron emission and thermal bremsstrahlung); knowledge of the fundamental properties of distant objects and of the sources of gamma ray emission and gravitational waves. Applying knowledge and understanding: interpretation of in-situ and remote observations in light of the physical processes studied in different astrophysical environments. Independent judgment: independent ability of identifying processes in plasma physics and general relativity related to high energy sources in astrophysics. Communication skills: ability of describing phenomena of particle acceleration and transport related to X-ray, radio, and gamma emissions in galactic and extragalactic sources. Learning skills: understanding the physical mechanisms that give rise to the most energetic phenomena in the Universe.
Prerequisities	None

Teaching Unit	**LINEAR AND NON-LINEAR SPECTROSCOPIES**
SSD	**FIS/07**
ECTS	**6**
Learning outcomes	The teaching unit of **Linear and non-linear spectroscopies** aims at providing the student with the basic notions of quantum mechanics necessary for understanding the physical mechanisms underlying the operation of lasers. The course also includes an introduction to non-linear optical spectroscopy techniques.

	At the end of the course the student will be able to understand the physical mechanisms underlying the operation of continuous and pulsed lasers, ii) to describe the physical principles that underlie the techniques of linear and nonlinear optical spectroscopy. EXPECTED LEARNING OUTCOMES Knowledge and understanding: ability to understand the physical mechanisms underlying laser technology and ultra-fast non-linear optical spectroscopies. Ability to apply knowledge and understanding: the student will be able to understand the operating parameters of continuous and pulsed lasers and to understand the experimental results obtained using frequency-sum vibrational spectroscopy techniques. Independent judgment: the student will learn to characterize some properties of laser emission and to obtain information on molecular architecture at an interface from data obtained by frequency sum vibrational spectroscopy. Communication skills: ability to describe the physical mechanisms underlying laser technology, the principles of operation of continuous and pulsed lasers and ultra-fast non-linear optical spectroscopies. Learning skills: ability to interpret the phenomenology linked to the generation and use of laser radiation in terms of advanced notions of quantum mechanics on the interaction between radiation and matter.
Prerequisities	None

Teaching unit	**MACHINE LEARNING FOR PHYSICS**
SSD	**FIS/02**
ECTS	**3**
Learning outcomes	The teaching unit of **Machine Learning for Physics** aims at providing the student with the core techniques of machine learning with a special focus on deep neural networks. The different concepts will be explored in the Python programming language taking advantange of modern open-source packages. At the end of the course the student will be able to design and implement machine learning solutions to complex scientific problems. EXPECTED LEARNING OUTCOMES Knowledge and understanding: knowledge of the main techniques of machine learning and their applications.

	Ability to apply knowledge and understanding: ability to apply the techniques presented in the course to address complex problems. Independent judgment: ability to autonomously identify the most convenient methodologies for specific problems and to evaluate their effectiveness. Communication skills: development of the ability to communicate, both in oral and written form, information, ideas, problems and solutions concerning the topic of the course. Learning skills: development of the ability to acquire knowledge on alternative and more complex techniques beyond the content of the course and to apply them to a variety of problems.
Prerequisites	None

Teaching Unit	**MATHEMATICS EDUCATION**
SSD	**MAT/04**
ECTS	**6**
Learning outcomes	EXPECTED LEARNING OUTCOMES Knowledge and understanding: acquisition of advanced knowledge of the subject, concerning mathematics education and its applications; ability to abstraction and ductility in using formal language; ability to organize and develop mathematics and mathematics education topics with a clear identification of historical and epistemological aspects; ability to read and understand even advanced texts of mathematics and of mathematics education research articles and to expose the content in front of an experienced audience. Ability to apply knowledge and understanding: ability to understand statements written in mathematical language; ability to produce rigorous demonstrations even of original results; ability to use the scientific method of investigation, in particular for the construction of mathematical models and their verification; ability to solve problems of high difficulty in different areas of mathematics education, identifying in an autonomous way the necessary tools to deal with them; ability to analyze problematic situations in the light of educational research, planning educational activities for school even with the use of technologies; ability to carry out defined technical and professional tasks in the field of learning-teaching mathematics or spreading culture scientific; ability to use computer tools, for example programming languages and specific software, as an aid to the solution of mathematical and mathematics education problems of both theoretical and application type; ability to summarize and clearly explain mathematics and mathematics education topics even of high difficulty. Independent judgment: ability to deal with mathematical and mathematical education problems, even of high complexity, identifying

