SCUOLA DI SCIENZE

UNIVERSITÀ DEGLI STUDI DI PADOVA

**SCHOOL OF SCIENCE** **UNIVERSITY OF PADOVA**

# CATALOGUE OF ENGLISH LANGUAGE COURSES FOR ERASMUS, FOREIGN AND ITALIAN STUDENTS

## ACADEMIC YEAR 2019-2020:

First semester: September 30th, 2019 to January 18th, 2020
Winter exams session: January 20th, 2020 to February 29th, 2020
Second semester: March 2nd, 2020 to June 12th, 2020
Summer exams session: June 15th, 2020 to July 18th, 2020
Extra exams session: August 17th, 2020 to September 19th 2020

## ERASMUS MASTER DEGREES AND MASTER DEGREES WITH A PROGRAM OF COOPERATION WITH OTHER EUROPEAN UNIVERSITIES

ALGANT (Algebra, Geometry And Number Theory)
see information on http://lauree.math.unipd.it/algant/

### MASTER DEGREES WITH A PROGRAM OF COOPERATION WITH OTHER EUROPEAN UNIVERSITIES FOR COMMON DEGREES

An agreement between the University of Padova and the French Universities Paris Diderot-Paris 7 and Paris Descartes. has been established since the academic year 2010-11 for the release of a common degree between the Master Degree in Molecular Biology and the Master de Sciences Santé et Application. This project requires the mobility of students (up to 6 per year) within the ERASMUS program. More information is available on http://biologia-molecolare.biologia.unipd.it/lauree-magistrali/lm-in-biologia-molecolare/

# INDEX

## SECOND CYCLE DEGREES WITH ALL THE COURSE UNITS HELD IN ENGLISH:

### ASTROPHYSICS AND COSMOLOGY

#### ADVANCED ASTROPHYSICS

Master degree in **Astrophysics and Cosmology**, First semester
Lecturer: Andrea Paola Marigo
Credits: 6 ECTS
**Prerequisites:**
General astrophysics, fundamentals of radiative processes and stellar evolution
**Short program:**
1) Stellar Winds. Introduction. Coronal winds: Isothermal case. Generale case. Topology of the solution of the momentum equation. Line-driven winds: Wind dynamics. Radiative acceleration due to one single line. Optically thick case and optically thin case. Multiple line models. Kastor-Abbott-Klein formalism. Application to hot and luminous stars. Dust-driven winds: Momentum equations for the gas and dust components. Drift velocity. Drag force. Dynamical coupling gas-dust. Dust grains: chemical composition and optical properties. The single-scattering limit. Dust grain opacities. Grain cross sections. Planck mean opacities (silicates, graphite, amorphous carbon). Condensation radius and temperature of dust species. Effect of stellar pulsation in the subsonic region. Application to cool giant stars.
2) Variable stars. Overview of history, observations, classification. Introduction to the theory of stellar pulsation, time scales, period-mean density relation, linearization. Adiabatic approximation and LAWE. Non-adiabatic oscillations, stability conditions, quasi-adiabatic approximation. Driving: epsilon and kappa+gamma mechanisms, opacity bump, classical instability strip. RR Lyr and Cepheid variables. Red giant variables. Overview of non-radial oscillations and asteroseismology.
3) Deaths and final fates of massive and very massive stars: electron-capture supernovae, core-collapse supernovae, pair-instability supernovae, neutron star-merger kilonovae. Physics of the explosions and related uncertainties. Successful and failed explosions and related remnants (neutron star, black hole, none). The initial mass- final mass relation. Explosive nucleosynthesis.
**Examination:**
Written and/or oral examination
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/001PD/SCP9086382/N0

#### ASTRONOMICAL INTERFEROMETRY

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Mauro D'Onofrio
Credits: 6 ECTS
**Prerequisites:**
A good knowledge of the Fourier transform and Calculus is required.
**Short program:**
1) Fundamentals of optical and radio astronomy.
2) Optical and radio telescopes. Resolution and observational techniques.
3) Elements of interferometry.
4) Optical and radio interferometry.
5) The UV plan.
6) Image synthesis at optic and radio wavelengths.
7) Elements of disturbance and calibration of interferometric observations.
8) Data reduction tests of interferometric data in the computer laboratory.
**Examination:**

Oral exam about the topics discussed in the lectures.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP9086348/N0

## ASTRONOMICAL SPECTROSCOPY

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Stefano Ciroi
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge of Physics 1 and 2, Mathematical Analysis 1 and 2, Atomic Physics, Astrophysics 1 and 2, Laboratory of Astronomy.
**Short program:**
1) A brief introduction to spectroscopy as observational technique.
2) Characteristics of emission-line spectra: gaseous nebulae, Novae, Supernovae, Supernova remnants, star forming regions, active galactic nuclei.
3) The Boltzmann and the Saha equations.
4) The Radiative Transport Equation. The Equivalent Thermodynamic Equilibrium. Radiation density. Radiation transport in the lines. Deviations from thermodynamic equilibrium.
5) The cross-section of collisional interactions. The collisional efficiency rate.
6) Study of the population ratio in a two-level system. The two-level system in the optical range. Conditions for the emission of forbidden lines. The two-level system at radio frequencies. The H I 21 cm and the CO 2.6 mm lines. Line intensity as a function of density and temperature. Determination of the gas density and temperature.
7) Recombination lines. Population of the levels. Intensity of the optical recombination lines of H I. Intensity of the radio recombination lines.
8) Sources of continuous emission and absorption. Free-free transitions of thermal electrons. The thermal radio continuum. The synchrotron continuum. Bound-free and free-bound transitions in the optical-UV. Continuum emission from recombination. The 2-photons emission.
9) Statistical equilibrium in ionized nebulae. Radiative ionization and recombination. Ionization equilibrium in H II regions. The Stroemgren sphere. Stratification of ionization. H I regions. Cold dense and hot tenuous neutral cloud. Photoionization heating in H II regions. Cooling from metastable level transitions. Thermal equilibrium in H II regions.
10) Extinction by dust grains.
**Examination:**
Oral exam on the topics discussed during the lectures. Foreign student can ask to do a written exam with open questions on the topics discussed during the lectures.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCN1035986/N0

## ASTROPARTICLE PHYSICS

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Antonio Masiero
Credits: 6 ECTS
**Prerequisites:**
Taking for granted the notions of Quantum Mechanics and Relativity provided in previous undergraduate courses, the present course is self-consistent in so far as it intends to provide the necessary basic notions of relativistic quantum mechanics, quantum field theory and elementary particle physics, and cosmology.
**Short program:**
1) Introduction: the observable Universe and its expansion, dark matter, Big Bang relics;
2) Relativistic Quantum Mechanics: Klein-Gordon equation; Dirac equation; particles and

antiparticles; discrete symmetries: P, T, C and CPT theorem;
3) Quantum Field Theory: Klein-Gordon and Dirac quantum fields; quantum electrodynamics (QED); elements of the scattering theory: S matrix, propagators, Feynman rules, cross sections and decay rates
4) Spontaneous Symmetry Breaking (SSB): SSB of discrete and continuous symmetries; Goldstone theorem; SSB of local (gauge) symmetries; Higgs mechanism; Higgs; finite temperature SSB.
5) The Standard Model (SM) of Particle Physcs: Fermi theory; V-A theory; Yang-Mills theories; electroweak standard theory; SSB of the electroweak symmetry; CP violation; baryon and lepton numebr conservation; Higgs boson searches and discovery.
6) Neutrino Physics: Dirac and Majorana masses; see-saw mechanism; neutrino oscillations; solar and atmospheric neutrinos; Supernovae neutrinos;
7)Beyond the SM: Grand Unified Theories (GUTs); SSB and the gauge hierarchy problem; proton decay.
8) Elements of General Relativity: equivalence principle; curved space-time; energy-momentum tensor; Einstein equations, Schwarzschild solutions
9) Cosmological Models: De Sitter model; Standard cosmological model; FLRW metrics and Friedmann equations; the cosmological constant
10) Thermodynamics of the Early Universe:thermodynamical equilibrium; entropy; decoupling temperature.
11) Dark Matter (DM): observational evidence; Boltzmann equations; cold and hot DM; Weakly Interacting Massive Particles (WIMPs); particle physics DM candidates; cosmological limits of the neutrino masses; direct and indirect DM searches.
12) Inflation: the problems of the horizon, flatness and lifetime of the Universe; the problem of the cosmological monopoles; inflation mechanism; quantum fluctuations of the inflaton; inflation models; dark energy
13) Baryogenesis and the cosmic matter-antimatter asymmetry: Sacharov conditions; baryon and lepton violating interactions; matter-antimatter asymmetry and neutrino masses: leptogenesis.
**Examination:**
Oral examination.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP7081703/N0

## ASTROPHYSICS LABORATORY 1

Master degree in **Astrophysics and Cosmology**, First semester
Lecturer: TO BE DEFINED
Credits: 6 ECTS
**Prerequisites:**
Fundamentals of Physics and Astronomy.
**Short program:**
1) Basic principles of optics and image formation: Nature of light and geometrical nature of thin lenses and of conical sections. Concept of stigmatic and non stigmatic imaging. Optical copies and Lagrange invariant. Relevance of the position and size of the stop in an optical system and its effects on the overall property.
2) Two mirrors telescope: Schwarzschild, Cassegrain, Gregorian and Ritchey-Chretienne solutions. The problem of the background in astronomical imaging and in particular in the infrared. Definition of the thermal and non-thermal infrared portion of the spectra. Vignetting and field of view in Cassegrain telescopes. Difference between images formed by parabolic and spherical mirrors and the case of Arecibo-like design. Examples of telescopes and instrumentation employing the various concepts devised.
3) Adaptive and active optics. Basic definitions, Kolmogorov turbulence and isoplanatic angle,

Fried's parameter and Greenwood frequency. Deformable mirrors and wavefront sensors in open and closed loop operations. Tip-tilt four quadrants sensing and Poissonian nature of photons effect on them. High order aberrations and Hamilton, Zernike and Karhunen-Loeve modes. Shack-Hartman and pyramid wavefront sensors. Concept of multi-conjugated adaptive optics. Star and Layer Oriented approaches. Adaptive optics with multiple field of views.
4) Detectors: Charge Coupled Devices Detectors, principles of working and basic parameters. Quantum efficiency, charge transfer efficiency, read out noise. CCD principle of working and effects on the Poissonian apparent noise. Concept of the avalanche photo diodes and quenching.
5) Experiments in the optical laboratory: Poisson's spot, turbulence simulation and speckle formations.
6) Observations at the Asiago Astronomical Observatory: Speckle interferometry.
**Examination:**
Oral exam about the topics discussed in the lectures..
**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/SC2490/000ZZ/SCP9086379/A1301

## ASTROPHYSICS OF GALAXIES

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Alessandro Pizzella
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge of extra-galactic astrophysics. In particular, about morphology, photo-metric profiles, kinematics of galaxies.
**Short program:**
1) Luminosity function of galaxies. Spectroscopic and photometric classification of galaxies at high redshift. Effect of the environment. Main extragalactic surveys from space and ground-based telescopes. The local group and the nearby universe.
2) Galaxy kinematics with integral field spectroscopic, 5 hours
3) Scaling relations in elliptical galaxies: The fundamental plane and its evolution with redshift. Kormendy relation. Faber-Jackson relation. Dn-sigma relation.
4) Scaling relations in spiral galaxies: Tully-Fisher relation and its evolution with redshift. Low and high surface brightness disks.
5) Galaxy clusters and dark matter distributions: Mass of galaxy clusters with X ray halos and gravitational lensing. Dark matter properties in galaxies and clusters.
6) Supermassive black holes in the center of galaxies.
7) Chemical properties of stellar populations in galaxies: Evolution, metal enrichment and chemical abundance gradients (spectro-photometric indices, Lick system). Mg-sigma relation. Mg-escape velocity relation. Color-magnitude relation. Star formation rate with morphological type, environment, and redshift. Passive evolution and hierarchical clustering.
**Examination:**
Oral exam.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/002PD/SCN1035987/N0

## CELESTIAL MECHANICS

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Stefano Casotto
Credits: 6 ECTS
**Prerequisites:**
Students are expected to be familiar with Rational Mechanics and Mathematical Analysis, including the elementary theory of Ordinary Differential Equations.

A fair amount of curiosity about dynamical phenomena observed in the Solar and other planetary systems is useful, together with an interest in their precise modeling and computation and the design of exploration missions.

**Short program:**

1) The equations of motion of gravitating systems.
2) The Two-Body Problem and an initial value problem (IVP).
3) The Two-Body Problem and a boundary value problem (BVP).
4) Orbital maneuvers.
5) Space and time reference systems.
6) The computation of a Keplerian ephemeris.
7) Preliminary orbit determination.
8) Keplerian relative motion and its generalization.
9) Regularization and Universal Formulation of the Two-Body Problem.
10) The TBP as a boundary value problem (BVP) – Lambert targeting.
11) The Problem of Three Bodies and its homographic solutions.
12) The Circular Restricted Three-Body Problem – Jacobi's integral, surfaces of zero velocity, Lagrangian points, Stability, Periodic orbits.
13) The theory of Patched Conics and the design of gravity-assist interplanetary trajectories.
14) Elements of perturbations and a the motion of an artificial Earth satellite.

**Examination:**

Evaluation of the homework and final project report. Oral presentation of final report and discussion of the results and other topics covered during the lectures.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCN1035988/N0

**FUNDAMENTALS OF ASTROPHYSICS AND COSMOLOGY (ALSO OFFERED IN THE MASTER DEGREE IN PHYSICS OF DATA – EXAM OF THE PHYSICAL UNIVERSE)**

Master degree in **Astrophysics and Cosmology**, First semester
Lecturer: Sabino Matarrese
Credits: 6 ECTS

**Prerequisites:**

Fundamental concepts of quantum mechanics and special relatività

**Short program:**

Fundamental concepts of galactic and extra-galactic astrophysics

• The classification of galaxies
• Statistical properties of the galaxy population
• Groups and clusters of galaxies

Fundamental concepts of Cosmology

* Main components of the Universe. Observational evidence for the existence of dark matter and dark energy.
* Expanding Universe and Cosmological Principle.
* Robertson-Walker line-element. Geometrical properties.
* Hubble constant and deceleration parameter.
* Distances in Cosmology; redshift and Hubble law (low-redshift approximation).
* Derivation of Friedmann equations (dust case); Newtonian and relativistic contributions
* Friedmann models.
* Cosmological constant: Einstein's static solution and de Sitter solution. Dynamical dark energy
* Cosmological solutions for the spatially flat case. Universe models with non- zero spatial curvature.
• Exact treatment of the Hubble law.

Thermal history and early Universe

* Number density, energy density and pressure of a system of particles in thermodynamic equilibrium.
* Entropy conservation in a comoving volume.
* Time-temperature relation in the Early Universe.
* Shortcomings of the standard cosmological model: horizon, flatness problems, etc.
* Inflation in the Early Universe: solution of the horizon and flatness problems.
• Kinematics and dynamics of inflation; the "inflaton".
• Old, new and chaotic inflation; slow-roll dynamics (basic account).
* Baryon asymmetry in the Universe (basic account)
• Primordial nucleosynthesis of light elements.
* Hydrogen recombination: Saha equation. Matter-radiation decoupling. Cosmic Microwave background.
* General definition of decoupling.

