PhD Course in Physics and Astronomy
University of Florence

List of courses for the academic year 2023-2024

APPLIED PHYSICS

contact: Prof. Silvia Nava, silvia.nava@unifi.it

Digitization and numerical signal processing, Gabriele Pasquali - 12 h (2 CFU), April-June
gabriele.pasquali@unifi.it
The course is an introduction to digitization and signal processing applied to sensors/detectors in physics. After a brief section on the principles and characteristics of analog-to-digital converters, we deal with sampling theory and signal reconstruction. Other subjects are: digital signal processing with LTI (Linear Time-Invariant) systems, discrete Fourier transforms, Z-transform, design of custom processing systems. Part of the subject can be adapted to the particular needs of the students.

Nuclear analytical techniques for forensics science, Massimo Chiari - 12 h (2 CFU), January-March,
chiari@fi.infn.it
Nuclear Analytical Techniques (NATs) include accelerator-based techniques, Ion Beam Analysis (IBA) for elemental and molecular analysis and Accelerator Mass Spectrometry (AMS) mainly for "radiocarbon dating", and Neutron Activation Analysis (NAA), carried out in nuclear reactors for elemental analysis. In this course we will review NATs and we will present applications to a wide collection of forensic problems, such as analysis of drugs of abuse, food fraud, counterfeit medicine, gunshot residue, glass fragments, forgery of art objects and documents, and human material.

Novel frontiers in imaging CT for medicine, Mara Bruzzi and Adriana Taddeucci - 12 h (2 CFU), April-June
mara.bruzzi@unifi.it, adriana.taddeucci@unifi.it
Computed tomography (CT) has a profound impact on the practice of medicine. By enabling a deepened understanding of anatomy, physiology, and pathology, CT facilitates the detection and management of disease. Recent advances in CT concern the development of spectral imaging techniques and the use of artificial intelligence (deep learning, DL). Photon-counting CT (PC-CT) can measure the energy of each individual photon interacting with the detector, thus enabling the identification of individual materials (e.g. iodinated blood, soft tissues, bones). In proton therapy, relative stopping power (RSP) maps are usually extracted from x-CT images translating the photon attenuation coefficients (Hounsfield's units—HU) by appropriate conversion and calibration coefficients. proton CT (pCT) is an emerging technique providing the direct estimation of RSPs hence improving treatment planning and verification in proton therapy. This course will present and discuss state-of-art and frontier research in photon CT and proton CT technologies.

Detectors for medical physics, Cinzia Talamonti - 12 h (2 CFU), April-June
cinzia.talamonti@unifi.it
This course introduces modern methodologies to detect particles in medical physics. The concepts of "dosimetry" and "dosimeter" and the interpretation of dosimetric measurements will be described. The Bragg-Gray cavity theory and the Ionization chamber are the cornerstone of the dosimetry. Moreover, cutting-edge detectors like diamond, organic scintillators, amorphous Silicon, scintillating fibers and passive dosimeters, which fulfill the new requirements in clinical absolute and relative dosimetry, will be discussed. New international protocols of measurements and code of practice are included in the program together with the comparison between Ionization chambers and "solid state chambers" (silicon, diamond) in small field dosimetry. Eventually the concept of micro-dosimetry will be introduced.

ASTROPHYSICS

contacts: Prof. Marco Romoli, marco.romoli@unifi.it; Prof. Stefania Salvadori, stefania.salvadori@unifi.it

Local courses:

Accretion/ejection in astrophysics, Daniele Galli, Francesca Bacciotti - 12 h (2 CFU) – January-March
daniele.galli@inaf.it, francesca.bacciotti@inaf.it
This course is an introduction to the role played by the processes of accretion and ejection in various astrophysical contexts, in particular in the formation of stars. The first part is focused on the accretion of mass induced by gravity and counteracted by rotation and magnetic forces and presents the physics of accretion disks in detail. The second part addresses the physics of protostellar jets and outflows, and their role in the transfer of angular momentum. The mechanism of magneto-centrifugal acceleration is analyzed in detail, as well as the main diagnostics techniques that allow to test the validity of the proposed mechanisms for jet launch.

