iSAS International Interdisciplinary Intersectoral School of Advanced Studies	**Università degli Studi di Camerino School of Advanced Studies** **Corso di Dottorato di ricerca in** **Physics, Earth and Materials Sciences**

Attività didattiche VERTICALI a.a. 2025/2026

Docente	SSD	Titolo attività formativa	Codice	CFU	CFU modulo	Mutuato parzialmente da:	Valutazione	Ore didattica	Semestre	Curriculum riferimento
Perali Andrea	PHYS-03/A	Condensed Matter Theory		3		CdL in Fisica LM-FI	Idoneità	42	II	Physics
Gabriele Giuli	GEO/06	Introduction to crystallography		3			idoneita'	21	II	Earth Science
Miller Zambrano	GEOS-04/B	Advanced seismic interpretation		3			Idoneità	21	I	Earth Science
Orlando Luongo	PHYS-02/A	Advanced Quantum Field Theory		3			Idoneità	24	II	Physics
Josephin Giacomini	MATH-05/A	Computational Fluid Dynamics		3			Idoneità	21	II	Material Science
Piangerelli Marco Pilati Sebastiano	INFO-01/A PHYS-03/A	Machine Learning and its applications **	DOCS M013	4	2+2	PhD in Computer Sciences and Mathematics	Idoneità	14+ 14	II	Physics

Licciardi Silvia	MATH-05/A	Mathematical Methods for Physics and Engineering.		3		CdL in Matematica LM-MAT	Idoneità	21	ii	math
Muccino Marco	PHYS-02/A	Observational methods in astrophysics		3		CdL in Physics LM-FIS	Idoneità	21	II	Physics
Massaro Alessandro	GEOS-04/B	Geostructural analysis for rockfall susceptibility investigations and rock blocks trajectory modelling		3			Idoneità	21	II	Earth Science

VERTICAL teaching activities: Contents / Contenuti Attività didattiche VERTICALI

Perali Andrea	PHYS-03/A	Condensed Matter Theory for PhD

The course "Condensed Matter Theory" provides theoretical and phenomenological concepts and tools, in close connections with experiments, for understanding the microscopic properties of quantum systems constituted by a macroscopic number of interacting particles. The focus of the course will be on building a deep knowledge of the microscopic mechanisms and fundamental models for describing the behavior of electrons, ions and excitations in solids and ultracold matter made by atomic gaseous clouds. Key quantum phenomena in Condensed Matter Physics will be considered in detail: superconductivity, superfluidity, ultra-cold gases in traps, BCS-BEC crossover and pseudogap phenomena, electron-hole heterostructures and excitons and their condensation and superfluidity, nanostructured superconductors and resonant phenomena.

Prerequisites: Basic knowledge of quantum and statistical mechanics, structure of matter, atomic and molecular physics.

Syllabus of the course:

1. Hamiltonian in first and second quantization. Non-interacting Fermi and Bose gases; Bose-Einstein condensation.
2. Review of solid state physics: Electronic bands, Fermi surfaces, Density of States; lattice dynamics; phonons.
3. Electron-phonon interaction: perturbative treatment and the Froelich Hamiltonian; deformation potential, the polaron, the Cooper instability.
4. Electron-electron interaction: Hartree-Fock approximation; Coulomb screening and Thomas-Fermi approximation; Landau's theory for the Fermiliquid; Mott insulator and repulsive Hubbard model and connections with cuprate superconductors.

5. Feynman diagrams and the diagrammatic approach for Condensed Matter Physics. Relevant examples.
6. BCS microscopic theory of superconductivity. The variational approach. Self-consistent gap and Tc equations.
7. BCS-BEC crossover and pseudogap phenomena in solids and ultracold matter: theory and experiments.
8. Superconductivity at the nanoscale. Quantum confinement effects. Systems of sub-bands and Lifshitz transitions. Density of states in different geometries at the nanoscale. Renormalization of the interaction. Equation of gaps and for the Tc at the nanoscale. Superconducting nanofilms and nanostripes. Super-lattices of slabs and stripes: amplification and stabilization of superconductivity. Nanofabrication techniques.
9. Superfluidity of electrons and holes in van der Waals heterostructures of graphene and other two-dimensional semiconductor materials. Theoretical and experimental aspects.

