Università degli Studi di Camerino School of Advanced Studies
Corso di Dottorato di ricerca

Physics, Earth and Materials Sciences a.a. 2024/2025

Docente	SSD	Titolo attività formativa	Codice	CFU	CFU modulo	Mutuato da	Valutazione	Ore didattica	Semestre	Curriculum riferimento
Carroll Michael Robert	GEO/07	Applications of radiogenic and stable isotopes to Earth Sciences, Environmental Sciences and Cosmology	DOPEMS012	3		-Mutuato parz CdL LM-Geo	Idoneità	21	II	Earth Science
Perali Andrea	FIS/03	Condensed Matter Theory for PhD		6		Mutuato parz CdL in Fisica LM-FI	Idoneità	42	II	Physics
Gabriele Giuli	GEO06	Introduction to crystallography		3			idoneita'	21	II	Earth Science
Danica Jablonska	GEO/07	Carbonate Diagenesis		3		-	Idoneità	21	II	Earth Science

Miller Zambrano	GEO/11	Near-surface Geophysical Methods		3			Idoneità	21	I	Earth Science
Orlando Luongo	FIS/02	Advanced Quantum Field Theory		3			Idoneità	24	II	Physics
Di Cicco Andrea	FIS/01	Advanced Physics Laboratory for PhD		6		Mutuato parz CdL in Fisica LM-FI	Idoneità	42	II	Physics
Tatiana Guidi	FIS/03	Solid State Physics for PhD		3		Mutuato parz. CdL in Fisica LM-FI	Idoneità	21	I	Physics
Roberto Gunnella	FIS/03	Advanced Nanotechnologies for PhD		3		Mutuato parz CdL in Fisica LM-FI	Idoneità	21	I	Material Science
Angela Trapananti	FIS/01	Advanced Spectroscopy for PhD		3		Mutuato parz CdL in Fisica LM-FI	Idoneità	21	II	Physics
Josephin Giacomini	MAT/08	Computational Fluid Dynamics		3			Idoneità	21	II	Material Science
S. Javid Rezvani	Fis/03	Advanced Nanoscience Laboratory		3			Idoneità	21	ii	physics
Marco Muccino	FIS/02	Observational Methods in Astrophysics		2			Idoneità	12	ii	Physics
Simone Biondini	FIS/02	Introduction to Particle Dark Matter		2			Idoneità	12	ii	Physics

Silvia Licciardi	Mat/08	Mathematical Methods for Physics and Engineering		2			Idoneità	12	ii	Material Science
Matassa Roberto	Fis/03	A deep look into Micro and/or Nanostructured materials		3		Mutuato pz Synthesis of Functional Materials	Idoneità	21	ii	physics
Piangerelli Marco/Pilati Sebastiano	INF/01 Fis/03	Machine Learning and its applications	DOCSM013	4	2+2	Mutuato da PhD in Computer Sciences and Mathematics	Idoneità	28	II	Physics
Gianluca Castignani	FIS/05	An introduction to Super-Massive Black Holes		2			Idoneità	9	II	Physics

Descrizione corsi

Carroll Michael Robert	GEO/07	Applications of radiogenic and stable isotopes to Earth Sciences, Environmental Sciences and Cosmology

Isotope geochemistry - radioactive isotopes and applications
- PHYSICS OF THE NUCLEUS AND THE STRUCTURE OF NUCLEI (basic decay info-not details)
- BASICS OF RADIOGENIC ISOTOPE GEOCHEMISTRY
- DECAY SYSTEMS AND THEIR APPLICATIONS
- Rb-Sr,Sm-Nd, Lu-Hf, Re-Os, La-Ce

- U-Th-Pb
- U and Th Decay Series Isotopes
- Isotopes of He and Other Rare Gases
- 14Carbon, other cosmogenic isotopes

Isotope geochemistry - stable isotopes and applications
- Introduction
- Theoretical Consideration
- Temperature Dependence of the Fractionation Factor
- Composition and Pressure Dependence
- Kinetic Isotope Fractionations
- Isotope Geothermometry
- Isotope Fractionation in Hydrologic Systems
- Isotope Fractionation in Biological Systems (briefly)
- Paleoclimatology
- Hydrothermal Systems and Ore Deposits
- Stable isotopes in the mantle and magmatic systems
- non-traditional stable isotopes

