**List of courses of the doctorate of research in Physics, University of Ferrara - 2018**

*Courses are activated on demand*

## List of courses and lectures

- Alessandro Drago: *Extreme Matter* – 10 h – 3.3 CFU
- Alessandro Drago: *Artificial intelligence, Montecarlo techniques and neural networks* – 10 h – 3.3 CFU
- Alessandro Drago: *An introduction to the use of Mathematica* – 10 h – 3.3 CFU
- Roberto Cherubini: *Radiation biology* – 32 h – 6 CFU
- Giulio Stancari: *Introduction to beam physics and accelerator technology* – 15 h – 5 CFU
- Gianluigi Cibinetto*: Advanced Detection Techniques* – 16 h – 5.3 CFU
- Alberto Quaranta: *Optical Propeties of Nanomaterials* – 12 h – 4 CFU
- Enrico Bagli and Gianfranco Paternò: *Geant4 Tutorial* – 30 h – 6 CFU
- Giuseppe Ciullo: *Vacuum Technology* – 20 + 20 h – 6 CFU
- Cristiano Guidorzi: *The new era of multi-messenger and time domain Astronomy* – 14 h – 4.7 CFU
- Lorenzo Amati: *Extreme physics, cosmology and multi-messenger astrophysics with Gamma-ray Bursts* - 8 h – 2.7 CFU
- Marco Baldi: *Dark energy and modified gravity* – 6 h – 2 CFU
- Massimo Meneghetti: *Gravitational Lensing* – 6 h – 2 CFU
- Piero Rosati: *Astrophysical Probes of Dark Matter* – 6 h – 2 CFU
- Roberto Gilli: *The First Black-Holes* – 6 h – 2 CFU
- Mauro Orlandini: *Time-series analysis techniques* - 6 h – 2 CFU
- Massimiliano Lattanzi: *Particle Cosmology* – 16 h – 5.3 CFU
- Augusto Sagnotti: *Introduction to String Theory* – 16 h – 5.3 CFU
- Alessandro Gruppuso: *Introduction to theoretical cosmology with example of data analysis* – 16 h – 5.3 CFU
- Paolo Natoli: *Cosmic Microwave Background statistics and data analysis* – 8 h – 2.7 CFU

Loris Giovannini: *Spin waves in solids, films and nanostructures* - 24 h – 8 CFU
Ferruccio Petrucci: *Le applicazioni dell'Archeometria all'Università di Ferrara* – 24h - 8 CFU
Luca Tomassetti: *Phyton in Physics* – 12h – 4 CFU
Luca Caneschi: *Group Theory* - 6h – 2 CFU

## Conversion rate of course duration into credits is 1/3 CFU per hour with a saturation at 6 CFU per course

# Programs

Title:
Extreme Matter

Lecturer:
Prof. Alessandro Drago (unife)
drago@fe.infn.it

Duration:
10 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
The course will discuss the theoretical ideas about matter under extreme conditions of density and temperature and how those ideas can be tested in lab experiments and by analyzing astrophysical observations. In particular this will be discussed:
- Which resonances can be excited going to large baryonic density?
- Can quark matter appear in compact stars?
- How to describe the behavior of matter at very large temperatures?
- What are the freeze-out temperatures, the critical end-point and the softest point?
- What can we learn from new experiments as the one planned at GSI?
- What can we learn from the detection of gravitational waves?

Title:
Artificial intelligence, Montecarlo techniques and neural networks

Lecturer:
Prof. Alessandro Drago (unife)
drago@fe.infn.it

Duration:
10 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
A short introduction to artificial intelligence will be provided, by discussing toy-problems and how they can be approached. The course will then touch upon Montecarlo techniques (including Metropolis algorithm and simulated annealing) and will introduce a couple of examples of neural networks able to memorize a pattern and to interpolate-extrapolate some given data.

