PhD Course in Physics and Astronomy

University of Florence

List of courses for the academic year 2024-2025

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.

Innovation in photovoltaic technologies and applications Mara Bruzzi - 12 h (2 CFU), April-June,
mara.bruzzi@unifi.it
The course will review photovoltaic cells principles and performances with special regard to new generation solar cells. Applications of photovoltaic modules in various sectors (buildings, transportation, wearable technologies, agriculture...) will be explored. The course will follow an experimental approach in laboratory with measurements of different prototypes: (mono/polycrystalline, amorphous) Si, GaAs triple junctions, dye sensitized, flexible and rigid solar cells/modules in different illumination conditions.

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.

Numerical resolution of Differential Equations for applications using Physics-informed Neural Networks, Alessandro Bombini - 18 h (3 CFU), January, offered at PhD in Smart Computing, UniFi
bombini@fi.infn.it
The goal of the course is to introduce the concept of Physics Informed Deep Neural Networks (PINN), discuss its implementation from scratch in PyTorch and using advanced ad-hoc developed open-source libraries such as nvidia-modulus for addressing real-world problems in various fields (engineering, physics, petroleum reservoir). We discuss recent topics such as Mixture-of-Models, Neural Operators, Physics-Informed Kolmogorov-Arnold Networks and Physics-Informed Computer Vision.
Link 2023/2024: https://androbomb.github.io/teaching/

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.

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, Luca Olmi - 12 h (2 CFU) April-June
fabrizio.massi@inaf.it, luca.olmi@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.

A hand-on introduction to Machine Learning, Francesco Belfiore and Sandra Doria - 18 h (3 CFU) April-June
francesco.belfiore@inaf.it, sandra.doria@lens.unifi.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. Throughout the course we will use examples from data science, astrophysics and medical imaging datasets. 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

Theoretical and computational aspects of stellar dynamics, Pierfrancesco Di Cintio – 18 h (3 CFU) - March-April
pierfrancesco.dicintio@unifi.it
- Potential teory , spherical systems, spherical, axisymmetrical and trisymmetrical systems
- Collisional and non-collisional systems: derivation of relaxation times, dynamical friction e violent relaxation
- Non collisional Boltzmann equation and distribution functions, Eddington inversion, Osipkov-Merritt anisotropic models
- Introduction to various N-body simulation techniques
- Numerical integrators
- Methods to treat collisions and Kustaanheimo-Stiefel rgularization

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

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 detection, Alessio Tiberio - 12 h (2 CFU), February-April
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.

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, Elena Vannuccini - 12 h (2 CFU), April-June
vannuccini@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.granchi

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@unifi.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), February-April
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.

Laboratory instrumentation control, signal generation and data acquisition, Vladislav Gavryusev and Simone Valdré - 18 h (3 CFU), January-March
vladislav.gavryusev@unifi.it, simone.valdre@unifi.it
The course is a practical introduction to digitally controlling laboratory instrumentation through SPI over USB, USB-TMC or Ethernet and to using digital to analog and analog to digital converters (DAC and ADC) to generate arbitrary waveforms and digitize the output of arbitrary devices.
First, the key concepts of handshaking between computer and measuring instruments, properties of data communication buses, DAC and ADC characteristics and limits, and the basics of sampling theory and signal reconstruction will be introduced. Next, these concepts will be implemented through a hands-on a laboratory experience using Python and C++: control a voltage-controlled oscillator (VCO) through a

RedPitaya DAC channel and read the response signal through a RedPitaya ADC channel, extracting the Fourier spectrum and determining the voltage-frequency response. An introduction to ZeroMQ library will be provided and a data stream from a digitizer will be handled.

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)
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, 12 h (2 CFU), January-March
fabrizio.martelli@unifi.it, federico.tommasi@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 12 h (2 CFU), April-June
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.

Experimental techniques in semiconductor research, Francesco Biccari and Nicoletta Granchi 12 h (2 CFU) April-June
francesco.biccari@unifi.it, nicoletta.granchi@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 A: Optical constants; Kramers-Kronig relations; Spectrophotometry; FTIR; Cyclotron resonance. 5. Optical techniques B: 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, Raffaele Marino and Stefano Martina, 18 h (3 CFU), January-March
lorenzo.buffoni@unifi.it, raffaele.marino@unifi.it, stefano.martina@unifi.it,
The course will consist of a (mostly) theoretical introduction to the fundamentals of Machine Learning models: covering topics like Maximum Likelihood estimators, Hopfield Networks, Automatic Differentiation, Gradient Descent, Universal Approximation Theorem, Multilayer Perceptrons, Convolutional Networks, Generative models and Quantum Machine Learning. A focus on their application in Physics will be maintained throughout the course, the course does not require any specific prerequisites, so it can be taken by both theorists and experimentalists.

Quantum information and algorithms, Lorenzo Buffoni and Paola Verrucchi 24 h (4 CFU), January-March
verrucchi@fi.infn.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, Davide Bacco, Nicola Poli and Leonardo Salvi, 18 h (3 CFU), January-March
davide.bacco@unifi.it, nicola.poli@unifi.it, leonardo.salvi@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.