Perali Andrea	FIS/03	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 Fermi-liquid; 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

Danica Jablonska	GEO/07	Carbonate Diagenesis

Understanding carbonate diagenesis is a crucial tool for deciphering the paleo-environmental settings during deposition; physical and chemical conditions during burial; and circumstances of subsequent uplift. Moreover, it is possible to define geological processes that impacted the petrophysical properties of the carbonate rocks. Carbonate diagenesis has a vast application in many disciplines, such as characterization of geofluid reservoirs, CCS reservoir assessment and geothermal potential.
This course is divided into 2 main parts: The theoretical part will address: carbonate mineralogy, early diagenesis in different settings; burial diagenesis in various structural settings and telegenesis.The practical part will be focussed on interpretation of the thin sections and results of analyses.

Miller Zambrano	GEO/11	Near-surface Geophysical Methods

This course, *Near-surface Geophysical Methods*, equips PhD students with practical skills in various geophysical techniques for imaging the near-surface Earth. It focuses on methods used in engineering and geological risk assessment, covering seismic techniques like MASW, seismic refraction, and HVSR, as well as electrical methods like 3D resistivity and induced potential.

Orlando Luongo	FIS/02	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).

Di Cicco Andrea	FIS/01	Advanced Physics Laboratory for PhD

Program:

The students will carry out experiments in the laboratory, complemented by classroom lectures on the following topics:
1) X-ray interaction with matter. X-ray fluorescence (XRF). Experimental set-up: x-ray source, optics, detectors. Theory of photoabsorption. Fluorescence yield. Methods for quantitative x-ray fluorescence analysis. X-ray diffraction. Peak-fitting analysis.
2)Conducting measurements by scanning microscopy carried through an AFM and scanning electron microscope. Determination of the properties of an elastic tip interacting with the surface. Frequency spectrum measurements of the elastic cantilever.
Microanalysis by X-ray fluorescence field of SEM.
3) Measurements of the spectrum of vibrations on a sample surface by means of a RAMAN experiment. Characterization of the sample properties, both from the composition and the structure point of view.

Tatiana Guidi	FIS/03	Solid State Physics for PhD

- Electrons in a periodic potential: Adiabatic approximation. Bloch’s theorem. Energy levels and band structure. Classification of solids Tight-binding and LCAO approximations. Approximation of weak potential and perturbative approach. Wannier functions. Orthogonalized plane wave (OPW) method. Pseudopotential. Transport properties in a periodic potential. Landau levels. De Haas-van Alphen effect.
- Lattice dynamics: Acoustic and optical branches. Normal modes in one dimension:

dispersion relations for a monoatomic and diatomic chain. Brillouin zones. Three-dimensional Bravais lattice with base: harmonic approximation. Quantum theory of the harmonic crystals: Phonons. Lattice and electronic specific heat at low temperature. Debye and Einstein models. Phonon density of states. Van Howe singularities. Anharmonic effects. Thermal expansion. Second quantization formalism. Measuring phonons with neutron scattering. Electron-Phonon Interaction: temperature-dependent electrical resistivity of metals.
- Semiconductors: Valence and conduction bands. Statistics of holes and electrons in bands. Chemical potential and its dependence on temperature. Intrinsic semiconductors. Law of mass action. Doped semiconductors of type n and p. n-p junctions. Rectification by p-n junction.
- Superconductivity: Characteristic properties of a superconductor: critical temperature, persistent current. Magnetic properties: Meissner effect, critical current, critical field, Type I and II superconductors. London equation and London penetration depth.
- Magnetism: Magnetization and susceptibility. Diamagnetism. Hund's rules. Paramagnetism. Curie's law. Magnetic interaction. Spin Hamiltonian. Heisenberg model. Exchange interaction. Types of magnetic structures. Spin waves.

