PhD Course in Physics and Astronomy
University of Florence

List of courses for the academic year 2025-2026

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 from samples. Other subjects are: digital signal processing with LTI (Linear Time-Invariant) systems, discrete Fourier transforms, Z-transform, design of custom processing systems, wavelets.

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.

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.

Biophotonics applied to clinical biomedical imaging, Francesco Pavone – 12 h (2 CFU), April -June
francesco.pavone@unifi.it
Elements of biomedical imaging” introduces biophotonics-based techniques designed to characterize pathological tissues in both ex vivo and in vivo diagnostic contexts. Special focus is given to oncological applications, particularly for intraoperative guidance and anatomopathological support. The course will cover a range of imaging and spectroscopic methods, illustrated with examples such as online and liquid biopsies, which provide insights into tissue morphochemistry and chemical composition to support diagnosis and therapeutic decision-making.

ASTROPHYSICS

contacts: Prof. Romoli, marco.romoli@unifi.it; Prof. 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: from molecular clouds to planetary systems, Eleonora Bianchi, Linda Podio - 12 h (2 CFU), April-June
eleonora.bianchi@inaf.it
linda.podio@inaf.it
The course offers a comprehensive introduction to Astrochemistry, focusing on the formation, evolution, and destruction of molecules in space. We establish the foundation of the field by covering key theoretical aspects, including gas-phase and surface reactions alongside the principles and methods of Radiative Transfer. The second half of the course focuses on cutting-edge science and open questions in the field. We trace the complex chemical evolution of star and planet formation through various astrophysical environments, examining the chemistry of molecular clouds and prestellar cores, protostars, jets, outflows, and shocks. We then analyze chemical complexity in planet-forming disks and explore the chemistry of comets and the Solar System. Finally, we discuss current observational challenges and the capabilities of future instruments.

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

Gaussian Beam Quasioptical Propagation and Application to the Design of Antennas and Radio Telescopes, Luca Olmi - 12 h (2 CFU) March-May
luca.olmi@inaf.it
This course combines a general introduction to Gaussian beams and quasioptical propagation with practical applications, in particular devoted to the design of radio telescopes and their auxiliary optical components. Quasi-optics refers to using a combination of waveguide and optical techniques to design high performance instruments and systems, from the cm- to the (sub)mm-wave regime. Quasi-optical techniques are commonly used in multi-band radiometers, large telescopes, and other microwave instrumentation. An introduction to Gaussian beams and quasioptical analysis will be given as well as a look at the use of ray matrices and higher-order modes. All of these methods are discussed in the context of the design of optical systems. Then, an introduction will be given to the computational techniques commonly used to solve electromagnetic problems in microwave engineering, together with an introduction to the use of commercially available EM software packages (such as GRASP and FEKO).

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.

Star Formation in the Milky Way in the era of large surveys, Eleonora Zari - 12 h (2 CFU) - March-May
eleonoramaria.zari@unifi.it
The advent of large-scale stellar surveys has revolutionized the field of star formation by enabling precise studies of young stars and their spatial distribution, kinematics, and ages. On small scales, the fine spatial and kinematic structure of young stellar populations has been revealed, uncovering subgroups and complex dynamics within star formation regions. On large scales, maps of massive stars and young associations across the Milky Way have provided direct constraints on its spiral structure and recent star formation history. The goal of this course is to provide an overview of modern observational approaches to studying star formation, covering both methodologies and their scientific applications. The course will introduce major stellar surveys (Gaia, SDSS-V, 4MOST) and their role in mapping the Milky Way's stellar populations. It will cover the identification of young stars through photometric, spectroscopic, and astrometric diagnostics, the use of kinematics to study clustering and Galactic dynamics, and techniques for age determination. Finally, it will address the role of young stars in tracing spiral arms and uncovering the Milky Way's recent star formation history.

Theoretical and computational aspects of stellar dynamics, Pierfrancesco Di Cintio - 18 h (3 CFU) - March-April
pierfrancesco.dicintio@unifi.it
- Potential theory , 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 regularization

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, Eugenio Berti - 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 ray physics and their detection through direct measurements. After a brief historical introduction and a survey of cosmic ray phenomenology, the course will outline the classical models of cosmic rays and the techniques used for direct detection. Finally, an overview will be presented of the most recent measurements that have challenged our understanding of cosmic ray acceleration and propagation. To follow the course, it is not necessary to have attended specific courses in particle physics or astrophysics. A seminar-style approach will be followed, while revisiting the fundamental concepts necessary to understand the latest developments.

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.

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 and Dark Matter search. Giuseppe Latino - 12 h (2 CFU), January-March
giuseppe.latino@unifi.it
The aim of this course is to give an introduction to the rapidly-evolving interdisciplinary field related to the development of new detection techniques for particle physics based on quantum sensing (QS).