	autonomously the most appropriate theoretical tools for their solution; ability to propose and analyze mathematical models associated with problems, even of high complexity, that originate in other disciplines; ability to construct and develop complex logical arguments independently. Communication skills: ability to communicate problems, ideas and methods of mathematics and of mathematics education, even advanced, in front of a specialized public, both in their own language and in English; ability to communicate educational activities in writing and oral for an audience of students at secondary school; ability to contribute to the dissemination of mathematical culture among the general public through dissemination activities; ability to work in groups and with broad autonomy, also assuming scientific and organizational responsibilities. Learning ability: ability to start research activities with a good degree of autonomy in specialized fields of mathematics and mathematics education and other disciplines; ability to have a flexible mentality and an ability to fit quickly into work environments, easily adapting to new problems, easily acquiring specific skills and also demonstrating managerial skills.
Prerequisities	None

Teaching Unit	**MESOPHASES AND METASTRUCTURES**
SSD	**FIS/03**
ECTS	**6**
Learning outcomes	The teaching unit of **Mesophases and metastructures** aims at providing the student with a rigorous description of the physical properties of the liquid crystalline mesophases and the experimental techniques used for their characterization, together with the introduction of advanced hybrid composite systems, such as metastructures and metasurfaces, both nano and micro structured. The student will learn to describe the physical properties of the above-mentioned systems, to understand and describe the changes related to external stresses (such as mechanical, electrical, magnetic, optical, etc. stress), and to provide examples of innovative and functional materials and their possible applications. EXPECTED LEARNING OUTCOMES Knowledge and understanding: the ability to understand i) the differences between the various types of liquid crystalline mesophases and hybrid metal/dielectric metastructures, ii) the physical mechanisms underlying the interaction between these systems and external stresses (light, electric, magnetic fields, etc.), iii) the most commonly techniques used to characterize their properties. Ability to apply knowledge and understanding: the ability to use the acquired knowledge for understanding the operation mechanisms of liquid crystalline-based devices, as well as for the hybrid organic/inorganic metastructures.

	Independent judgment: the ability to independently extract the fundamental information useful for the description of the physical properties of the studied systems. Communication skills: the ability to describe the physical properties of the most common introduced systems, of the common investigation techniques and the possible applications of these systems in real life. Learning skills: have an effective overview of the various features and properties of mesophases and metastructures, as well as understanding their working principles and application aspects.
Prerequisities	None

Teaching Unit	**MICROSCOPY**
SSD	**FIS/03**
ECTS	**6**
Learning outcomes	The teaching unit of **Microscopy** aims at providing students with knowledge of microscopic analysis techniques, used to investigate and characterize phenomena and materials from the micro to the atomic scale. In particular, it is intended that students will learn these techniques and their use in research, applications, and technology. The course aims at providing students with direct experimental knowledge through laboratory activities. At the end of the course the student will be able to understand and use these techniques autonomously. EXPECTED LEARNING OUTCOMES Knowledge and understanding: knowledge and understanding of microscopy techniques such as optical, electron and scanning probe microscopy and their applications in the field of materials and nanotechnology and phenomena at the nano and atomic scale. Ability to apply knowledge and understanding: apply the techniques to study materials. Independent judgment: ability to extract fundamental information from measurement results. Communication skills: ability to describe instruments and measurements methods, and the results of investigations, conducted on various materials and phenomena. Learning skills: have an effective overview of the various techniques and their use for the study and optimization of systems and materials.
Prerequisities	None

Teaching Unit	**MOLECULAR SPECTROSCOPY**
SSD	**FIS/07**
ECTS	**6**
Learning outcomes	The teaching unit of **Molecular spectroscopy** aims at providing the student with the main contents of the interaction between radiation and matter, focusing on Molecular Symmetry, basic principles of Quantum Mechanics and Spectroscopy techniques (Rotational, IR, Raman and UV/VIS). At the end of course the student will be able to obtain information about the symmetry of active IR and Raman normal modes, by using Group Theory. The student will be able to understand the phenomena associated with the interaction between radiation and matter in the range of the electromagnetic spectrum related to rotational, vibrational and electronic transitions. Students will also increase their ability to study independently and to look for additional books and materials useful to widen their knowledge. EXPECTED LEARNING OUTCOMES Knowledge and understanding: knowledge of the main contents of Group Theory and Quantum Mechanics related to the main spectroscopic techniques. Ability to apply knowledge and understanding: application of main contents of symmetry and Quantum Mechanics for the comprehension of the obtained spectra, from the main spectroscopic techniques (rotational, IR, Raman, UV/VIS). Independent judgment: autonomous identification of the appropriate approaches that allow the acquisition and the interpretation of rotational, vibrational (IR and Raman) and UV/VIS spectra. Communication skills: ability in describing the phenomenology and the modeling related to Optical and Electronic Spectroscopies. Learning skills: understanding the description of spectral results and correlating them to the physical and chemical properties of matter, subject of the investigation.
Prerequisities	None

