UNIVERSITÀ degli STUDI di NAPOLI «Federico II»

**DOTTORATO di RICERCA in FISICA – PhD program in Physics**

# Physics PhD course catalog – 2017/2018

(last updated on May 2nd, 2017)

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- **Introduction to Mesoscopic Physics** *(Procolo Lucignano)*
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- **Introduction to Supersymmetric Gauge Theories** *(Raffaele Marotta)*
- **Introduction to Ultra-high energy cosmic rays** *(Fausto Guarino)*
- **Mathematical aspects of gauge theories** *(Patrizia Vitale)*

- **Non-Maxwellian theories, applications in observational astrophysics, space and laboratory experiments** *(Alessandro Spallicci)*
- **Non Perturbative Structures in QFT** *(Mario Abud)*
- **Nuclear Physics for Astrophysics** *(Andreas Best, Gianluca Imbriani, Antonino Di Leva)*
- **Observational Cosmology** *(Giovanni Covone)*
- **Optical Spectroscopy** *(Salvatore Amoruso)*
- **Ordered phases of Condensed Matter** *(Arturo Tagliacozzo, Gabriele Campagnano, Procolo Lucignano, Domenico Giuliano)*
- **Photonics** *(Carlo Altucci)*
- **Physics and applications of Superconducting and Spintronic Devices** *(Giampiero Pepe)*
- **Physics and Astrophysics of Gravitational Waves** *(Enrico Calloni)*
- **Physics of Plasmas and Particle Beams in Laboratory and Space** *(Renato Fedele)*
- **Quantum Communication** *(Alberto Porzio)*
- **Quantum Computing and Artificial Intelligence** *(Giovanni Acampora)*
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- **Scientific writing** *(Paolo Russo)*
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- **Statistical Methods for Data Analysis** *(Luca Lista)*
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- **Strong interactions** *(Giulia Ricciardi)*
- **Structure and Formation of Galaxies** *(Nicola Rosario Napolitano, Francesco La Barbera)*
- **Theoretical Astroparticle Physics** *(Ofelia Pisanti)*
- **Theory of Nuclear Matter** *(Luigi Coraggio)*
- **Thin films: physics and applications** *(Alessia Sambri)*
- **Topics in Non-Perturbative Quantum Field Theory (from two to four dimensions)** *(Luigi Rosa)*
- **Topics in Non-Perturbative Quantum Field Theory (Gauge Theories)** *(Luigi Rosa)*
- **Ultrafast processes and femtosecond laser pulses** *(Andrea Rubano)*
- **Waves and Interactions in Nonlinear Media** *(Renato Fedele)*

**Important note: normally, each listed course will be actually "activated" in a given year only if at least two graduate students, even of different classes or different PhD programs, choose to attend it. If only one student is interested, then the course can be often transformed into a "supervised reading" option (see the PhD educational program for details about this option).**

| Advanced Nuclear Physics | |
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| **Lecturer** | **Dr. Ivano Lombardo** (ivano.lombardo@unina.it) |
| Credits (planned) | 5 |
| Planned hours | 30 |
| Planned schedule | April – June 2017<br>(to be defined in details with students) |
| Prerequisites | Introduction to Nuclear and Particle Physics, Quantum Mechanics, Relativity, Mathematical Methods of Physics. |
| Description | The course will examine in depth some aspects of Nuclear Physics. In particular, the following topics will be developed during the course:<br>**1 – Complements of Radioactivity (~8 h)**<br>*Alpha decay*: Screening effects – Centrifugal Barrier: Hindrance Factors – Fine Structure of alpha spectra: prediction based on the Gamow theory – Alpha decay of odd nuclei – □ spectroscopic factors – Test of parity conservation in strong interaction.<br>*Beta decay*: Electron Capture theory – Symmetry breaking in beta decay – Details of the Goldhaber-Grodzins-Sunyar experiment – Simple matrix element calculations in beta decay – neutrino mass measurements with nuclear techniques – Double beta decay.<br>*Gamma emission*: Shell model traps: isomerism – E0 transitions – theory of internal conversion – Nuclear Fluorescence – Mossbauer effect – Photonuclear reactions – Coulomb excitations.<br>*New types of Radioactivity*: Cluster radioactivity – Rose & Jones experiment – proton radioactivity – two-proton radioactivity.<br>**2 – Complements of Nuclear Reactions (~16 h)**<br>*Classical theory of scattering*: Classical scattering from a central potential – Near side and far side trajectories – Deflection Function – Classical Catastrophe – Effects of the Centrifugal Barrier – The Glory scattering – Grazing trajectories: Rainbow – Double Rainbow – Nuclear Rainbow – Elephant Scattering – Strong interaction radius measurements: Halo nuclei.<br>*Quantum theory of scattering*: Schrodinger equation for a central potential – Phase shift analysis – Ramsauer-Townsend effect – Optical theorem and its generalizations – Bethe relation – Cross section phase diagram – Quantum paradoxes – Resonances: the *S*-matrix – Analytical study of the *S*-matrix – Left-hand cut – Ghost states – Regge poles.<br>*Approximation methods*: Born approximation – ZR and FR Distorted Wave Born Approximation – Optical Model – Eikonal approximation.<br>*Analysis tools for Nuclear Spectroscopy with Nuclear Reactions*: Catania plot – Angular correlations in particle emission – Dalitz plot – Momentum correlations and HBT interferometry – Energy and angular autocorrelations: doorway states – Quantum chaos in nuclear scattering.<br>**3 – Cluster Models in Nuclear Physics (~6 h)**<br>*Introduction*: origin of the Cluster model – Structure of self-conjugated nuclei – Ikeda diagrams – the role of symmetries: the Algebraic Cluster Model.<br>*Corrections to the Shell Model*: Nilsson model – Nilsson-Strutinsky corrections – two centres shell model – Correlations due to the residual interaction.<br>*Quasi-molecular resonances*: C+C resonances – Band Crossing model– Orbiting Cluster Model.<br>*Recent experimental findings*: Be, C, O, Ne isotopes structure: rotational bands – structure and decay of the Hoyle state in $^{12}C$ – search for Hoyle-like states in $^{16}O$ and $^{20}Ne$.<br>***Final examination***: Oral discussion about the programme of the course. |

| Advanced Spectroscopies in strongly correlated systems | |
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| **Lecturer** | **Dr. Gabriella Maria De Luca** (gabriellamaria.deluca@unina.it) |
| Credits (planned): | 4/5 |
| Planned hours: | 24<br>12 lectures, 2 hours each |
| Planned schedule: | |
| Prerequisites: | None. One or two lessons (depending on the students background) will be dedicated to the few needed concepts of solid state physics. |
| Description: | The aim of this course is to give an outline of the characteristic of the most important spectroscopy's techniques and to provide to the PhD student the necessary basis to plan or to develop its own spectroscopy experiment using synchrotron light and/or scanning probe microscopy.<br><br>Advanced spectroscopies are the most powerful experimental tools to investigate the electronic and magnetic properties of complex materials. These techniques are based on the study of the interaction of the matter with radiation, being typically X-rays or electrons.<br><br>Modern X-rays spectroscopy's takes advantages from the high brilliance third generation synchrotron sources. These techniques can achieve high momentum and energy resolution, but are typically unable to get spatially resolved information. Scanning tunneling microscopy's/Spectroscopy's are on the other hand based on the extremely high spatial resolution achieved by probing the tunneling electronic current coming from a tip in close proximity with a sample. These combined techniques can probably offer the largest possible number of information about the electronic properties of the solids. Examples of application of these techniques to different undisclosed issues in condensed matter physics will be given during the course, like the microscopic mechanism of superconductivity in the High Critical Temperature Superconductors and Novel oxides Interfaces, Proximity effect in Ferromagnetic/Superconducting heterostructures and Multiferroicity (coexistence of more of two ferroic orders).<br><br>The detailed program will include:<br>1) Introduction to the Physics of complex, strongly correlated materials<br>2) Electrons and X-rays as probes of the electronic density of states<br>3) Introduction to the synchrotron light<br>a. X-ray Absorption and X-ray Photoemission Spectroscopies<br>b. Examples: HTS and other metal transition oxides<br>c. Resonant Inelastic X-ray Scattering<br>d. Angle resolved Photoemission Spectroscopy |

| **Advanced Topics in Theoretical Physics** | |
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| **Lecturer** | **Prof. Fedele Lizzi** (fedele.lizzi@na.infn.it) |
| Credits (planned) | 4-6 (to be agreed with the students) |
| Planned hours | 24-36 |
| Planned schedule | Lectures will be held starting from the second week of March 2017 |
| Prerequisites | usual courses of a physics's master degree |
| Description | The course will be a must for theoretical physics students, but can be also useful for the other students. Its main aim is to cover important topics, which should be in the baggage of every theoretical physicist, but are not necessarily covered in the usual core study. Some lectures may be held by other researchers to offer a broader perspective. In case only some students require covering some parts, a portion of the course can be individual study.<br><br>The topics to be covered will be discussed and agreed with the participants, an indicative list is the following:<br><br>Topological solitons: Kinks, defects, monopoles, Skyrmions …)<br><br>Nonlinear evolution equations and dynamical solitons (Sine Gordon, solutions of the Burger, Sine-Gorgon, Kortweg de Vires equations…)<br><br>Caotic Systems: (logistic equation, Lorenz equation, strange attractors).<br><br>Renormalization<br><br>The theory of groups and Lie algebras (including quantum groups)<br><br>Advanced method in quantum field theory (heath kernel expansion, spacetime approach to qft…)<br><br>Phase transitions in quantum field theory.<br><br>Quantum mechanics and measurement (Bell's Theorem…)<br><br>Approaches to quantum spacetime (noncommutative geometry…) |

