List of courses of the doctorate of research in Physics,
University of Ferrara – 2023/24

Courses are activated on demand

List of courses and lectures

- Alessandro Drago: *Extreme Matter* – 9 h – 3 CFU
- Alessandro Drago: *Artificial intelligence, Montecarlo techniques and neural networks* – 12 h – 4 CFU
- Giulio Stancari: *Introduction to beam physics and accelerator technology* – 15 h – 5 CFU
- Gianluigi Cibinetto*: Advanced Detection Techniques* – 15 h – 5 CFU
- Alberto Quaranta: *Optical Propeties of Nanomaterials* – 12 h – 4 CFU
- 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* – 6 h – 2 CFU
- Lorenzo Amati: *Extreme physics, cosmology and multi-messenger astrophysics with Gamma-ray Bursts* - 9 h – 3 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* – 9 h – 3 CFU
- Alessandro Gruppuso: *Introduction to theoretical cosmology with example of data analysis* – 15 h – 5 CFU
- Paolo Natoli: *Cosmic Microwave Background statistics and data analysis* – 9 h – 3 CFU
- Loris Giovannini: *Spin waves in solids, films and nanostructures* - 24 h – 8 CFU
- Ferruccio Petrucci: *Le applicazioni dell'Archeometria all'Università di Ferrara* – 6h - 2 CFU
- Luca Tomassetti: *Phyton in Physics* – 12h – 4 CFU
- Augusto Sagnotti: *Introduction to String Theory* – 16 h – 5.3 CFU
- Nicoletta Krachmalnicoff : *Neural Networks: Theory and Practice* – 6 – 2 CFU
- Luca Pagano*: Statistical techniques in Cosmology* – 9 ore – 3 CFU
- Martina Gerbino: *Neutrino Cosmology* – 6 h – 2 CFU
- Laura Bandiera e Paolo Cardarelli: *Innovative x- and γ- radiation sources and their applications* – 15 h – 5 CFU
- Isabella Masina and Domenico Stanzial: *Waves, Acoustics and Music* – 15 h – 5 CFU
- Tiziana Trombetti: *Cosmic backgrounds and peculiar motion* - 9h - 3 CFU
- Jorge Rueda: *Self-gravitating systems in general relativity* – 6 h – 2 CFU
- Sebastiamo Fabio Schifano, Enrico Calore and Luca Tomassetti: *High performance and high throughput computing in data science* – 12h – 4 CFU
- Alessandro Minotti: *Neutrinos – a history of oscillations*– 12h – 4 CFU
- Paolo Lenisa - *Energy and Society* – 3 to 6 CFU
- Marco Guarise - *Cryogenic particle detectors* - 9 ore – 3 CFU

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

Programmes

Title:
Extreme Matter

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

Duration:
9 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:
12 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:
Introduction to beam physics and accelerator technology

Lecturer:
Dr. Giulio Stancari (Fermilab)
For info contact cibinetto@fe.infn.it

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:
15 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 Properties of Nanomaterials

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

Duration:
2-3 seminars
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. Gianfranco Paternò (FE-INFN)
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:
6 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:
9 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:
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/OAS Bologna)
mauro.orlandini@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:
15 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:
9 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
- 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:
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:
Applicazioni dell'Archeometria all'Università di Ferrara

- Lecturer:

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

Duration:
ciclo di seminari, 6 ore

Argomento:
le tecniche archeometriche sviluppate ed eseguite 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:
Neural Networks: Theory And Practice

Lecturer:
Dr.ssa Nicoletta Krachmalnicoff (SISSA)
nkrach@sissa.it

Duration:
6 hours
Lectures will be started at a time of common availability of the students and lecturer, during spring semester
Credits:
2 CFU

-Abstract:
The field of Neural Networks (NN) and Deep Learning is experiencing an unprecedented growth with important applications in several fields of Physics.

In this course, divided into two lectures of about 2 hours each, I go through the fundamental concepts beneath NNs, providing to the students the knowledge needed to understand how NNs work, together with practical tools on how to develop them.

In the first lecture I revise the basic theory of NNs, with a deep explanation on how fully connected NNs can be built and train.
The first practical tutorial (in python) is focused on the development of a simple NN from scratch, with the explicit coding of all the steps needed for the computation.