Title:
Radiation biology

Lecturer:
Dr. Roberto Cherubini (LNL-INFN)
roberto.cherubini@lnl.infn.it

Duration:
32 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:

The course will focus on:
• the interaction of the ionising radiation with the matter and in particular with living-matter (biological structures); the parameters characterizing the energy deposition process; introduction to dosimetry
• the mechanisms underlying the radiation induced DNA damage, chromosome aberrations, mutations, cell inactivation, somatic effects; how the "radiation quality" affects the radiation induced biological effects
• outline of experimental (in-vitro and in- vivo) and theoretical (phenomenological and mechanistic biophysical models; Monte Carlo simulation techniques) approaches
• implications for radiation protection (on Earth and in Space) and applications in radiotherapy (with external beams and internal emitters; hadron-therapy).

Title:
Introduction to beam physics and accelerator technology

Lecturer:
Dr. Giulio Stancari (Fermilab)
For info contact massimiliano.fiorini@cern.ch

Duration:
To be defined

Abstract:
In this lecture series, the main concepts and observations related to charged-particle beams in accelerators will be explored, including the following topics: purpose of accelerators and overview of the field; luminosity; linear longitudinal and transverse dynamics; nonlinear dynamics and chaos; intense beams with self fields. The course will conclude with a discussion of current research areas and opportunities for young researchers.
The lectures are open to undergraduate and graduate students. Prerequisites are classical mechanics, electromagnetism, and special relativity at the undergraduate level. No previous knowledge of particle or accelerator physics is necessary.

Title:
Advanced Detection Techniques

Lecturer:
Dott. Gianluigi Cibinetto (INFN Ferrara)
cibinett@fe.infn.it

Duration:
16 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
The course aims primarily at experimental nuclear/particle or astro-particle physics PhD students, interested in learning about the state-of-the-art development in particle detection techniques. Among the topics covered are silicon detectors, gas detectors, calorimeters and particle identification systems. Particular attention will be given to the reconstruction software and to the detector simulation. Depending on the availability, laboratory exercises might also be possible.

Title:
Optical Propeties of Nanomaterials

Lecturer:
Prof. Alberto Quaranta (University of Trento)
alberto.quaranta@unitn.it

Duration:
12 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
The aim of the course is to review the optical properties of materials and nano-materials, starting from the interaction of IR-visible electromagnetic waves with matter and defining optical parameters. Optical transitions involving luminescence will be also presented. Then optical analyses techniques on bulk, thin film and particulate materials will be presented. The optical properties of nano-materials deal the second part of the course, where the dependence of optical transitions with the nanoparticle dimension are discussed for quantum dot semiconductors, and light scattering from metal nanoparticles is discussed. Analyses methods and applications will be also presented.

Title:
Geant4 Tutorial

Lecturer:
Dr. Enrico Bagli (FE-INFN) and Dr. Gianfranco Paternò (FE-INFN)
enrico.bagli@gmail.com, paterno@fe.infn.it

Duration:
30 hours - Lectures will be started at a time of common availability of the lecturer and the students

Abstract:
Geant4 is a Monte Carlo toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. The course will present a full overview of the main characteristics of the Geant4 toolkit. The goal of the course is to make the participants able to install and to use Geant4 through both theoretical lessons and hands-on practical sessions.

The following topics will be covered:
- Geant4 installation for Linux
- Definition of geometry and materials
- Definition of primary particles sources
- Definition of physical processes and selection of a physics list
- User interfaces, macros, visualization
- Accounting physical quantities (« scoring »)

A basic level of C++ programming language is required:
- basic/syntax: if statements, loop constructs functions, pointers, references, passing function arguments
- classes: class definition and implementation, class data members and member functions/methods, static data members, member functions/methods, base class and derived class, pure virtual function/method
- standard template library: iostream, vector

Title:
Vacuum Technology

Lecturer:
Dr. Giuseppe Ciullo (Physics and Earth Department – University of Ferrara and INFN of Ferrara)
cllgpp@unife.it

Duration:
20 hours - Lectures will be arranged in the period September-December in agreement with the PhD students.
10 h of lectures and 10 or more, if student are interested to more experience, of laboratory work.

Abstract:
The course will cover a practical approach to the vacuum technology, having as main purpose to provide practical indication on how to design and implement a vacuum system, with it's control and automatization.

The following topics will be covered:
- Vacuum technology, physical fundamental laws of gases and their application to vacuum technology.
- Physical quantities of interest for vacuum dimensioning: Throughput, Pumping Speed, Conductance, and their use in real systems. Macroscopic description for its practical use, and microscopic description, in order to understand proper uses of vacuum formulae.
- Source of throughput in vacuum systems, production of vacuum, measurements of vacuum. Example of system and design of at least one system to be verified in laboratory works.