| A general overview of the Physics of Surfaces and Interfaces | |
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| **Lecturer** | **Dr. Roberto Di Capua** rdicapua@fisica.unina.it |
| Credits (planned) | 6 |
| Planned hours | 36 hours (18 lectures, 2 hours each) |
| Planned schedule | The detailed schedule can be arranged with students (it can be organized in order to meet the specific demands) |
| Prerequisites | Basic knowledge of classical general physics and quantum mechanics. One or two lectures will be devoted to the few needed basic concepts of solid-state physics. |
| Description | The course aims to provide the foundation of physics of surfaces and interfaces. It is conceived to be of potential interest not only for Ph.D. students working in the physics of matter, but also for those involved in other fields, due to the development of fundamental issues and methodologies of wide application.<br><br>The lectures are intended as an ideal prosecution of the general concepts provided by the master degree in physics on quantum mechanics, atomic-scale and many-bodies physics, structure of matter, interaction between matter and radiation: such concepts will be developed and applied to the study of solid surfaces and interfaces, a subject which is gaining more and more importance in Physics and in many other fields.<br><br>One or two lectures, depending on the background of the students, will be devoted to the introduction of the few basic concepts of solid-state physics needed for the understanding of some arguments. Then, the main body of the course will be organized along the following three lines.<br>1) Illustration of basic phenomenological and theoretical aspects of the physics of surfaces: electronic states, charge distribution at surfaces and interfaces, the importance of strain and defects, thermodynamic aspects of the equilibrium, role of collective excitations and related states and interactions.<br>2) Interface phenomena: arising of new functionalities and properties at interfaces between different materials, interplay between electronic, magnetic and crystal properties, applications and perspectives of nanotechnology and engineering at atomic-scale, illustration of some current research results in this field.<br>3) Description of the main experimental techniques, and underlying physics, for probing and measuring the properties of surfaces and interfaces: atomic force microscopy and related techniques, scanning tunnelling microscopy and spectroscopy, diffraction analysis, photoemission spectroscopy techniques, synchrotron-based techniques. |

# An introduction to the Physics of Nanostructures: phenomenology, applications and theoretical aspects

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| **Lecturer** | **Dr. Giovanni Cantele** (CNR-SPIN, giovanni.cantele@spin.cnr.it) |
| Credits (planned): | 4 |
| Planned hours: | 24 |
| Planned schedule: | March – July 2017 |
| Prerequisites: | Basic knowledge of quantum mechanics. One or two lessons (depending on the students background) will be dedicated to the few needed basic concepts of solid-state physics. |
| Description: | This course aims to give an overview of the basic properties and applications of nanostructured materials.<br>The course can be schematically divided into two parts. The first part focuses on the most recent achievements of nanotechnology and related phenomenology. The main observed phenomena occurring at the nanoscale (electronic, optical and transport properties) are described, with a focus on applications (optoelectronics, single electron transistors, self-powered devices, nanomedicine and many others). Also, a short history of nanotechnology and its development is presented.<br>The second part is focused on the interpretation and understanding of the observed properties in terms of basic concepts, such as electron and hole quantum confinement, effects induced by the system size and dimensionality, and so on. The main theoretical models needed to describe the optical, electronic and transport properties in nanostructured materials will be analysed. The starting point will be recent seminal experiments showing the ability of controlling and tuning the materials structure and electronic properties with atomic resolution (truly onedimensional metallic wires, two-dimensional systems and graphene, single-electron transport, etc.).<br><br>**<u>Course outline</u>**<br><br><u>Introduction</u><br>• nanotechnology and its connection with microelectronics<br>• synthesis techniques (very short overview)<br>• new instruments and spectroscopies: STM and AFM<br>• applications (special topics: nanopiezotronics, nanomedicine, nanoplasmonics)<br><br><u>Nanostructures: from zero- to two-dimensional systems</u><br>• atomic nanoclusters: physical and structural properties<br>• quantum dots or nanocrystals: electronic properties and devices (quantum dot lasers, single-electron transistor)<br>• nanostructured carbon: nanotubes, fullerenes, graphene<br><br><u>Optical and electronic properties</u><br>• nanocrystals, nanowires, quantum wells<br>• elementary excitations in solids<br>• the quantum confinement and its effects on the optical properties<br>• transport in nanostructures<br><br>The students can give indication for topics of their interest that could be part of the program of the course.<br><br>Please refer to the course web page for more information:<br>http://people.na.infn.it/~cantele/index.php?n=Teach.Nano |

| **Astroinformatics** | |
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| **Lecturer** | **Dr. Massimo Brescia (Oss. Astronomico di Capodimonte) brescia@na.astro.it** |
| Credits (planned) | 8 |
| Planned hours | 64 |
| Planned schedule | **October 2017 – January 2018**<br>**6 hours/week**<br>***course offered in the frame of the Master's programme*** |
| Prerequisites | |
| Description | The Course aims at providing the fundamental concepts at the base of the theory of data mining, data warehousing and machine learning (neural networks, fuzzy logic, genetic algorithms, soft computing), approached by the point of view of Astrophysics and Information Communication Technology.<br>During the course some practical experiences with students are foreseen: from data handling, to software design and development, statistical analysis, investigation on diagrams and tables (trend analysis, plotting, data quality). In specific cases students are allowed and invited to investigate in-depth topics and to discuss during lectures. |

## Charged Particle Accelerators

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| **Lecturer** | **Dr. Luigi Campajola** (campajola@na.infn.it)<br>Physics Department, University of Naples *Federico II* |
| Credits (planned) | 5 |
| Course objectives | The course provides an introduction to the physical principles used to accelerate charged particles and on the various techniques used in accelerator physics. This course also provides information on the main applications in fundamental physics and applied physics. Some experiments will be carried out in the laboratory with ion beams. |
| Tentative schedule | May – June 2017 |
| Planned hours | Frontal lectures: 16 h total, 2h/lecture, to be held at the Physics Department at MSA.<br>Laboratory: 10 h |
| Contents and topics | 1. Fundamental principles of particle acceleration<br>2. Ion sources: operating principles and applications<br>3. Principles of operation of the accelerators: linear and circular, pulsed and continuous<br>4. Elements of beam dynamics and magnetic optics: emittance and brightness<br>5. Applications in the field of innovative technologies:<br>• Ion beam analysis: Rutherford Backscattering (RBS), Particle Induced X-ray Emission (PIXE)<br>• Accelerator Mass Spectrometry (AMS)<br>• Ion implantation<br>• Radioisotopes production |
| Final evaluation | The students will be required to make an oral presentation on a selected subject. |

## Effective theories and flavour physics

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| **Lecturer** | **Dr. Giancarlo D'Ambrosio** gdambros@na.infn.it |
| Credits (planned) | 5 |
| Planned hours | 24 |
| Planned schedule | March –May 2017 |
| Prerequisites | |
| Description | Cross sections, decay widths, calculation of Feynman diagrams<br>Quantum electrodynamics, precision tests: Lamb shift and g-2<br>Gauge theories , Yang Mills<br>Fermi theory , beta decay,<br>muon decay, universality of weak interactions, parity violation in weak interactions, V-A structures, effective theories<br><br>Phenomenology of strong interactions, Goldstone theorem, pion as Goldstone mode spontaneous and explicit symmetry breaking<br><br>Higgs mechanism<br><br>Standard model of particle physics<br><br>Flavour theory, quark and meson mixing, Cabibbo Kobayashi Maskawa matrix and determination of matrix elements, absence of flavor changing neutral currents, GIM mechanism and minimal flavor violation (MFV)<br><br>Effective field theories, chiral perturbation theory |

| Electrodynamic properties of novel materials and devices | |
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| **Lecturers** | **Prof. Antonello Andreone[1], Dr. Vito Mocella[2]** |
| Affiliation | [1]Physics Department, University of Naples *Federico II*<br>[2]CNR – Istituto per la Microelettronica e Microsistemi, Unità di Napoli |
| Course objectives | This is an introductory course to the electromagnetic properties of special materials, like superconductors, magnetic and dielectric materials, and artificial materials (photonic crystals and metamaterials) for operation in a wide frequency range, from microwaves up to the optical region. Applications include: telecommunication systems, microwave photonics, imaging, sensing and security |
| **Tentative schedule** | **June – July 2017** |
| General information | 8 lectures, 2 hours each, to be held at the Department of Physics, Engineering Faculty, Piazzale Tecchio 80 |
| Contents and topics | - Electrodynamics of metals, superconductors and dielectric media: basic principles<br>- A short introduction to artificial materials: metamaterials and photonic band gap crystals and quasicrystals<br>- Transformation optics: a new approach to defining the light geometry using metamaterials<br>- Cutting edge THz technology<br>- Plasmonics and plasmonic structures<br>- Some exemplary applications of "natural" and "artificial" materials: from microwave systems to optical devices and sensors, cloaking, solar cells |
| Evaluation | All participants are required to make an oral presentation or write an essay on a selected subject after the course. The participants may suggest a topic related to their own research subject. |
| **Course weight** | **4 FCs** |