Teaching Unit	**NUCLEAR AND PARTICLE PHYSICS**
SSD	**FIS/01**
ECTS	**6**
Learning outcomes	The teaching unit of Nuclear and particle physics aims at providing the student with a detailed description of the nuclear structure, radioactive decays and nuclear reactions as well as the basics results of Standard Model of elementary particle physics. The topics will be presented at an introductory level but making full use of the results of

	quantum mechanics and special relativity. On completion of this unit, the student will be able to apply the knowledge of core concepts to more advanced topics in nuclear and particle physics and formulate solutions to problems in nuclear and particle physics involving new concepts with limited guidance. EXPECTED LEARNING OUTCOMES Knowledge and understanding: ability to characterize and quantitatively describe processes in nuclear and particle physics extracting their main characteristics. Ability to apply knowledge and understanding: skills in problem solving, starting from the topics of the course. Ability to manage own learning, to think, interpret and model data within the field of nuclear and particle physics. Judgment autonomy: Self-assessment of degree of knowledge. Ability, with Independent judgement, in the description of experimental procedures as well as in the modelling of the studied physical systems. Communication skills: summarise current thinking in nuclear and particle physics in a variety of written and oral forms, both alone and in collaboration with others. Learning skills: ability to formulate solutions to problems in nuclear and particle physics involving new concepts. Skills and abilities essential for the profile of an expert in basic research in nuclear and particle physics.
Prerequisities	None

Teaching Unit	**NUCLEAR AND PARTICLE PHYSICS LABORATORY I**
SSD	**FIS/01**
ECTS	**6**
Learning outcomes	The teaching unit of **Nuclear and particle physics laboratory I** aims at providing the student with the main notions related to the radiation-matter interaction theory and at describing the different technologies used in the construction of detectors for nuclear and subnuclear physics. The course also provides an accurate description of the working principle of general-purpose experiments (e.g. ATLAS and CMS at LHC and ALEPH and DELPHI at LEP) and the main methods used for data analysis. Ample space is left to laboratory activities where the student is called to participate in the commissioning, analysis of the collected data and presentation of the results obtained. At the end of the course the student will be able to critically analyze the experimental apparatus that have been created in the laboratory of nuclear and subnuclear physics. EXPECTED LEARNING OUTCOMES

	Knowledge and understanding: knowledge of the main results of the radiation-matter interaction theory and their applications in the development of detectors for nuclear and subnuclear physics. Ability to apply knowledge and understanding: ability to design and implement a medium complexity nuclear or subnuclear physics experiment. Independent judgment: development of the ability to select the best particle detection technique in a generic experiment of nuclear and subnuclear physics. Communication skills: development of the ability to communicate, both in oral and written form, information, ideas, problems and solutions concerning the topics of the course in question. Learning skills: development of the understanding of the close relationship between the theory of radiation-matter interaction and the theory of detectors for the physics of elementary particles.
Prerequisities	None

Teaching Unit	**NUCLEAR AND PARTICLE PHYSICS LABORATORY II**
SSD	**FIS/01**
ECTS	**6**
Learning outcomes	The teaching unit of **Nuclear and particle physics laboratory II** aims at providing the student with knowledge of the advanced statistical methods used in elementary particle physics; Monte Carlo techniques and the main features and functionality of the FLUKA simulation program. At the end of the course the student will be able to set up a data analysis and use Monte Carlo simulations both in the analysis and in the study of medium complexity detectors used in nuclear and subnuclear physics, as well as useful equipment in applied physics. EXPECTED LEARNING RESULTS Knowledge and understanding: ability i) to understand the main statistical methods used in the analysis of the data produced in a typical High Energy Physics experiment ii) to perform detailed simulations of detectors using the FLUKA program iii) to understand the physical processes at the basis of the functioning of useful tools, for example, also in hadrotherapy. Ability to apply knowledge and understanding: ability to apply the techniques acquired for data analysis and Monte Carlo simulation to physics cases of interest in high energy physics or its applications.