The second lecture is focused on Convolutional Neural Networks (CNNs) and Generative Adversarial Networks (GANs). This lecture is again divided into a theoretical part, where the two architectures are introduced, and practical tutorials, developed using the Keras Library for NNs.
In the first exercise a CNN for Galaxy classification is built. In the second tutorial an example on how to use GANs to generate Cosmic Microwave Background maps is provided.
Although the two tutorials are applied to problems in the Astrophysics field, the concepts therein introduced are of valuable interest also for other branches in Physics.

The lectures and tutorials are available on github at:
https://github.com/NicolettaK/NN_lectures

Title:
Statistical techniques in Cosmology

Lecturer:
Dr. Luca Pagano (UniFe)
luca.pagano@fe.infn.it

Duration:
9 hours
Lectures will be started at a time of common availability of the students and lecturer, during spring semester
Credits:
3 CFU

Abstract:
In the last decades cosmology entered in the era of large datasets, leading to a breakthrough in our knowledge and understanding of the Universe. This has been supported by a corresponding improvement of the data analysis techniques.
In this course, divided into 3 lectures of about 3 hours each, I will cover a number of topics in cosmological data analysis.
In particular:
* In the first lecture, I will briefly recall the basis of probability and of the bayesian approach, introducing the general problem of interpreting data in the context of a theoretical model. I will then discuss the Fisher matrix formalism and how to use it to forecast the capability of a forthcoming survey to constrain cosmological parameters
* In the second lecture I will introduce, for different cosmological observables, the likelihood function for connecting experimental data to cosmological models
* In the third lecture I will discuss the usage of Monte Carlo Markov Chains methods to explore efficiently the parameter space, focussing on Metropolis-Hastings, Multinest and Gibbs sampling.
The field of application and the examples shown are connected to cosmology and astrophysics but the methods introduced are directly applicable to other branches in Physics.

Title: Neutrino Cosmology

Lecturer:
Dr. Martina Gerbino (INFN)
gerbinom@fe.infn.it

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

Credits:
2 CFU

Abstract:
The presence of a cosmic background of relic neutrinos is a robust prediction of the standard cosmological model. A direct detection is extremely difficult and still lacking. Nevertheless cosmological observations are a powerful probe of neutrino properties, and cosmological bounds on neutrino masses and number are in agreement with both theoretical predictions and laboratory searches.

In this series of lectures, we first discuss the role of neutrinos in shaping the cosmological evolution at both the background and perturbation level, and describe their effects on cosmological observables such as the cosmic microwave background and the distribution of matter at large scale (3h). We then present the state of the art concerning the constraints on neutrino masses and neutrino properties beyond their mass from those observables, and also review the prospects for future experiments (2h). We also discuss the prospects for determining the neutrino hierarchy from cosmology, and the complementarity with laboratory experiments (1h).

Title: Waves, Acoustics and Music

Lecturers: Prof. I. Masina (Unife) (coordinator), in collaboration with: Dr. D. Stanzial (CNR – IMM Bologna), Dr. G. Lo Presti (CERN), Prof. G. Rispoli (UniFe), Dr. C. Visentin (Eurac Research)

Contact: masina@fe.infn.it

Duration: 21 hours (7 cfu), lectures will start in March 2024

Methodology: blended learning

Target: PhD students in Physics, Mathematics and Engineering

Abstract:
After an introduction to the general theory of waves (including electromagnetic and gravitational waves), we will discuss sound waves. We will then focus on relevant case studies for musical instruments, such as vibrating strings and air columns.
The second part is devoted to the earing system, from the point of view of biophysics, and to psychoacoustics, from the point of view of signal processing. We will present auditory demonstrations about harmonics, timbre, beatings, critical bandwidth, fundamental bass, etc.
The third part deals with acoustic aesthetics and music: we will review the physical foundations of consonance and dissonance for dyads and triads. We will then review the historical development of Western musical scales, from Pythagoras to microtonal temperaments, also in relation to harmony and tonality. In addition, we will analyze the recent mathematical representations based on the Tonnetz, introduced by Euler.
In the fourth part, we will introduce the notions related to the engineering of ambient acoustics; a visit will be organized to the Anechoic Chamber. We will also discuss issues related to acoustic energetics; a visit will be organized to the Acoustic Laboratory, in agreement with CNR-IMM.