| **Elliptic and hyperbolic PDEs of Physics** | |
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| **Lecturer** | **Dr. Giampiero Esposito** (gesposit@na.infn.it) |
| Credits (planned) | 6 |
| Planned hours | 36 |
| Planned schedule | September 15 – December 15, 2017 |
| Prerequisites | none |
| Description | ELLIPTIC EQUATIONS (L1-L9):<br><br>Lecture 1: HARMONIC FUNCTIONS. [29-2-2016]<br>Motivations for the Laplace equation. The vector space R**n endowed with a Euclidean metric. Role of the metric in the divergence and in (div grad). The Laplacian is -(div grad). The three Green identities and their consequences. Mean-value theorem for the sphere and the Euclidean ball. The maximum principle. Mollifiers. From the mean-value property to the harmonic condition. Derivative estimates. Bounded harmonic functions on R**n are constant. Ellipticity of the Laplace-Beltrami operator with constant coefficients or variable coefficients. Laplacian vs. wave operator vs. ultrahyperbolic operator in four dimensions. Statement of the Dirichlet and Neumann boundary-value problems.<br><br>Lecture 2: MATHEMATICAL THEORY OF SURFACES. [2-3-2016]<br>Quadratic differential forms. Invariants and differential parameters. Differential parameters of order 1. Equivalence of quadratic forms and Christoffel formulas. Properties of Christoffel symbols of first and second kind. The Laplacian viewed as a differential parameter of order 2. Isothermal systems and Laplace equation. Isometric parameters. Lie theorem on the lines belonging to a doubly isothermal system.<br><br>Lecture 3: DISTRIBUTIONS AND SOBOLEV SPACES. [4-3-2016]<br>The space D(Omega) and its strong dual. Normal spaces of distributions. The space C^{1,alpha)(Omega) and its abstract completion. The Sobolev space H^{1,alpha}(Omega), and its isomorphism with the abstract completion of C^{1,alpha}(Omega). The spaces C^{k,alpha} and H^{k,alpha}. The trace map for elements of H^{1,alpha}(Omega). The space H_{0}^{k,alpha}(Omega) and its strong dual. The Green formula in distributional language. The concepts of fundamental solution and parametrix of a linear partial differential operator.<br><br>Lecture 4: THE CACCIOPPOLI-LERAY THEOREM. [7-3-2016]<br>Second-order linear elliptic equations in n variables. The Leray Lemma and its proof. The Caccioppoli proof of integral bounds. The concept of weak solution of linear equations. The modern proof of the Caccioppoli-Leray theorem (beginning).<br><br>Lecture 5: CACCIOPPOLI-LERAY INEQUALITY AND RELATED TOPICS. [9-3-2016]<br>Weak form of the generalized Poisson equation. Modern proof of the Caccioppoli-Leray inequality, with the help of a test function depending on the weak solution itself. Ellipticity in the vector case: Legendre vs. Legendre-Hadamard condition. Traditional formulations: ellipticity, uniform ellipticity, strong ellipticity, uniform strong ellipticity, proper ellipticity.<br><br>Lecture 6: ASPECTS OF SPECTRAL THEORY. [11-3-2016]<br>Resolvent set and spectrum of a linear operator. The resolvent. Modified resolvent set. The modified resolvent. Eigenvalues and characteristic values of a linear operator. Directions of minimal growth of a linear operator. Decay rate of the resolvent along rays of minimal growth. Strongly elliptic boundary-value problems, and an example.<br>Lecture 7: LAPLACE EQUATION WITH MIXED BOUNDARY CONDITIONS. [18-3-2016]<br>Uniqueness theorems for elliptic equations with mixed boundary conditions. The De Giorgi family of solutions. Reflections on the concepts used by De Giorgi for the analysis of mixed problems, in particular a clever use of characteristic function of a set. A hint to its application to define the perimeter of a set and the reduced boundary of finite-perimeter sets. |

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| | Lecture 8: NEW FUNCTIONAL SPACES. [30-3-2016]<br>Holder, Morrey and Campanato spaces: definitions and properties. Functions of bounded mean oscillation, and an example (the logarithm). Glancing again at distributions: the spaces W(1,p;loc) and W(1,p).<br><br>Lecture 9: PSEUDO-ANALYTIC AND POLYHARMONIC FRAMEWORKS. [1-4-2016]<br>Pseudo-holomorphic functions (local theory) and linear elliptic equations: generalized Cauchy-Riemann systems. Global theory of pseudo-holomorphic functions, through differential inequalities. Upper and lower bound for the increment ratio of non-holomorphic functions. Decomposition theorem of biharmonic functions. Parametrix of the squared Laplacian in open sets of R**2. Mean-value property for polyharmonic functions.<br>------------------------------------------------------------------------<br>HYPERBOLIC EQUATIONS (L10-L18):<br><br>Lecture 10: CHARACTERISTICS AND WAVES, I. [4-4-2016]<br>The existence theorem for the integrals of a system of partial differential equations. Characteristic manifolds for first- and second-order systems. The concept of wavelike propagation. The Riemann function (or kernel) for an hyperbolic equation in two independent variables. The Hadamard counterexample: the Cauchy problem for the Laplace equation has solutions which do not depend in a continuous way on the data.<br><br>Lecture 11: CHARACTERISTICS AND WAVES, II. [6-4-2016]<br>Detailed derivation of Riemann's integral formula for expressing the solution of an hyperbolic equation in two independent variables. Concept of wavelike propagation for a generic normal system. Digression on the general concept of wavelike motion. The Cauchy method for integration of a first-order partial differential equation. The bicharacteristics. Appendix: the spacetime manifold; geodesics and arc-length; bicharacteristics are null geodesics.<br><br>Lecture 12: FUNDAMENTAL SOLUTION AND CHARACTERISTIC CONOID. [8-4-2016]<br>Relation between fundamental solution and Riemann's function for a linear equation in two independent variables. The concept of characteristic conoid. Fundamental solutions with an algebraic singularity. Introduction of geodesics. The world function and the equation for the characteristic conoid.<br><br>Lecture 13: THE FUNDAMENTAL SOLUTION: HOW TO BUILD IT. [11-4-2016]<br>Hamiltonian form of geodesic equations for Riemannian and pseudo-Riemannian metrics. The unique real-analytic solution of the nonlinear equation for the world function. Construction of the fundamental solution in m variables, for an equation with analytic coefficients: the case of odd values of m. Convergence of the power-series solution.<br><br>Lecture 14: EXAMPLES OF FUNDAMENTAL SOLUTIONS. [15-4-2016]<br>Fundamental solution with even values of m. The need for the logarithm of the world function in the fundamental solution. The coefficient of such a logarithm solves a characteristic initial-value problem. The smooth part of the fundamental solution. Parametrix for the scalar wave equation in Kasner and in a generic curved spacetime. Nonlinear equations for amplitude and phase functions. Their equivalence to finding a divergenceless vector field, and then solving a tensor generalization of the Ermakov-Pinney equation. The Laplace and Coulon equations. Damped waves and the logarithmic solution.<br><br>Lecture 15: LINEAR SYSTEMS OF NORMAL HYPERBOLIC FORM. [18-4-2016]<br>Equations defining the characteristic conoid associated with a linear hyperbolic system of normal form. Nonlinear integral equations satisfied by the bicharacteristics. Linear combinations of the original set of hyperbolic equations. Evaluation of the auxiliary functions of linear combination, which are factorizable and differentiable.<br><br>Lecture 16: LINEAR SYSTEM ASSOCIATED TO A NONLINEAR HYPERBOLIC SYSTEM. [20-4-2016]<br>Kirchhoff formulas for solving a linear hyperbolic system. Nonlinear equations and their differentiation. Integral equations and Cauchy data. Solution of the Cauchy problem when the coefficients of second derivatives do not depend on first partial derivatives of the unknown functions. Spacetime manifold, lightcone structure, timelike and null geodesics. |

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| | Lecture 17: CAUCHY PROBLEM FOR GENERAL RELATIVITY. [22-4-2016]<br>Connection and Riemann curvature. The vacuum Einstein equations. Isothermal coordinates. Assumptions on the Cauchy data for vacuum Einstein equations. The solution of vacuum Einstein satisfies the de Donder-Lanczos supplementary (or gauge) condition. Comparison with the Lorenz gauge in classical electrodynamics. Remarks on why Lorenz and de Donder gauge are different realizations of the same structure. Uniqueness of the solution for vacuum Einstein in de Donder gauge.<br><br>Lecture 18: CAUCHY PROBLEM AND GLOBAL HYPERBOLICITY. [26-4-2016]<br>Summary of Lecture 17. Chronological future and past of a point; causal future and past of a point; past end-point of a curve; domain of dependence and Cauchy horizon; Cauchy surfaces. Strong causality. Alexandrov topology. Compact-open topology, open topology and fine topology on the space of Lorentzian metrics. Stable causality. Global hyperbolicity: three definitions of the concept, and a theorem. |

| Emergence of complexity in plankton communities | |
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| **Lecturers** | **Dr. Annalisa Fierro**[1] (annalisa.fierro@spin.cnr.it)<br>**Dr. Daniele Iudicone**[2] (iudicone@szn.it)<br>**Dr. Antonella Liccardo**[3] (liccardo@na.infn.it)<br>**Prof. Maurizio Ribera d'Alcalà**[2] (maurizio@szn.it)<br>**Dr. Romain Watteaux**[3] (romain.watteaux@szn.it) |
| Affiliation | [1]CNR-SPIN<br>[2]Stazione Zoologica A. Dohrn<br>[3]Physics Department, University of Naples Federico II |
| Credits (planned) | 3 |
| Planned hours | 18 h (9 lectures of 2 h) |
| Planned schedule | to be fixed together with the students |
| Prerequisites | None |
| Description | The dynamics of complex systems, i.e., the dynamics of multi-agent systems with multiple and non linear interactions, is still a frontier topic in science. Post-graduate courses dealing with the topic are often structured to provide an overview of the theoretical framework and demonstrate how it works for various typical case studies. In this course we propose to follow an alternative approach focusing on one specific case study. That is, we intend to describe the patterns, known interactions and processes acting in a crucial natural complex system: the plankton community. Building on this background, we formulate the key questions yet to be tackled within the framework of the theory and dynamics of complex systems.<br><br>Plankton is the ensemble of organisms, mostly microscopic, which make the largest part of the biomass in the ocean. Even though some may have the ability to swim, the corresponding swimming velocity is much lower than the velocity of oceanic currents, therefore making plankton exposed to water motion. The role of plankton is crucial in several biogeochemical cycles including the carbon cycle, They are abundant, though in a size dependent manner, with the very small ones (order of 10^-6 m) found in concentration of 10^6 m^-3 and the larger ones reaching concentrations of 10^3 m^-3. In a cubic meter of marine water, which can be considered to a large extent homogeneous, live millions of 'agents' displaying also a high specific diversity. All these interact quite frequently and generate resilient food webs despite the dispersion due to fluid motion at small scale and the displacement by the currents at large scales.<br><br>Recent studies have shown that composition of species in plankton communities varies over space across the oceans while displaying repetitive patterns over time in the same regions. These studies also shed light on a multiplicity of interactions |