Dark matter: general properties
* Boltzmann equation in Cosmology and cosmic relics.
* Hot/Cold/Warm Dark matter: definition, present abundance and general cosmological properties.

Elements of stellar astrophysics
* Gravitational contraction and conditions for hydrostatic equilibrium.
* Adiabatic index and equilibrium.
* Conditions for gravitational collapse.
* Jeans theory of gravitational instability.
* Contraction of a protostar.
* Star formation and degenerate electron gas.
* The Sun: general properties, radiative diffusion, thermonuclear fusion.
* Stellar nucleosynthesis.
* Stellar cycles.
* Hertzsprung-Russell diagram.
* Basics of stellar structure. Clayton model: Minimum mass of a star; maximum mass for a Main-Sequence star.
* End-points of stellar evolution: white dwarfs, neutron stars, Chandrasekhar mass, black holes.

The formation of cosmic structures
* Linear evolution of perturbations in the expanding Universe (basic principles).
* Spherical collapse of a cosmic proto-structure.
* Mass-function of cosmic structures: Press-Schechter theory.

**Examination:**
Oral interview.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP9086381/N0

## FUNDAMENTALS OF MODERN PHYSICS

Master degree in **Astrophysics and Cosmology**, First semester
Lecturer: Chiara Maurizio
Credits: 6 ECTS
**Prerequisites:**
Fundamentals of quantum physics and structure of matter.
**Short program:**
1) Solution of the Schroedinger equation for a system of two particles in a central potential. Spherica harmonics and radial solution. Relevant expectation values. Virial theorem for a one-electron atom.
2) Time independent perturbation theory (non degenerate and degenerate case). Examples.

Time-dependent perturbation theory: perturbation switched on at to and then constant, periodic perturbation. Rabi frequency.
3) Interaction of one-electron atom with an electromagnetic field. Transition rate, dipole approximation, cross section for stimulate absorption/emission. Spontaneous emission. Selection rules for one-electron atoms. Spin of photons: Beth experiment. Sum rule.
4) Lifetime of an electronic state. Line shape: pressure and Doppler broadening. Examples. Laser, maser. Ammonia maser, solid-state laser. Modern spectroscopies: examples of sub-Doppler spectroscopies.
5) Photoelectric effect: cross section for one-electron atom in 1s state. Comparison with experimental data.
6) Scattering: differential cross section for elastic and inelastic (Rayleigh and Thomson) scattering. Partial waves and corresponding cross section calculation.
7) Composition of angular momenta. Fine structure of one-electron atoms: spin-orbit, Darwin and relativistic terms. Calculation of some electronic energy levels for on-electron atoms. Lamb shift. Elements of hyperfine structure. 21-cm transition of H.
8) Zeeman effect: normal (examples, observed transitions and polarization, Paschen-Bach case), anomalous, case of ultra strong magnetic fields.
9) Stark-Lo Surdo effect for one-electron atoms: linear (n=1, n=2) and quadratic (n=2). Atomic static polarizability. Quenching of the 2s state of hydrogen. Ionization indiced by an electric field.
10) Many-electron atoms. Triplet and singlet states. Pauli exclusion principle (strong and weak conditions). Helium atom (independent electron model, nuclear effective charge). Ground state for a two-electron atom: first order perturbation. Pure discrete excited states, Auger effect. Variational method and application to for the ground state of a two-electron atom.
11) Central potential for a two-electron atom. Hartree theory and results. Slater determinant. Note on the Hartree-Fock method. Results, periodic table of the elements.
12) Correction to the central field: L-S coupling (examples of electronic configuration, degeneracy.). j-j coupling.
13) Molecules: Born-Oppenheimer approximation. Schroedinger solution of H2+ molecule by linear combination of atomic orbitals and of H2. Vibrational and rotational dynamics.
14) Quantum statistics, occupation index: Bose-Einstein and Fermi-Dirac cases with examples.

**Examination:**
Oral exam about topics discussed during lectures.
**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/SC2490/000ZZ/SCP9086380/N0

## GALACTIC DYNAMICS

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Enrico Maria Corsini
Credits: 6 ECTS
**Prerequisites:**
Fundamentals of Astronomy, Astrophysics, Physics, and Numerical Methods.
**Short program:**
1) Overview of the properties of galaxies: Morphology. Photometry. Kinematics. Scaling relations.
2) Potential theory: Gravitational potential. Poisson equation. Laplace equation. Gauss theorem. Potential energy. Potential energy tensor. Spherical systems. Newton theorems. Point mass. Homogeneous sphere. Hubble density profile. Power-law density profile. Axisymmetric systems. Logarithmic potential.
3) Orbits of the stars: Costants and integrals of the motion. Surfaces of section. Orbits in a static spherical potential. Orbits in a Keplerian potential. Orbits in a static axisymmetric

potential. Motion in the meridional plane. Nearly circular orbits. Epicyclic approximation. Orbits in a two-dimensional non-axisymmetric non-rotating potential. Loop and box orbits. Stable and unstable orbits. Orbits in a two-dimensional nonaxisymmetric rotating potential. Jacobi integral. Lagrangian points. Corotation. Families of orbits x1, x2, x3, x4. Introduction to the orbits in a three-dimensional triaxial potential.
4) Collisionless systems: Geometric collisions. Strong collisions. Weak collisions. Crossing time. Relaxation time. Distribution function. Collisionless Boltzmann equation. Continuity equation. Euler equation. Jeans equations. Applications of the Jeans equations. Velocity ellipsoid. Asymmetric drift. Mass density in the Solar neighborhood. Velocity dispersions in spherical systems. Mass-anisotropy degeneracy. Spheroidal systems with isotropic velocity dispersions. Disk heating mechanisms. Virial theorem. Mass-to-light ratio of spherical systems. Rotation of elliptical galaxies. Jeans' theorem. Density profile from the distribution function. Spherical systems with isotropic velocity dispersion. Polytropes. Plummer sphere. Isothermal sphere. Singular isothermal sphere. King radius. King method to derive the mass-to-light ratio. King models. Tidal radius. Concentration parameter. Distribution function from the density profile. Eddington equation. Introduction to spherical systems with anisotropic velocity dispersion. Michie models.
**Examination:**
Oral exam on different topics discussed during lectures.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP9086385/N0

**GENERAL RELATIVITY (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS OF DATA)**

Master degree in **Astrophysics and Cosmology**, First semester
Lecturer: Marco Peloso
Credits: 6 ECTS
**Prerequisites:**
Knowledge of Special Relativity
**Short program:**
1. Preliminaries
Lorentz transformations and addition of velocities in special relativity. The geometry of flat spacetime. Time dilatation, length contraction, and the relativity of simultaneity. Four-vectors and special relativistic kinematics. Special relativistic dynamics and the energy-momentum tensor. Variational principle for Newtonian mechanics and for a free motion in special relativity. Light rays and Doppler shift. Observers and Observations.
2. Space, Time, and Gravity in Newtonian Physics.
Inertial frames. The principle of relativity. Newtonian Gravity. Gravitational and Inertial Mass.
3. Gravity as Geometry
The equivalence principle. Clocks in a gravitational field and gravitational redshift. Coordinates, line element, and the metric. Light cones and world lines. Length, area, volume computations. Vectors in curved spacetime. Hypersurfaces. Newtonian gravity in spacetime terms (weak field approximation).
4. The Einstein equations
Parallel transport and curvature. Covariant derivative, Riemann, Ricci, and Einstein tensor. The source of curvature. Einstein equations and weak field approximation.
5. Geodesics
The geodesic equation. Symmetries and Killing vectors. Local inertial frames and freely falling frames.
6. Schwarzschild Geometry
Gravitational redshift. Particle orbits: the precession of the perihelion. Light ray orbits: the deflection and time delay of light. Solar system tests of general relativity.

7. Horizons and Coordinate Systems
Minkowski spacetime in Rindler coordinates. Schwarzschild black-holes. Eddington-Finkelstein, and Kruskal-Szekeres coordinates, Kruskal and Penrose diagrams.
8. Rotations and Kerr Geometry
Geodetic precession around a non-rotating, and a slowly rotating body. Kerr metric and the ergosphere.
9. Cosmology
FLRW geometry. Spatial curvature. Evolution in presence of matter, radiation, and a cosmological constant. Cosmological redshift. Luminosity and angular distance.
10 Gravitational waves (if time permits)

**Examination:**
Questions on the topics presented during the course and solution of a simple / medium problem.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP7081661/N0

## GRAVITATIONAL PHYSICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS AND IN PHYSICS OF DATA – EXAM OF RELATIVISTIC ASTROPHYSICS)

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Giacomo Ciani
Credits: 6 ECTS

**Prerequisites:**
Basic knowledge of general relativity is suggested, but not mandatory.

**Short program:**
Elements of general relativity. Gravitational waves (GW) in linearized theory; TT-gauge and detector frame; interaction with free falling masses and rigid bodies.
Generation of GW. Quadrupole and post-newtonian approximations. Energy and momentum loss by gravitational wave emission. Examples of GW sources: stable and coalescing binary systems, rotating rigid bodies, extreme mass-ratio inspirals.
GW detection. Hulse-Taylor system. Fundamentals of stochastic signals and noise theory. Resonant bars detectors. Modern GW interferometers: basic principle, noise sources, fundamental and technical limitations. Future GW experiments. Elements of data analysis.
Astronomy and science with gravitational waves. Current observations of black hole and neutron star mergers. Tests of general relativity. Astrophysical implications. Multi-messenger astronomy.

**Examination:**
Oral examination aimed at verifying the conceptual understanding of the topics presented and the ability to correctly approach and analyze specific problems related to GW theory and detection.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP7081719/N0

## MATHEMATICAL AND NUMERICAL METHODS

Master degree in **Astrophysics and Cosmology**, First semester
Lecturer: Michela Mapelli
Credits: 6 ECTS

**Prerequisites:**
Basics of Mathematical Analysis I, Linear Algebra and Geometry. Basics of Kinematics and Dynamics (General Physics I).

**Short program:**
Each lecture will consist in a part of theory and a part of exercises.
1. Summary of python programming notions with exercises.

2. Sorting algorithms (selection sort, bubble sort); application of these methods to a physical set of data.
3. Random numbers (random generators, uniform deviates, inversion method, rejection methods); examples of random generation of astrophysical distributions (e.g. Maxwellian distribution of velocities).
4. Solution of linear algebraic equations (direct and indirect methods; example: Gauss-Seidel method).
5. Interpolation and extrapolation (polynomial, cubic spline); application to an astrophysical sample (e.g. stellar isochrones).
6. Root Finding (bisection method, Newton Raphson method) and exercises.
7. Integration of functions (Monte Carlo method, trapezium method, Romberg integration).
8. Integration of ordinary differential equations (Euler scheme, Leapfrog scheme, Runge-Kutta scheme, Hermite scheme); example: the astrophysical N-body problem.
9. Partial differential equations with finite difference methods.
10. Fast Fourier transform (FFT); examples of FFT in astrophysics.
11. Notions of machine learning in astrophysics.

**Examination:**
Written report on the exercises done during the classes. Oral exam based on the written report and on the topics of the course.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP9086342/N0

## MULTIMESSENGER ASTROPHYSICS

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Elisa Bernardini
Credits: 6 ECTS

**Prerequisites:**
This course is addressed to students with basic knowledge of elementary particles and their interactions and nuclear physics.

**Short program:**
The term "multi-messenger" is quite new and increasingly used in astronomy and astroparticle physics. It refers to combining information from different types of particles and waves to gain a deeper understanding of the astrophysical objects we observe in the sky. Visible light only reveals a very small portion of the mysteries of the Universe. Astronomical observations are nowadays routinely performed with different telescopes across the electromagnetic spectrum, from radio waves through visible light, all the way to gamma-rays. At the highest energies, the most violent processes in the Universe are at work. Whatever produces high energy gamma-rays, is expected to accelerate particles to energies that exceed the capabilities of man-made accelerators a billion times. Such particles can reach the Earth as cosmic rays, first discovered more than 100 years ago, still nowadays one of the most mysterious "messages" from our Universe.
Cosmic rays may interact in the vicinity or their sources or even along their way to Earth, to produce elusive particles called neutrinos and gamma-rays. While cosmic rays are deflected during their journey by intergalactic magnetic fields, neutrinos and photons, being neutral particles, keep memory of their source's direction. Their trajectory becomes thus crucial to unravel the origin of cosmic rays.
Neutrinos are extremely difficult to detect. Kubic-kilometer detectors are necessary to observe neutrinos at energies larger than few tens of GeV. The year 2013 witnessed the first clear observation of neutrinos from distant astrophysical objects by the IceCube detector at the South Pole, opening a new observational window to the Universe.
The most extreme astrophysical objects, connected with the most violent phenomena in our Universe, are often associated with black holes or neutron stars. Whenever two such compact

objects orbit around each other, they are expected to produce gravitational waves. The year 2015 witnessed the first direct observation of gravitational waves emitted by two merging black-holes (GW150914), measured by the LIGO detectors in the USA. The discovery was celebrated by the Nobel-prize for physics.
The year 2017 witness the triumph of multi-messenger astrophysics with the first identification of a source of cosmic neutrinos, the blazar TXS 0506+056, helped by the electromagnetic observations that followed the detection of a high energy neutrino (iceCube-170922A). This event happened just few days after another success of multi-messenger astrophysics: the detection of gravitational waves from two merging neutron stars (GW170817), followed by a burst of gamma-rays (GRB 170817A).
Both results greatly demonstrate the potential of multi-messenger astrophysics in observing and understanding the most extreme and mysterious phenomena in our Universe.
This course will illustrate its foundations.
**Examination:**
Oral examination.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP7081762/N0

**NUCLEAR ASTROPHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)**
Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Antonio Caciolli
Credits: 6 ECTS
**Prerequisites:**
Elements of quantum mechanics and general physics
**Short program:**
Thermonuclear reactions.
Definition of nuclear cross section, astrophysical S-factor, reaction rate, and Gamow peak.
Nuclear burnings during hydrostatic and explosive stellar evolutionary phases.
Elements of stellar modelling.
Hydrogen burning: p-p chains, CNO, NeNa, MgAl cycles.
Helium burning: triple-alpha reaction and alpha + 12C.
Advanced nuclear burnings (C, Ne, O, Si).
Neutron-capture reactions (s and r: slow and rapid)
For each topic we provide an overview of the most relevant results in the recent literature.
How to determine the reaction rate for several cases (direct capture, narrow resonances, broad resonances)
How to perform a nuclear astrophysics experiment (every topic will be discussed with of existing experimental facilities and their most recent results)
The environmental background and how to shield it (passive and active shielding)
Underground experiment
Brief discussion on ion beam accelerators
Elements on detectors (gamma, neutrons, and charged particles)
Experimental measurements of the cross section (from the experimental yield to the S-factor)
Targets typology (gas, jet, and solid target). Target production techniques and how targets influence
the experimental measurements.
Brief discussion on indirect methods (Trojan Horse, ANC, ...)
**Examination:**
Oral/written examination on all topics covered during the course.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP7081704/N0