	Independent judgment: ability to choose the best design solutions related to the development of a simulation of a typical detector used in nuclear and subnuclear physics. Communication skills: development of the ability to communicate both oral and written information, ideas, problems and solutions concerning the topics of the course in question. Learning skills: ability to understand the various aspects related to the field of study also using specialized texts and publications in general.
Prerequisities	None

Attività formativa	**OPTICS AND PHOTONICS**
SSD	**FIS/03**
ECTS	**6**
Learning outcomes	The teaching unit of **Optics and photonics** aims at providing the student with knowledge of the main aspects of classical physical optics, light matter interaction and photonic applications. The course also includes the study of these phenomena in the laboratory with the use of advanced scientific and didactic instruments. At the end of the course the student will be able to describe 1) the interactions of electromagnetic waves (optical frequencies) with matter; 2) the phenomena of interference and diffraction; 3) the propagation of light in optically isotropic, anisotropic and nonlinear media and layered systems; (introductory) laser physics. EXPECTED LEARNING OUTCOMES Knowledge and understanding: ability to understand the main phenomena of classical optics and the optical properties of materials. Ability to apply knowledge and understanding: ability to set up design and carry out experiments on the main optical phenomena and measurements of the optical properties of materials. Independent judgment: ability to autonomously identify the main aspects of the propagation of light in materials and classical physical optics; interpretation of the results of measurements of the optical properties of materials; basis of laser physics. Communication skills: development of the ability to communicate acquired knowledge in oral and written form, ability to write a report on experimental activities concerning the phenomena studied and the optical characterizations of the materials. Learning skills ability to understand the basic concepts of physical optics, optical properties of materials, and laser physics.
Prerequisities	None

Teaching Unit	PARTICLE PHYSICS PHENOMENOLOGY I
SSD	**FIS/01**
ECTS	**6**
Learning outcomes	The teaching unit of **Particle physics phenomenology I** aims at providing the student with knowledge relating to non-Abelian gauge theories in general and the Electroweak Standard Model in particular. The phenomenology of electroweak interactions is introduced through a quantitative description of the main results of the SPS, LEP and LHC colliders. The course also provides an accurate description of the main discrete symmetries and their application in elementary particle physics. At the end of the course, the student will be able to tackle, from a phenomenological point of view, the analysis and solution of problems related to electroweak processes and to apply the principles of symmetry in the description of subnuclear processes. EXPECTED LEARNING RESULTS Knowledge and understanding: knowledge of the main elements and results of the electroweak theory. Ability to apply knowledge and understanding: ability to apply the results of non-Abelian gauge theories in the phenomenological description of electroweak processes. Independent judgment: development of the ability to identify the physical aspects characterizing an electroweak interaction process. Communication skills: development of the ability to communicate information, ideas, problems and solutions concerning the topics of the course in both oral and written form. Learning skills: understanding of the fundamental elements of the Higgs mechanism and of the violation of C, P, T symmetries in the development of the electroweak Standard Model.
Prerequisities	None

Teaching Unit	PARTICLE PHYSICS PHENOMENOLOGY II
SSD	**FIS/01**
ECTS	**6**
Learning outcomes	The teaching unit of **Particle physics phenomenology II** aims at providing the student with knowledge on the quark model for the classification of hadrons and Quantum Chromodynamics. The phenomenology of strong interactions is introduced through a quantitative description of the main results at the SPS, Tevatron and LHC colliders. The course also provides a description of the main results relating to deeply inelastic diffusion processes with particular reference to the structure of the proton.

	At the end of the course, the student will be able to tackle, from a phenomenological point of view, the analysis and solution of problems related to the main characteristics of strong interaction processes. EXPECTED LEARNING OUTCOMES Knowledge and understanding: knowledge of the main elements and results of Quantum Chromodynamics. Ability to apply knowledge and understanding: ability to apply the results of non-Abelian gauge theories in the phenomenological description of strong processes. Independent judgment: development of the ability to identify the physical aspects that characterize a strong interaction process. Communication skills: development of the ability to communicate information, ideas, problems and solutions concerning the topics of the course in both oral and written form. Learning skills: understanding of the fundamental elements underlying the development of Quantum Chromodynamics, in particular in relation to the properties of confinement and asymptotic freedom.
Prerequisities	None

Teaching Unit	**PHYSICAL METHODS IN BIO-MEDICINE**
SSD	**FIS/07**
ECTS	**6**
Learning outcomes	The teaching unit of **Physical methods of bio-medicine** aims at providing the student with the basic knowledge to interpret the effects of ionizing and non-ionizing radiations on the matter. The student will be introduced to the experimental techniques of EPR dosimetry, magnetic resonance imaging, ultrasound, infrared and thermoanalytic techniques. EXPECTED LEARNING OUTCOMES Knowledge and understanding: ability to understand the physical principles underlying the advanced biomedical methodologies. Ability to apply knowledge and understanding: ability to use the physical principles underlying the advanced biomedical methodologies and instruments for the interpretation of experimental results. Independent judgment: the student will learn to recognize the potential and limitations of the most common biomedical investigation techniques. Communication skills: ability to describe the physical principles underlying EPR dosimetry techniques, nuclear magnetic resonance imaging, ultrasound and thermal analysis and their functioning.