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| | among the 'agents' spanning the whole suite of biotic interactions and feeding behaviors.<br><br>Plankton community is therefore a very challenging system to analyze and is characterized as multi agent systems with complex dynamics and emergent properties.<br><br>This course is thus an opportunity to understand and use the typical tools of complex system dynamics in the context of Plankton dynamics.<br><br>The course will devote a first part to describe the key processes in plankton communities and the methods to characterize them. We'll then provide an overview of the most important aspects of fluid motion that affect plankton ecology, from micro-turbulence to the large scale currents, as well as the mechanisms by which plankton access to their resources, from chemical diffusion to stochastic or directed encounter rates. Basic mechanistic models to reconstruct the processes above will also be described. The last part of the course will be devoted to the development of an integrated approach on a real, though simplified system, with a continuous feedback between theoretical modeling and experiments in the experimental setup.<br><br>References<br><br>[1] Souissi, S., Ginot, V., Seuront, L., & Uye, S. I. (2004). Using multi-agent systems to develop individual based models for copepods: consequences of individual behaviour and spatial heterogeneity on the emerging properties at the population scale. *Handbook of scaling methods in aquatic ecology: measurement, analysis, simulation. CRC Press, Boca Raton*, 527-546.<br><br>[2] Medvinsky, Alexander B., Tikhonov, Dmitry A., Enderlein, Jorg, Malchow, Horst (2000) Fish and Plankton Interplay Determines Both Plankton Spatio-Temporal Pattern Formation and Fish School Walks: A Theoretical Study. Nonlinear Dynamics, Psychology, and Life Sciences, 4: 135–152.<br><br>[3] Parrish, J. K., & Edelstein-Keshet, L. (1999). Complexity, pattern, and evolutionary trade-offs in animal aggregation. *Science*, *284*(5411), 99-101.<br><br>[4] Benincà, E., Huisman, J., Heerkloss, R., Jöhnk, K. D., Branco, P., Van Nes, E. H., ... & Ellner, S. P. (2008). Chaos in a long-term experiment with a plankton community. *Nature*, *451*(7180), 822-825.<br><br>[5] Roques, L., & Chekroun, M. D. (2011). Probing chaos and biodiversity in a simple competition model. *Ecological Complexity*, *8*(1), 98-104.<br><br>[6] Jumars, P. A. (1993). *Concepts in biological oceanography*. Oxford University Press.<br><br>[7] Kiørboe, T. (2008). *A mechanistic approach to plankton ecology*. Princeton University Press. |

| **Extended theories of Gravity and the problem of Dark Energy and Dark Matter** | |
|---|---|
| **Instructor**: | **Prof. Salvatore Capozziello**<br>(University of Naples, capozziello@na.infn.it) |
| Credits (planned): | 2 |
| Planned hours: | 12 |
| Planned schedule: | May – June 2017 |
| Prerequisites: | General Relativity, Cosmology, Quantum Field Theory |
| Description: | **Abstract:** Extended theories of gravity can be related to several unification approaches and fundamental theories of interactions. They have recently attracted a lot of interest as alternative candidates to explain the observed cosmic acceleration, the flatness of the rotation curves of spiral galaxies, the gravitational potential of galaxy clusters, and other relevant astrophysical phenomena. Very likely, what we call "dark matter" and "dark energy" are nothing else but signals of the breakdown of General Relativity at large scales. Furthermore, PPN-parameters deduced from Solar System experiments do not exclude, a priori, the possibility that such theories could give small observable effects also at these scales. I review these results giving the basic ingredients of such an approach.<br><br>**Topics:**<br><br>1. Observational cosmology: an overview<br>2. Dark Energy and dark Matter from the observations<br>3. Physical and Mathematical Foundations of Extended Theories of Gravity<br>4. Dark Energy and Dark Matter as Curvature Effects<br>5. Probing Extended Theories of Gravity at Fundamental Level<br>6. Advanced issues: GRBs to discriminate among Cosmological Models<br><br>**References:**<br>S. Capozziello, V. Faraoni "*Beyond Einstein Gravity*"<br>Fundamental Theories of Physics, Springer, Dordrecht 2010 |

| Flavour Physics | |
|---|---|
| **Lecturer** | **Prof.ssa Giulia Ricciardi** (University of Napoli Federico II, giulia.ricciardi@na.infn.it) |
| Credits (planned) | 4-6 |
| Planned hours | 24-36 |
| Planned schedule | to be fixed together with the students |
| Prerequisites | basics of particle physics |
| Description | Flavour physics, in contrast to 'gauge physics', addresses questions such as why there are so many different species (flavours) of quarks and leptons, why they come in groups (families), why they have their masses, what their couplings are, etc.<br>Recently, the dedicated study of b-flavoured hadrons has developed into one of the most active and promising areas of high-energy physics.<br>Neutrino physics and oscillations are also discussed, in their theoretical aspects and in connection with recent experimental advances.<br><br>Topics:<br>1. Introduction to flavour physics. The standard Model and the CKM matrix<br>2. What are and how to reveal discrete symmetries: C, P, T<br>3. CP violation in neutral meson systems<br>4. The Standard analysis of the Unitarity triangle(s)<br>5. Effective field theories and related theoretical tools<br>6. Heavy Quark Effective Theory: a short exposition<br>7. Applications to B systems, present status of the field<br>8. Physics beyond the Standard Model<br>9. Neutrino physics and oscillations |

| **Fluctuation Relations and Nonequilibrium Thermodynamics** | |
|---|---|
| **Lecturer** | **Prof. Alberto Imparato** (alberto.imparato@unina.it) |
| Credits (planned) | 2 |
| Planned hours | 12 |
| Planned schedule | Short course – 1 week between the end of June and the beginning of July 2017 |
| Prerequisites | knowledge of classical equilibrium statistical mechanics |
| Description | Nonequilibrium thermodynamics provides a conceptual framework for describing a large class of microscopic systems under well specified but still fairly general non-equilibrium conditions.<br>Typical examples comprise colloidal particles driven by time-dependent laser traps and polymers or biomolecules like RNA, DNA or proteins manipulated by optical tweezers, micropipets or AFM tips.<br>For such systems, the thermal energy available per degree of freedom, can be comparable to the work performed on the system. In other words, small thermodynamical systems are not simple rescaled version of their larger counterpart.<br><br>Program of the course<br>- Classical theory of quasi-equilibrium. Fluctuation-dissipation theorem, Onsager relations.<br>- Path probabilities. Work and heat production. Crook's inversion relations.<br>- Jarzynski's relation and its applications.<br>- Different forms of the fluctuation theorem.<br>- Experiments and applications.<br>- Gallavotti-Cohen relation.<br>- Heat and particle current in out-of-equilibrium systems: is there an entropy out of equilibrium? |

| **General relativity and graphene** | |
|---|---|
| **Lecturer** | **Maria A. H. Vozmediano** vozmediano@icmm.csic.es |
| Affiliation | **Instituto de CIencia de Materiales de Madrid,**<br>Consejo Superior de Investigaciones CIentíficas, Spain |
| Credits (planned) | |
| Planned hours | |
| Planned schedule | **May 2017** |
| Prerequisites | Fundamentals of quantum field theory in curved spaces |
| Description | Dirac physics has emerged in condensed matter in the 21th century. Graphene, a flat material is well described by the (2+1) massless Dirac equation and Weyl semimetals obey the (3+1) equation. The roughness of the graphene samples allow to apply techniques of quantum field theory in curved spaces to compute some of the properties of the material. We will describe the application of these techniques to actual materials and the limits of applicability of general relativity to this - ultimately non relativistic -systems. |

| **Geometric and topological methods in Theoretical Physics** | |
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| **Lecturer** | **Prof.ssa Patrizia Vitale** (vitale@na.infn.it) |
| Credits (planned) | 3 |
| Planned hours | 20 |
| Planned schedule | March – June 2017 |
| Prerequisites | Background in theoretical/mathematical physics |
| Description | Differential calculus on manifolds<br>Topological invariants (homology, cohomology and homotopy groups)<br>Lie groups and Lie algebras<br>Riemannian geometry<br>Fiber bundles |

| Guided propagation of electromagnetic waves | |
|---|---|
| **Lecturer** | **Prof. Salvatore Solimeno (solimeno@na.infn.it)** |
| Credits (planned) | 5 |
| Planned hours | 30 |
| Planned schedule | **June – December 2016** |
| Prerequisites | None |
| Description | The course deals with the optical and optoelectronic fundamentals, based on classical and quantum properties of radiation and matter, which are the theoretical basis of modern applications such as the guided propagation and optical fibres. |
| Contents and topics | 1. Electromagnetic fields: Maxwell equations, Helmotz equation, ray fields and Fermat principle, Lienard-Wieckart potentials, wave equation.<br>2. Guided propagation in anisotropic media, plane stratified media, periodic media, fibre Bragg gratings<br>3. Dielectric waveguides, optical fiber modes, step index fibers |

| Heavy Meson Physics | |
|---|---|
| **Lecturer**: | **Prof. Pietro Santorelli**<br>(Università di Napoli *Federico II*, pietro.santorelli@na.infn.it) |
| Credits (planned): | 2-3 |
| Planned hours: | 14-16 |
| Planned schedule: | October – November 2017 |
| Prerequisites: | Basic concepts of Quantum Field Theory. Suitable for theorists and experimentalists |
| Description: | This course will provide an introduction to effective field theory of the QuantumChromoDynamics for heavy quarks and its application to weak decays of heavy mesons. The following arguments will be discussed:<br><br>1. A very short review of the Standard Model<br>2. Integrating out heavy particles, scale separation, radiative corrections<br>3. Heavy Quark Effective Theory<br>4. Semileptonic and rare decays of B mesons<br>5. Non-leptonic two body decays of B and D mesons<br>6. CP Violation |