Astrochemistry, Maria Teresa Beltrán, Francesco Fontani - 12 h (2 CFU) - January-March
maria.beltran@inaf.it, francesco.fontani@inaf.it
This is an introductory course to astrochemistry in which basic aspects of interstellar chemistry and molecular astrophysics are presented. This includes detection and formation of molecules, chemistry of important species such as H_3^+, CO, deuterium, and complex organic molecules, maser emission, radiative transfer, derivation of physical parameters, catalogues and databases, and line identification tools. The course will also present astrochemistry in low and high-mass star-forming regions, evolved stars, and external galaxies.

Galactic cosmic rays and star formation, Marco Padovani - 12 h (2 CFU) - April-June
marco.padovani@inaf.it
Observations from radio to infrared wavelengths and theoretical modelling have shown that low-energy cosmic rays (< 1 TeV) play a fundamental role in shaping the chemical richness of the interstellar medium and in determining the dynamical evolution of molecular clouds, from diffuse cloud scales to protostellar discs and jets. The course will provide an introduction to the effects of Galactic and locally accelerated cosmic rays in star-forming regions, focusing on microphysical processes and observational signatures such as ionisation, synchrotron and gamma-ray emission.

Radio and optical interferometry, Fabrizio Massi, Gianni Comoretto - 12 h (2 CFU) April-June
fabrizio.massi@inaf.it, giovanni.comoretto@inaf.it
After reviewing the basic principles of interferometry, the course will deal with the astronomical applications of interferometry at optical and radio wavelengths. Observational methods, and technical and practical issues will be discussed, as well as the main differences between radio and optical astronomical interferometry. An overview of available and future observational facilities (SKA, ALMA, VLA, VLT, LBTI, etc.) will conclude the course. The main aim of the course is to provide the students with the basic knowledge needed to interpret interferometric observations and to plan their own interferometric observations.

Machine learning for astrophysics, Lorenzo Spina, Francesco Belfiore - 18 h (3 CFU) April-June
lorenzo.spina@inaf.it, francesco.belfiore@inaf.it
This course will cover the basics of Machine Learning following a hands-on approach. We will introduce machine learning techniques via worked examples in python using scikit-learn, keras, and tensorflow. The goal of the course it to provide students with the necessary concepts and software tools to easily adapt these algorithms for use in their own research. The course will cover introductory concepts in regression and classification, supervised and unsupervised learning algorithms, such as clustering, random forests, fully connected and convolutional neural networks. No previous knowledge of machine learning is required, but familiarity with the python programming language is expected.

Astronomical observations with adaptive optics: Carmelo Arcidiacono - 12 h (2 CFU) - April-June
carmelo.arcidiacono@inaf.it
(also for Dottorato nazionale in Tecnologie per la ricerca fondamentale in Fisica e Astrofisica)
Adaptive optics (AO) is a technology that can be used to improve the image quality of astronomical telescopes by compensating for the blurring effects of the Earth's atmosphere. AO systems work by measuring the distortions in the atmosphere in real-time and then using a deformable mirror to correct for these distortions.
This course will introduce students to the principles of AO and its applications in astronomy. Students will learn about the different types of AO systems, how they work, and how they are used to make astronomical observations.
The course will cover the following topics:
- The physics of the Earth's atmosphere and its effects on astronomical observations
- The principles of adaptive optics
- Different types of AO systems
- The design and implementation of AO systems
- Applications of AO in astronomy

Courses of the National School in Space Science and Technology - SST (University of Trento):

Space and astrophysical plasmas, Simone Landi and Andrea Verdini – 16 h (2.7 CFU) - April-June
simone.landi@unifi.it, andrea.verdini@unifi.it
The course will provide an introduction to plasma physics focusing in particular on application related to astrophysics and space physics: plasma equilibria and instabilities, waves and turbulence in magnetised gas, magnetic energy dissipation in natural plasmas. Special emphasis will be given to those processes related to space-weather and sun-earth connection, such as the physic of the earth magnetosphere and solar wind.

Observation of the sun from space, Marco Romoli – 16 h (2.7 CFU) - April-June
marco.romoli@unifi.it
The Sun influences the life, the climate and the technology of planet Earth. Studies the Sun in all its manifestations is important and necessary. The course will provide an overview on the mechanisms that characterize the solar corona and the heliosphere with its observables, the instrumentation and the available space data from present solar missions.