Title:
Cosmic backgrounds and peculiar motion
Lecturer**:** Tiziana Trombetti (INAF)
trombetti@ira.inaf.it

Duration: 9h
Lectures will be started at a time of common availability of the students and lecturer
Credits: 3 CFU

Topics:

- Peculiar motions in the Universe and bulk effects
- Peculiar motion of an observer and boosting effects
- Cosmological and astrophysical backgrounds from radio to far-IR
- Effects on the dipole and higher multipoles
- Data analysis and implications

Brief description:

The global velocity of a galaxy is the sum of the velocity due to the Hubble flow and the local motion of the galaxy within its cluster or group environment due to local gravitational effects. The deviations from a pure Hubble flow is referred to as a peculiar velocity. Its analysis represents a valuable tool to probe the underlying distribution of dark matter on large scales and test the cosmological predictions.
Peculiar velocities are predicted by all structure formation scenarios and confirmed by many surveys.

An observer does not simply follow the smooth universal expansion, but has its own peculiar motion as well. The dipolar anisotropy of the Cosmic Microwave Background (CMB), in particular, has been essentially interpreted as the result of our drift flow (at roughly 600 km/sec) relative to the cosmic rest-frame.

The observer peculiar motion produces boosting effects in several observable quantities. They are remarkable in the anisotropy patterns at low multipoles, particularly in the dipole, with frequency spectral behaviours depending on the spectrum of the isotropic monopole emission.

The neutral and the re-ionized phase of the intergalactic medium associated with the primeval formation phases of bound structures, which are sources of photon and energy production, generates a remarkable 21-cm redshifted line signal, Comptonization and free free distortions. Important extragalactic background signals from the radio to the far-IR are expected from the integrated contribution of discrete sources. Remarkably, the early phases of stars and galaxies formation produces the Cosmic Infrared Background (CIB).

Using the spherical harmonic expansion, the frequency spectra of the background isotropic monopole emissions can be studied with a differential approach evaluating how they are transferred to the frequency spectra of the patterns at higher multipoles because of the observer motion, linking monopole and anisotropy analyses. The method relies on the quality of inter-frequency and relative data calibration by-passing the need of precise absolute calibrations.

Numerical simulations allow to assess the impact of instrumental performance, potential residuals from imperfect subtraction of foregrounds, mainly from our galaxy, and relative calibration uncertainties in the reconstruction of the above types of signals. Differently from the Galactic foreground, all the signal variations in various sky patches should be described by a well-defined pattern related to the observer motion.

Title:
Self-gravitating systems in general relativity

Lecturer:
Dr. Jorge Rueda (ICRANet/Unife)

email: jorge.rueda@icra.it

Duration: 6 hours
Lectures will be started at a time of common availability of the students and lecturer
Credits:
2 CFU

Abstract:
These lectures are devoted to study the formulation of the self-consistent equations of equilibrium governing self-gravitating systems in general relativity. The equations of the theoretical framework are then solved to infer the equilibrium structure of compact stars such as white dwarfs and neutron stars, as well of the dark matter in galaxies, under specific assumptions of the nature of the interior matter. Non-rotating and rotating, zero and finite temperature systems are treated. The effects of the structure on the object observables is analyzed. Focus on the study of realistic, astrophysical, state-of-the-art examples is given. These lectures are on the interior and exterior spacetime structure and not on the details on the derivation of the equations of state of matter, for which previous knowledge of statistical physics, solid state physics, thermodynamics, and basics of nuclear physics is assumed.

Title:
High performance and high throughput computing in data science

Lecturers:
Prof. Sebastiano Fabio Schifano (Unife) - Dr Enrico Calore – INFN – Prof. Luca Tomassetti (Unife)
schifano@fe.infn.it
luca.tomassetti@fe.infn.it
enrico.calore@fe.infn.it

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

Abstract:
Modern supercomputers are parallel processors, gaining their power from the concurrent execution of thousands of individual CPU-cores, each core in turn able to process vector operations. Developing efficient software to run on these systems requires parallel programming technologies to map at best the computing requirements of the application onto the hardware features of these systems. This course will cover all the fundamental concepts that underpin modern HPC providing hands-on experience, as students will explore these topics through the analysis of real parallel programs. These techniques can also be applied to standard multi-core processors as well as many-core processors, such as recent GP-GPUs and Xeon-Phi systems. Beside the high performance paradigm, high throughput computing is nowadays widely used in virtualized environments, when computation is loosely parallel or embarrassingly parallel. In these cases the work-load can be divided in several independent tasks to be executed on different cpus or cores. The course will cover the architectural aspects and provides practical examples.
As example of learning outcomes we expect students to

- Understand the key components of HPC architectures.
- Understand the key components of HTC architectures.
- Be able to develop parallel and efficient scientific codes for modern computing systems.
- Be able to use and develop scientific applications on virtualized environments.
- Measure and comment on the performance of parallel codes