| High-Energy Physics at the Large Hadron Collider (LHC) | |
|---|---|
| **Lecturers:** | **Dr. Luca Lista** (INFN, luca.lista@na.infn.it)<br>**Prof. Vincenzo Canale** (DF – UniNapoli *Federico II* - canale@na.infn.it)<br>**Prof.ssa Giulia Ricciardi** (DF - UniNapoli *Federico II* - ricciardi@na.infn.it) |
| Credits (planned): | Module 1: Experiment and phenomenology (4 FCs)<br>Module 2: Theoretical aspects (2 FCs)<br>Students can decide to follow only one module |
| Planned hours: | Module 1: 24<br>Module 2: 12 |
| Planned schedule: | Supervised readings |
| Prerequisites: | Basic knowledge of particle physics |
| Description: | For the first time since the deep inelastic experiments of the '60s the high energy physics community is approaching an energy frontier where we can expect the unexpected. The high energy physics community is shifting back to focusing on experiment-driven interpretation of collider data as we approach the era of the Large Hadron Collider, LHC.<br>The course will cover some aspects of the physics at the LHC from both experimental, phenomenological and theoretical point of view, and will cover the following topics:<br>- The Standard Model of particle physics after LEP data<br>- The LHC: accelerator and detectors<br>- Hadron interactions (QCD, structure functions, jets, diffractive physics)<br>- The hunt for the Higgs boson<br>- Electroweak Physics<br>- Physics Beyond the Standard Model<br>- Connection with Cosmology: the search for Dark<br>- Physics during the first two years of data taking<br>- Top Quark physics |

| **Introduction to Mesoscopic Physics** | |
|---|---|
| Instructor: | **Dr. Procolo Lucignano** (CNR-SPIN) (procolo.lucignano@spin.cnr.it) |
| Credits (planned): | 4 – 5 depending on the students |
| Planned hours: | 24 / 30 |
| Planned schedule: | March – June 2017 |
| Prerequisites: | Elementary quantum mechanics and solid state physics. One or two preliminary lectures to Green functions technique will be given if necessary. |
| Description: | • Quantum electron transport at the nano-scale: coherent vs. incoherent transport.<br>• Ballistic limit: the Landauer approach and the Scattering matrix.<br>• Diffusive limit: electron propagation in disordered media.<br>• From Drude Boltzmann theory to Weak Localization. Universal Conductance Fluctuations.<br>• Scaling theory of electron transport.<br>• Random Matrix Theory of quantum electron transport: universalities and simple applications.<br>• Quantum dots: Coulomb blockade and Kondo effect.<br>• Impurity models, phenomenology, perturbation theory and RG.<br>• Mesoscopic superconductivity: disordered superconductors.<br>• Quantum Hall effect, Quantum Spin Hall effect and Topological Insulators.<br><br>Depending on the audience we will make a fine tuning of the proposed program. |

| **Introduction to Neutrino Physics** | |
|---|---|
| **Lecturer** | **Prof.ssa Giulia Ricciardi** (University of Napoli Federico II, giulia.ricciardi@na.infn.it) |
| Credits (planned) | 4-6 |
| Planned hours | 24-36 |
| Planned schedule | to be fixed together with the students |
| Prerequisites | basics of particle physics |
| Description | This course aims at providing the basics of the theory of neutrino physics and their oscillations. Some recent experimental results are also discussed. It can be extended to include the basics of leptogenesis. |

| Introduction to QCD | |
|---|---|
| **Lecturer** | **Dr. Francesco Tramontano** (francesco.tramontano@na.infn.it) |
| Credits (planned) | 2 |
| Planned hours | 12 |
| Planned schedule | May 15th – June 15th, 2017<br>2 lectures per week, 1.5 hours each |
| Prerequisites | Particle physics background |
| Description | The lectures introduce to some basic aspects and concepts of perturbative QCD: runing coupling and asymptotic freedom, the parton model, infrared divergences and the factorization theorem, parton densities and parton evolution, colour coherence. Applications to e+e-annihilation, deep inelastic lepton-nucleon scattering and hadron-hadron collisions are discussed. |

## Introduction to Supersymmetric Gauge Theories

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|---|---|
| **Lecturer** | **Dr. Raffaele Marotta** (INFN, lmarotta@na.infn.it) |
| Credits (planned) | 3-4 depending on the type of exam chosen by the students |
| Planned hours | 20 |
| Planned schedule | December 2017 – January 2018 |
| Prerequisites | Quantum Field Theory |
| Description | • Quadratic divergences in QFT<br>• The reasons for SuSy<br>• Non perturbative effects and susy Quantum Mechanics<br>• SuSy in D=4 and superspace formalism: chiral superfields;Wess-Zumino model; non renormalization theorem<br>• Matter content of the MSSM and soft susy breaking<br>• Vector superfields and susy gauge theories; inequivalent vacua and moduli space<br>• Wilsonian effective action<br>• Non linear Sigma Model<br>• Chiral anomalies<br>• Instantons<br>• The power of holomorphicity: non-renormalization theorem, derivation of the Novikov, Shifman, Vainshtein, Zakharov exact Beta-function<br>• Supersymmetry breaking |

| Introduction to Ultra-high energy cosmic rays | |
|---|---|
| **Lecturer** | **Prof. Fausto Guarino** (guarino@na.infn.it) |
| Credits (planned) | 4-6 |
| Planned hours | 24-36 |
| Planned schedule | April – May 2017 |
| Prerequisites | None |
| Description | The course is designed for students performing doctoral studies in experimental astroparticle physics or experimental particle physics.<br>The focus is on the Ultra-high energy component of cosmic ray radiation and will address<br>1. Introduction on Cosmic Rays<br>2. Ultra-high energy Cosmic Rays: status of present knowledge and open questions<br>3. Experimental techniques<br>4. Spectral features (ankle, cutoff)<br>5. Composition<br>6. Anisotropy<br>7. Possible sources and propagation scenarios |

| Mathematical aspects of gauge theories | |
|---|---|
| **Lecturer** | **Prof.ssa Patrizia Vitale** (patrizia.vitale@na.infn.it) |
| Credits (planned) | 3 |
| Planned hours | 20 |
| Planned schedule | March - June 2017 |
| Prerequisites | background in theoretical/mathematical physics |
| Description | • Principal G-bundles and associated vector bundles<br>• Gauge connections<br>• Abelian and non Abelian gauge theories as theories of connections on fiber bundles |

| **Non-Maxwellian theories, applications in observational astrophysics, space and laboratory experiments** | |
|---|---|
| Lecturer | **Prof. Alessandro Spallicci** (Université de Orléans)<br>spallicci@cnrs-orleans.fr<br>http://lpc2e.cnrs-orleans.fr/~spallicci/ |
| Credits (planned) | 3 |
| Planned hours | 16 |
| Planned schedule | 17-24 February, 2017 |
| Prerequisites | Theoretical physics and astrophysics background and interests at doctorate and master levels |
| Description | • Summary of Maxwellian electromagnetism<br>• Introduction to Maxwellian tensors and electromagnetism in the covariant form Lagrangian formulation<br>• Massive electromagnetism<br>• Effective photon mass by supersymmetry breaking and Lorentz invariance violation<br>• Non-linear electromagnetism and experiments in Italy (PVLAS) and France (BMV)<br><br>*Applications*: Pulsar, Magnetar, Fast Radio Bursts, Solar Wind Satellite Measurements, Nano-Satellites for Very Low Radio Frequency Astronomy Perspectives of laboratory measurements of the Hubble constant and frequency invariance in non-Maxwellian theories |

## Non Perturbative Structures in QFT

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| **Lecturer** | **Prof. Mario Abud**<br>**(**abud@na.infn.it) |
| Credits (planned) | 5 |
| Planned hours | 30 |
| Planned schedule | **May 2017** |
| Prerequisites | Field Theory, Fundamental Interactions |
| Description | **Non Perturbative Structures in QFT**<br><br>Slavnov -Taylor Identities, BRST Symmetry, Anomalies.<br><br>Extended Structures, Solitons, Magnetic Monopoles.<br>Instantons, t'Hooft solution of the U(1)_A problem.<br>The Peccei-Quinn Proposal. The role of axions |

| **Nuclear physics for astrophysics (an experimental approach)** | |
|---|---|
| **Lecturers** | **Prof. Gianluca Imbriani** (g.imbriani@unina.it)<br>**Dr. Antonino Di Leva** (antonino.dileva@unina.it)<br>**Dr. Andreas Best** (andreas.best@na.infn.it) |
| Credits (planned) | 3 – 4 |
| | 18 – 24 |
| Planned schedule | May – July 2017 |
| Prerequisites | Basic knowledge of nuclear and/or astrophysics |
| Description | The theories of nucleosynthesis have identified the most important sites of element formation and also the diverse nuclear processes involved in their production. The detailed understanding of the origin of the chemical elements combines astrophysics and nuclear physics, and forms what is called nuclear astrophysics. Nuclear fusion reactions are at the heart of nuclear astrophysics: they influence sensitively the nucleosynthesis of the elements in the earliest stages of the universe and in all the objects formed thereafter, and control the associated energy generation, neutrino luminosity, and evolution of stars. A good knowledge of the rates of these reactions is thus essential for understanding the broad picture outlined above.<br>In the astrophysical environments the energy available to nuclear species is usually much lower than the Coulomb barrier, i.e. the nuclear reactions happen via the tunnel effect and therefore the probability decreases exponentially with energy.<br>The aim of experimental nuclear astrophysics is to determine such extremely low reaction rates at the relevant astrophysical energies.<br>The problems posed by the experimental determination of the reaction cross section are really challenging, and they require the development of peculiar detection techniques.<br><br>The detailed program will include:<br>1. Aspects of Astrophysics<br>a. Big bang nucleosynthesis<br>b. Star formation and evolution<br>c. Quiescent and explosive stellar burnings<br>2. Stellar nucleosynthesis:<br>a. Definitions and general characteristics of thermonuclear reactions<br>b. Hydrogen burning<br>c. Helium burning<br>d. Advanced burnings<br>e. r and s processes<br>3. Measure of nuclear processes of astrophysical interest<br>a. Experimental techniques<br>b. Some examples |