## OBSERVATIONAL ASTROPHYSICS

Master degree in **Astrophysics and Cosmology**, First semester
Lecturer: Sergio Ortolani
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge of general astronomy and physics.
**Short program:**
The first part is dedicated to instrumental techniques and observational aspects in photometry. One of the application is the instrumental and reddening corrections of the data. Then the interpretation of the near infrared color-magnitude and color-color diagrams of young stellar populations. The second part of the course is dedicated to the physical properties of the planets and to some basic concepts on the study of the extrasolar planets. The third part is a detailed analysis of emissions connected to the galactic interstellar medium evolution.
1) Basic concepts in astrophysics: magnitudes, distance modulus, metallicity indices. Distance measurements.
2) Signal-to-noise ratio of the observational data. Calibrations.
3) Interstellar reddening effects on the photometry.
4) Young stellar populations. HR diagrams and two color infrared diagrams.
5) General properties of the planets in the Solar System.
6) Atmosphere of the planets. Gas escape mechanisms.
7) Effective temperatures of the planets and greenhouse effect.
8) Origin and evolution of the Solar System. Urey and Lewis theory. Age of the Solar System. Formation of the Earth.
9) General characteristics of the planet Mars. Comparison with the Earth.
10) Basic principles of the extrasolar planets detection techniques.
11) The gas in the Galaxy. HI 21 cm line.
12) Supernovae remnants and basics of evolutionary models.
13) Stellar and interstellar maser sources.
**Examination:**
Oral exam about the topics discussed during lectures.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/002PD/SCP9086344/N0

## OBSERVATIONAL COSMOLOGY

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Alberto Franceschini
Credits: 6 ECTS
**Prerequisites:**
The course is self-consistent, having acquired the whole fundamental notions of mathematics and physics of the 3-year degrees in Astronomy or Physics.
**Short program:**
1) The homogeneous and isotropic (Friedmann) Universe: Hubble law. The Cosmological Principle. Isotropic curved spaces. The Robertson-Walker metric. Cosmic dynamics, the Newtonian and general-relativistic approach. Cosmological models and parameters. Fundamental observables. The redshift. Luminosity and angular diameter distances. Time-redshift relations. Hubble diagrams. Generalized dynamical equations. The cosmological constant.
2) The large scale structure of the Universe: Local properties. Angular and spatial correlation functions. Higher order correlations. Limber relation. Power-spectrum of the cosmic structures. Relationship of the power-spectrum and $\xi(r)$. Observational data on the large scale structure. The initial power-spectrum of the perturbations. 3D mapping of galaxies, clusters,

AGNs. Counts-in-cells. Outline of fractal and topological analyses of the large-scale structure of the universe.
2) Deviations from homogeneity: Gravitational lensing. Point-like lenses and isothermal spherical distributions. Lens potentials. Einstein radius. Lensing cross sections. Lensing effects on time lags. Caustics. Observations of the gravitational lensing and cosmological applications. Estimate of the total galaxy cluster mass. Estimates of H0. Effects of a cosmological constant L in the lensing statistics. Micro lensing and weak-lensing. Mapping of the mass distribution.
3) Cosmological evolution of perturbations in the cosmic fluid: Cosmological evolution of perturbations in the thermo-dynamical parameters of the various components of the cosmic fluid. General equations in a static universe and in an expanding one. Evolution in a matter dominated universe. Hubble drag. Relationship of perturbations and velocity fields.
4) Perturbations in an expanding universe: Peculiar motions of galaxies and structures. Deviations from the Hubble flow, peculiar velocity fields in the cosmos. Observations of peculiar velocity fields. The cosmic viral theorem. Origin of the large scale motions.
5) Brief thermal history of the Universe: The matter and radiation content of the Universe. Energy densities and their evolution. Radiation-dominated universes. The epochs of recombination and equivalence. Primordial nucleo-synthesis and its consequencies.
6) The Cosmic Microwave Background (CMB): Discovery, observations from ground and from space. Origin of the CMB. Statistical description of the angular structure. Origin of the CMB angular fluctuations. Physical processes in operation on the large scales. Fluctuations on intermediate angular scales. Contributions of sources to the anisotropies on small scales. Cosmological re-ionization and its impact on CMB. Constraints of CMB observations on the cosmological parameters. The CMB spectrum, spectral distorsions. The Sunyaev-Zeldovich effect. Polarization.
7) The primordial Universe: Big Bang singularity. Planck time. Propagation of the information in the universe. Cosmological phase transitions. Open questions about the standard Big Bang model. The horizon problem. The flatness problem. Cosmological inflation and solutions to the problems. The Anthropic Principle.
8) Origin and evolution of the cosmological structure: Generation of the perturbation field. General composition of the cosmic fluid: the dark matter, cold and hot dark matter. Stagnation of the dark matter perturbation before the equivalence. Transfer function. Non-linear evolution. The Press-Schechter theory.
9) Post-recombination universe. Intergalactic diffuse gas. Absorption-lines in quasar spectra, Lyman-alpha clouds. The missing baryon problem. Evolutionary history of star formation and black hole accretion in quasars. Origin of the galaxy mass function.
**Examination:**
Oral discussion
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/002PD/SCP9086346/N0

## PLANETARY ASTROPHYSICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS)

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Francesco Marzari
Credits: 6 ECTS
**Prerequisites:**
Basic courses of the 3--year period.
**Short program:**
1) Dynamical and physical properties of planets and exoplanets.
2) Planetary formation from circumstellar disks, migration and planet-planet scattering. Short tutorial on fluid dynamics and tidal interaction between planets and disks.

3) Magnetic fields of the planets, origin and morphology.
4) Plasma motion in planetary fields, Van Allen Belts, magnetospheres and solar wind.
5) Tidal interaction planet-satellite and planet-star, lengthening of the terrestrial day and Moon outward drift.
6) Physics of planetary interiors, state and structure equations.
7) Non-gravitational forces acting on planetary precursors: Poyting-Robertson drag, Yarkowski effect, gas drag.
7) Three-body problem: Lagrangian points (Trojan orbits), their stability, Hill's sphere and its applications (cataclysmic variables, asteroid satellites).
8) Secular perturbations in multiple planet systems.

**Examination:**
Oral exam

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP7081805/N0

## RADIATIVE PROCESSES IN ASTROPHYSICS

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Roberto Turolla
Credits: 6 ECTS

**Prerequisites:**
Classical electrodynamics, special relativity, general astronomy and astrophysics

**Short program:**
The radiation field
The basic properties of radiation. The specific intensity and its moments. Emission, absorption and scattering. Radiative transfer. Thermal radiation. The diffusion approximation.
Particles and waves
Plane electromagnetic waves. Polarization and the Stokes parameters. Electromagnetic potentials. Radiation from moving charges. The Liènard-Wiechart potential for a single charge. Radiation from a system of non-relativistic charges, the dipole approximation.
Bremsstrahlung
Emission from a single speed electron. Emission from thermal electrons. Bremsstrahlung absorption. Relativistic bremsstrahlung.
Electron scattering. Thomson scattering. Compton scattering. Scattering onto moving charges. Repeated scatterings from non-relativistic thermal electrons. Comptonization, the y-parameter and the Kompaneets equation. The relativistic Kompaneets equation. Bulk motion Comptonization.
Synchrotron radiation. Cyclotron and synchrotron power. Synchrotron emission spectrum for a single charge and for a power-law energy distribution of electrons. Polarization of synchrotron radiation. Synchrotron self-absorption.
Radiative transitions. Semi-classical description. Einstein coefficients and oscillator strengths. Selection rules. Transition rates, bound-bound and bound-free transitions for Hydrogen. Line broadening mechanisms.

**Examination:**
Oral examination

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/001PD/SCP9086347/N0

## STELLAR ASTROPHYSICS

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Antonino Milone
Credits: 6 ECTS

**Prerequisites:**

Fundamentals of stellar astrophysics (photometry, astrometry, spectroscopy, stellar evolution)
**Short program:**
1) Color-magnitude diagrams: transformation luminosity-magnitude and color-temperature, bolometric corrections, effect of reddening, metallicity and chemical composition.
2) Definition of stellar population. historical background, present-day view. Stellar clusters as prototype of simple populations. The initial mass function.
3) Determination of the physics and structure parameters of stellar population from photometry (age, reddening, metallicity).
4) Chemical composition of stellar populations.
5) Binaries, Blue Stragglers, X-ray Binaries, black holes and other exotic objects in star clusters.
6) Population III stars. Hunting the first stars of the Universe.
7) The Galactic halo
- Ultra faint dwarfs
- Dwarf galaxies
- Globular clusters. Multiple stellar populations. Horizontal branch and second-parameter problem.
8) Galactic Bulge.
9) Thin and thick disk.
Open clusters. Multiple stellar populations in Magellanic Clouds clusters and the eMSTO phenomenon. Solar neighbours.
10) Star formation history in dwarf galaxies and in the Milky Way.
**Examination:**
Oral exam based on the topics discussed during the lectures.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/002PD/SCP9086345/N0

**SUBNUCLEAR PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)**
Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Donatella Lucchesi
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge on quantum mechanics, relativity, nuclear and subnuclear physics. Quantum field theory and Feynman graphs. Interaction of radiation and particles with matter.
**Short program:**
A brief reminder of basic concepts: symmetries, conservation laws, quantum numbers and elementary particle classification. Lifetime, resonances and Breit Wigner distribution.
QED: brief reminder of theoretical foundation, tree levels processes and loop diagrams. The running coupling constant. Experimental tests: success and open issues.
Weak interactions of leptons and quarks. Fermi constant(Gf), weak gauge bosons, relation between Gf and MW. Muon and tau decays: lepton universality. P,C violation in charged and weak currents. Nuclei, baryon and meson weak decays: "helicity suppression". Neutrino scattering. Spontaneous symmetry breaking and the Higgs boson. Measurements at LEP and at the LHC. Status and perspectives.
QCD. Hadron spectroscopy. ee annihilation to hadrons. Deep inelastic scattering of electrons and neutrinos; nucleon structure functions.
Hadron flavour Physics. The CKM matrix. Flavour oscillations and CP violation.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP7081697/N0

**THEORETICAL COSMOLOGY (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS OF DATA – EXAM OF COSMOLOGY)**

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Sabino Matarrese
Credits: 6 ECTS

**Prerequisites:**
Fundamentals of Cosmology and Astrophysics

**Short program:**
General introduction

- Derivation of the Friedmann eqs. from Einstein's eqs. (after a very synthetic introduction to the latter), assuming the Robertson-Walker line-element.

The Cosmic Microwave Background (CMB) Radiation

- Boltzmann eq. and hydrogen recombination: beyond Saha equation
- The Boltzmann eq. in the perturbed universe: the photon distribution function
- The collision term
- Boltzmann eq. for photons in the linear approximation
- Boltzmann eq. for cold dark matter (CDM) in the linear approximation
- Boltzmann eq. for baryons in the linear approx.
- Evolution eq. for the photon brightness function
- Linearly perturbed Einstein's equations (scalar modes)
- Initial conditions
- Super-horizon evolution
- Acoustic oscillations and tight coupling
- Free-streaming – role of the visibility function
- Evolution of gravitazional potential and Silk damping
- Temperature anisotropy multipoles
- Angular power-spectrum of the temperature anisotropy
- Sachs-Wolfe effect
- Small angular scales: acoustic peaks and their dependence on cosmological parameters

The gravitational instability

- Gravitational instability in the expanding Universe
- Boltzmann eq. for a system of collisionless particles and the fluid limit
- The Zel'dovich approximation
- The adhesion approximation
- Solution of the 3D Burgers equation
- Approach based on the Schroedinger equation.

Statistical methods in cosmology

- The ergodic and the "fair sample" hypotheses
- N-point correlation functions
- Power-spectrum and Wiener-Khintchine theorem
- Low-pass filtering techniques
- Up-crossing regions and peaks of the density fluctuation field
- Gaussian and non-Gaussian random fields
- The path-integral approach to cosmological fluctuation fields**Examination:**

The exam of this course can be made in two alternative ways:
1. Oral interview on the main topics analyzed during the course.
2. (only for the students who attended the classes) Short written dissertation on a topic discussed during the course, to be agreed with the lecturer. The dissertation should contain a detailed of the chosen subject, based upon one or a few review articles (and or some cosmology textbook chapters).
The content of this dissertation, to be discussed with the professor is expected to show how

much the student has
become acquainted with the main concepts presented in the lectures.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/001PD/SCP9086384/N0

## THEORETICAL PHYSICS

Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Gianguido Dall'Agata
Credits: 6 ECTS
**Prerequisites:**
Classical Mechanics. Quantum Mechanics.
**Short program:**
1. Classical and quantum mechanics of particles.
Lagrangian, action, principle of least action, Hamiltonian, Poisson brackets, Quantization, Symmetries in Quantum Mechanics, Schroedinger, Heisenberg and interaction picture.
2. Classical field theory.
Functional derivative. Principle of least action for fields, Hamiltonian, Hamilton equations.
3. Symmetries and conservation laws.
Noether's theorem, Spacetime symmetries and conserved quantities, internal symmetries and conserved charges.
4. Scalar field.
Classical real scalar field. Klein-Gordon equation and solution. Canonical quantization. Normal ordering. Fock space. Microcausality.
Classical and quantum complex scalar field. Internal symmetry and conserved charge. The scalar propagator.
5. Spinors.
Lorentz group and its representations. Spinor fields. Lagrangian for a Dirac spinor field. General solution of the Dirac equation. Energy and helicity projectors. Canonical quantization for the Dirac field (and anticommutators). Fermion propagator. Minimal coupling and covariant derivative. Non-relativistic limit, gyromagnetic factor.
6. Vector fields.
Classical vector field. Proca equation. Classical electromagnetic field theory. Gauge invariance. Lorentz gauge. Gauge fixing. Lagrangian and Hamiltonian densities in the Feynman gauge. General solution. Covariant quantization. Fock space and indefinite metric. Unphysical polarizations. Gupta-Bleuler condition. Propagator.
7. Interactions.
Interactions in a classical field theory. The S-matrix expansion and transition probability. T-products.
8. QED.
S-matrix expansion in QED. Feynman diagrams in coordinate space and in momentum space. 2->2 scattering processes. Photon and electron self-energies. The Compton scattering. QED Feynman rules. The cross-section.
**Examination:**
Written. Solution of one or more problems.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/001PD/SCP7081638/N0

**DATA SCIENCE**

**ALGORITHMIC METHODS AND MACHINE LEARNING**

Master degree in **Data Science**, Second semester
Lecturer: Gianmaria Silvello
Credits: 12 ECTS

**Prerequisites:**

The student should have basic knowledge of programming.