- Installation and test of the designed systems.

As a conclusion of the courses, it's required a short report on the experimental work, dealing with designing and testing at least one vacuum system.

Title:
The New Era of Multi-messenger and Time Domain Astronomy

Lecturer:
Dr. Cristiano Guidorzi (Unife)
guidorzi@fe.infn.it

Duration:
14 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
We just entered the era of multi-messenger and time domain astronomy, where a number of synoptic and sensitive facilities survey the sky across different windows (whole electromagnetic spectrum, gravitational waves, high-energy neutrinos) to detect transient sources and alert the community for multi-wavelength follow-up campaigns. In August 2017 the simultaneous detection of gravitational and electromagnetic waves from a binary neutron star merger has spectacularly ushered in a golden age of the study of the transient Universe. The multi-messenger campaigns harvested an unprecedented amount of data that turned into a giant leap across intertwined disciplines, such as general relativity, stellar evolution, nuclear physics, and cosmology, and in the future holds the promise for analogous ground-breaking discoveries.
In the years to come, there will be a fleet of big experiments operating at several wavelengths (e.g., LSST, SKA) that will deliver a flood of alerts per night. Furthermore, experiments devoted to astrophysical messengers other than electromagnetic waves (high-energy neutrinos in addition to the already mentioned gravitational waves) have just begun to real-time report on transients sources. This increasing flood of information poses a challenge to everyone involved in follow-up programmes as for an effective processing and mining.
I will go through the following topics:
- A revolution in astronomy caught in its infancy: current status.
- The multidisciplinary facets in the era of big astronomical data.
- A survey of new kinds of transients discovered so far and their astrophysical implications (e.g., superluminous supernovae, fast blue transients, fast radio bursts, superflares from solar-type stars, tidal disruption events).
- What's next?

Title:

Extreme physics, cosmology and multi-messenger astrophysics with Gamma-Ray Bursts

Lecturer:
Lorenzo Amati (INAF – IASF Bologna)
amati@iasfbo.inaf.it

Duration:
8 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
GRBs are the most luminous electromagnetic explosions in the universe, occurring roughly once or twice per day, producing most of their energy in the form of gamma-rays and lasting from seconds to minutes. Because of their huge luminosities (up to > 1053 erg radiated in few tens of seconds) emitted by the most relativistic jets known (Gamma > 100) and their redshift distribution extending up to at least z ~9-10, these sources offer enormous potential as powerful probes of the universe, as test-beds for fundamental physics, and as laboratories for matter and radiation under extreme conditions. Despite the huge observational and theoretical efforts of the last 20 years, our full comprehension of the GRB phenomenon and is still affected by several open issues, including: GRBs as probes of the early Universe, GRBs as probes of fundamental physics, physics of GRB prompt emission and nature / structure / collimation of the jet, GRB/SNe connection. Moreover, as demonstrated by the recent historical detection of gravitational waves from the merger of two neutron stars and of its associated e.m. emission, the study of GRB constitutes a pillar of the newly born field of multi-messenger astrophysics. Sensitive measurements by next generation gamma-ray experiments, also complemented by lower-energy instrumentation, will allow a substantial step forward in these GRB-related research areas which are of extreme interest for several fields of astrophysics, cosmology and fundamental physics, and will provide an ideal synergy with the large multi-wavelength and multi-messenger facilities that will be operative in the next decade (e.g., E-ELT, SKA, CTA, ATHENA, Gravitational Waves Observatories, neutrino observatories).