# Observational Cosmology

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|---|---|
| **Lecturer** | **Dr. Giovanni Covone** (giovanni.covone@unina.it) |
| Credits (planned) | 2 / 3 |
| Planned hours | 12 / 18 |
| Planned schedule | To be defined with the students |
| Prerequisites | Basic concepts in Astrophysics and General Relativity will be introduced in the course when necessary. |
| Description | The goal of the course is to introduce the students to the modern observational cosmology.<br>In the first part of the course, key concepts will be derived from first principles.<br>We will then introduce the basic concepts and techniques to interpret the data from the modern cosmological surveys (CMB, large scale distribution, weak gravitational lensing). Focus of the second part of the course is on the probes of dark matter and dark energy, and the tests of the general relativity in the cosmological context.<br><br>**Syllabus**:<br>Basics of general relativistic cosmology.<br>Cosmological world models.<br><br>Hierarchical formation of cosmic structures.<br>The Press–Schechter theory.<br>Role of dark energy and dark matter in cosmic structures formation.<br>Nature of dark matter: Warm versus cold dark matter.<br><br>Gravitational lensing.<br>Cosmological distance and the distance scale.<br>Weak gravitational lensing surveys as cosmological probes. Observational probes of the dark matter.<br>Large scale distribution of galaxies and galaxy clusters.<br>Present and future surveys: KIDS, Planck, EUCLID, SKA.<br>Tests of general relativity in the cosmological context.<br><br>**Textbooks**:<br>J. Peacock, "Cosmological Physics"<br>H. Mo, F. van den Bosch, S. White, "Galaxy Formation and Evolution". |

| Optical Spectroscopy | |
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| **Lecturer** | **Prof. Salvatore Amoruso** salvatore.amoruso@unina.it |
| Credits (planned) | 8 |
| Planned hours | 50 |
| Planned schedule | **March 9th – June 17th, 2017**<br>***course offered in the frame of the Master's programme*** |
| Prerequisites | |
| Description | 1) Absorption, emission and scattering of optical radiation from a medium: Macroscopic view and classical analyses – Definition of the main physical quantity – Complex refractive index of materials and related phenomena (dispersion and absorption);<br>2) Absorption, emission and scattering: the quantum description;<br>3) General spectral features of atoms, molecules and solids – Spectral line/band characteristics and correlated phenomena – line broadening mechanisms;<br>4) A typical setup for optical spectroscopy - Optical elements, main instruments, light sources, samples, detectors, methods.– Brief discussion on light generation by non-linear optics: II and III harmonics, sum and difference frequency generation, parametric generation and amplification.<br>5) Absorption spectroscopy: Spectrophotometry; F-TIR Spectroscopy; Cavity Ring Down Spectroscopy;<br>6) Optical Emission Spectroscopy: Laser induced breakdown spectroscopy and Laser Induced Plasma Spectroscopy; Laser Induced Fluorescence;<br>7) Photoluminescence;<br>8) Raman Spectroscopy (scattering);<br>9) Time resolved and pump-probe techniques: Ultrashort laser sources and ultrashort pulses characterization methods; Transient absorption, Fluorescence up-conversion;<br>10) Time correlated single photon counting technique.<br>11) Application of optical spectroscopy to diverse fields as environmental/atmospheric studies and monitoring, material analyses, biology. |

| **Ordered phases of Condensed Matter** | |
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| **Lecturers** | **Prof. Arturo Tagliacozzo** (Univ. “Federico II”)<br>**Dr. Gabriele Campagnano** (postdoc Univ. “Federico II”)<br>**Dr. Procolo. Lucignano** (CNR)<br>**Dr. Domenico Giuliano** (Univ.Calabria)<br>mail: arturo@na.infn.it |
| Credits (planned) | 5 (about = no. hours 30 / 6) or according to students request |
| Planned hours | 30 |
| Planned schedule | May – July 2017: four hours, twice a week (tentative) |
| Prerequisites | Phenomenology of Condensed Matter, Quantum Mechanics |
| Description | It is a theoretical overview on<br>• broken symmetry in Superconductivity and Magnetism in various space dimensions,<br>• Quantum Hall effect, Topological Insulators.<br>• Mesoscopic devices<br><br>Tools are: functional integration of Fermions and coherent spin states, non-linear sigma model and XY model, Berezinskii-Kosterlitz-Thouless transition, Berry phase |

| **Photonics** | | |
|---|---|---|
| **Lecturer** | **Prof. Carlo Altucci** | carlo.altucci@unina.it |
| Credits (planned) | 8 | |
| Planned hours | 50-60 | |
| Planned schedule | **1st semester – October 2017 / January 2018**<br>***course offered in the frame of the Master's programme*** | |
| Prerequisites | Basic optics and Electromagnetism – Fundaments of lasers | |
| Description | Course introduction. Reminds on Maxwell Equation and their basic properties. Reflection and Refraction. The wave nature of light: Interference. Application: Reflection and Interference in thin films, anti-reflection coatings, dielectric mirrors.<br><br>Reminds on diffraction theory. X-ray diffraction by crystals. Fraunhofer far-field and Fresnel near-field diffraction. The Poynting theorem in vacuum and in the matter. Momentum and angular momentum carried by the EM field. The Maxwell's stress tensor.<br><br>Waves in one dimension. Sinusoidal waves. Boundary conditions: reflection and transmission. Polarization. Monochromatic plane waves. Generalized boundary conditions: the Fresnel's equations for TM and TE polarization. The Brewster's angle. EM waves in conductors: absorption and dispersion.<br><br>The frequency dependence of permittivity. Absorption and dispersion: the complex refractive index. Ray optics. Postulates of Ray Optics, the Fermat's Principle. Simple optical components: mirrors, planar boundaries, Cartesian Surfaces, spherical boundaries and lenses, light guides.<br><br>Graded-index optics. The ray equation and analogy Optics-Lagrangian Mechanics. Graded-index optical components. Matrix Optics. Ray-Transfer Matrix, matrices of simple optical components, Matrix of cascaded optical components. Examples and problems.<br><br>Wave Optics: monochromatic waves. Complex representation and the Helmholtz Equation. Noticeable waves: plane, spherical. Paraxial waves. Relation between wave and ray optics. Transmission through optical components in complex | |

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| | representation. Interference: multiple wave interference. Polychromatic light: Fourier decomposition, light beating.<br><br>Fourier Optics. Properties of 1D and 2D Fourier Transform. Propagation of light in Free Space. Optical Fourier Transform and applications<br><br>Fourier Optics applied to Diffraction theory. The general problem of Diffraction. Scalar and paraxial Diffraction: the Fresnel's theory. The far-field: Fraunhofer approximation. An interesting and recent application in the near field: SNOM.<br><br>Electromagnetic Optics. Waves in dielectric media. Absorption and Dispersion. Kramers-Kroenig relations. Pulse propagation in dispersive media.<br>Polarization of light. Reflection and Refraction. Optics of Anisotropic media. Optical activities and magneto-Optics.<br><br>Optics of liquid crystals. Polarization devices. Applications and problems.<br>Photonic Crystal Optics. Optics of dielectric layered media. One-Dimensional Photonic Crystals. Two- and three-dimensional photonic crystals. Applications.<br><br>Guided-Wave Optics. Planar-mirror waveguides. Dispersion relation and photonic band structure. Phase and group velocities. Planar dielectric waveguides. Modes, Field distributions, Confinement factor, Dispersion Relation and Group Velocities, Two-dimensional waveguides, rectangular dielecric waveguides.<br><br>Photonic crystal waveguides. Coupling in waveguides. Sub-wavelength waveguide: plasmonics. Brief introduction to the Optics of metamaterials.<br>Doubly negative materials and their optical properties. Negative refraction makes a perfect lens (Pendry). Practical realization of doubly negative materials: the case of Wire Medium + Split Ring Resonator. Latest applications: On-Chip Zero-Index Metamaterials. Applications: Control of a Quasiperiodic Waveguide.<br><br>Semiconductor Optics. Semiconductors: energy bands and charge carriers, semiconductor materials, electron and hole concentrations, generation, recombination, injection, Junctions and heterojunctions, quantum-confined structures, photon |

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| | interactions in bulk semiconductors, band-to-band transitions in bulk semiconductors, absorption, emission, gain in bulk materials, photon interaction in quantum-confined systems, refractive index. Semiconductor photon sources: light emitting diodes, semiconductor optical amplifiers, laser diodes, quantum confined and microcavity lasers.<br><br>Semiconductor photon detectors: photodetectors, photoconductors, photodiodes, avalanche photodioses, array detectors, noise in photodetectos.<br><br>Ultrafast Optics and ultrafast light sources. Ultrafast lasers: gain and cavity modes, self-phase and self-amplitude modulations, dispersion management, amplifiers, chirp-pulse-amplification (CPA).<br><br>Applications: Pulse compression and manipulation. Coherent control: pulse shaping for optimization of chemical reactions and DNA-protein crosslinking.<br><br>Characterization of Ultrashort pulses. Measurement of pulse duration: Streak camera. First-order autocorrelator: Fourier limit. Second-order autocorrelator: Pulse duration. Collinear second-order autocorrelator. Noncollinear (background-free) second-order autocorrelator<br>Ultrashort pulse characterization. Amplitude and Phase: FROG and FROG-like methods. SPIDER. |