**Short program:**

The course will cover the topics listed below:
- Algorithmic Methods:
Preliminaries: definition of problem, instance, solution, algorithm. Models of computation.
Analysis of algorithms: correctness and running time,. Asymptotic analysis.
Basic data structures: lists, stacks, queues. Trees and their properties. Dictionaries and their implementation. Priority queues.
Graphs: representation of graphs. Basic properties. Graph searches and applications.
Divide and Conquer paradigm: the use of recursion. Recurrence relations. Case study: sorting.
Dynamic programming: coping with repeating subproblems. Memoization of recursive code.
Case study: optimization algorithms on sequences.
Greedy paradigm: solving by successive choices. Applicability of the paradigm. Case study: data compression.
- Machine Learning
Introduction to Machine Learning: why machine learning is useful; when to use it.; where to use it; Machine Learning paradigms; basic ingredients of Machine Learning; complexity of the hypothesis space; complexity measures; examples of supervised learning algorithms.
Application Issues: classification pipeline, representation and selection of categorical variables; model selection, evaluation measures.
in Depth (theory and practice using Python and Scikit-Learn): Support Vector Machines; Decision Trees and Random Forest; Neural Networks and Deep Learning; Manifold Learning; Kernel Density Estimation.

**Examination:**

Written exam and (individual) project. The project is due by the end of the course.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079257/N0

**BIG DATA COMPUTING (OFFERED IN THE MASTER DEGREE IN COMPUTER ENGINEERING)**

Master degree in **Data Science**, Second semester
Lecturer: Andrea Alberto Pietracaprina
Credits: 6 ECTS

**Prerequisites:**

The course has the following prerequisites: competences regarding the desing and analysis of algorithms and data structures, knowledge of fundamental notions of probability and statistics, and programming skills in Java or Python.

**Short program:**

The course will cover the following topics:
Introduction to the Big Data phenomenon
Programming frameworks: MapReduce/Hadoop, Spark
Clustering
Association Analysis
Graph Analytics (metriche di centralità, scale-free/Power-law graphs, fenomeno dello small

world, uncertain graphs)
Similarity and diversity search.
**Examination:**
The exam consists of a number of programming homeworks, assigned approximately every 2-3 weeks and to be carried out in groups of 3-4 students, and of an individual written test comprising both theory questions and exercises.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079297/N0

## BIOINFORMATICS (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)

Master degree in **Data Science**, First semester
Lecturer: Giorgio Valle
Credits: 6 ECTS
**Prerequisites:**
There are no particular prerequisites other than what it is expected from a master student in informatics.However, a basic knowledge of genetics and molecular biology will help in the understanding of the biological motivations of bioinformatics.
The course is in English, therefore the students should have a reasonable command of spoken and written English.
**Short program:**
This is a six credits course: five credits will be from lessons while one credit will be from practical activities, either the implementation and of some algorithm or the in-depth investigation of the literature on given arguments.
The lessons are divided in three main parts.
The first part is an extensive introduction on Biology presented as a scientific field centered on Information. The mechanisms that facilitate the transmission and evolution of biological information is used to introduce some biological problems that require computational approaches and bioinformatics tools.
The second part of the course describes the main algorithms used for the alignment of biological sequences, including those designed for “next generation sequencing”. The algorithms used for de novo genomic assembly are also described.
Finally, the third part of the course covers several aspects of bioinformatics related to functional genomics, such as the analysis of transcription, gene prediction and annotation, the search of patterns and motifs and the prediction of protein structures. The role of Bioinformatics in individual genomic analysis and personalized medicine is also discussed.
**Examination:**
The exam will be articulated into three parts: 1) a practical session in which the student must describe a project of data analysis, that must be submitted at least two days before the date of the exam, 2) a quiz session on Moodle, that will take place at the beginning of the exam day, 3) an oral discussion in which the student must describe his/her project and answer questions on the topics of the course. A continuous process of assessment will be carried out throughout the course, to verify the level of understanding of the students.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079405/N0

## BIOINFORMATICS AND COMPUTATIONAL BIOLOGY (OFFERED IN THE MASTER DEGREE IN PHARMACEUTICAL BIOTECHNOLOGIES)

Master degree in **Data Science**, Second semester
Lecturer: Silvio Tosatto
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge of bioinformatics, e.g. alignment methods and databases.

**Short program:**
1) Evolutionary reletationship between protein structure / function / interactions
2) Folding and evolution theories of proteins
3) Prediction of 3D structure by homology and ab initio methods; The CASP experiment
4) Prediction of structural features
5) Prediction of protein function; The CAFA experiment
6) Interactions between proteins
7) Concepts of Network Biology
8) Genotype-phenotype correlation and proteins; The CAGI experiment.
**Examination:**
The exam is composed of four parts, each of which has to be passed: (weight in parenthesis)
1) Practicals (25%)
2) Journal club presentation (25%)
3) Final essay on an unknown protein (25%)
4) Oral exam (25%)
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079317/N0

**BIOLOGICAL DATA**
Master degree in **Data Science**, First semester
Lecturer: Silvio Tosatto
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge of computer science, optimization methods and machine learning. Python programming language.
**Short program:**
The course consists of four parts, corresponding to different types of biological data:

1) Sequences
1.1) DNA and proteins
1.2) Databases
1.3) Alignments

2) Structures
2.1) Protein folding
2.2) Databases
2.3) Structure prediction

3) Interaction networks
3.1) Biological interactions
3.2) Databases
3.3) Emergent properties

4) Literature
4.1) Scientific papers
4.2) Databases
4.3) Text mining
**Examination:**
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis)
1) Test for the practicals (ca. 20%)

2) Project (ca. 50%)
3) Project presentation and critical evaluation (ca. 30%)
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079337/N0

## BUSINESS ECONOMIC AND FINANCIAL DATA

Master degree in **Data Science**, First semester
Lecturer: Mauro Bernardi
Credits: 6 ECTS
**Prerequisites:**
statistics: descriptive statistics and probability. Inferential statistics: estimation, confidence intervals and hypothesis testing.
**Short program:**
Decomposing and analysing economic time series: latent component approaches and ARMA modelling.
Enhancing the analysis of economic and financial time series data: some case studies.
Business and marketing data analyses: the joint use of cross-sectional and temporal dimension and the introduction of dynamic modelling.
**Examination:**
Homework and Final Presentation.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079231/N0

## COGNITIVE, BEHAVIORAL AND SOCIAL DATA

Master degree in **Data Science**, First semester
Lecturer: Giuseppe Sartori
Credits: 6 ECTS
**Prerequisites:**
Notions of machine learning
**Short program:**
The aim of the course is to provide an overview of concrete data science applications in behavioural science, cognitive science, neuroscience and social science. The course gives an underground of methods to analyse and learn behavioural, cognitive and brain functional/structural data. It provide a review of studies, with several examples of recent practical applications, also according with the students interests. Limits in the state of the art and future directions will be discussed. The course contents are the following:
- Basic concepts of human brain cognitive functioning (attention, memory, learning, language, etc.) and how to measure it
- Basic concepts of social psychology and social behaviour (preferences, judgments, group identity, etc.) and how to measure it
- What are behavioural measures and how to measure them (e.g., RT); implicit and explicit behavioural measures (e.g., the IAT)
- Extracting and predicting information from behaviour (e.g. lie detection, predicting malicious behaviour from social networks activity, fake online reviews, security applications, etc.)
- What are psychophysiological measures and how to measure them (e.g., HR variability, SCR, facial expressions, EEG, fRMI, etc.)
- Extracting and predicting information from psychophysiological measures
- Extracting and predicting information from brain activity: mind reading applications (e.g., psychopathology detection, reconstructing visual experiences from brain activity, brain computer interface devices, etc.)

• Social and behavioural data for marketing application (e.g. skill assessment and prediction, psychology of taxes, predicting preferences and personality from social networks activity, sentiment analysis, etc.)
• Issue related to the application of machine learning in behavioural research (e.g. the problem of reproducibility)

**Examination:**
Oral exam and project.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079219/N0

## COMPUTER AND NETWORK SECURITY (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)

Master degree in **Data Science**, First semester
Lecturer: Mauro Conti
Credits: 6 ECTS

**Prerequisites:**
No strict prerequisites on previous exams.
However, it is suggested to have basic knowledge of networking, cryptography, and distributed systems (typically acquired in BSc degrees in Computer Science).

**Short program:**
Theory: RFID security, captcha, untrusted storage, smartphone security, attacks on smartphone, password protection, distributed Denial of Service attacks, deep learning, behavioural biometrics, VoIP security, secure content delivery, anonymous communications, keyloggers detection, anonymity in WSN, botnet detection, trusted HW, security of RFID ePassports, node replication attack in WSN, secure data aggregation in WSN, privacy issues in social networks, Google Android smartphone security, electronic voting, P2P botNet detection, taint mechanisms, browser security, privacy of location based services, Named Data Networking security, Named Data Networking privacy, cloud security, anonymity in wireless network, smartphone user profiling, SSL security issues in Android, circumvent censorship, secure messaging, operational technology security, cyber-physical systems security
Laboratory: advanced security tools, including: traffic analysis with machine learning tools, data inference, Android security tools, advanced analysis of malware systems and advanced persistent threat; web security; social network analysis tools, trusted platform modules.

**Examination:**
Project with written essay + oral exam.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP6076342/N0

## DEEP LEARNING (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)

Master degree in **Data Science**, Second semester
Lecturer: Alessandro Sperduti
Credits: 6 ECTS

**Prerequisites:**
It is advisable to have the basic knowledge related to Probability, Programming, and Algorithms.

**Short program:**
The topics covered in the course are as follows:
- Introduction to the course contents;
- Deep Feedforward Networks;
- Regularization for Deep Learning;
- Optimization for training Deep Models;
- Basic concepts for Convolutional Neural Networks;

- Recurrent Neural Networks for sequence modelling;
- Autoencoder
- Deep Generative Models;
- TensorFlow.

**Examination:**
The student must pass a written exam. In addition, the student must develop a notebook agreed with the teacher.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP9087561/N0

## FUNDAMENTALS OF INFORMATION SYSTEMS

Master degree in **Data Science**, First semester
Lecturer: Giorgio Maria Di Nunzio
Credits: 12 ECTS
**Prerequisites:**
The student should have basic knowledge of computer programming and problem solving skills.
**Short program:**
The course is structured into 3 submodules:
- Python Programming (for Data Science)

This submodule provides students with the foundational coding skills they need as data scientists. First, the basics of the Python programming language are covered (i.e., built-in data types, fuctions, I/O, etc.) along with the environment which is used throughout the class (i.e., Jupyter Notebook). Afterwards, students will dig into a set of the most up-to-date data science Python packages; those are: numpy/scipy (for numerical/scientific computing), pandas (for data manipulation), matplotlib/seaborn (for data visualization), and finally scikit-learn (for learning from data). Eventually, at the end of this submodule students will be able to implement all the stages of a typical machine learning pipeline: from collecting data to building predictive models for solving either a classification or a regression problem.
- Databases

This submodule is dedicated to data storage, and it covers the following topics:
Architecture of Database management systems (DBMS). Relational modelling.
Logical and Physical Design of a Relational Database.
Basic Principles of Normalization.
SQL Language: Data Definition and Data Manipulation Language, Database Query
The PostgreSQL database: Creation and Definition of a Database, SQL Queries.
- Networking

This submodule allows students to get familiar with computer networking. In particular, it focuses on the following topics:
Networking Fundamentals: Network architectures (OSI Model); TCP and UDP Transport layer protocols; IP Addressing and Routing; Link Layer Forwarding; DNS and DHCP.
Advanced Networking: Virtual LAN (VLAN) and Virtual eXtensible Lan (VXLAN), Software Defined Networking: control, data plane and virtualization; concepts on Cloud Computing: service and deployment models: data centers architectures, topologies, addressing, routing, traffic characteristics; Case Study: The Web of Things (IoT standards and protocols).
**Examination:**
The student is expected to pass a written and an oral exam.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7078720/N0

## GAME THEORY (OFFERED IN THE MASTER DEGREE IN COMPUTER ENGINEERING)

Master degree in **Data Science**, First semester

Lecturer: Leonardo Badia
Credits: 6 ECTS
**Prerequisites:**
A course, even a basic one, on probability theory.
**Short program:**
Basic concepts of game theory
Utility, market, discount factor
Static games in normal form
Dominance, Nash equilibrium
Efficiency, price of anarchy
Zero-sum games, minmax games
Mixed strategies, mixed equilibria
Nash theorem, minmax theorem
The tragedy of the commons
Dynamic games
Strategy and subgames
Backward utility
Stackelberg equilibria
Repeated games and cooperation
Dynamic duopolies, collusion
Cooperation, pricing
Imperfect/incomplete information
Bayesian games, signaling, beliefs
Revelation principle
Axiomatic game theory
Fictitious play
Best response dynamics
Distributed optimization
Algorithmic game theory
Computation, complexity, and completeness of equilibria
Auctions, bargaining
First-price and second-price auctions
VCG principle
Cooperative games: the core, the Shapley value
Resource allocation
Utilities, choices, and paradoxes
Potential games, coordination
Bio-inspired algorithms
Evolutionary games
Cognitive networks
Selfish routing
Game-theory enabled multiple-input systems
**Examination:**
For the students of engineering programs with regular attendance to the course (differently from other kinds of students), the exam involves the development of a project in 1-3 person groups, on course-related topics applied to ICT. This is agreed half-way through the course together with the lecturer.
For all the students, in any event the exam also includes a mandatory open-book written test, containing four problems of game theory focusing on different topics of the course. Every exercise involves three questions.
For engineering students with regular attendance to the course, the written test is limited to solving three exercises out of four. For the other students (non-engineering students or

students without regular attendance), the written test involves all of the four exercises. If the written test is sufficient, non-engineering students or students without regular attendance can directly finalize the passing score. Engineering students with regular attendance instead discuss their project with an oral exam after the written test. Oral exams are scheduled in the same day of written tests (even though students can decide to give the two parts on separate days). Both the written test and the oral exam must be sufficient to pass.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079401/N0

## HUMAN COMPUTER INTERACTION (OFFERED IN THE MASTER DEGREE IN APPLIED COGNITIVE PSYCHOLOGY)

Master degree in **Data Science**, First semester
Lecturer: Luciano Gamberini
Credits: 6 ECTS
**Prerequisites:**
There are no specific prerequisites.
**Short program:**
- Interaction design, models and users style. Paradigms and strategies for building interactive systems (Chapters 1, 2)
- Human limits and their implication for the design of technologies . Social Interaction - Emotional Interaction (Chapters 3, 4, 5)
- Interfaces (Chapter 6)
- Data and Evaluation; UX/usability: the lab and the real world; advanced techniques (eyes tracking, video analysis, EEG, EDA, T, HR-ECG and other bio-signals, etc (Chapters 7, 13, 14, 15 + materials)

**Examination:**
The examination will be in written modality (5 questions).
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079403/N0

## HUMAN DATA ANALYTICS

Master degree in **Data Science**, Second semester
Lecturer: Michele Rossi
Credits: 6 ECTS
**Prerequisites:**
Prior knowledge on Calculus and Linear Algebra (vector spaces, singular value decomposition, etc.), Probability Theory (random variables, conditional probability and Bayes formulas, probability distributions), and some basic computer programming (e.g, Matlab and some exposure to Python) is useful. Although not strictly required, basic knowledge of signal processing techniques (e.g., discrete Fourier transforms) is also helpful.
Note that the instructor will review basic concepts from the above fields whenever necessary, providing material and/or pointer to refresh the related theories. So, although such previous knowledge is very helpful to the student, the course is intended to be self-contained.
Although non mandatory, prospective students will benefit from prior attendance of the course "Machine Learning" from the Master Degree in ICT for Internet and Multimedia, course code: INP6075419.
**Short program:**
Part I – Introduction (2 hours)
- Intro: course outline, graduation rules, office hours, etc.
- Applications: health, activity-aware services, security and emergency management, authentication systems, analyzing human dynamics