Suggested textbooks:

1) N. Ashcroft, and N. Mermin, Solid-State Physics, Harcourt College Publisher, 1976
2) Superconductivity of Metals and Alloys, P. G. De Gennes, Advanced Book Classics, CRC Press.
3) One-Dimensional Superconductivity in Nanowires, Fabio Altamare, Albert M. Chang, Wiley-VCH

Gabriele Giuli	GEO06	Introduction to crystallography

- Introduction to crystallography (definition of a mineral, differences between crystalline and amorphous matter);
- crystal lattice, simmetry elements compatible with periodic structures;
- point groups, space groups;
- polymorphysm, isomorphism and solid solutions;
- direct lattice and reciprocal lattice;
- X-ray diffraction: basics of X-ray diffraction, Bragg equation, how to read powder X-ray diffractograms; - Introduction to the Rietveld method

Miller Zambrano	GEOS-04/B	Advanced seismic interpretation

The course is intended for PhD students and advanced graduate students with experience or some basis in seismic reflection data interpretation. The objective of the course is to provide skills and workflows for the interpretation of 3D seismic data.

The first part of the course will cover the theoretical aspects of the seismic data acquisition and processing. The second part focuses on the practical aspect of the interpretation of seismic data. The main aspect evaluated in the course includes the seismic-well calibration, interpretation of horizons and faults, map generations, construction of velocity models and seismic attributes. During the course the student will have access to advanced seismic interpretation software like Petrel and OpendTect thanks to academic licenses.

The evaluation of the course is continuous due to its immersive characteristics. The final evaluation will be oral in the form of a presentation of a project developed during the practical lessons

Orlando Luongo	PHYS-02/A	Advanced Quantum Field Theory

The functional approach to quantum field theory and instantons. The free Rarita-Schwinger field (4 hours). Quantum Chromodynamics (7 hours). Faddeev-Popov method and BRST symmetry. Quantum Field in Curved Space: Quantization in curved space time (7 hours). Solitons in field theories (2 hours).Bogoliubov transformation. The Hawking effect. The Unruh effect (4 hours).

Josephin Giacomini	Math 05/A	Computational Fluid Dynamics

Program:

This course has the scope of giving fundamentals of Fluid Dynamics and showing how to use them in a model of a real-life problem to obtain a reliable approximate solution. In particular, the course will introduce the physical principles and the mathematical modelling of Fluid Dynamics. Then, it will briefly describe some approximation schemes to give the basic tools to understand a CFD simulator. Extensive use of computer simulations will be carried out. In addition, a representative case study will be built and solved by the students.

Licciardi Silvia	Math 05/A	Mathematical Methods for Physics and Engineering.

A Deep look into Micro and/or Nanostructured Materials **Learning Aims** On these lectures, we are going to provide a set of tools to address a range of problems which often occur in different fields of pure and applied Mathematics, from Geometry to Mathematical Physics, Quantum Physics to Laser Physics, from Optics to Thermodynamics, Biology, Chemistry, Engineering, Power production, Deep Learning and so on. The same tools, indeed, can be exploited to model different aspects of applied Math. We will show classical and innovative tools, like umbral calculus or Neural Networks architectures, which requires the use of combinatorics, formal series, special functions, generating functions and operator theory to solve PDE and ODE, in fractional dynamics too, not known indefinite integrals, repeated derivative, products of special functions, number theory, matrices or machine learning problems.

Muccino Marco	PHYS-05/A	Observational methods in astrophysics

A Deep look into Micro and/or Nanostructured Materials **Learning**

Aims

The best suite to describe our Universe is the standard paradigm known as the 🔍 CDM cosmological model. Its current understanding comes from the observables of standard cosmic probes, such as standard "candles" like type supernovae Ia (SNe Ia), "rulers" like the cosmic microwave background radiation (CMB) and baryonic acoustic oscillations (BAO), and "chronometers" like the observational Hubble rate data (OHD). Each probe has its own range of observability (in terms of redshift or look back time), systematics and shortcomings affecting the cosmic bounds on the considered model.

The course deals with these probes, tackles their observables description and physics, and provides up-todate status of hot topics like dark matter and dark energy. Finally, gamma-ray bursts (GRBs) are introduced as potential distance indicators that can bridge the gap between low/intermediate and high-redshift probes in solving the cosmological puzzle.