Management and engineering of space missions, Emanuele Pace – 16 h (2.7 CFU) - April-June
emanuele.pace@unifi.it
The course will provide the professional and technical expertise needed to scientific ideas into scientific instruments on board future space missions. The approach is addressing a systemic view of space instrumentation, starting from scientific requirements and flowing down to technical requirements and verification activities. This includes topics as project management, system engineering, product assurance and optical, mechanical, thermal and electronics engineering, as well.

Calorimetric techniques for high energy particles, Eugenio Berti – 12 h (2CFU) - January-March
eugenio.berti@fi.infn.it
The course will provide an overview of the high energy calorimetric techniques used in cosmic-ray and collider experiments. After a phenomenological description of the main characteristics of electromagnetic and hadronic showers, we will describe the detector solutions generally adopted and the techniques used to optimize the performances. By using several examples from past and present experiments, the current status and future frontiers of calorimetry will be presented.

Stellar Archaeology to study the first stars, Stefania Salvadori, Asa Skuladottir – 16 h (2.7 CFU) - January-March
stefania.salvadori@unifi.it, asa.skuladottir@unifi.it
The first stars profoundly influenced the overall galaxy formation process. Their properties are unknown (e.g. their mass distribution) but fundamental, since they control the injection of energy, momentum, and newly created heavy elements into the gas, thus affecting subsequent star-formation along with the build-up of the first galaxies. In this theoretical and observational course we will explain how we can study the nature of this elusive stellar population by finding, studying, and interpreting the chemical properties of their descendants,which can be found in our Milky Way and nearby dwarf galaxies.

Principles of astrobiology, John Brucato - 8 h (1.3 CFU) – April-June
john.brucato@inaf.it
The study of the origin of life on Earth and the search for signs of life in space are topics which, in addition to their great fascination, represent an important direction in which contemporary science is moving in order to find answers to questions which have always accompanied mankind.
It is now possible to establish a detailed chronology of the extraordinary and complex evolutionary history of life, punctuated by violent catastrophes. What factors led to the emergence of only three domains of life? What conditions on planet Earth led to the emergence of eukaryotes? How can we detect signs of life in other environments in space?
This course aims to provide a basic understanding of the central problems of astrobiology, allowing you to integrate knowledge of astrophysics with that of chemistry and biology.

NUCLEAR – SUBNUCLEAR PHYSICS

contact: Prof. Giuseppe Latino, giuseppe.latino@unifi.it

Dynamics of heavy ion reactions, Silvia Piantelli - 12 h (2 CFU), January-March or April-June
silvia.piantelli@fi.infn.it
Main properties of heavy ion collisions; compound nucleus and low energy reactions; statistical model for compound nucleus decay; Fermi energy reactions; equation of state for nuclear matter, symmetry energy and related observables; transport models; detectors and data analysis techniques; examples taken from the literature.

Astro-particle physics 1, Lorenzo Pacini - 12 h (2 CFU), April-June
lorenzo.pacini@fi.infn.it
The purpose of the course is to provide an overview of galactic cosmic rays physics and detection through direct measurements. After a brief historical introduction and an overview of the phenomenology of cosmic rays, the course will simplify the classical models of cosmic rays and direct detection techniques. Finally, an overview will be given of the latest measurements that have recently shaken our understanding of the acceleration and propagation of cosmic rays.

Astro-particle physics 2, Sergio Bottai - 12 h (2 CFU), April-June
bottai@fi.infn.it
The Physics of Ultra high energy cosmic rays. Phenomenology of atmospheric showers and indirect detection techniques. Discussion concerning the problem of cosmic particle acceleration to energies greater than 10^15 eV and phenomenology of extragalactic cosmic rays propagation. Astronomy with ultra-high energy neutrinos: motivations and detection techniques. Physics of solar and atmospheric neutrinos and related phenomenology of neutrino oscillation.