Part II – Vector Quantization (12 hours)
- Vector quantization (VQ):
--- Aims, quality metrics
--- K-means, soft K-means, Expectation Maximization
- Unsupervised VQ algorithms:
--- Self-Organizing Maps (SOM), Gas Neural Networks (GNG)
- Application to quasi-periodic biometric signals (ECG):
-- Signal pre-processing, normalization, segmentation
--- Dictionary learning: concepts, architectures
--- Efficient representation of ECG signals: description of state-of-the-art algorithms
--- Unsupervised dictionary designs for ECG via GNG-based dictionaries
--- Final system design and numerical results
Part II – Sequential data analysis (10 hours)
- Hidden Markov Models (HMM):
--- Maximum Likelihood for the HMM
--- Forward-backward algorithm
--- Sum-product algorithm, Viterbi algorithm
- Applications
--- Authentication: user identification from keyboard keystroke dynamics
--- Speech recognition: audio feature extraction, automatic speech recognition through HMM
Part III - Deep Neural Networks (10 hours)
- Gradient descent and general concepts (supervised learning, overfitting, cost models, etc.)
- Feed Forward Neural Networks: models, training, back-propagation
- Convolutional Neural Networks (CNN): structure, description of constituting blocks, training
- Applications: human activity learning
--- Activities & sensors: definitions, classes of activities
--- Features: sequence features, statistical features, spectral features, activity context features
--- Activity recognition: activity segmentation, sliding windows, unsupervised segmentation, performance measures and results
- User authentication from motion signals: combination of CNN-SVM and sequential estimation theory
- Object / face recognition through CNN
Part IV: Laboratory classes (12 hours)
In the laboratory classes the students will go through a guided tour through the construction of Python code for neural networks, writing all the building blocks related to: the creation of the neural network structure, its training using several gradient descent-based algorithms. The students will be exposed to Python programming, including the use of the Keras and TensorFlow frameworks for the implementation and training of neural network structures. The software composing the different blocks of the presented neural network architectures will be pre-written and checked for correctness, so that the students, after attempting to implement their own version of it, will succeed to combine the various blocks and complete the assigned task. Upon connecting the blocks into the selected neural network architecture, the obtained neural network models will be trained using several gradient descent algorithms, and tested against selected and real datasets. The topics that will be covered are:
- Introduction to Python programming
- Solving a baseline inference problem
- Feed forward neural networks
- Convolutional neural networks

**Examination:**
This is a course on advance and applied machine learning techniques, that are applied to real world problem within the human data domain. Given this, the examination of the student will be carried out through a project which will involve the following phases of work:

1. The instructor will identify a problem to solve, using an open, rich, and freely accessible data set. The problem to tackle will be thus described by the instructor during a specific lesson where he will as well present how to carry out the final exam, which will consist of: 1) delivering a written report and 2) giving a conference-style talk
2. The students will split into groups, with a maximum of two students per group, and will start to work to the assigned project. The choice of the specific technique to use, the data pre-processing algorithm to obtain informative features, etc., will all be identified in full autonomy by the students, as a first step. The instructor will be available to steer the work and follow the students along all the work phases
3. Each group will solve the assigned problem using the selected technique and will: 1) present a final written report, 2) give a conference-style talk describing: the problem, the selected models / techniques, the software written as part of the project development, the obtained results. It is also recommended that the students will showcase their software during the presentation
A final grade will be provided by the instructor upon a close inspection of the written report at point 1) and the assessment of the talk at point 2).
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079397/N0

## INTRODUCTION TO MOLECULAR BIOLOGY

Master degree in **Data Science**, First semester
Lecturer: Maria Pennuto
Credits: 6 ECTS
**Prerequisites:**
None.
**Short program:**
This course has the goal to provide students with the notions necessary to understand the following aspects:
GENETICS:
1. Mendel's laws (Mendelian genetics)and exceptions to Mendel's laws (non-Mendelian genetics): Hereditary characters.
2. The theory of evolution: From Lamarck to Darwin.
3. Historical perspective on the discovery of DNA: From transmission of characters to the concept of GENE.
4. The dogma of biology: DNA->RNA->PROTEIN.
5. The cell: Organelles, compartments, functions.
DNA
1. Chemistry: Nitrogenous bases.
2. Structure: Double helix.
3. The genetic code: DNA is read in triplets.
4. DNA replication.
5. Techniques for DNA purification: Large scale and small scale DNA preparations.
6. Techniques to amplify DNA: PCR.
7. Gene cloning: The restriction and modification enzymes.
RNA
1. Chemistry: Nitrogenous bases.
2. Structure: Single helix.
3. RNA transcription: Regulation of gene expression.
4. Techniques for RNA purification and conversion to cDNA.
5. Techniques for analysis of gene expression of a gene of interest and omics: RT-PCR, microarrays, NGS.
PROTEIN

1. Chemistry: Amino-acids.
2. Structure: Primary, secondary, tertiary, and quaternary structure.
3. The process of translation: From RNA to protein synthesis.
4. Techniques of analysis of proteins: Western blotting, Coomassie, mass spectrometry.

This course includes LABORATORY experience with the preparation of DNA, RNA, and proteins, expression of target genes in cells and analysis of protein function in cultured cells.

**Examination:**

Oral exam: The student will be asked to present a subject of his/her own choice. We will ask two more specific questions to the student. The student may use slides on the subject of choice.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP8084903/N0

## KNOWLEDGE AND DATA MINING

Master degree in **Data Science**, Second semester

Lecturer: TO BE DEFINED

Credits: 6 ECTS

**Prerequisites:**

Suggested basic knowledge of logics and statistics.

**Short program:**

(A) Logics for knowledge representation:

(A.i) introduction to propositional logics, syntax, semantics, decision procedure. Satisfiability, weighted satisfiability, and best satisfiability.

(A.ii) First order logics, syntax, semantics, resolution and unification.

(A.iii) Fuzzy logics, syntax, semantics, and reasoning.

(B) statistical relational learning:

(B.i) Graphical models

(B,ii) Markov Logic Networks

(B.iii) Probabilistic prolog,

(B.iii) Logic Tensor Networks

**Examination:**

Final examination based on: written examination or project development.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079318/N0

## LAW AND DATA

Master degree in **Data Science**, First semester

Lecturer: Andrea Pin

Credits: 6 ECTS

**Prerequisites:**

No prerequisites

**Short program:**

- the concept of data; personal, sentitive and economic data; big data
- the concepts of identity and digital identity
- property of data, choices in the management of data
- supranational, international and national laws on data processing
- civil and criminal protection of privacy
- new contents and concepts of privacy: big data, cell phones; videos; wearable technologies, etc.
- the right to be forgotten
- social network, right to be forgotten, responsibility
- provider's criminal responsibility

- civil and criminal aspects of profiling activity
- automatic data processing, human responsabilities
- big data (collection, analysis, processing) and their influence on fundamental rights
- the issue of genetic data
- big data and economy
- phishing
- financial crimes and artificial intelligence

**Examination:**
Written Exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079399/N0

## MATHEMATICAL MODELS AND NUMERICAL METHODS FOR BIG DATA

Master degree in **Data Science**, First semester
Lecturer: TO BE DEFINED
Credits: 6 ECTS
**Prerequisites:**
Background on Matrix Theory: Type of matrices: Diagonal, Symmetric, Normal, Positive De nite; Matrix canonical forms: Diagonal, Schur; Matrix spectrum: Kernel, Range, Eigenvalues, Eigenvectors and Eigenspaces Matrix Factorizations: LU, Cholesky, QR, SVD
**Short program:**
Numerical methods for large linear systems
◦ Jacobi and Gauss-Seidel methods ◦ Subspace projection (Krylov) methods ◦ Arnoldi method for linear systems (FOM) ◦ (Optional) Sketches of GMRES ◦ Preconditioning: Sparse and incomplete matrix factorizations
Numerical methods for large eigenvalue problems
◦ The power method ◦ Subspace Iterations ◦ Krylov-type methods: Arnoldi (and sketches of Lanczos + Non-Hermitian Lanczos) ◦ (Optional) Sketches of their block implementation ◦ Singular values VS Eigenvalues ◦ Best rank-k approximation
Large scale numerical optimization
◦ Steepest descent and Newton's methods ◦ Quasi Newton methods: BFGS ◦ Stochastic steepest descent ◦ Sketches of inexact Newton methods ◦ Sketches Limited memory quasi Newton method
Network centrality
◦ Perron-Frobenius theorem ◦ Centrality based on eigenvectors (HITS and Pagerank) ◦ Centrality based on matrix functions
Data and network clustering
◦ K-Means algorithm ◦ Principal component analysis and dimensionality reduction ◦ Laplacian matrices, Cheeger constant, nodal domains ◦ Spectral embedding ◦ (Optional) Lovasz extension, exact relaxations, nonlinear power method (sketches)
Supervised learning
◦ Linear regression ◦ Logistic regression ◦ Multiclass classi cation ◦ (Optional) Neural networks (sketches)
**Examination:**
Written exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079406/N0

## METHODS AND MODELS FOR COMBINATORIAL OPTIMIZATION (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)

Master degree in **Data Science**, First semester
Lecturer: Luigi De Giovanni

Credits: 6 ECTS
**Prerequisites:**
Basic notions of Operations Research, Linear Programming, and computer programming.
**Short program:**
1. Advanced linear programming and duality with applications: primal-dual simplex, column generation, applications to network
optimization.
2. Advanced methods for Integer Linear Programming (ILP): Branch & Bound and relaxation techniques, alternative ILP formulations,
cutting planes method and Branch & Cut, application to relevant examples (Traveling Salesman Problem, location, network design etc.).
3. Meta-heuristics for combinatorial optimization: local search based, evolutionary algorithms.
4. Application of graph modeling and optimization.
5. Labs: optimization software packages and libraries.
**Examination:**
Oral examination about course contents and exercises on the application of optimization methods to solve realistic problems. Each student may chose to present a short project concerning a case study about models and exact/heuristic solution methods for a realistic application of combinatorial optimization.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079402/N0

## NETWORK SCIENCE

Master degree in **Data Science**, First semester
Lecturer: Tomaso Erseghe
Credits: 6 ECTS
**Prerequisites:**
This course has the following prerequisites: knowledge in Probability Theory, and Computer Programming in any language which is appropriate for network analysis (e.g., MatLab, Python, C, Java, Linux). Moreover: 1. for the INTERNET module: to be familiar with the most basic networking and communication concepts and terms (ISO/OSI model, packet-based networks, routing); 2. for the NETWORK SCIENCE module: knowledge in Calculus and Linear Algebra; any further knowledge of networking processes in economics, biology, telecommunications, semantics, etc. might be useful.
**Short program:**
The module will cover the following topics:
1. Network models - Basic network properties: graphs, adjacency matrix, degree distribution, connectivity; Erdos-Renyi model; Random graphs with general degree distribution; Power laws and scale free networks; Small world phenomena; Hubs; Network generation and expansion; Barabasi-Albert model; Preferential attachment; Evolving networks; Assortativity; Robustness.
2. Ranking - Hubs and authorities; PageRank: teleportation, topic specific ranking, proximity measures, trust rank; Speeding up by quadratic interpolation.
3. Community detection - Dendrograms; Girvan Newman method and betweenness; Modularity optimization; Spectral clustering; Other clustering algorithms; Core-periphery model for overlapping communities; Clique percolation method; Cluster affiliation model and BigCLAM.
4. Miscellaneous aspects - Link prediction; Applications scenarios
**Examination:**
The course has the following methods of examination:
INTERNET module:

The final exam will be the same for both ATTENDING and NON-ATTENDING students since it does not rely on in-class activities. The exam consists of two parts, namely: 1. a WRITTEN EXAM at the computer, 2. a LAB TEST. Students will be offered four attempts to pass the written and the lab tests. During in-class lectures, the students may be offered to participate to some (in class or at home) activities, such as peer-reviewing of other students' reports, participating in-class discussion and taking part to problem-solving competitions. The active participation to such initiatives may bring a few extra points (up to 3) to the students.
NETWORK SCIENCE module:
The verification of the expected knowledge and skills is carried out with the DEVELOPMENT OF A PROJECT aimed at verifying the ability to apply theory in interdisciplinary contexts, and which requires: the choice, the collection of data, and the analysis of a different network for each student; computer implementation (in any programming language known to the student) of the algorithms required for the analysis; the drafting of an essay. The project is foreseen in two ways: 1. for ATTENDING students in which the students are guided towards intermediate project objectives (HOMEWORKS) coherently with the development of the lessons, and complete the project at the end of the course; 2. for NON-ATTENDING students, in which the development of the project takes place in a single solution and is discussed in an oral exam in one of the four institutional dates. A bonus of up to 3 points is available for attending students that take part to an INTERDISCIPLINARY PROJECT with social science students attending the twin course on SOCIAL NETWORK ANALYSIS.
The final grade is expressed as a combination of the judgments in the two modules (50%+50%).
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP8082723/N0

## OPTIMIZATION FOR DATA SCIENCE

Master degree in **Data Science**, Second semester
Lecturer: Francesco Rinaldi
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge of
- Real Analysis and Calculus;
- Linear Algebra;
- Probability theory.

**Short program:**
1. Linear optimization: Theory and algorithms
(a) LP models for Data science;
(b) Duality;
(c) Simplex method;
(d) Interior point methods;
2. Convex sets and convex functions
(a) Convexity: basic notions;
(c) Convex functions: Basic notions and properties (gradients, Hessians..);
3. Unconstrained convex optimization
(a) Models in data science;
(b) Characterizations of optimal sets;
(c) Gradient-type methods;
(d) Block coordinate gradient methods;
(e) Stochastic optimization methods;
4. Constrained convex optimization
(a) Models in data science;
(b) Characterizations of optimal sets;

(c) Polyhedral approximation methods;
(d) Gradient projection methods;
5. Large scale network optimization
(a) Network models in data science;
(b) Methods for distributed optimization.

**Examination:**

- Written exam
- Homeworks
- Project (Optional)

1) Homeworks will periodically be assigned based on reading and lecture and will be due at given deadlines.
2) Written exam consists of 5 open questions.
3) Project (optional) can be requested to better analyze specific topics.