	Learning skills: ability to interpret experimental results in light of the knowledge acquired on the interaction between matter and ionizing and non-ionizing radiations.
Prerequisities	None

Teaching Unit	**PHYSICS EDUCATION**
SSD	**FIS/08**
ECTS	**6**
Learning outcomes	The teaching unit of **Physics education** proposes to provide the student with the knowledge of the main didactic and pedagogical tools for teaching physics. Particular attention will be given to the preparation of laboratory experiences. EXPECTED LEARNING OUTCOMES Knowledge and understanding: main objectives of teaching physics. Ability to apply knowledge and understanding: ability to prepare physics lessons for high school and to perform laboratory. Independent judgment: ability to autonomously identify teaching methodologies more appropriate to a given class of students. Communication skills: ability to describe the content of lessons using appropriate language. Learning ability: ability to consult both historical and recent texts on physics teaching, and to understand the mechanisms of training interest of students.
Prerequisities	None

Teaching Unit	**PHYSICS OF COMPLEX SYSTEMS**
SSD	**FIS/02**
ECTS	**6**
Learning outcomes	The teaching unit of **Physics of complex systems** unit aims at describing the concepts of complexity and chaos, which now play an important role in physics. Nonlinear phenomena are described in various contexts of physics, and their interpretative models are discussed. The course includes three laboratory experiences concerning the transition to chaos in mechanical, fluid-dynamic and electrical systems. EXPECTED LEARNING OUTCOMES Knowledge and understanding: understanding of the concepts underlying the theoretical description of Complexity Physics and acquisition of physical models that allow the interpretation of chaotic phenomena in complex systems of various kinds.

	Ability to apply knowledge and understanding: ability to apply the fundamental models of non-linear physics to the interpretation of complex and / or chaotic phenomena; ability to solve simple problems concerning non-integrable systems. Independent judgment: ability to evaluate the consequences of the non-linear behavior of simple physical systems. Communication skills: ability to describe the salient qualitative and quantitative aspects of phenomenology and basic theoretical modeling of complex, non-linear and chaotic systems. Learning skills: concepts of complexity, non-predictability and chaos.
Prerequisities	None

Teaching Unit	**PLASMA ASTROPHYSICS**
SSD	**FIS/05**
ECTS	**6**
Learning outcomes	The teaching unit of **Plasma astrophsyics** aims at providing the student with advanced knowledge of the kinetic theory of plasmas and the ability to quantitatively solve problems involving the formalism of the Boltzmann and Vlasov equations. At the end of the course the student will be able to determine the properties of waves and instability in the kinetic regime of plasmas. EXPECTED LEARNING OUTCOMES Knowledge and understanding: basic principles and methodology of kinetic plasma theory. Ability to apply knowledge and understanding: apply the basic principles of kinetic plasma theory to obtain a solution in analytical form of selected problems. Independent judgment: ability to autonomously extract the fundamental information on the distribution function of plasmas in the phase space. Communication skills: ability to describe the phenomenology that underlies the dynamics of a plasma even outside the thermodynamic equilibrium. Learning skills: ability to understand the importance of selecting the most appropriate description for astrophysical and laboratory plasmas.
Prerequisities	None

Teaching Unit	**QUANTUM FIELD THEORY I**

SSD	**FIS/02**
ECTS	**6**
Learning outcomes	The teaching unit of **Quantum field theory I** aims at providing the student with the basic principles for the quantization of relativistic quantum theories, the methods for extracting conservation laws from their symmetries and the perturbative approach for the calculation of transition amplitudes in theories with interacting fields. At the end of the course the student will be able to calculate in perturbation theory, through the use of Feynman diagrams, the transition amplitude for diffusion processes in relativistic quantum field theories, with special reference to perturbative Quantum Electrodynamics (QED). EXPECTED LEARNING OUTCOMES Knowledge and understanding: knowledge of the main results and methods in relativistic quantum field theories. Ability to apply knowledge and understanding: ability to apply the results of field quantum theory in the description of the physical properties of elementary particles and their interactions. Independent judgment: ability to autonomously identify the most convenient approach in field theory calculations. Communication skills: development of the ability to communicate, both in oral and written form, information, ideas, problems and solutions concerning the topics of the course. Learning skills: development of the ability to extend principles and methods beyond the content of the course and to apply them also to different kinds of interacting systems.
Prerequisities	None