Title:
Neutrinos – a history of oscillations

Lecturer:
Prof. Alessandro Minotti (UniMIB)

email: alessandro.minotti@unimib.it

Duration: 12 hours
Lectures will be started at a time of common availability of the students and lecturer
Credits: 4 CFU

Abstract:
This lecture will cover the topic of experimental neutrino physics, with a focus on neutrino oscillations. The discovery of neutrinos, the first measurements of flavor disappearance, the final solution of the puzzle with the proof of their oscillation, and the following journey towards the full characterization of neutrino mixing, will be discussed with a historical approach, focused on the experimental point of view. The idea behind, design, and challenges of different experiments will be discussed, that measured neutrinos from a variety of energy ranges and sources. The theoretical framework for neutrino mixing and its evolution to account for experimental results will also be covered. These theoretical and experimental endeavors laid the basis of the next generation of neutrino detectors, the discussion of which will conclude the lecture.

Lecture 1 – **Introduction**: from the neutrino hypothesis to its discovery (0.5h)
Lecture 2 – **Neutrino sources**: reactor neutrinos, solar neutrinos, atmospheric neutrinos, other neutrino sources (1h)
Lecture 3 – **Neutrino oscillation**: from the emergence of the solar neutrino problem the final proof of neutrino mixing by Super-Kamiokande & SNO, water Cherenkov detectors (2h)
Lecture 4 – **Neutrino oscillation II**: the theoretical framework of neutrino mixing and a the MSW effect (1.5h)
Lecture 4 – **The comeback of reactor neutrinos**: the measurement of θ_{13} and its implications, liquid scintillator detectors (1.5h)
Lecture 5 – **Neutrino beams**: from K2K to NOVA & T2K, neutrino physics becomes high energy (2h)
Lecture 6 – **Neutrinos and astronomy**: DM, supernovae and neutrinos, heavy neutrinos and CP-violation (1h)
Lecture 7 – **Reactors again!** sterile neutrinos and other anomalies (1h)
Lecture 8 – **The road ahead**: Daya Bay, DUNE and Hyper- Kamiokande (1.5h)

Title: Energy and Society

Lecturer: prof. Paolo Lenisa (lenisa@fe.infn.it)

Modality: 2 lectures per week – schedule to be defined in agreement with the students

Credits: 3 CFU to 6 CFU – depending on the number of lectures attended

The course is organized in modules. The student can also selectively attend the lectures of personal interest.

- ○ Dedicated seminars by "professionals" will be foreseen.
- ○

Objectives and contents:

- Goal of the course is to provide basic knowledge on the different aspects of energy systems.
- The following arguments will be discussed, at an introductory level:
- Additional aim of the course is to stimulate the students to critically address problems identifying correlations among different sectors.
- Emphasis will be given on dimensional analyses and orders of magnitude estimate.
- Concrete problems will be addressed together with students and professor.
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- According to attendance and interest a visit to the waste-to-energy plant in Ferrara might be organized.

Learning assessment procedures:
The oral exam will be based on the discussion of a report and a presentation by the student.

Title:
Cryogenic particle detectors

Lecturer: Dr. Marco Guarise (Unife)
marco.guarise@unife.it

Duration:
9 hours
Lectures will be started at a time of common availability of the students and the lecturer
Credits: 3 CFU

Abstract:
The course of cryogenic particle detectors will cover the fundamental aspects of:
cryogenics systems,
main properties of materials and fluids at low temperatures,
low-temperature refrigeration systems.
Special focus will be on the physics features of liquid Argon and other noble liquids, Helium refrigerators and sub-Kelvin systems, with examples and applications in the cooling of detectors, sensors and particle accelerators.

The course will begin with an introduction to cryogenics, a brief discussion of the properties of materials at cryogenic temperatures and a description of the cryogenic fluids. The standard methods to achieve cryogenic temperatures will be briefly described, with particular focus on liquefaction and closed-cycle refrigeration, followed by a short introduction to fluid and superfluid properties of helium. The discussion of refrigeration technologies will be extended for temperatures below 1 Kelvin with the introduction of Helium-3 cryogenics and the dilution refrigerator, among other techniques such as the optical cooling. Also, a description of Argon purification to parts per trillion levels, necessary to enable very high purity neutrino and dark matter experiments, will be introduced. Finally, a very brief description of cryogenic instrumentation and cryogenic safety will be presented.