Written exams represents 85% of grade.
Homeworks represent 15% of grade.
Project gives an increase (1 up to 3 points) of the grade.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079229/N0

**PROCESS MINING (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COMPUTER SCIENCE)**

Master degree in **Data Science**, First semester
Lecturer: TO BE DEFINED
Credits: 6 ECTS

**Prerequisites:**
Basic notions of algorithms, data structures and programming.

**Short program:**
The course will cover the topics listed below:
1. MODELING AND ANALISYS: THE BPMN PERSPECTIVE
- Process Identification
- Essential and Advanced Process Modeling in BPMN
- Qualitative Analysis
- Quantitative Analysis
- Process redesign

2. MODELING AND ANALISYS: THE PETRI NET PERSPECTIVE
- An introduction to Petri Nets
- Petri nets and colored petri nets
- Simulation based analysis
- Reachability and coverability analysis
- Process modeling and analysis with PN

3. PROCESS MINING
- Data & Process mining
- Getting the data: the construction of event logs
- An introduction to Process discovery
- Advanced process discovery
- Conformance checking - replay based
- Conformance checking - logic based
- Mining additional perspectives
- Typical use cases, e.g., medical processes

4. DECLARATIVE APPROACHES
- Declarative approaches and Declare
- Declarative process mining (discovery in Declare) and hybrid approaches

5. PREDICTIVE PROCESS MONITORING
- Basic Predictive Process Monitoring techniques
- Advanced Predictive Process Monitoring techniques

**Examination:**
Written exam and project. The project is due and has to be discussed by the end of the course.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079235/N0

## STATISTICAL LEARNING (C.I.)

Master degree in **Data Science**, Annual
Credits: 12 ECTS
***Modules of the integrated course unit:***
- STATISTICAL LEARNING 1 (MOD. A)
- STATISTICAL LEARNING 2 (MOD. B)

***Common characteristics of the Integrated Course unit:***
**Prerequisites:**
Basic probability theory; multivariable calculus; linear algebra; basic computing skills.
**Examination:** written test for mod-A
project work and oral exam for mod-B
**STATISTICAL LEARNING 1 (MOD. A)**
***Specific characteristics of the Module***
Lecturer: Alberto Roverato
**Short program:**
Part 1: Modes of Inference
- Data: summary statistics, displaying distributions; exploring relationships
- Likelihood: the likelihood, likelihood for several parameters
- Estimation: maximum likelihood estimation; accuracy of estimation; the sampling distribution of an estimator; the bootstrap
- Hypothesis testing
- Other approaches to inference**.**

**STATISTICAL LEARNING 2 (MOD. B)**
***Specific characteristics of the Module***
Lecturer: Alberto Roverato
**Short program:**
Part 2
- Models : normal linear models; inference for linear models; generalized linear models; inference for generalized linear models
- Model selection
- Multivariate Analysis: dimension reduction; classification; clustering

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079226/N0

## STATISTICAL METHODS FOR HIGH DIMENSIONAL DATA

Master degree in **Data Science**, First semester
Lecturer: Bruno Scarpa
Credits: 6 ECTS
**Prerequisites:**
Statistical learning, Stochastic methods.
**Short program:**
Every year some of the following topics will be presented, according also to the preferences of the students.
1. REGRESSION MODELS FOR HIGH-DIMENSIONAL DATA

1.1 Incremental algorithms with limited memory, stochastic gradient descent, inference
1.2 Sparsity, penalization inducing sparsity
1.3 Recall of Lasso and Elastic-Net for GLM
1.4 Extensions: adaptation, fusion, dealing with categorical variables
1.5 Group LASSO
1.6 Non-convex penalties
2. STATISTICAL ANALYSIS OF NETWORK DATA
2.1 Introduction to network structures of data
2.2 Network and nodes indicators
2.3 Community detection
2.4 Basics statistical models and inference (Erdos-Renyi, p1, ERGM)
2.5 Bayesian models (Stochastic block models, Latent space models)
3. STATISTICAL METHODS FOR TEXT MINING
3.1 Introduction
3.2 Data preparation and preprocessing (text scanning, stemming, tagging)
3.2 Dimensionality reduction and t-SNE
3.3 Topic models and Latent Dirichlet Allocation
3.4 Classification models
3.5 Sentiment analysis and iSA (integrated Sentiment Analysis
4. CLUSTERING
4.1 Introduction to clustering and recall of basic algorithms (hierarchical and non-hierarchical
4.2 Model-based clustering
4.3 Gaussian mixtures
5. TOPICS IN STATISTICAL LEARNING AND DATA MINING METHODS
5.1 Generalization of boosting: Adaboost as additive logistic model, Gradient boosting and XGboosting
5.2 Association rules and Market basket analysis
6. COMPUTATIONAL ISSUES

**Examination:**
Practical and oral exams.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079197/N0

## STOCHASTIC METHODS

Master degree in **Data Science**, First semester
Lecturer: Paolo Dai Pra
Credits: 6 ECTS
**Prerequisites:**
Basic notions of differential and integral calculus, linear algebra and probability.
**Short program:**
1. Probability reviews.
• discrete and continuous distributions
• random variables, expectation and conditional expectation
• approximation of probability distributions.
2. Markov chains and random walks
• Markov Chain and their stationary distribution
• Monte Carlo (MCMC), convergence of MCMC-based algorithms
• Electrical networks.
3. Random graphs
• Erdos-Renyi graphs: connectivity, giant component.

• Random regular graphs
• Dynamic graphs. Preferential attachment.

**Examination:**
Written exam.

**More information:**
http://en.didattica.unipd.it/off/2018/LM/SC/SC2377/000ZZ/SCP7079197/N0

## STRUCTURAL BIOINFORMATICS (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)

Master degree in **Data Science**, Second semester
Lecturer: Damiano Piovesan
Credits: 6 ECTS

**Prerequisites:**
Basic knowledge of optimization methods and machine learning. Python programming language.

**Short program:**
The course consists of two parts:
1) Introduction to living matter (2 credits):
1.1) Introduction to organic chemistry, weak interactions and energy
1.2) Structure and function of DNA and proteins
1.3) Lipids, membranes and cellular transport
1.4) Experimental methods for structure determination
2) Computational Biochemistry (4 credits):
2.1) Biological Databases
2.2) Software libraries and concepts for sequence alignments and database searches
2.3) Sequence - structure relationship in proteins and structural classification
2.4) Methods for the prediction of protein structure from sequence, the CASP experiment
2.5) Methods for the prediction of protein function and interactions, the CAFA experiment
2.6) Non-globular proteins, disorder and structural repeats

**Examination:**
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis)
1) Written test of the biochemistry concepts (ca. 30%)
2) Software project (ca. 40%)
3) Project presentation and critical evaluation (ca. 30%)

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP7079278/N0

## VISION AND COGNITIVE SERVICES (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)

Master degree in **Data Science**, Second semester
Lecturer: Lamberto Ballan
Credits: 6 ECTS

**Prerequisites:**
The student should have basic knowledge of programming and algorithms. It is also advisable to be familiar with basic concepts in probability and analysis of multivariate functions.

**Short program:**
The course will cover the topics listed below:
- Introduction:
From human cognition to machine intelligence and cognitive systems; brief intro to artificial intelligence, cognitive computing and machine learning; the AI revolution: current trends and applications, major challenges.

- Cognitive Services:
Basic concepts; Language, Speech, and Vision services; major providers and APIs (IBM Watson, AWS, Google Cloud); enabling technologies.
- Machine Learning and applications:
Classification; intro to deep learning and representation learning; training and testing; evaluation measures; algorithm bias.
- Early Vision and Image Processing:
Machine perception; image formation, sampling, filtering and linear operators; image gradients, edges, corners; designing effective visual features (SIFT and gradient based features); image matching.
- Visual Recognition and beyond:
"Teaching computers to see": bag-of-features, spatial pyramids and pooling; representation learning in computer vision, convolutional neural networks; R-CNN and segmentation; image captioning, multi-modal scenarios and beyond the fully-supervised learning paradigm.
- Hands-on Practicals:
What's in the box? How to build a visual recognition pipeline; using cognitive services for image recognition/understanding; combining different services and modalities.

**Examination:**
The student is expected to develop, in agreement with the teacher, a small applicative project. In addition, the student must submit a written report on the project, addressing in a critical fashion all the issues dealt with during its development. During the exam students are asked to present and discuss their project and answer to a few questions about the topics addressed in class.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2377/2017/000ZZ/SCP9087563/N0

**MOLECULAR BIOLOGY**

**APPLIED STATISTISTICS**

Master degree in **Molecular Biology**, First semester
Lecturer: Alessandra Rosalba Brazzale
Credits: 6 ECTS

**Prerequisites:**
The style is informal and only minimal mathematical notation will be used. There is no real prerequisite except elementary algebra. However, a previous introductory course in statistics is recommended.

**Short program:**
- General ideas. From the research problem to probabilistic models. Sampling. Observational and experimental studies. Statistical tests: hypotheses, p-values and their interpretation, types of error, power. The problem of multiple comparisons/tests. Confidence intervals.
- Elementary methods. Inference on a proportion and comparison of two proportions. Student's t: one sample, two samples, paired data. Large sample inference. Nonparametric methods: Wilcoxon (one and two samples) and Kruskal-Wallis tests. Correlation coefficient.
- Advanced methods. One-way and two-way analysis of variance. Regression analysis: linear and logistic model. Exploring multivariate data: principal components and cluster analysis.

**Examination**:
Written exam. Students are required to answer a number of questions concerning the statistical analysis of a real data set.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2445/2018/000ZZ/SCP8085059/N0

**BIOCHEMISTRY**

Master degree in **Molecular Biology**, First semester

Lecturer: Ildiko' Szabo'
Credits: 8 ECTS
**Prerequisites:**
Basic level of biochemistry, cellular biology and physiology.
**Short program:**
The course will give an in depth knowledge of some aspects of modern, advanced biochemistry regarding protein import mechanisms into organelles (mitochondria, chloroplasts and peroxisomes) including illustration of the importance of the above processes in plant and animal physiology. Connected to these themes, mechanisms of photoprotection in higher plants will be treated. In addition, the study of membrane proteins (topology, structure,structure/function relationship) will be discussed with illustration of advanced techniques, with particular reference to ion channels. In addition, the most important aspects of tumor metabolism will be discussed.
**Examination**:
Written exam comprising open questions.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2445/2018/005PD/SCP8085067/N0

**BIOCHEMISTRY OF DISEASES (OFFERED IN THE MASTER DEGREE IN SANITARY BIOLOGY)**
Master degree in **Molecular Biology**, First semester
Lecturer: Luca Scorrano
Credits: 8 ECTS
**Prerequisites:**
Biochemistry, Physiology and Pathology
**Short program:**
1. Introduction to the course
2. Mechanisms of protein homeostasis
3. Mechanisms of cellular ion homeostasis
4. Mechanisms of redox homeostasis and cellular bioenergetics
5. Biochemical mechanisms of reversible cellular damage
a. atrophy
b. hypertrophy
c. Metaplasia (EMT)
6. Biochemical mechanisms of irreversible cellular damage
a. apoptosis
b. necrosis
c. necroptosis
d. Autosis
7. Biochemical mechanisms of senescence and aging
8. Biochemical mechanisms of cell transformation and oncogenesis
9. Role of biochemistry in mitochondrial disease
These topics will be covered in specific workshops, Journal Clubs, lectures held by the teacher and by ad-hoc invited international experts.
Tutorials
Laboratory tutorials on biochemical assays of cell death and autophagy and on the analysis of mitochondrial dysfunction
**Examination**:
Evaluation of the overall active participation to classes and tutorials (30%)
Evaluation of the lab report (30%)
Evaluation of the final public presentation (40%)
**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2445/2018/006PD/SCP8085083/N0

## CELL BIOLOGY

Master degree in **Molecular Biology**, First semester
Lecturer: Chiara Rampazzo
Credits: 9 ECTS
**Prerequisites:**
Basic level of Cell Biology, Molecular Biology and Genetics
**Short program:**
The 9 CFU course is organized in about 7 CFU of frontal lectures and 2 CFU dedicated to the presentation and discussion of recent articles on the topics covered in class. The discussion of the articles is an integral part of the program.
Lectures will cover 5 main topics:
1) In vitro cultures, methods for cellular molecular biology. Physical principles behind the most common microscopy techniques.
2) Chromatin Biology and nuclear organization to address fundamental questions in Epigenetics and Gene Regulation as well as in cellular differentiation and nuclear reprograming. Mechanisms of epigenetic regulation, including DNA methylation and post-translational modification of histones, and the roles of chromatin-assembly modifying complexes, non-coding RNAs and nuclear organization. X chromosome inactivation. Cell Memory and Genomic Imprinting. Centromeres and telomeres chromatin.
3) Main principles of autophagy and related diseases
4) Stem cell origins, plasticity and epigenetics. Bivalent Chromatin. Stem cell niche. Adult, Embryonic, and induced pluripotent Stem cells.
5) Signal transduction and cancer. Immortalization, role of telomeres. Malignant transformation, disturbances in signal transduction pathways resulting in malignant transformation, role of failure in signaling pathways regulating cellular proliferation, apoptosis and DNA-repair pathways. Cancer stem cells.
**Examination**:
The knowledge acquired by the student will be evaluated with a written exam organized in two parts.
First part (1 CFU) described in the course contents at section 1 will be assesed with one open question that include a long answer.
the second part (7 CFU) described in the course content at section 2 to 5 will be assessed with six questions that include short or longer answer.
The final grade is expressed as a weighted average between the two parties.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2445/2018/000ZZ/SCP8085218/N0

## COMPUTATIONAL ANTHROPOLOGY

Master degree in **Molecular Biology**, First semester
Lecturer: Luca Pagani
Credits: 6 ECTS
**Prerequisites:**
Prior knowledge needed for the classes in Computational Anthropology is that normally provided for students at the final class of the first degree in Molecular Biology. Particularly, the basic understanding of Genetics, Statistics, Phylogeny, and Evolutionary Biology in their fundamental principles and processes, is required. Students must also be familiar with the Unix/Shell environment. No prior knowledge is requested about specific contents in Population Genetics and Genomics, however scientific contents of the "Anthropology" course may be of great help during this course.
**Short program:**

The course aims at blending basic knowledge within the fields of Molecular Anthropology and Human Population Genetics with practical (bioinformatic) skills, transferable to the expanding occupational sectors of Personal Genomics and Ancestry analyses.
The following topics will be explored from a theoretical and a practical/applicative angle:
1) Genetic admixture and local ancestry;
2) Ancestry deconvolution and ancestry-specific analyses;
3) Population differentiation among human groups, both at a genome-wide and at a locus-specific level;
4) Effect on the genome of natural selection events;
5) Introgression events between Homo sapiens and Archaic humans;
These general objectives are addressed through critical discussion of case-studies taken from primary scientific literature on Molecular Anthropology, and through extensive hands on exercise in a computer lab.

**Examination**:
Examination will be based on a practical exercise of approximately 3 hours, to be carried out in the computer room. The exercise will include the main topics of the course and will be comparable to what already experienced during the hands on lectures. Final evaluation will be based upon the obtained results and will follow a discussion with the teacher about the information and procedures carried out to solve the exercise.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2445/2018/005PD/SCP8085072/N0

## ENVIRONMENTAL BIOTECHNOLOGY AND BIOENERGY PRODUCTION (OFFERED IN THE MASTER DEGREE IN INDUSTRIAL BIOTECHNOLOGY)

Master degree in **Molecular Biology**, First semester
Lecturer: Fiorella Lo Schiavo
Credits: 8 ECTS

**Prerequisites:**
No specific prerequisites. Students should have a general background in basics of plant biology and biotechnology.