Physics with High Energy particle detectors: from photographic plates to the LHC experiments, Simone Paoletti and Antonio Cassese - 18 h (3 CFU), April-June (it can be also split between the two trimesters).
simone.paoletti@fi.infn.it , antonio.cassese@fi.infn.it
In the first part of the course, we will retrace the main experiments that have contributed to the knowledge of the electroweak physics. While following the steps made to solve the main puzzles that have engaged the particle physicists from the 20th century, we will take the chance of exploring the ideas underlying the design and development of detectors. In the second part of the course we focus on the scientific goals of the LHC accelerator, how LHC works, the interaction process in proton-proton high energy collisions, specific details of the ATLAS and CMS detectors and their design differences, a brief overview of the Higgs physics at LHC and of the detector upgrades being prepared for High Luminosity LHC (HL-LHC).

Future generation particle detectors, Sandro Gonzi - 12 h (2 CFU), April-June
sandro.gonzi@fi.infn.it
The aim of this course is to describe the state of the art and technological developments relating to High Energy Physics experiments at particle colliders. Plans relating to the upgrades of the particle accelerators and experiments installed there currently in operation and the implementation of new projects will be presented. Finally, the technological developments aimed at creating future generation

particle detectors (in particular trackers, calorimeters, timing detectors and muon detectors) will be illustrated so that they can obtain the best performance in the expected operating conditions.

Quantum sensing for particle physics, Giuseppe Latino - 12 h (2 CFU), January-March
giuseppe.latino@unifi.it
Answering the most puzzling questions in fundamental physics drives a continuous quest for the development of new detection techniques for particle physics. Among the novel detection approaches under investigation, the ones based on exploiting the extreme sensitivity of quantum systems are considered to have promising potentialities to go beyond traditional measurement techniques. This course aims to give an introduction to this rapidly developing interdisciplinary field, as well as to present some examples selected in a wide range of quantum technologies and methodologies which are currently being actively explored.

Calorimetric techniques for high energy particles detection, Alessio Tiberio - 12 h (2 CFU), January-March
alessio.tiberio@unifi.it
The course will provide an overview of the high energy calorimetric techniques used in cosmic-ray and collider experiments. After the course the student will have a good understanding of the operating principles of electromagnetic and hadronic calorimeters. Furthermore, he will know the detector solutions generally adopted and the techniques used to optimize the calorimeter performances. Finally, by using several examples from past and present experiments he will get familiarity with the current status and future frontiers of calorimetry.

Gravitational Waves 1, Massimo Lenti - 12 h (2 CFU), January-March
massimo.lenti@unifi.it
General Relativity in a nutshell. Gravitational Waves emission by astrophysical binary systems. Interferometric detectors: seismic attenuation, quantum noise, Fabri-Perot cavities. optical readout, thermal noise. Present and future interferometers.

Gravitational Waves 2, Francesca Bucci - 12 h (2 CFU), April-June
francesca.bucci@fi.infn.it
Statistical theory of signal detection: topics covered include the classical hypothesis testing, detection of known signals in white noise, maximum likelihood estimation of unknown parameters, application of nonlinear filtering in signal detection and the use of pre-whitening filters to handle correlated noise. Environmental noise in advanced LIGO/Virgo detectors: topics covered include techniques used to investigate the environmental effects, methods to mitigate noise sources and the role that environmental monitoring has played in the validation of gravitational wave events.

PHYSICS OF MATTER

contacts: Prof. Fabrizio Martelli, fabrizio.martelli@unifi.it; Prof. Francesco Piazza, francesco.piazza@unifi.it