Title:
Astrophysical Probes of Dark Matter

Lecturer:
Piero Rosati (Unife)
rosati@fe.infn.it

Duration:
6 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
Lectures will review the main methodologies, as well as recent advances, in constraining Dark Matter (DM) properties from astrophysical observations on galactic and cosmological scale. Specifically,
- the inner structure of DM halos on galaxy and cluster scale from lensing, dynamics and X-ray observations
- recent constraints on DM properties from the distribution of matter from wide and deep surveys
- the role of baryons when constraining DM properties
- other indirect probes of DM from high-energy astrophysics

Title:
Gravitational Lensing

Lecturer:
Massimo Meneghetti (INAF – OA Bologna)
massimo.meneghetti@oabo.inaf.it

Duration:
6 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
I will give a brief introduction on the basic of gravitational lensing and then I will focus on the modeling of gravitational lenses on the scale of galaxy clusters.
More extensively, I will cover the following topics:
- light deflection
- lens equation
- lens distortion, magnification, and multiple images
- extended lenses
- the modeling of a galaxy cluster: strategies for combining weak and strong lensing

Title:
Dark energy and modified gravity

Lecturer:
Marco Baldi (University of Bologna)
marco.baldi5@unibo.it

Duration: 6 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
The observed acceleration of the expansion of the Universe represents one of the deepest mysteries of modern physics. Despite more than two decades of theoretical and observational investigations, no evidence has been found to disregard the standard cosmological constant as the simplest description for the acceleration. However, alternative models might provide a more natural framework to explain this phenomenon and their observational footprints might be detected through an anomalous growth of cosmic structures by the next generation of wide surveys.
In these lectures I will introduce the most relevant alternatives to the cosmological constant and discuss their implications for present and future observations. In particular, the lectures will cover the following aspects:
- The observational evidence of cosmic acceleration
- The standard cosmological model and the role of the cosmological constant
- Dynamical Dark Energy and Modified Gravity as alternatives to the cosmological constant
- Structure formation in the standard and non-standard models
- Nonlinear structure formation and N-body simulations

Title:
The first black holes

Lecturer:
Roberto Gilli (INAF – OA Bologna)
roberto.gilli@oabo.inaf.it

Duration:
6 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
The course will review current observations of the most distant quasars in the Universe and discuss theories on the formation and growth of the black holes powering these systems. Some of the fundamental, yet open, questions that will be touched in the course are:
- at what epoch the first generation of super-massive black holes (SMBHs) form?
- what is their origin (e.g. light vs heavy seeds)?
- where and how early seeds could grow to SMBHs?
- do BHs form before their host galaxies?
- who re-ionized the Universe?

Title:
Time-series analysis techniques

Lecturer:
Mauro Orlandini (INAF/IASF Bologna)
orlandini@iasfbo.inaf.it

Duration: 6 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
The study of time-series, that is data obtained from observations collected sequentially over time, is an essential tool for many disciplines, ranging from astronomy to economics.
Their study allows the derivation of important properties of the processes that originated them, both from a physical and a statistical point of view. For example, in the study of variability of compact objects in astrophysics, the correlation between the spectral and temporal properties of the sources allows the derivation of important quantities, like mass and angular momentum, that should not be available through the two data analysis alone.
The course will give the basics of the analysis, both from a theoretical and practical point of view. Real data series will be analyzed by using the Xronos package, freely available from the NASA/HEASARC site. Power spectra will be extracted, modeled and discussed in order to obtain information on the possible physical processes that originated them.

Title:
Introduction to theoretical cosmology with example of data analysis

Lecturer:
Dr. Alessandro Gruppuso (INAF - OAS Bologna)
gruppuso@iasfbo.inaf.it

Duration:
16 hours
lectures will be started at a time of common availability of the lecturer and the students

Abstract:
These lectures provide an introduction to modern cosmology and include exercises and examples of data analysis. The overall approach is theoretical with clear connections between analytical expressions and astrophysical/cosmological observations. Main topics covered: cosmological principle and Einstein equations, derivation of the Friedmann-Lemaitre-Robertson-Walker (FLRW) equations, solutions of the FLRW equations for important cosmological fluids (matter, radiation and vacuum energy), basics of the Big Bang model with its main conceptual shortcomings, inflation, concept of distance and its fundamental dependence on the cosmological parameters, cosmic microwave background (CMB), constraints of the cosmological parameters with two independent observations (SuperNovae Type Ia and CMB acoustic scale) that are treated both separately and jointly, test of the cosmological principle with CMB anisotropies using the so called Maxwell vectors expansion.

Title:
Particle Cosmology

Lecturer:
Dr. Massimiliano Lattanzi (INFN-FE)
lattanzi@fe.infn.it

Duration:
16 hours
The schedule of the lectures will be agreed with the students.