Roberto Gunnella	FIS/03	Advanced Nanotechnologies for PhD

This course has the scope of giving fundamentals of mesoscopic and quantum effects at the boundary of nanometric systems. The course is divided into 4 main main sections: 1) optical properties of nanometric solids and their influences in the plasmonics technologies and in related spectroscopies; 2) effects in conduction devices and correlated problems in integrated electronics and limitations to overcome by using new materials; 3) nanometric materials for optical devices in use for quantum technologies (photonics) and photocatalysis devices for application to environmental technologies.

Angela Trapananti	FIS/01	Advanced Spectroscopy for PhD

Spectroscopic techniques have been crucial in the development of some fundamental theories in physics and still underpin a wide range of research in physics and chemistry as well as serving as valuable analytical tools.
This course will introduce general aspects of spectroscopy, some of the key principles, tools and techniques that govern spectroscopic measurements and the theoretical principles of photon and electron spectroscopy.

Topics include:
- Rotational, vibrational and electronic spectroscopies
- Infrared and Raman spectroscopies
- Auger, X-ray and ultraviolet photoelectron spectroscopies
- X-ray Absorption Spectroscopy
- X-ray Emission Spectroscopy

Josephin Giacomini	MAT/08	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.

S. Javid Rezvani	Fis/03	Advanced Nanoscience Laboratory

The course will provide experiences by putting hands on several physical and chemical physics aspects of nanostructured materials. The experiments will be introduced by the quantitative description of what is obtained by the experiment

1) 2D flakes of layered materials obtained by exfoliation.

a) exfoliation of 2d materials (graphite, $CrCl_3$, and other materials on chosen substrates (SiO_2, ITO...).

b) Analysis at the optical microscope for the determination of the interference and thickness by means of contrast analysis

c) Multitechniques characterization (AFM,SEM RAMAN)

2) Nanoparticles (metals and oxides) synthesis and their study in terms of the plasmon resonance, confinement effects
:

a) Silver, Gold, SiO_2 nanoparticles and other types. Characterization of the physical parameters by study in solution. Raman and optical properties.

b) Characterization after deposition on substrates. Study of the plasmon resonances by Surface enhanced Raman spectroscopy.

Matassa Roberto	Fis/03	A deep look into Micro and/or Nanostructured materials

A Deep look into Micro and/or Nanostructured Materials

Learning Aims

This module aims to introduce students to the basic concepts in optical microscopy to be easily driven to the foundation-level knowledge on the essential setting of the electron microscopy: sources, lens, interaction electron-matter, and imaging-spectroscopy detection. It covers the most essential topics necessary on how to use the optical-electron microscopy correctly to perform imaging, diffraction, and spectroscopy techniques. These are applied to the characterization experiments in which the results can be analysed to investigate the morphology, chemistry, and structure of any matter (Biology, Pharmacy, Medicine, and Chemistry), as well as introducing students to enhancing their future outcomes by quantitative imaging analysis.

Lecture Content:

- Introduction from optical and to the electron microscopy.
- Conventional and advanced electron microscopy techniques
- Specimen preparations: “An essential outcome!” in Biological, Pharmaceutical, Medicine, and Chemistry research fields.
- Morphological, chemical, and structural analyses of micro and nanometric regions.
- Taking advantages from quantitative imaging analysis (QIA).

Muccino Marco	Fis/02	Observational methods in astrophysics

12 hours in 6 lessons of 2 hours

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-to-date 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.

Analytical list of topics:

• ”Standard candles”: SNe Ia
• ”Standard rulers”: CMB and BAO
• ”Cosmic chronometers”: OHD • Cosmic bounds on dark matter and dark energy: status and perspectives
• GRBs: physics and standardization

Verification test
Oral and presentation/research project

Simone Biondini	Fis/02	Introduction to Particle Dark Matter

12 hours in 6 lessons of 2 hours

Evidence for the existence of dark matter (DM) comes from a very wide range of astronomical scales, from a few kiloparsecs (the dimension of small galaxies) to essentially the whole size of the observable Universe. It all started with Fritz Zwicky, who, in the early ’30s, undertook a systematic study of the Coma Cluster. After almost one century, we still do not know what dark matter is. Although this is not the only viable option, the interpretation of DM as due to new particles has been put forward in a plethora of models and triggered exciting theoretical and experimental programs. This is the focus of this course, namely an introduction to particle dark matter. This multi-disciplinary research field mixes astrophysics, cosmology and particle physics. We shall review the evidence for DM, its production mechanisms in the early universe and the current strategies to detect it via its non-gravitational interactions.