**Short program:**
Environmental Biotechnology:
Responses of Plants To Abiotic Stresses: Stresses involving water deficit, osmotic stress and its role in tolerance to drought and salinity, impact of water deficit and salinity on transport across plant membranes. Freezing stress. Flooding and oxygen deficit. Oxidative stress. Heat/Cold stress.
Plant responses to mineral toxicity: Molecular Physiology of mineral nutrients, acquisition, transport and utilization. Aluminium toxicity, heavy metal ion toxicity ($Cd^{+2}$, $Hg^{2+}$, $Pb^{2+}$).
Phytoremediation approaches to remove soil/water contaminants.
Biotechnologies for Energy production:
Introduction: current energy sources and the necessity of renewable fuels.
Production of bioethanol from ligno-cellulosic biomasses.
Production of biodiesel from oleaginous crops.
Algae as biofuels producers. Evaluation of advantages and disadvantages with respect to plants.
Hydrogen production from algae and bacteria.
The biotechnological challenges for biofuels production: the optimization of conversion of solar into chemical energy.
Examples of genetic engineering for biofuels.
Exploitation of unicellular algae for wastewater treatment and bioremediation.

**Examination**:

The evaluation consists of two parts:
1. presentation and critical analysis of some recent scientific papers.
2. written test on the class contents.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2445/2018/006PD/SCP8085085/N0

## GENOMICS

Master degree in **Molecular Biology**, Second semester
Lecturer: Giorgio Valle
Credits: 9 ECTS

**Prerequisites:**
The content of the course has been defined keeping in mind the program of the first level degree in Molecular Biology of the University of Padua. In particular it is expected that the students have a good knowledge of Genetics, Molecular Biology and Bioinformatics. The course is in English, therefore the students should have a reasonable command of spoken and written English.

**Short program:**
This is a 9 credit course, 7 of which will be lessons, the remaining 2 will be practicals. Each title reported below corresponds to approximately two hours of classroom teaching plus four hours of home study. The lessons will be articulated as follows.
Part 1.
Presentation of course and practicals
Introduction: Life, Biology, Information, Genomes, Evolution
History of genomics
Next Generation sequencing (NGS)
NGS: data formats for reads
Classical sequence alignment and assembly algorithms
NGS read alignment
Alignment formats: gff, sam and bam
Genome assembly with NGS data
Mate pair libraries and scaffolding
Metagenomics
Part 2
Transcriptome: Northern, EST, Full length, Microarrays
RNAseq
Analysis of RNAseq data
Proteomics
miRNA,
miRNA target prediction; lincRNA
Interactomics, and functional associations
Gene prediction, gene ontology and gene annotation
DNA methylation and methylome analysis
Histone modification and ChIP analysis"
Part 3
Analysis of human mutations and polymorphisms
GWAS
Genome re-sequencing and Exome sequencing
Personalized medicine and related bioinformatics
Genome browsers
Data integration and systems biology
General summary, discussion and conclusions

**Examination**:

The exam will be articulated into three parts: 1) a written session in which the student must describe the results of the laboratory practicals, that must be submitted at least one week before the official date of the exam, 2) a quiz session on Moodle, that will take place at the beginning of the day of the exam, 3) an oral discussion in which the student must describe his/her laboratory activity and answer questions on the topics of the course. A continuous process of assessment will be carried out throughout the course, to verify the level of understanding of the students.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2445/2018/000ZZ/SCP8085063/N0

**HUMAN PHYSIOLOGY (OFFERED IN THE MASTER DEGREE IN SANITARY BIOLOGY)**

Master degree in **Molecular Biology**, First semester
Lecturer: Luigi Bubacco
Credits: 9 ECTS

**Prerequisites:**
The class requires previous knowledge of basic Biochemistry, cell Biology and General Physiology.

**Short program:**
The Central Nervous System (8 hours)
Neurons: Cellular and Network organization and Properties,
Efferent Division: (10 hours) Autonomic and Somatic Motor Control. Sensory Physiology.
Muscles physiology (8 hours) Control of Body Movement
Cardiovascular Physiology (10 hours) Blood Flow and the Control of Blood Pressure and functional properties of Blood
Respiratory Physiology (8 hours) Mechanics of Breathing. Gas Exchange and Transport
The Kidneys (8 hours) Fluid and Electrolyte Balance
Digestion (8 hours) Energy Balance and Metabolism.
Endocrine Control of Growth and Metabolism (8 hours)
Reproduction and Development (8 hours)

**Examination**:
Written exam, four open questions to be answered in two hours

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2445/2018/006PD/SCP8085086/N0

**IMMUNOLOGICAL BIOTECHNOLOGY (OFFERED IN THE MASTER DEGREE IN INDUSTRIAL BIOTECHNOLOGY)**

Master degree in **Molecular Biology**, First semester
Lecturer: Emanuele Papini
Credits: 8 ECTS

**Prerequisites:**
The student must have a good preparation in general Immunology

**Short program:**
- Classic Vaccinology
- Main problems in the development of a vaccine.
- production of recombinant vaccines
- Microbial, animal and plant models for vaccine production.
- Reverse vaccinology: genome based antigen individuation (in silico). Production, quality control.

Main vaccines in pediatric prevention in Italy.
Adjuvants - Mucosal adjuvants - micro-nanosized new generation adjuvants.
- Use of dendritic cells in therapy: perspectives.

Practical part:

Evaluation in vitro of adjuvancy in human dendritic cells. Isolation of monocytes fromm blood, thier differentiation into Dendritic Cells (DCs). Stimulation of DCs with various adjuvants and analysis of cell activation by Elisa (TNFa) and flow cytometry (CD86, CD11), RT-PCR (tnfa gene transcription). Aultologous/heterologous T lymphocytes proliferation and characterisation of their immunological competence by FACS.

**Examination**:

Oral examination plus evaluation of a laboratory activity written report

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2445/2018/006PD/SCP8085084/N0

## MICROBIAL METAGENOMICS

Master degree in **Molecular Biology**, First semester

Lecturer: Stefano Campanaro

Credits: 6 ECTS

**Prerequisites:**

The course requests basic knowledge reagrding molecular biology, microbiology and bioinformatics.

**Short program:**

Introduction: metagenomics as a new approach for the study of the microbial communities.

PART 1: Background.

Diversity of rRNA Genes within Individual Prokaryotic Genomes.

Use of the rRNA Operon and Genomic Repetitive Sequences for the Identification of Bacteria.

Use of Different PCR Primer-Based Strategies for Characterization of Natural Microbial Communities.

Horizontal Gene Transfer and Recombination Shape Microbial Populations.

PART2 : The Species Concept.

Population Genomics Informs Our Understanding of the Bacterial Species Concept.

Metagenomic Approaches for the Identification of Microbial Species.

PART 3 : Metagenomics.

Microbial Ecology in the Age of Metagenomics.

Empirical Testing of 16S PCR Primer Pairs.

The Impact of Next-Generation Sequencing Technologies on Metagenomics.

Accuracy and Quality of Massively Parallel DNA sequencing.

Environmental Shotgun Sequencing: Its Potential and Challenges for Studying the Hidden World of Microbes.

Metagenomic Libraries for Functional Screening.

Towards Automated Phylogenomic Inference.

High-Resolution Metagenomics: Assessing Specific Functional Types in Complex Microbial Communities.

Gene-Targeted Metagenomics to Explore the Extensive Diversity of Genes of Interest in Microbial Communities.

Phylogenetic Screening of Metagenomic Libraries Using Homing Endonuclease Restriction and Marker Insertion.

PART 4 : Consortia and Databases.

Soil Metagenomic Exploration of the Rare Biosphere.

The BIOSPAS Consortium: Soil Biology and Agricultural Production.

The Human Microbiome Project.

The Marine Microbiome Projects.

The Anaerobic Digestione Microbiome.

The Ribosomal Database Project: Sequences and Software for High-Throughput rRNA Analysis.

The Metagenomics RAST Server.

The EBI Metagenomics Archive.
PART 5 : Computer-Assisted Analysis.
Comparative Metagenome Analysis Using MEGAN.
Phylogenetic Binning of Metagenome Sequence Samples.
Iterative Read Mapping and Assembly Allows the Use of a More Distant Reference in Metagenome Assembly.
Ribosomal RNA Identification in Metagenomic and Metatranscriptomic Datasets.
SILVA: Comprehensive Databases for Quality Checked and Aligned Ribosomal RNA Sequence Data.
ARB: A Software Environment for Sequence Data.
The Phyloware Project: A Software Framework for Phylogenomic analysis.
MetaGene: Prediction of Prokaryotic and Phage Genes in Metagenomic Sequences.
Primers4clades: A Web Server to Design Lineage-Specific PCR Primers for Gene-Targeted Metagenomics.
ESPRIT: Estimating Species Richness Using Large Collections of 16S rRNA Data.
PART 6 : Complementary Approaches.
Metagenomic Approaches in Systems Biology.
Towards “Focused” Metagenomics: A Case Study Combining DNA Stable-Isotope Probing, Multiple Displacement Amplification, and Metagenomics.
Suppressive Subtractive Hybridization Reveals Extensive Horizontal Transfer in the Rumen Metagenome.
PART 6A : Metatranscriptomics
Isolation of mRNA from Environmental Microbial Communities for Metatranscriptomic Analyses.
PART 6B : Metaproteomics.
Proteomics for the Analysis of Environmental Stress Responses in Prokaryotes.
Microbial Community Proteomics.
Synchronicity Between Population Structure and Proteome Profiles.
PART 6D : Metabolomics.
The Small-Molecule Dimension: Mass-Spectrometry-Based Metabolomics, Enzyme Assays, and Imaging.
Metabolomics: High-Resolution Tools Offer to Follow Bacterial Growth on a Molecular Level.
PART 6E : Single-Cell Analysis.
Application of Cytomics to Separate Natural Microbial Communities.
Capturing Microbial Populations for Environmental Genomics.

**Examination**:
Final test will be based on written examination, questions will evaluate acquired knowledge, ability to summarize answers and critical discussion. Test is based on topics covered during the course.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2445/2018/005PD/SCP9087942/N0

## MODELS IN GENETIC DISEASE RESEARCH

Master degree in **Molecular Biology**, First semester
Lecturer: Mauro Agostino Zordan
Credits: 4 ECTS

**Prerequisites:**
The course consists in a series of specific seminars dealing with the general topic of genetic diseases and the model organisms employed to study the molecular mechanisms involved in the physiopathology of the diseases. Consequently, all of the courses entailed by the Master's degree are considered preparatory to this course.

**Short program:**

The course is organized as a series of one-hour seminars on topics dealing mainly with genetic diseases and the use of model organisms in genetic disease research. Topics typically touch upon molecular aspects of select genetic diseases and on the application of models such as in vitro mammalian cells, yeast, Drosophila, zebrafish and mouse to study the pathogenetic mechanisms of specific genetic defects.

**Examination:**

The final exam will be written and consists in reading a scientific paper dealing with the subject exposed in one of the seminars and, on the basis of the paper's content, writing an abstract, which for the occasion, will have been concealed from the original paper.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2445/2018/000ZZ/SCP8085071/N0

**MOLECULAR BIOLOGY OF DEVELOPMENT**

Master degree in **Molecular Biology**, Second semester

Lecturer: Francesco Argento

Credits: 8 ECTS

**Prerequisites:**

The students should have already acquired the fundamentals on eukariotic cellular biology, on control of gene expression, differentiation, histology and developmenta biology.

**Short program:**

1) Presentation of the course, history and principles of developmental genetics (1.5 CFU): cell fate analysis, organizers and transplants, mutagenesis, cellular asymmetry, chemoaffinity hypothesis, sex determination, lateral inhibition, somitogenesis.

2) Cellular Developmental Mechanisms (0.5 CFU): Survival, Apoptosis, Shape, Movement, Differentiation, Gene Expression

3) Morphogenetic theory (0.5 CFU): Diffusion reaction, French flag theory.

4) Genetic pathways controlling development, their function and visualization (1.5 CFU): Wnt, TGFb, BMP, HH, Notch, Hypoxia, Hippo, STAT

5) germ layers induction and regionalization of the main axes (DV, AP, LR) in vertebrates and Drosophila, Examples of organ formation. (1 CFU)

Angiogenesis in model animals (1 CFU): Use of genetic animal models to study angiogenesis. Molecular biology of endothelial cells. Developmental and pathological angiogenesis.

Fluorescent and digital microscopy (1 CFU): Use of genetically encoded fluorophores in molecular genetic development. Different fluorescent techniques and microscopes. Advance microscopic techniques for in vivo studies.

Laboratory (1 CFU): manipulation of the zebrafish embryo: whole mount staining and imaging of fluorescent embryo; Pharmacological treatment of zebrafish embryos with non-specific teratogens (alcohol) and specific agonists or antagonists.

**Examination**:

Three essay on open questions on theoretical, practical and critical topics of the class.

For the laboratory experience, students must prepare a written report of their practicals on whole mount analysis of development.

Students are also asked during the progress of the class to present a developmental genetic topic.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2445/2018/000ZZ/SCP8085061/N0

**MOLECULAR AND CELL BIOLOGY OF PLANTS**

Master degree in **Molecular Biology**, First semester

Lecturer: Barbara Baldan

Credits: 9 ECTS

**Prerequisites:**

Students should have already acquired a basic knowledge of Cell Biology, Plant Biology, Biochemistry and Molecular Biology.

**Short program:**

Ca2+-mediated signal transduction in response to biotic and abiotic stresses in plants: Ca2+, an intracellular second messenger; methods of measuring intracellular Ca2+ concentration; calcium transients and calcium signatures (4h).

Plant hormones (auxins, gibberellins, cytokinins, ethylene, abscissic acid): biosynthesis, actions, transport and developmental effects; signal transduction pathways (16h).

Growth and development: Shoot and root apical meristems: their establishment and maintenance. Determination of the developmental axes and the involved genes. Molecular aspects of lateral organ formation (6h).

Blue light and red light responses: light perception, signal transduction and plant responses to light environmental conditions (6h).

Plant reproductive development: floral meristem development, floral organ identity genes, ABCDE model to explain the flower development; the control of flowering (8h).

Molecular aspects in micro and macro-gametogenesis; self-incompatibility during the pollen-pistil interactions; genes involved in control of double fertilization; embryo, seed and fruit development (14h).

Plant–microorganism interactions: cellular and molecular surveys about mycorrhiza, Rhizobium-Leguminosae symbiosis and plant-Agrobacterium interaction (10h).

16h (1 CFU) of practical work are planned on the following topics:

1) Somatic embryogenesis in the model system Daucus carota, tobacco micropropagation

2) Isolation of protoplasts from plant cell suspension cultures; fluorescence imaging of intracellular compartments

3) Protein extraction and quantification from Arabidopsis thaliana cell cultures stably expressing the calcium-sensitive photoprotein aequorin

4) Analysis of protein expression by SDS-PAGE and immunoblotting.