## Physics and applications of Superconducting and Spintronic Devices

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|---|---|
| **Lecturer** | **Prof. G.P. Pepe** (University, gpepe@na.infn.it) |
| Credits (planned): | 4 /5 |
| Planned hours: | about 30 (2-3 hours/week) |
| Planned schedule: | September – December 2017 |
| Prerequisites: | basic knowledge of solid state physics and electronics |
| Description: | The aim of the course is to furnish competences on both fundamental and applied aspects related to the superconducting electronics mainly in nanosized regime, including deposition techniques, nano-patterning, cryogenics, diagnostic tools for advanced microscopy (AFM, MFM, SQUID-based microscopy) and time resolved spectrometry, superconducting detectors and nonequilibrum physics. Moreover, the recent achievements in spintronics (mainly containing superconducting structures ) will be also presented and discussed.<br><br>A brief overiew of the program is the following:<br><br>The physics of superconductivity: linear electrodynamics, The Ginzburg-Landau theory, weak superconductivity, the Josephson effect, some non-equilibrium effects in superconductors, superconducting quantum devices, superconductivity in low dimension systems.<br><br>Nanotechnologies: thin films deposition and characterization, top-bottom nano-litography, the self-assembling processes in nanotechnology, advanced imaging on the nano-scale (AFM, STM, advanced microscopy). Cryogenic techniques.<br><br>Materials and devices for spintronics: magnetism and nanostructures, magneto-resistance and magneto-optics mainly in superconducting based systems.<br><br>Students will be asked to present seminars on topics related to the above program, producing final reports using general templates as proposed by international scientific journals. |

| **Physics and Astrophysics of Gravitational waves** | |
|---|---|
| **Lecturer** | **Prof. Enrico Calloni** (enrico.calloni@na.infn.it) |
| Credits (planned) | 3 |
| Planned hours | 18 |
| Planned schedule | April – June 2017 |
| Prerequisites | knowledge of 4-dimensional formulation of special relativity |
| Description | The lessons describe the Advanced Detectors Era for Gravitational Waves. The main topics are:<br>1) The detectors of Gravitational waves: the working principles of the detectors, focusing on the most relevant techniques, the present status of the world-wide detectors network, the Italian-European detector Virgo.<br>2) The most important gravitational waves sources, the rates and the implications in the fundamental physics of gravitation and in astrophysics and cosmology.<br>3) The future of gravitational wave astrophysics. The future detectors, the International Network, the third generation and scientific objectives. The course is updated at the present day of knowledge. |

| Physics of Plasmas and Particle beams in Laboratory and Space | |
|---|---|
| **Lecturer** | **Prof. Renato Fedele** (University, renato.fedele@na.infn.it) |
| Credits (planned): | 5 |
| Planned hours: | 32 |
| Planned schedule | April – May 2017 , or July – September 2017 |
| Prerequisites: | General Physics, Fundamentals of Quantum Mechanics |
| Description: | This course provides an introduction to the physics of both plasmas and charged particle beams in the presence of collective effects.<br>The course contains a short preparatory part on kinetic theory and statistical mechanics, then develops the subject matter on the basis on the kinetic and fluid theories within the contexts of both classical and quantum physics, with emphasis on the relevant applications t plasma-based particle accelerators, condensed matter physics and astrophysics.<br>In particular, the course includes the following topics:<br>- nonlinear stability and confinement theorems;<br>- collective waves and instabilities in laboratory and space physics;<br>- coherent electromagnetic radiation generation by free electron lasers;<br>- nonlinear processes and particle acceleration in astrophysical environments;<br>- nonlinear processes related to compact plasma-based accelerator concepts. |

| **Quantum Communication** | |
|---|---|
| **Lecturer** | **Dr. Alberto Porzio** (**alberto.porzio@spin.cnr.it)** |
| Credits (planned) | 4/6 |
| Planned hours | 20 to 24 |
| Planned schedule | **Dec 2017 – Jan 2018** |
| Prerequisites | Quantum mechanics; Quantum Optics (basic) |
| Description | The program overviews: a) basic principles of quantum information (entanglement, Bell inequalities, no-cloning theorem, measurement theory in QM, coherence and de-coherence); b) the concepts of fidelity and state reconstruction (with experimental aspects); c) q-bit and Continuous Variable QI (with examples of physical implementations); d) simple quantum protocols (quantum cryptography and teleportation); e) intrinsic and technological limits of QI. |

## Quantum Computing and Artificial Intelligence

| | |
|---|---|
| **Lecturer** | **Prof. Giovanni Acampora** giovanni.acampora@unina.it |
| Credits (planned) | 4/6 |
| Planned hours | 20 to 24 |
| Planned schedule | **March – April 2018** |
| Prerequisites | Foundations of Computer Science and Computer Programming |
| Description | The program overviews: a) concepts of Artificial Intelligence; b) Machine Learning; c) Implementation of Machine Learning algorithms in Python; d) Quantum Computing; e) Quantum Architectures; f) Quantum Algorithms; g) An embryonic view on Quantum Machine Learning. |

| **Quantum Technologies: Principles and Engineering** <br> **(mostly in Condensed Matter Physics)** | |
|---|---|
| **Lecturer** | **Prof. Francesco Tafuri** (francesco.tafuri@unina.it) |
| Credits (planned) | 8 |
| Planned hours | 48 |
| Planned schedule | **April – July 2017** |
| Prerequisites | Elementary Quantum Mechanics and Solid State Physics |
| Description | Quantum hardware is what transforms the novel concepts of quantum computation and communication into reality. The key challenge is to control, couple, transmit and read out the fragile stage of quantum systems with great precision, and in a technologically viable way. This course aims at illustrating some aspects of this key challenge in realizing quantum technology, focusing on solid state and superconducting hardware. Some key notions on advanced solid state physics will be introduced as a bridge to standard courses. <br><br> Description by keywords: <br><br> • Introduction to Mesoscopic with Superconductivity <br> • Macroscopic Quantum Phenomena and broken symmetry <br> • Superconducting Devices, the Josephson effect, introduction to dissipation, decoherence and noise, macroscopic quantum tunneling <br> • Nanoelectronic Devices: main notions and physical principles, nanoscale Processing for Advanced Devices <br> • Quantum bits and essential concepts that distinguish quantum from classical, Quantum states superpositions: <br> • Superconducting and hybrid qubits: principles, design and read-out and fate of Macroscopic Quantum mechanics <br> • Sensors at the quantum limit, quantum memories <br> • Superconducting single photon detectors, principles of operation, interface with quantum optics experiments <br><br> Fine tuning of the program on the basis of students' background. |

| **Radiation biophysics of charged particle exposure** | |
|---|---|
| **Lecturer** | **Dr. Lorenzo Manti** **manti@na.infn.it** |
| Credits (planned) | 3 |
| Planned hours | 18 |
| Planned schedule | **From October 2017-subject to arrangements with students** |
| Prerequisites | None |
| Description | The course has the objective of illustrating the basic principles underlying the biological effects ionising radiation, and particulalry of charged particles, as a result of their phyiscal properties. In particular, the consequences of radiation exposure for human health (both acute and delayed) and the radiobiological rationale for the medical use of accelerated ions for cancer treatment will be discussed. |

| **Scientific writing** | |
|---|---|
| **Lecturer** | **Prof. Paolo Russo** (russo@na.infn.it) |
| Credits (planned) | 5 |
| Planned hours | 30 |
| Planned schedule | **March - June 2017**<br>**http://www.symposium.it/eventi/2017/scientific-writing** |
| Prerequisites | none |
| Description | The course provides basic intro to the professional task of scientific publication in international journals, with reference to motivations for publishing, scientific journal selection, writing style, ethical issues, manuscript editing, revision and proofs reading, manuscript correspondence. Moreover, the following aspects will be covered: description of the basic aspects of the Editorial structure of a scientific Journal (Editor, associate editors, editorial board members, publisher, journal manager); basic aspects of the manuscript review process; methods for manuscript review; understanding and evaluation of bibliometrical indices.<br>The course evaluation will be based on exercises assigned to attendees on selected aspects of the course material. |

## Spectral theory of Schrödinger operators

| | |
|---|---|
| **Lecturer** | **Prof. Rodolfo Figari** figari@na.infn.it |
| Credits (planned) | 2 |
| Planned hours | 10 |
| Planned schedule | 5 two hours classes: May: 8 – 12 - 15 - 19 - 22 (2017) |
| Prerequisites | An elementary course in Mathematical methods of Physics and an elementary course in Quantum Mechanics |
| Description | - Self-adjoint operators<br>- Spectral theory for self-adjoint operators<br>- Spectral theory for self-adjoint operators<br>- Generalized eigenfunctions of Schroedinger operators<br>- Resonances and the Fermi Golden Rule |

| **Statistical Mechanics of Complex Systems** | |
|---|---|
| Lecturer: | **Dr. Antonio De Candia** (Università Federico II, decandia@na.infn.it) |
| Credits (planned): | 2-3 |
| Planned hours: | 12-18 |
| Planned schedule: | Ottobre 2017 – Febbraio 2018 |
| Prerequisites: | basic knowledge of statistical mechanics |
| Description: | Sherrington - Kirkpatrick model. Replica - symmetric solution. The Parisi solution. The p - spin model. The cavity method. Dynamics and Mode - Coupling theory. TAP equations. The spin - glass on the Bethe lattice. Reconstruction on trees and point – to - set correlations. |

| **Statistical Methods for Data Analysis** | |
|---|---|
| **Lecturer:** | **Dr. Luca Lista** (INFN, luca.lista@na.infn.it) |
| Credits (planned): | 2-3 |
| Planned hours: | 12-18 |
| Planned schedule: | March / April 2017 |
| Prerequisites: | Basic knowledge of the concept of probability. Examples and exercises will be done in C++, so basic knowledge of computer programming is recommended. |
| Description: | Statistical methods for data analysis:<br>• Statistics and probability distributions<br>• Parameter estimates and maximum likelihood (ML) and extended ML methods<br>• The Bayes theorem: frequentistic and Bayesian approaches<br>• Computation of upper limits<br>• Combining measurements<br>• Monte Carlo techniques<br>• Fit quality with Toy Monte Carlo<br>• Multivariate discrimination methods<br>• Artificial Neural Networks<br><br>Introduction to statistics application frameworks based on ROOT toolkit:<br>• RooFit<br>• TMVA |