Transport phenomena in complex and biological media (12+12 h, 2+2 CFU)
fabrizio.martelli@unifi.it, francesco.piazza@unifi.it
The exam for this course can be given by choosing whether to take it on Part 1 or Part 2 topics.
Part 1: **Light propagation in dense materials such as biological samples with laboratory sessions**
Fabrizio Martelli and Federico Tommasi (January-March, 12 h)
fabrizio.martelli@unifi.it
The first part of the course aims to provide the fundamentals of light propagation through turbid media characterized by absorption and scattering properties. The optical properties of a turbid medium will be introduced through absorption and scattering coefficients and the scattering function. The description of light propagation will be through the radiative transport equation (RTE). Solutions in the geometries of greatest application interest, with emphasis on biological tissue optics and its applications, will be provided in the simplified diffusion approximation scheme. In the final part of the course, part of the exercises will be carried out in a computer lab, where the solutions of the diffusion equation will be calculated and verified by direct comparison with the solutions of the RTE reconstructed from the results of Monte Carlo simulations.
Part 2: **Mass transport in complex biological systems**, Francesco Piazza (April-June, 12 h)
francesco.piazza@unifi.it
Mass transport in complex biological systems is a challenging problem to describe mathematically. Examples may be diffusion of little molecules across the skin layered structure or the diffusion of a protein or a nucleic acid in the viscoelastic, nano-porous cytoplasm of a eukaryotic cell. Molecules not only experience random collisions with the solvent (simple Brownian motion) but have to cross barriers, clear pore entrances and are subject to severe volume-excluded effects and "sticky" interactions with all sorts of cellular and extracellular components.
In this second part of the course, we will discuss the main phenomenology, pinpoint the crucial observations and experimental facts and go on to introduce some of the main mathematical approaches to attack this class of problems in a biologically sensible way. These include microscopic stochastic processes as well as coarse-grained transport equation to model transport in the continuum. Moreover, we will insist on the challenging problem of deriving transport equations (typically some kind of Fokker-Planck equation) from the underlying stochastic processes in a thermodynamically consistent way.
This second part of the course is structured in ex-cathedra lectures and exercise sessions of computational lab.

State of the art techniques in semiconductor research, Anna Vinattieri and Francesco Biccari, 12 h (2 CFU), April-June
anna.vinattieri@unifi.it, francesco.biccari@unifi.it
The course consists of 6 lectures, 2 hours each. The exam is a presentation of a research paper or the writing of some notes about a specific topic. List of the lectures:

1. Introduction to the research on semiconductors: historical breakthroughs in semiconductor science and technologies; current research areas.
2. Growth of semiconductors: Crystal growth from melt; Crystal growth methods from solutions; The concept of epitaxy; Evaporation based techniques.

3. Morphological, compositional, and structural characterization: SEM, TEM, STM, AFM; EDS, XPS; XRD with Rietveld analysis.
4. Optical techniques 1: Optical constants; Kramers-Kronig relations; Spectrophotometry; FTIR; Cyclotron resonance.
5. Optical techniques 2: Photo-Luminescence spectroscopy; Time-resolved PL spectroscopy; Raman spectroscopy.
6. Electrical characterization: electrical properties; junctions and ohmic contacts; two-contact method; four-contact method; Hall measurements; current-voltage measurements on junctions; capacitance-voltage measurements; DLTS.

Machine learning techniques for physics, Lorenzo Buffoni, 12 h (2 CFU), April-June
lorenzo.buffoni@unifi.it
The course will consist of a formal introduction to the fundamentals of Machine Learning models: covering topics like Automatic Differentiation, Gradient Descent, Universal Approximation Theorem, Multilayer Perceptrons and Manifold Learning. A focus on their application in Physics will be maintained throughout the course and there will be some hands-on programming examples from various physics domains. The course does not require any specific prerequisites, so it can be taken by both theorists and experimentalists.

Quantum information and algorithms, Leonardo Banchi and Lorenzo Buffoni, 24 h (4 CFU), January-March
Leonardo.banchi@unifi.it, lorenzo.buffoni@unifi.it
The course will be adapted to the students' interests. Typical topics: Basics on quantum computation, gates, complexity. Experimental constraints, with emphasis on superconducting quantum devices. Famous quantum algorithms capable of exponential speedup: phase estimation, quantum Fourier transform, Shor (prime factoring, breaking RSA), HHL (linear algebra), density matrix exponentiation. Quantum simulation of many-particle systems, equilbrium and non-equilibrium. Quantum Machine Learning. Quantum communication theory and quantum cryptography. Open Quantum systems. Geometric description of quantum computing.

Experimental quantum computation, Carlo Sias, 20 h (3.3 CFU), January-March
sias@lens.unifi.it
The goal of the course is to present the main architectures for quantum computers: ultracold atoms, trapped ions, single photons, superconducting qubits. The first part of the course covers some fundamental aspects of theory (theory of measurement in quantum mechanics, algorithms, quantum error correction), the second (main) part of the course is devoted to the description and explanation of the experimental platforms. At the end of the course the student should be able to understand the state-of-the-art in experimental quantum computation and be able to understand the background of a new publication in a mayor journal like Nature/Science.