Analytical list of topics

- Evidence for dark matter from astrophysics and cosmology
- Identikit of a particle dark matter, candidates and connection with Physics Beyond the Standard Model
- Production mechanism: freeze-out
- Production mechanism: freeze-in
- Direct detection and indirect detection
- Collider searches for dark matter

Verification test

Oral and eventually with an additional test or research project

Licciardi Silvia	Mat/08	Mathematical Methods for Physics and Engineering

10/12 hours in 5/6 lessons of 2 hours

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.

Analytical list of topics

• Operator Theory
• Umbral Calculus
• Special Functions
• Fractional Dynamics
• Anomalous Distributions
• Solutions for not trivial indefinite integrals
• Deep Learning architectures

Verification test
Oral and eventually with an additional test or research project

M. Piangerelli S. Pilati	INF/01 FIS/03	Machine learning and its applications

4 CFU, 28 hours
14 by M. Piangerelli, 14 hours by S. Pilati

Aims:
The goal of this course is to provide students with the basic skills in the field of statistical modeling of big-data and machine learning. The course will present the basic theoretical concepts and some practical techniques to analyze data and to develop statistical modes, focusing in particular on artificial neural networks.

Requirements:
Basic knowledge of algebra, differential calculus and statistics. Basic programming skills.

Syllabus:
Introduction to Probabilistic Learning
Paradigms of ML
Unsupervised (KMeans- Hierarchical)

Supervised (SVM-Linear/Logistic)
Artificial neural networks
Classification VS Regression
Evaluation Metrics
Overfitting / Underfitting
Deep learning - Convolutional neural networks
Boltzmann Machines
Autoregressive neural networks for density estimation
Hands on tutorial

The course is based on frontal theoretical lectures, complemented with a hands-on tutorial in the final part.
Each student will agree with the teachers on a project for the final exam. The project has to involve the application of the concepts and the techniques discussed during the course, or extensions thereof.
While working on the project, the student will regularly report to one or both teachers on the progress, presenting also partial results. A final report (a few pages long) has to be sent in pdf format to both teachers before the day of the exam. During the (oral) exam, the student will present the final results, discussing the goal and the techniques employed, with the support of a very brief presentation in pdf/ppt format.
Books:
C.M. Bishop, Pattern Recognition and Machine Learning, Springer - 2006
D. Barber, Bayesian Reasoning and Machine Learning, Cambridge University Press. - 2012
T. Hastie, R. Tibshirani, J. Friedman, The Elements of Statistical Learning, Springer - 2008
Hastie, Tibshirani, Friedman, “The Elements of Statistical Learning”,Springer (2008) (free pdf online)
Sebastian Raschka, "Python Machine Learning"
Gavin Hackeling, "Mastering Machine Learning with scikit-learn"
A. Fischer and C. Igel, "An introduction to restricted Boltzmann machines" in Iberoamerican congress on pattern recognition (Springer, 2012) pp. 14-36.
G. E. Hinton, "A practical guide to training restricted Boltzmann machines". In Neural networks: Tricks of the trade (pp. 599-619). Springer, Berlin, Heidelberg (2012).

G. Castignani	FIS/05	An introduction to Super Massive Black Holes

On these lectures, we are going to provide a set of skills about the birth, formation, thermodynamics, structure, existence of black holes (SMBHs), i.e., among which the most prominent structures of our universe that can give hint about the gravitational morphology, the luminosity and thermodynamics of baryons around them, and possibly on the cosmological dynamics at large scales. The course is devoted to those students that aim at improving their skills in general relativity, field theory, astrophysics and cosmology.
Analytical list of topics:
Formation and evolution of supermassive black holes (SMBHs)
SMBHs in normal galaxies
SMBHs and active galactic nuclei
Accretion disks and jets
Black hole mass estimates
Observational evidence of SMBHs
Simulations and SMBHs
Future perspectives based on ongoing and forthcoming facilities (e.g., ELISA, SKA PTA).