Teaching Unit	**QUANTUM FIELD THEORY II**
SSD	**FIS/02**
ECTS	**6**
Learning outcomes	The teaching unit of **Quantum field theory I**I aims at providing the student with an advanced knowledge of quantum electrodynamics (QED), with particular reference to the calculation of cross sections at tree-level of elementary processes and the theory of renormalization, and a basic knowledge of non-Abelian quantum field theories. At the end of the course the student will have learned the basic notions necessary for the perturbative calculation of cross sections and decay lengths in the Standard model of particle physics. EXPECTED LEARNING RESULTS

	Knowledge and understanding: knowledge of the main results of quantum field theory with particular reference to the perturbative calculation of cross sections and decay lengths in the Standard models of particle physics. Ability to apply knowledge and understanding: ability to apply the concepts learned in the course to the calculation of theoretical predictions of electroweak processes. Autonomous judgment: ability to identify the most convenient approach in organizing a perturbative calculation for a physical process in the Standard model of particle physics. Communication skills: development of the ability to communicate, both in oral and written form, information, ideas, problems and solutions concerning the subject of the course in question. Learning skills: development of the ability to extend principles and methods beyond the content of the course and to apply them also to different kinds of interacting systems.
Prerequisities	None

Teaching Unit	**SCIENTIFIC DATA ACQUISITION AND PROCESSING**
SSD	**FIS/07**
ECTS	**6**
Learning outcomes	The teaching unit of **Scientific data acquisition and processing** intends to describe advanced techniques for the acquisition and processing of experimental data, with particular attention to real-time acquisition and representation of data in digital tools. The representation on the time axis is compared with the Fourier representation and all the elements for the analysis of the discrete Fourier transform are introduced, which is analyzed in detail both from a theoretical and operational point of view. EXPECTED LEARNING OUTCOMES Knowledge and understanding: noise control, sampling of a signal, filtering, signal in Fourier space. Ability to apply knowledge and understanding: knowing how to program and use acquisition systems in processes of physical interest. Independent judgment: independent evaluation of the experimental methods to be used. Communication skills: knowing how to represent and discuss the data obtained from the analysis of signals due to physical processes. Learning skills: data acquisition and filtering.
Prerequisities	None

Teaching Unit	**SOFT MATTER PHYSICS**
SSD	**FIS/07**
ECTS	**6**
Learning outcomes	The teaching unit of **Soft matter physics** aims at providing the student with a detailed description of the physical properties of soft matter, with particular reference to intermolecular interactions. During the course some examples of soft matter are highlighted and their properties are described with particular reference to technological applications in transdisciplinary fields. At the end of the course the student will be able to: i) describe the characteristics of soft materials and he will understand the models that determine their behavior, ii) to describe the main experimental techniques that are used in the study of soft materials. EXPECTED LEARNING OUTCOMES Knowledge and understanding: ability to understand: i) the physical mechanisms underlying the weak interaction between molecules in soft materials, ii) the mechanisms underlying the interactions between microscopic bodies in air and in electrolyte solutions, iii) the mechanisms that regulate surface wettability phenomena, and iv) the physical properties of some soft materials such as polymers, colloids, surfactants and liquid crystals. Ability to apply knowledge and understanding: ability to use the acquired knowledge to understand the working mechanisms of different soft matter systems and to choose the experimental methodologies suitable for the characterization of their physical properties. Independent judgment: ability to autonomously identify the main mechanisms underlying the description of the physical properties of soft matter systems. Communication skills: ability to describe the interaction forces between microscopic bodies in air and in electrolytic solutions, the phenomena of wettability of surfaces and the physical properties of some soft materials. Learning skills: ability to interpret the properties of complex soft materials in terms of their intermolecular interactions.
Prerequisities	None