Advanced laboratory of quantum technologies, Giovanni Modugno and Nicola Poli, 18 h (3 CFU), April-June
giovanni.modugno@unifi.it, nicola.poli@unifi.it
The course aims at introducing some of the fundamental phenomena at the basis of quantum technologies with atoms and photons, at both theoretical and experimental level. Theoretical lectures on the phenomena and their key roles in current quantum technologies will be followed by laboratory

demonstrations using state-of-the-art experimental setups. For the year 2024 the phenomena under study will be "laser cooling" and "optical trapping" of neutral atoms. The laboratory part will consist in performing basic quantitative measurements of the phenomena and will not require previous knowledge of the experimental methods at play. The course is therefore open to any student interested in getting to know the phenomena and their applications to current quantum technologies.

Electronics for atomic, molecular and optical physics, Nicola Poli, in collaboration with Davide Bacco and Leonardo Salvi, 18 h (3 CFU), January-March
nicola.poli@unifi.it
The course aims at providing the tools to build and make use of electronic instrumentation for experiments in physics. It treats linear systems, noise processes and negative feedback and exploits these concepts to cover applications that are commonly encountered in everyday experimental activities. These include the basic configurations of operational amplifiers, low-noise and precision measurements, light detection, temperature and current controllers, oscillators and phase locked loops.
A substantial part of the course will be dedicated to laboratory sessions where the students will learn to design and build simple electronic circuits for a given application, get acquainted with electronic instrumentation and process the acquired data.

Quantum sensing and metrology, Nicole Fabbri, 18 h (3 CFU), April-June
fabbri@lens.unifi.it
Quantum sensors exploit the inherent sensitivity of quantum states to external perturbations, to detect the most minute variations in magnetic and electrical fields, time and frequency, rotations, temperature and pressure, with disruptive potential applications to material science and nanotechnology, biology and medicine, navigation and earth monitoring. The course aims at providing an introduction to the principles, methods, and concepts of quantum sensing from the viewpoint of experimentalist (quantum sensing protocols; noise and decoherence; sensitivity; sensing of time-varying signals; entanglement for quantum metrology; sensing assisted by ancillary qubits; advanced control tools for sensing), and to provide a description and explanation of quantum sensing platforms based on atoms, photons, and quantum defects in the solid state, for the realization of different kind of sensors (clocks, gravimeters, magnetometers, gyroscopes).

Atom-based quantum simulators, Leonardo Fallani, 12 h (2 CFU), April-June
leonardo.fallani@unifi.it
The course aims at providing an overview of the research field of experimental quantum simulation with cold atoms. We will focus on the realization of analog quantum simulators, where advanced optical manipulation of atomic systems provides direct laboratory implementations of target many-body models and Hamiltonians. The course will cover various research directions, in connection with recent progress on different atom-based hardware: quantum degenerate gases of bosonic and fermionic atoms, neutral Rydberg atoms in programmable optical tweezer arrays, trapped ions. The lectures will be based on an introduction to the different theoretical models and phenomena that can be simulated on those platforms, followed by the presentation of the experimental strategies and of the most important achievements, with a direct discussion of milestone research papers in the field. Students attending the course are expected to have a general knowledge of the main concepts of quantum physics, atomic physics and solid-state physics. The course is suited for students with either experimental or theory interests, and no specific knowledge of techniques for laser cooling and trapping is required.

THEORETICAL PHYSICS

contact: Prof. Aldo Cotrone, aldolorenzo.cotrone@unifi.it

Random Matrix Models: an introduction, Filippo Colomo, 12 h (2 CFU), April-June
colomo@fi.infn.it
Random Matrix Models has found numerous applications over the years, ranging from high energy physics to condensed matter, from quantum chaos to number theory, and beyond. In the first part of the course, we shall provide the main analytical tools (classical ensembles, orthogonal polynomial techniques, spectral densities and spacings) to investigate such models. Next, we shall present a few applications to be chosen according to the interests of the students.

Quantum Integrable Models: an introduction, Filippo Colomo, 12 h (2 CFU), April-June
colomo@fi.infn.it
We introduce the basic notions and techniques to investigate the physical behaviour of one-dimensional quantum integrable models. We consider in particular the Lieb-Liniger mode and present its solution by means of the coordinate Bethe Ansatz. We extend the obtained result to the case of the XXZ quantum spin chain. Time permitting, we introduce the modern approach to quantum integrability in terms of the Algebraic Bethe Ansatz.