## String Theory

| | |
|---|---|
| **Lecturer** | **Dr. Wolfgang Mueck** **wolfgang.mueck @ unina.it** |
| Credits | 8 |
| Planned hours | 64 |
| Planned schedule | October - December 2017 (first semester)<br>***course offered in the frame of the Master's programme*** |
| Prerequisites | Basic knowledge in General Relativity and Quantum Field Theory |
| Description | Outline:<br>1) Historical Introduction<br>2) Point particle<br>3) Bosonic String – canonical quantization<br>4) Conformal Field Theory<br>5) String interactions<br>6) BRST and path integral quantization<br>7) Low-energy effective actions<br>8) T-duality and D-branes<br>9) Superstrings<br>10) Type IIA and IIB supergravity |

| Strings and branes | |
|---|---|
| **Lecturer** | **Dr. Franco Pezzella** (INFN, pezzella@na.infn.it) |
| Credits (planned): | 4 |
| Planned hours: | 24 |
| Planned schedule: | to be agreed with students |
| Prerequisites: | General Relativity, Quantum Field Theory |
| Description: | Classical and quantum aspects of superstrings are discussed together with the properties of D-branes, string dualities and more recent developments in String Theory. |

| **Strong Interactions** | |
|---|---|
| **Lecturer** | **Prof.ssa Giulia Ricciardi**<br>(University of Napoli Federico II, giulia.ricciardi@na.infn.it) |
| Credits (planned) | 4-6 |
| Planned hours | 24-36 |
| Planned schedule | to be fixed together with the students |
| Prerequisites | basics of particle physics |
| Description | The aim of the course is to provide the necessary background to fully understand and work on processes involving hadrons.<br><br>Topics:<br>- Non abelian gauge theories: QCD<br>- Renormalization group, infrared and ultraviolet divergencies<br>- Asymptotic freedom and confinement<br>- Fundamental applications of perturbative QCD<br>- Deep Inelastic Scattering; Parton Model<br>- Structure Functions; DGLAP equations, their solution and interpretation<br>- Effective field theories<br>- Introduction to the lattice |

| **Structure and Formation of Galaxies** | |
|---|---|
| **Lecturers** | **Dr. Nicola Rosario Napolitano** (napolita@na.astro.it)<br>**Dr. Francesco La Barbera** (labarber@na.astro.it)<br>Osservatorio Astronomico di Capodimonte |
| Credits (planned) | 5 |
| Planned hours | 30 |
| Planned schedule | October 2017 – February 2018 |
| Prerequisites | Physics, Classical Mechanics, Spectroscopy |
| Description | **Aims:** introduction to the galaxy structure and evolution, with particular emphasis to their baryonic and dark matter content and the implication on the efficiency of formation mechanisms.<br><br>**Galaxy structure** (20 hrs)<br>Components and classifications (2)<br>Galaxy colours and stellar populations (4)<br>Surface brightness laws and Galaxy shapes (2)<br>Galaxy kinematics (2)<br>Gravity potentials for spherical systems (2)<br>Galaxy dynamics: collisionless systems, Dynamical equilibrium, Virial Teorem and Jeans Equations (4)<br>Galaxy models: modeling rotation curves of spiral galaxies, dispersion profile of elliptical galaxies. Dark Matter evidences and dark halo models (4)<br><br>**Galaxy Assembly** (10 hrs)<br>Gas cooling and star formation (2)<br>Disk formation (2)<br>Dynamical friction and Merging (2)<br>Feedback from thermal and non thermal mechanisms. Shock heating (4)<br><br>**Textbooks**<br>Galactic Astronomy: Binney, J. and Merrifield, M., Princeton University Press<br>Galactic Dynamics: Binney, J. and Tremaine, S., Princeton University Press |

| **Theoretical Astroparticle Physics** | |
|---|---|
| **Lecturer** | **Prof.ssa Ofelia Pisanti** (pisanti@na.infn.it) |
| Credits (planned) | 8 |
| Planned hours | 64 |
| Planned schedule | March - June 2017<br>(see details on the web page of the lecturer) |
| Prerequisites | Basics of Elementary Particle Physics (Standard Model) |
| Description | The course is borrowed from "Laurea Magistrale in Fisica" and gives the opportunity of understanding modern theories on matter constituents and their liaison with the origin of the universe. |

| **Theory of Nuclear Matter** | |
|---|---|
| **Lecturer** | **Dr. Luigi Coraggio** - INFN (coraggio@na.infn.it) |
| Credits (planned) | 3 |
| Planned hours | 20 |
| Planned schedule | to be defined with the interested students |
| Prerequisites | none |
| Description | - Basic properties of the nuclear matter<br>- The Fermi gas model<br>- The nucleon-nucleon potential<br>- The Brueckner theory<br>- The reaction matrix G<br>- The Bethe-Brandow-Petschek theorem<br>- The Brueckner-Hartree-Fock approach<br>- Calculation of reaction matrix with the momentum space matrix equation method<br>- Lowest order Brueckner-Hartree-Fock theory<br>- Microscopic derivation of the nuclear matter equation of state and neutron stars |

| **Thin films: physics and applications** | |
|---|---|
| **Lecturer** | **Dr.ssa Alessia Sambri**<br>(Università di Napoli Federico II and CNR–SPIN, sambri@fisica.infn.it) |
| Credits (planned) | 4 |
| Planned hours | 24 |
| Planned schedule | Autumn 2017 (September/October) |
| Prerequisites | basic knowledge on Solid State Physics |
| Description | The course is focused on the very actual and appealing field of thin films. The fascinating properties exhibited by several compounds when combined together as thin film heterostuctures and the possibility to tune, or even enhance, some bulk physical properties when the compound are engineered as thin films, are driving a broad research in solid state physics labs worldwide. Moreover, the push toward devices miniaturization is taking great advantages of the constantly improving abilities to fabricate high quality thin films and heterostrucutre and to optimize the microfabrication processes that shape thin films into devices.<br>The course will give a broad overview on the physics related to thin films and interfaces, with a focus on the fabrication processes, on a number of structural, morphological and chemical characterization techniques, and on the technological issues related to the employment of thin films in the modern miniaturized devices.<br>Beside the frontal lessons, some practical examples of thin films depositions and characterizations are planned, accordingly to the calendar of the involved labs. |

| **Topics in Non-Perturbative Quantum Field Theory (from two to four dimensions)** | |
|---|---|
| **Lecturer** | **Dr. Luigi Rosa** (rosa@na.infn.it) |
| Credits (planned) | 3 |
| Planned hours | 20 |
| Planned schedule | March – June 2017 |
| Prerequisites | theoretical physics background |
| Description | NON-PERTURBATIVE METHODS IN TWO-DIMENSIONAL FIELD THEORY:<br><br>From massless scalar field to conformal field theories.<br><br>TWO-DIMENSIONAL NON-PERTURBATIVE GAUGE DYNAMICS:<br><br>Foundamental aspects of gauge theories in two dimensions<br><br>FROM TWO TO FOUR DIMENSIONS:<br><br>Conformal invariance in four-dimensional field theories and in QCD<br><br>From two-dimensional solitons to four-dimensional magnetic monopoles<br><br>Instantons in QCD |

| **Topics in Non-Perturbative Quantum Field Theory (Gauge theories)** | |
|---|---|
| **Lecturer** | **Dr. Luigi Rosa** (rosa@na.infn.it) |
| Credits (planned) | 3 |
| Planned hours | 20 |
| Planned schedule | March – June 2017 |
| Prerequisites | theoretical physics background |
| Description | GAUGE THEORIES:<br><br>The gauge principle; Functional quantization of gauge theories<br><br>BRST symmetry and physical states<br><br>Realizations of symmetry; Ward-Takahashi identities<br><br>Spontaneous symmetry breaking; Continuous global symmetry;<br><br>The Goldstone's theorem; the Higgs mechanism<br><br>Casimir energy and the cosmological constant problem<br><br>NON ABELIAN GAUGE FIELDS:<br><br>the Gribov ambiguity; path integral in QCD; Instantons; confinement and dual superconductivity; 't Hooft-Polyakov magnetic monopoles |

| Ultrafast processes and femtosecond laser pulses | |
|---|---|
| **Lecturer** | **Dr. Andrea Rubano** (SPIN – CNR, rubano@fisica.unina.it) |
| Credits (planned) | 3 |
| Planned hours | 18 |
| Planned schedule | March – July, 2017: the schedule is flexible |
| Prerequisites | Basic knowledge of Solid-state Physics would be helpful. Linear Optics and basics of Quantum Physics are required. |
| Description | The PhD Course will introduce the students to the realm of Ultrafast Processes, with a special focus on optical pulses and their interaction with matter. The introduction will give broad overview about pulsed light, pulsed sources, and especially commercial femtosecond lasers. Theoretical and technical description about the most common ways to produce and amplify short pulses will be given in some detail. In the main part, different applications of ultrafast pulses will be described as follows:<br><br>1) Metrology: How to measure optical frequencies? Frequency Comb, optical clockwork.<br>2) Nonlinear Optics: New frequencies, new probes? Nonlinear light-matter interaction, principles and main applications. Sum and difference frequency generation. Frequency doubling. Extreme cases: THz and X-rays generation schemes.<br>3) Novel states: How to access non-equilibrium states? Scanning microscopy approaches: two-photon microscopy, stimulated emission-depletion microscopy.<br>4) Fs-spectroscopy: How to resolve ultrafast dynamics? Overview about the general Pump&Probe experimental scheme. Examples: coherent phonon control, isomerization and structural transitions, charge transfer and separation, hot-electron dynamics in metals.<br>5) Fs-photonics: How to control light with light? Spectral lenses in photonic crystals.<br><br>The aim of the Course is to give a wide panorama on today's available techniques using ultrashort laser pulses and to provide technical skills and theoretical background to the student which intends to work within this field of research. The actual layout of the course can be extended in some aspects and reduced in others, depending on the student's interests and motivations. |

| Waves and Interactions in Nonlinear Media | |
|---|---|
| **Lecturer** | **Prof. Renato Fedele** (University, renato.fedele@na.infn.it) |
| Credits (planned): | 4 |
| Planned hours: | 25 |
| Planned schedule | May – June 2017, or July – September 2017 |
| Prerequisites: | Classical Electrodynamics, Fundamentals of Quantum Mechanics, Fundamentals of Statistical Mechanics |
| Description: | The course is interdisciplinary and gives a general description of the propagation of waves in nonlinear media and their interactions (three and four waves parametric processes). Some physical examples in nonlinear optics (Kerr media, optical fibers), surface gravity waves (ocean waves), large amplitude waves in plasmas (Langmuir wave packets) and matter waves physics (Bose-Einstein condensates) are given. From these examples, a unified description modelled by suitable nonlinear Schrödinger equations is extrapolated. Such a description is then extended to phase space by means of the Wigner quasi-distribution. Particular attention is devoted to both theoretical and experimental aspects of the modulational instability and the related stabilizing role of the Landau damping for an ensemble of partially incoherent waves. |