Teaching Unit	**SOLAR PHYSICS AND SUN-EARTH CONNECTION**
SSD	**FIS/06**
ECTS	**6**
Learning outcomes	The teaching unit of **Solar Physics and Sun-Earth connection** aims at providing the student with the knowledge of the fundamentals of solar

	activity and its influence on the terrestrial environment, and the ability to identify the most dangerous phenomena for high-tech human activities. At the end of the course the student will be able to design methodologies for the safety of artificial satellites. EXPECTED LEARNING RESULTS Knowledge and understanding: basic principles and phenomenology of solar activity. Ability to apply knowledge and understanding: apply the basic principles of solar physics to obtain a quantitative description of the observed phenomena. Independent judgment: ability to independently extract the fundamental information of solar activity. Communication skills: ability to describe the phenomenology of solar activity and its influence on the terrestrial environment. Learning skills: ability to understand the importance of the various factors that determine the Sun-Earth relations.
Prerequisities	None

Teaching Unit	**SOLID STATE PHYSICS**
SSD	**FIS/07**
ECTS	**6**
Learning outcomes	The teaching unit of **Solid state physics** aims at providing the student with theoretical and experimental knowledge on electronic transport properties in metals and semiconductors, presenting some application examples. The course also provides an accurate description of the magnetic properties of solids with particular reference to superconductivity and technological applications. At the end of the course the student will be able i) to describe from a theoretical point of view the electron transport models in metals and semiconductors, ii) to describe the physical principles underlying the magnetic properties of solids. EXPECTED LEARNING OUTCOMES Knowledge and understanding: ability to understand transport mechanisms in metals and semiconductors and physical principles underlying the magnetic properties of solids. Ability to apply knowledge and understanding: the student will be able to understand the properties of metals and semiconductors using electron spectroscopy and photoemission techniques.

	Independent judgment: ability to autonomously identify the main mechanisms that allow the description of the physical properties of metals and semiconductors. Communication skills: ability to describe the physical principles underlying the electronic transport properties in metals and semiconductors and the magnetic properties of materials also in reference to technological applications. Learning skills: ability to interpret the phenomenology related to the use of metallic and semiconductor materials and their magnetic properties in terms of advanced notions of quantum mechanics.
Prerequisities	None

Teaching Unit	**SPACE PHYSICS**
SSD	**FIS/06**
ECTS	**6**
Learning outcomes	The teaching unit of **Space physics** aims at giving students the fundamental knowledge on charged particles and plasmas around the Earth' space environment, as well as the capability to find a quantitative solution of problems which require the plasma fluid approach. At the end of the course the student will be able to obtain a general classification of waves propagating in either a ionospheric or a space plasma. EXPECTED LEARNING OUTCOMES Knowledge and understanding: basic principles and methods of plasma fluid theory. Capability to apply knowledge and understanding: capability to apply the basic principles of plasma fluid description to obtain analytical solutions for plasma wave propagation, and to correctly interpret in situ spacecraft data. Independent judgement: ability to obtain in an autonomous way the basic information on wave propagation in a magnetized plasma. Communication skills: capability to describe and present the phenomena related to the propagation of waves in the Earth's ionosphere and magnetosphere. Learning capability: ability to sort and discriminate in the wide field of spacecraft in situ data and to understand the importance of finding the correct plasma wave modes.
Prerequisities	None

Teaching Unit	**SPACE WEATHER**
SSD	**FIS/06**

ECTS	**6**
Learning outcomes	The teaching unit of **Space weather** proposes to provide the student with the knowledge of the fundamentals of solar activity and its influence on the terrestrial environment, and the ability to identify the most dangerous phenomena for high-tech human activities. At the end of the course the student will be able to design methodologies for the safety of artificial satellites. EXPECTED LEARNING OUTCOMES Knowledge and understanding: basic principles and phenomenology of solar activity. Ability to apply knowledge and understanding: apply the basic principles of solar physics to obtain a quantitative description of the observed phenomena. Independent judgment: ability to independently extract the fundamental information of solar activity. Communication skills: ability to describe the phenomenology of solar activity and its influence on the terrestrial environment and on the problems of Space Weather necessary for technological development. Learning skills: ability to understand the importance of various factors that determine the Sun-Earth relations.
Prerequisities	None

Teaching Unit	**STATISTICAL MECHANICS**
SSD	**FIS/02**
ECTS	**6**
Learning outcomes	The teaching unit of **Statistical mechanics** aims at deepening the use of quantum statistics to model interacting systems of bosons or fermions and to introduce the concepts of universality and critical behavior for lattice systems. EXPECTED LEARNING OUTCOMES Knowledge and understanding: understanding the concepts of universality and renormalization in critical phenomena; knowing of methods for solving problems with interacting particles, for classical systems, fermions and bosons. Ability to apply knowledge and understanding: applying the mean field approximation to different continuous and lattice models.