Introduction to conformal field theory, Andrea Cappelli, 24 h (4 CFU), April-June
andrea.cappelli@fi.infn.it
Generalities about conformal invariance in any dimensions. Conformal Ward identity in two dimensions. Virasoro algebra, central charge and representations. Example of free fermions and bosons. Current algebra. Bosonization. Minimal models of Virasoro algebra. Example of Ising model. Partition Function and modular invariance. Wess-Zumino-Witten model and non-Abelian current algebra. Conformal bootstrap in more than two dimensions.

Cellular automata: Phase transition, chaos, synchronization, control, Franco Bagnoli, 8 h (1.3 CFU), April-June
franco.bagnoli@unifi.it
Curriculum: Control, Optimization and Complex Systems.
Cellular automata are fully discrete systems and are used as simple models in many contexts, from physics to biology to computer science. They can be defined in a deterministic way, also thus be studied as dynamical systems, extending the notions of chaos, for instance, or in a probabilistic way furnishing many examples of phase transition. The two concepts can be mixed, for instance by studying the effect of a small noise. One of the recent fields of study is that of controlling such systems, which are highly non-linear, and these standard techniques cannot be used.

Black holes, quantum gravity and quantum information, Domenico Seminara (seminara@fi.infn.it) - Aldo Cotrone (cotrone@fi.infn.it), 18 h (3 CFU), January-March
General properties of Black Holes. Classical Thermodynamics of Black Holes. The 4 Laws and their consequences on dynamics. Introduction to field theory in curved space. Bogoliubov transformations. Rindler metric. Unruh effect. Accelerated detector. Thermofield double. Hawking radiation. Formulation of the old information paradox. Solutions to the old information paradox. Entanglement entropy. Page curve and the new information paradox.

Cosmological probes of fundamental physics, Andrea Tesi (andrea.tesi@fi.infn.it) - Diego Redigolo (redigolo@fi.infn.it) - Marko Simonovic (marko.simonovic@unifi.it), 36 h (6 CFU), January-March
The nature of dark matter and the mechanism driving inflation are two of the most pressing open questions in fundamental physics. Most of our knowledge about these comes from cosmological observations. Assuming standard cosmology, this course will provide first-principle derivations of the Cosmic Microwave Background temperature fluctuations and their angular power spectrum, the sky averaged spectrum and fluctuations in the intensity mapping of the 21cm line produced by neutral hydrogen and the power spectrum and higher-order n-point functions of the galaxy density field which traces matter fluctuations in the late universe, in the linear and mildly non-linear regime. Emphasis will be given on the theoretical tools required to describe the aforementioned observables and the possibility of using them to test deviations from the standard cosmological model.
1) Andrea Tesi: "The cosmic microwave background" 9 hours
2) Diego Redigolo: "The 21cm Spectrum" 9 hours
3) Marko Simonovic: "The Large-scale Structure of the Universe" 18 hours

PhD Schools at the Galileo Galilei Institute for Theoretical Physics
descriptions at the web page https://www.ggi.infn.it/schools.html

GENERAL COURSES

Foundations of experimental physics
Dr. Jacopo Parravicini, jacopo.parravicini@unifi.it, 18 h - 3 CFU, April - June

The course is aimed at covering some topics that are rarely systematically addressed in scientific courses. Several items will be discussed in relation to the foundations of experimental sciences in general and physics in particular. For example: What is a "physical law"? What is a model? What is the relationship between mathematics and science? What exactly does "measure" mean? What do we measure when we measure? What is a "physical quantity"? What do we mean by "true" and "false" in physics? What are the general characteristics of a measuring instrument?
Lectures will be based on examples taken from the experiments, experience and words of the most important physicists in history - with some excursus into other natural sciences - to show the evolution of scientific thought in relation to the new problems that have gradually arisen. For whom that are already "doing science" as their activity, I would like to inspire reflection on how “science should be done” (looking at the great scientists who built the discipline) and how “science should not be done” (also addressing the topic of scientific fraud), finally underlining the “cultural dignity” of the natural sciences.