Laboratory instrumentation control, signal generation and data acquisition, Vladislav Gavryusev and Simone Valdré - 18 h (3 CFU), January-March
vladislav.gavryusev@unifi.it, simone.valdre@unifi.it
The course is a practical introduction to digitally controlling laboratory instrumentation through SPI over USB, USB-TMC or Ethernet and to using digital to analog and analog to digital converters (DAC and ADC) to generate arbitrary waveforms and digitize the output of arbitrary devices.
First, the key concepts of handshaking between computer and measuring instruments, properties of data communication buses, DAC and ADC characteristics and limits, and the basics of sampling theory and signal reconstruction will be introduced. Next, these concepts will be implemented through a hands-on a laboratory experience using Python and C++: control a voltage-controlled oscillator (VCO) through a RedPitaya DAC channel and read the response signal through a RedPitaya ADC channel, extracting the Fourier spectrum and determining the voltage-frequency response. An introduction to ZeroMQ library will be provided and a data stream from a digitizer will be handled.

Quantum sensing and metrology, Nicole Fabbri, 12 h (2 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 Lorenzo Cotrone, aldolorenzo.cotrone@unifi.it

PhD Schools at the Galileo Galilei Institute for Theoretical Physics

descriptions at the web page https://www.ggi.infn.it/schools.html

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.

Black holes, quantum gravity and quantum information, Aldo Lorenzo Cotrone and Domenico Seminara,18 h (3 CFU), January-March
domenico.seminara@unifi.it, aldolorenzo.cotrone@unifi.it
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.

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.

Primordial non-Gaussianities, Marko Simonovic, 18 h (3 CFU), January-March
marko.simonovic@unifi.it
Cosmic inflation is one of the most interesting and mysterious phenomena that we have ever discovered. The energy scales that inflation probes can be as high as 10^{14} GeV, offering an indirect window into the regime that we cannot hope to explore with terrestrial experiments. Interestingly, cosmological observations can constrain many proposed mechanisms for generation of primordial fluctuations during

inflation and therefore have the direct impact on possible high energy theories. These lectures will focus on one aspect of this connection related to primordial non-Gaussianities. The course will cover the standard Maldacena's computation of the three-point correlation function in the single-field slow-roll inflation, derivation of soft theorems in inflation, effective field theory of inflation and its implications, as well as some more modern topics such as the role of massive particles during inflation, "cosmological collider" signatures and cosmological bootstrap. Finally, a part of the course will be devoted to making connection of theoretical predictions with observations and prospects for new discoveries with future CMB and large-scale structure data.

Computing in theoretical High Energy Physics, Mariapaola Lombardo, 12 h (2 CFU), January-March
lombardo@fi.infn.it
Non-perturbative aspects of strong interactions, Lattice Field Theory, Artificial Intelligence and Machine Learning for LFT, European Computing Landscape, One or two selected applications to be agreed upon by the students.

Cellular automata: Phase transition, chaos, synchronization, control, Franco Bagnoli, 8 h (1.5 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.

GENERAL COURSES

These courses can be recognized as "soft skill courses" under request by the students.

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

Insight: reflections on the method of physics, Gabriele Pasquali, 12 h (2 CFU), May-June
gabriele.pasquali@unifi.it
We will reflect on the analogies and differences between the cognitive process of the "hard" sciences and the cognitive process in other areas, identifying the peculiarities of the scientific method, the synergy between experimental activity and theoretical, the limits of the method itself.

Introduction to agent-based modelling with NetLogo, Franco Bagnoli, 8 h (1.5 CFU), April-June
franco.bagnoli@unifi.it
Agent-based models are computer simulations used to study the interactions between people, things, places, and time. They are (generally) stochastic models built from the bottom up, defining elementary objects and their interactions. These interactions may produce emergent effects that may differ from those of individual agents.
NetLogo https://ccl.northwestern.edu/netlogo/ is an open-source and free platform for experimenting with agent-based models. It is constituted by a "world" (a grid) of immobile agents (a background field) over which mobile agents (possibly linked among them) may move. One of the advantages of NetLogo is that the graphical interface is included and can be quickly modified and integrated with buttons, sliders and plots, so that it can be used also for visualizing other kinds of simulations. There is also a 3D version, and a server-client one for multiplayer simulations. Another advantage of this platform is that one can directly produce an html/javascript version of the model which can be distributed on the web and used by tablets or even cellular phones, making it an ideal platform for didactic purposes.

History of computers: from Babbage to ChatGPT (hardware, software, socialware), Franco Bagnoli, 12 h (2 CFU), April-June
franco.bagnoli@unifi.it
We shall review the evolution of computers and their applications, from the first mainframes dedicated to computing, to the evolution in the business world, the birth of the Internet, the switch to personal

computers, and finally to the internet & microprocessor world of today. In parallel, we shall examine the development of operating systems and computer languages, the social impact and its driving force, the connections with literature and science fiction.