Abstract:
The aim of the course is to provide an introduction to particle cosmology, discussing how the ideas of particle physics are applied to the study of the Universe, especially in its early stages, and how, on the other hand, cosmological observations can be used to test particle physics theories. In particular, the following topics will be discussed:
- thermodynamics in the expanding Universe
- particle abundances: freeze-out and freeze-in
- neutrino cosmology
- dark matter and the WIMP paradigm; supersymmetric DM candidates: the neutralino
- non-WIMP dark matter: sterile neutrinos, axions, majorons.

Prior knowledge of the basics aspects of the standard models of cosmology and particle physics is appreciated but not mandatory.

Title:
An introduction to the use of Mathematica.

Lecturer:
Prof. Alessandro Drago (Unife)
drago@fe.infn.it

Duration:
12 hours
The schedule of the lectures will be agreed with the students.

The course aims at providing a basic introduction to the use of Mathematica. It will cover the main features of the program so to learn how to plot functions, to compute derivatives and integrals, to solve ordinary and differential equations and to manipulate lists and matrixes. It will be based on the concrete use of the code running on the personal laptop of the students.

Title:
Cosmic Microwave Background statistics and data analysis

Lecturer:
Prof. Paolo Natoli (Unife)
paolo.natoli@unife.it

Duration:
9 hours
The schedule of the lectures will be agreed with the students.

Abstract:
I will discuss selected items in CMB statistics and data analysis, including:

Map making for CMB experiments
harmonic analysis and correlation functions on the 2-Sphere
Power spectrum estimation
Likelihood modelling

Prior knowledge of the basics aspects of CMB physics is is useful but not mandatory.

Title:
**Le applicazioni dell'Archeometria all'Università di Ferrara**

- Lecturer:
Prof. Ferruccio Petrucci (Unife)
petrucci@fe.infn.it

Duration:
12 seminari, 24 ore

Argomento:
le tecniche archeometriche sviluppate ed eseguite (con una sola eccezione) nel Laboratorio di Archeometria del Dipartimento di Fisica e Scienze della Terra, con seminari informativi e case reports.

**Title:**
Spin waves in solids, films and nanostructures

- Lecturer:
Prof. Loris Giovannini (Unife)
giovannini@fe.infn.it

Duration:
24 hours
Lectures will be started at a time of common availability of the students and lecturer.

Abstract:
This theoretical course primarily cover the magnetic behavior of nanostructures, a topic of current interest in fundamental physics, data storage and processing technology. After a preamble, where the tools used in the quantum description of collective excitations in solids are introduced and discussed in detail, the main properties of spin waves (polarization, dispersion curves) in different approximations and structures are considered. The models currently used for the interpretation and analysis of the behavior of these excitations in nanometric structures (single particles and arrays of interacting particles, i.e. magnonic crystals) are then presented.

The following topics are covered:

- Second quantization theory of fermion and boson fields, with application to the interacting electron gas in metals (Hartree and Hartree-Fock approximation).
- Magnons (ferromagnetic and antiferromagnetic).
- Classical (continuum) approach to spin waves in solids.
- Bulk equations, boundary conditions, film and surface spin waves.
- Micromagnetism.
- Spin waves in insulated nanoparticles of different shape and size.
- Spin waves in magnonic crystals.

A basic knowledge of solid state physics and of magnetism in condensed matter is required.

**Title:**
Phyton in Physics

Lecturer:
Prof. Luca Tomassetti (Unife)
luca.tomassetti@fe.infn.it

Duration:
12 hours
Lectures will be started at a time of common availability of the students and lecturer.

Abstract:
This course will mostly be practical. It will cover the basics of Python Language and its application in the data manipulation and analysis in Physics.
The main topics will be: Running Python and iPython; Language basics, core syntax, object orientation: Objects and operators, Numbers, Strings, Lists and looping, Dictionaries, Conditions, Methods, Scripting, Modules.
Additional topics will be addressed with the enrolled students.
A basic knowledge of programming is required.

**Title:**
Group Theory

Lecturer:
Prof. Luca Caneschi (infn)
Luca.caneschi@fe.infn.it

Duration:
6 hours
Lecture will be held from 19 to 21 of March