Exploiting the extreme sensitivity of quantum systems is in fact considered to have promising potentiality to go beyond the limits of traditional measurement approaches, in particular in the search for Dark Matter (DM). After a general introduction to the field, several examples of ongoing or foreseen direct DM search experiments based on QS will be given on a seminar level.
Given its introductory nature, this course can be attended by students with no previous background in the field.

Calorimetric techniques for high energy particles detection. Eugenio Berti - 12 h (2 CFU), February-April
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 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, Fabry-Perot cavities. Optical readout, thermal noise. Present and future interferometers.
The course will be held on a "basic" level and can also be attended by students with no previous background in the field.

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.
The course will be held on a "basic" level and can also be attended by students with no previous background in the field.

Into the Fog: Building and Exploring a Particle Detector. Antonio Cassese and Lorenzo Sestini - 24 h (4 CFU), January-June
antonio.cassese@cern.ch, lorenzo.sestini@cern.ch
This hands-on doctoral course guides students through the design, construction, and operation of a **cloud chamber,** one of the most iconic particle detectors in the history of physics. By combining theory and practice, participants will gain a deep understanding of how charged particles interact with matter and how their paths can be made visible through condensation trails. Students will develop practical skills in **scientific instrumentation, experimental problem-solving,** and **scientific communication,** culminating in the creation of a fully functional detector and a short scientific report. The course, aiming to hone instrumental science skills regardless of the detector developed and its applications, is suitable for physics students of all backgrounds.

PHYSICS OF MATTER

Contacts: Prof. F. Biccari, francesco.biccari@unifi.it; Prof. F. 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. (January-March)
Fabrizio Martelli (9 h, 1,5 CFU), Federico Tommasi (3 h, 0,5 CFU)
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 and will be offered using a tutorial approach for non-experts in the field. 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. (April-June)
Francesco Piazza 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, Nicoletta Granchi (12 h, 2 CFU, April-June)
francesco.biccari@unifi.it, nicoletta.granchi@unifi.it
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.

Quantum information and algorithms. Paola Verrucchi, (24 h, 4 CFU, January-March)
paola.verrucchi@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, equilibrium 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 (18 h, 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.

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 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

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, Domenico Seminara domenico.seminara@unifi.it) - Aldo Cotrone (aldolorenzo.cotrone@unifi.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.

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.

Gravitational Waves and Stochastic Backgrounds: Theory and Implications, Michele Redi, 12 h (2 CFU), April-June
michele.redi@fi.infn.it
This course will cover the basics of gravitational waves from a theoretical perspective, with a primary focus on stochastic gravitational wave backgrounds. Outline: Foundations of general relativity. Gravity waves in linearised theory. Quadrupole formula and Hulse-Taylor binary pulsars. Stochastic gravity waves from inflation. Stochastic gravity waves from first order phase transition and other mechanisms in physics beyond the Standard Model. Space and ground-based gravity wave experiments: LIGO, Lisa and future facilities. Pulsar timing Arrays. Hellings and Downs curve. Recent evidence of GW stochastic background at nanoHertz frequencies.

Phase Transitions and Renormalization Group. Stefania De Curtis, 18 h (3 CFU), April-June
decurtis@fi.infn.it
The course aims at emphasizing the relations between particle physics and the theory of critical phenomena. Quantum field theory has become the framework for the discussion of all the fundamental interactions except, possibly, gravity. Surprisingly it has also provided a framework for the understanding of second order phase transitions in statistical mechanics.
Contents: introduction to phase transitions, the Landau theory, the gaussian model, anomalous dimensions, critical exponents and scaling laws, the renormalization group à la Wilson (Kadanoff approach), fixed points, the renormalization group equations in differential form, perturbative calculation of the critical exponents: ε expansion.

GENERAL COURSES

These courses do not belong to a single research area, so they can be considered in the "courses outside your own area".

A hands-on introduction to Machine Learning for research. Michele Ginolfi, Sandra Doria (18 h, 3 CFU) January, at Garbasso
sandra.doria@lens.unifi.it, michele.ginolfi@unifi.it
This course will cover the basics of Machine Learning for research, 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 is 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, classification, and generative tasks, introducing both supervised and

unsupervised learning algorithms such as clustering, random forests, and neural network architectures ranging from fully connected to convolutional models. It will then progress toward more advanced approaches, including transformer-based multimodal large language models, with a focus on their core principles and cross-domain applications. 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.

Machine learning techniques for physics. Lorenzo Buffoni (18 h, 3CFU, January-March)
lorenzo.buffoni@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.

Random Matrix Models: an introduction. Filippo Colomo **(**12 h, 2 CFU), April-June
colomo@fi.infn.it
Random Matrix Models have 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.

Laboratory instrumentation control, signal generation and data acquisition. Vladislav Gavryusev, Simone Valdré (18 h, 3 CFU), December 2025 - January 2026
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.

Electronics for experimental physics. Davide Bacco, Nicola Poli, 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.

SOFT SKILL 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.