	Independent judgment: critically using the different methods of approximate solution of interacting systems, understanding their applicability limits. Communication skills: knowing how to explain in a technically correct manner the main characteristics of the statistical behavior of interacting particles in the classical and quantum description; knowing how to describe critical phenomena and explain the concept of universality. Learning skills: learning the role of classical and quantum correlations beyond the average field approximation.
Prerequisities	None

Teaching Unit	**SURFACE PHYSICS**
SSD	**FIS/07**
ECTS	**6**
Learning outcomes	The teaching unit of **Surface physics** aims at providing the student with theoretical and experimental knowledge on the electronic properties of materials and to describe the effects that a reduction in their dimensionality has on these properties. The course also provides an accurate description of the experimental techniques for the study of the electronic structure of surfaces and for the preparation and characterization of nanostructured surfaces. At the end of the course the student will be able i) to describe from a theoretical point of view the electronic structure in mono-, bi- and three-dimensional systems, ii) to describe the physical principles that are the basis of the investigation techniques of the electronic structure of materials crystalline and nanostructured materials. EXPECTED LEARNING OUTCOMES Knowledge and understanding: ability to understand the effects of size reduction on the electronic properties of crystalline systems and to describe the electronic properties of nanostructured systems. Ability to apply knowledge and understanding: the student will be able to understand the experimental results obtained using electron spectroscopy and photoemission techniques. Independent judgment: the student will learn to critically interpret the experimental results of the spectroscopic techniques and to use them to extrapolate information on the electronic properties of three-, two-dimensional and one-dimensional systems and nanostructured systems. Communication skills: ability to describe the physical principles underlying the electronic properties of different dimensional and nanostructured systems and of the main spectroscopic investigation techniques.

	Learning ability: ability to interpret the effect of reduction of the dimensionality and / or the presence of nanostructures starting from the notions acquired on three-dimensional systems.
Prerequisities	None

Teaching Unit	**SYNOPTIC AND MESOSCALE METEOROLOGY**
SSD	**FIS/06**
ECTS	**6**
Learning outcomes	The teaching unit of **Synoptic and mesoscale meteorology** concerns the study and analysis of the physical processes needed to describe meteorological systems at the synoptic and mesoscale scales at all latitudes, study their structure and predict, even in a qualitative way, the future evolution. The study concerns the analysis and predictability of these systems from mesoscale to planetary scales, including the basic techniques used. EXPECTED LEARNING RESULTS Knowledge and understanding: knowledge of the basic principles and phenomenology of meteorology. Ability to apply knowledge and understanding: ability to apply the basic principles of meteorology for a qualitative and quantitative description of the observed phenomena and for the development of space-time forecasts. Independent judgment: ability to autonomously identify the main atmospheric phenomena at different spatial scales (synoptic and mesoscale). Communication skills: ability to describe meteorological phenomena using appropriate scientific language, also for communication and dissemination purposes. Learning skills: ability to understand the role of different atmospheric phenomena in influencing meteorological variability, also in the context of climate change.
Prerequisities	None

Teaching Unit	**THEORETICAL CONDENSED MATTER PHYSICS**
SSD	**FIS/03**
ECTS	**6**
Learning outcomes	The teaching unit of **Theoretical condensed matter physics** aims at providing a basic understanding of theoretical models and methods employed to describe condensed matter systems, based on the second quantization approach. In particular, the course focuses on many-body

	systems, Green’s functions and diagrammatic techniques; linear response theory and its applications. EXPECTED LEARNING OUTCOMES Knowledge and understanding: understanding the implications of quantum indistinguishability and quantum statistics on the behavior of condensed systems; mastering the concepts of quasi particle, collective excitation, and emerging degree of freedom; understanding the meaning of Green’s and response functions; understanding the limits of applicability of the mean field and linear response approximations. Applying knowledge and understanding: to be able to solve simple ideal models of free and interacting many particle systems; to be able to evaluate response function for simple model-systems and to employ Kubo formulas in various contexts related to the properties of quantum gases. Independent judgement: to be able to assess the validity and goodness of different approximation methods in the description of quantum particles and their interactions (e.g., Bogolyubov method, diagrammatic approach, fermionization etc.). Communication skills: to be able to employ a suitable and technically correct language in order to describe phenomena and theoretical models of many-body systems; to be able to explain and use accurately the concepts of collective excitation, emergent physics, critical behavior and response function. Learning skills: students will be guided in order to extend their knowledge beyond the contents of the course, by deepening their understanding of some of the subjects according to their specific interest, under the supervision of the lecturer.
Prerequisities	None