**Examination:**

To verify the acquired knowledge, the exam will be in written form, with open questions on theoretical topics dealt with during the course, as well as questions concerning the practical activity carried out in the laboratory. The active partecipation to the discussions proposed during teaching classrooms will also be considered.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2445/2018/000ZZ/SCP8085062/N0

## MOLECULAR GENETICS

Master degree in **Molecular Biology**, First semester

Lecturer: Gabriele Sales

Credits: 6 ECTS

**Prerequisites:**

The basic knowledge deriving from the subjects of the first year of the Master Degree

**Short program:**

Introduction to Systems Biology.

Basics of Derivatives, Integrals and Differential Equations

Mathematical Modeling.

Static Network Models.

Markov Models.

Mutual Information, Relevance Networks and Bayesian Networks.

The Mathematics of Biological Systems.

Parameter Estimation from Noisy Data: Grid Searches, Hill Climbing, Genetic Algorithms.

Signaling Systems.

Population Systems.
SIR Model Simulation.
**Examination**:
The evaluation of the acquired knowledge will be based on a written exam based on 4 open questions. This will gauge the establishment of the proper knowledge, the scientific lexicon, the ability to discuss critically and to summarize the topics discussed in the lectures.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2445/2018/000ZZ/SCP8085070/N0

**NANOBIOTECHNOLOGY (OFFERED IN THE MASTER DEGREE IN INDUSTRIAL BIOTECHNOLOGY)**
Master degree in **Molecular Biology**, First semester
Lecturer: Alessandro Moretto
Credits: 8 ECTS
**Prerequisites:**
Basic background in chemistry and organic chemistry acquired in the previous fundamental courses. Basic knowledge about formation and properties of nanoparticles. Basic background in anatomy/physiology, cell biology and protein biochemistry.
Previous attendance of the "Nanosystems" course (previous semester) is suggested.
**Short program:**
I. Introductory lessons that summarize the general features of nanoassembled systems; these lessons are meant to go over the main contents of the course "Nanosystems", for the benefit of those students who followed it; at the same time, they are meant to provide a basis for those student who do not have it. Outline of the essential features of nano-structured systems. The ideal nanostructure: components. Modified "natural" nanostructures (bacterial Outer Membrane Vescicles, viruses). Engineered nanoparticles: inorganic (silica, gold), organic (nanoformulations, polymers), liposomes and lipidic nanoparticles, quantum dots. Derivatization with small organic molecules (conjugation, orthogonal bioconjugation), with proteins or antibodies for specific cell targeting.
II. Lectures on nano-biomedicine and nanotoxicology. Physio-structural features of living organisms that come primarily into play in the interaction with nanomaterials.
Blood circulation, endothelial cells, renal filter. Reticuloendothelial system (RES): tissue-resident macrophages. Professional phagocytes: PMN, monocytes-macrophages, APCs. Accessibility to tissues and systems: physiological and pathological endothelial permeability (in chronic inflammation, and neoplasms); Permeabilisation Retention Effect (lymphatic system); "Shrines": blood-brain barrier: structure and its alteration. Cellular and humoral responses to nano-materials, toxicology and pharmacokinetic aspects. The chemical basis of the interaction between nanomaterials and biomolecules: multivalency and cooperativity. Acute cytotoxic cell damage. Toxic mechanisms, principles, measurements. Current knowledge on the toxicity of inorganic (silica, gold) and organic (microgels, liposomes, nanotubes, polymers) nanostructures. Uptake-clearance, endocytosis and phagocytosis. Opsonization: plasma opsonins. Complement. Concept of protein crown. Concept of stealth property (or "invisibility") of a nano-structure. PEGylation. Proinflammatory, pro-immune, pro-coagulant activities: cytokines induction, radicals production, leukocyte and endothelial activation. Complement and coagulation cascades induced by macroscopic or nanoscopic bio-materials. Immune reaction. In vitro measurements. Biodegradation and elimination from the body (kidney, bile).
III. Bio-active (transported) portion and applications: drugs, immunostimulants, DNA. Direct action of the nanomaterial, photoactivation, magnetic field activation. Applications: fluorescent biomarking of tissues and cells, in vivo imaging, diagnosis. Drug and gene delivery. Vaccines. Immunological adjuvants. Detection of pathogens. Detection of proteins. Probing the structure of DNA. Tissue engineering.

Hyperthermal therapies. Separation and purification of biological molecules and cells. Contrast agents in magnetic resonance imaging (MRI). Phagokinetic studies.
IV. Laboratory. The practical part will be introduced by preparatory lectures. It will consist of the synthesis of nanosystems, among which will be nanoparticles (both organic and inorganic/metallic) coated with organic (charged) ligands; liposomes (some fluorophoric molecules will be incapsulated and released by appropriate stimuli); hydrogels based on amino acids and peptides. These nanosystems will be characterized using spectroscopic techniques, such as UV-vis, fluorescence, and dinamic light scattering. Next, the student will test the biocompatibility of the nanosystems produced in biological a-cellular (plasma) or cellular (stabilized human cell lines) models. Examples of possible characterization are: blood coagulation tests, complement activation, citotoxicity, cellular uptake.
**Examination**:
The evaluation will be partly based on a written report on the experimental part, which will have to be turned in by the end of the course, and on an oral exam. The oral exam consists in an open-answer questions on topics covered both in the practical and in the theoretical part of the course.
The time allotted to the discussion of the topics proposed is 40 minutes.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2445/2018/006PD/SCP8085082/N0

## NEUROBIOLOGY

Master degree in **Molecular Biology**, Second semester
Lecturer: Daniela Pietrobon
Credits: 10 ECTS
**Prerequisites:**
Physiology, Genetics, Cellular Biology, Molecular biology
**Short program:**
Module A (Prof Pietrobon): 7 CFU (56 hours)of lectures
1. Introduction. 2. anatomical and functional organization of the human nervous system. 3. Electrophysiological and optical techniques for measurement of neuronal electrical activity. Optogenetic techniques for selective stimulation of specific neurons. Examples of applications. 4. Specific firing patterns in different neurons, physiological role and experimental methods to investigate their molecular mechanisms. 5. Techniques for measurement of synaptic transmission.Biophysical and molecular mechanisms of neurotransmitter release; experimental methods for their study. 6. Mechanisms of short-term synaptic plasticity (facilitation, post-tetanic potentiation, depression)and of long-term synaptic plasticity (LTP, LTD, STPD). Learning and memory. 7. General functional organization of sensory systems; in depth discussion of one sensory system.
Module B (Prof Costa): 2 CFU (16 hours) of lectures + 1 CFU (16 hours) of laboratory.
The physiological basis of biological rhythms and the ramifications for the sleep-wake cycle. the normal modulation of circadian cycles and the effects when these are disrupted. The circadian rhythm and its relationship to the sleep/wake cycle examined along with the concepts of photic and nonphotic zeitgebers. Drosophila melanogaster as a Model System for molecular chronobiology. The genetic basis of circadian rhythm generation. The fly's circadian clock. The mammalian circadian clock. The neurophysiology of the pacemaker in the suprachiasmatic nuclei. The genetic basis of circadian rhythm generation. The internal sleep structure is governed by circadian rhythms and these rhythms also impact upon levels of alertness and cognitive performance. General day-time performance and quality of life if these rhythms are disrupted such as with sleep fragmentation or jet lag. The effects of sleep deprivation and shift work. Changes in sleep wake patterns with ageing. Clock related sleep syndroms. Laboratory training: practical exercises are organised to define the chronotype of

participants and to explore the hypothesis of a relationship between genetic variability in clock genes and sleep/wake preferences.

**Examination**:

Module A (Prof Pietrobon)

Written examination with three open questions, which aim to verify, besides the acquired knowledge on relevant topics, the ability of critical discussion and reasoning.

Module B (Prof Costa)

The examination is conducted in written form (open questions). The individual report on the practical experience maturated during the laboratory training is also evaluated.

The final mark is obtained as the weighted mean of the marks of the two modules.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2445/2018/000ZZ/SCP8085065/N0

## STRUCTURAL BIOCHEMISTRY AND BIOPHYSICS

Master degree in **Molecular Biology**, First semester

Lecturer: Laura Cendron

Credits: 8 ECTS

**Prerequisites:**

General Biochemistry concepts. Basic Mathematics and Physics courses.

**Short program:**

The course will be divided in two parts. The first will be devoted to the introduction of basic principles of Biophysical techniques focused on structural and functional characterization of biological macromolecules, supramolecular assemblies and cells. In the second part, three recently described paradigms in the analysis of sensorial system study will be introduced. Such examples will be proposed mainly focusing on the Byophisical Methods that allowed disclosing important links between structure and function of macromolecules.

First part

- X-ray crystallography

1. Crystals, mathematical lattice, symmetry in crystals, space groups.
2. Crystallization techniques in biochemistry.
3. Production of X-rays;
4. Mathematics (equations useful in the interpretation of diffraction);
5. Diffraction of X-rays (waves, interference);
6. Single crystal X-rays diffraction; Bragg's law; X-rays diffraction pattern; structure factors; the concept of Resolution
7. X-ray data collection, indexing and processing
8. From diffraction data to the protein model
9. Advanced topics: The phase problem and solution methods, MIR, MAD, MR
10. Structure refinement; The R index; Treatment and analysis of structural data;

- Neutron and Electron diffraction (basic concepts and applications);
- Mid to high resolution microscopy techniques;
- EXAFS/EPR/NMR (basic concepts);
- Examples of structural data usage in the investigation of relevant questions in biochemistry as well as for purposes related to applied research.

Second part:

1. Visual perception and molecular basis of photoperception;
2. Molecules involved in mechano-perception and role of the tactile perception;
3. molecular basis of chemoperception in the gustatory and olfactory systems.

**Examination**:

Written examination. Both general and specific questions for each of the two parts of the course will be proposed.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2445/2018/000ZZ/SCP8085069/N0

**PHYSICS**

**ADVANCED PHYSICS LABORATORY A**

Master degree in **Physics**, Second semester
Lecturer: Giampaolo Mistura
Credits: 6 ECTS

**Prerequisites:**
Laboratory courses of previous years and basic skills in optics and electronics

**Short program:**
General experimental techniques for the physics laboratory, in particular: electronics, optics, cryogenics and vacuum.

**Examination:**
Written report and oral exam.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081700/N0

**ADVANCED PHYSICS LABORATORY B**

Master degree in **Physics**, First semester
Lecturer: Marco Bazzan
Credits: 6 ECTS

**Prerequisites:**
Laboratory courses of preceding years and basic skills in optics and electronics

**Short program:**
General experimental techniques for the physics laboratory, in particular: electronics, optics, cryogenics and vacuum techniques.

**Examination:**
Written report and oral examination.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081758/N0

**ADVANCED QUANTUM FIELD THEORY**

Master degree in **Physics**, First semester
Lecturer: Marco Matone
Credits: 6 ECTS

**Prerequisites:**
Students should know the canonical quantization approach of a field theory, in particular of Quantum Electrodynamics, and should be acquainted with the path-integral formalism and the technique of Feynman diagrams.

**Short program:**
1) INTRODUCTION TO QUANTUM FIELD THEORY. Perturbative and axiomatic aspects.
2) CONSISTENT QUANTUM INTERACTIONS. Coleman-Mandula theorem. Characteristics of interactions versus particle spin. Axion-scalar field duality.
3) CLASSICAL FIELD THEORIES. Action and equations of motion. Universality of couplings. Chiral and Yukawa couplings. Global symmetries and Noether theorem. Theories with local abelian and non-abelian symmetries. Yang-Mills (YM) connection and field strength. Covariant derivative. Conserved currents and covariant currents. Self-interaction of YM fields. Color charge.
4) FUNCTIONAL INTEGRAL METHODS. Brief review of basic concepts. Generating functionals. Analyticity and euclidean space. Background field method. Linear classical symmetries and their quantum implementation. Applications to QED. Determinants of commuting and anticommuting fields. Coleman-Weinberg effective potential and radiative symmetry

breaking. Feynman rules for a generic local field theory. Scalar QED.
5) PERTURBATIVE METHOD AND RENORMALIZABILITY. Brief review of dimensional regularization and Feynman-parameters technique. Higher loop corrections. Locality of ultraviolet divergences. Perturbative renormalizability in diverse dimensions.
6) LAMBDA PHI^3 IN D = 6. Explicit one-loop renormalization. Exact one-loop propagator. Counterterms. Beta function and anomalous dimension. Asymptotic freedom and dimensional transmutation. Two-loop renormalization. Nested and overlapping divergences. Cancellation of non-local divergences.
7) QUANTIZATION OF YM THEORIES. Problems related with the quantization of non abelian gauge fields. Faddeev-Popov method and ghost fields. Independence of the gauge fixing. BRST invariance and physical Hilbert space. Slavnov-Taylor identities.
8) PERTURBATIVE ANALYSIS OF YM THEORIES. Feynman rules. Renormalizability. One loop counterterms and their interrelation. The role of ghosts. Beta function and asymptotic freedom. Lambda QCD. Finiteness of N = 4 Super-YM theories.
9) ANOMALIES. Classical and quantum chiral symmetries. Explicit evaluation of the chiral Schwinger action in two dimensions. ABJ anomalies, triangular graphs and extensions to higher dimensions. Anomalous vertex method. Adler-Bardeen theorem. Anomaly cancellation in the Standard Model. Index theorem.
10) INSTANTONS. Semi-classical solutions in field theory. Instantonic configurations. Theta vacua. The U(1) problem. Wilson-loops.
11) DEEP INELASTIC SCATTERING.
12) AXIOMATIC THEORY. Wightman functions and Schwinger functions. Reconstruction theorem. Triviality of lambda phi^4 theory. Infrared divergences and the problem of charged fields in QED. Goldstone theorem.

**Examination:**
Solution of a series of proposed problems, followed by an oral examination.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081759/N0

## ADVANCED TOPICS IN THE THEORY OF THE FUNDAMENTAL INTERACTIONS

Master degree in **Physics**, First semester
Lecturer: Ferruccio Feruglio
Credits: 6 ECTS

**Prerequisites:** A basic knowledge of theoretical physics of the fundamental interactions, in particular of quantum field theory.

**Short program:**
Part 1: INTRODUCTION AND EXAMPLES
- INTRODUCTION:
Characterization of a physical system:
degrees of freedom, relevant scale(s), symmetries.
- EXAMPLES OF EFT:
the Fermi theory of weak interactions;
derivation from the full electroweak theory.
beyond the tree-level: Euler-Heisenberg Lagrangian;
symmetry considerations and derivation from QED.
- THE SM AS AN EFT:
recap of SM non-anomalous global symmetries;
dimension 5 operators, violation of (B-L) and neutrino masses;
possible microscopic origin (seesaw mechanism).
dimension 6 operators, violation of B and proton decay;
possible microscopic origin (GUTs);
dimension 6 operators and flavour physics.

- EFT IN NON-PERTURBATIVE REGIME:
the chiral Lagrangian; chiral symmetry breaking in QCD;
EFT for light pseudoscalar mesons; breaking effects;
anomaly of iso-axial current and neutral pion decay.
- OTHER EXAMPLES
Part 2: FORMAL ASPECTS
- EFT AND POWER COUNTING.
- INTEGRATING OUT HEAVY MODES:
RGE flow and matching conditions;
revisitation of the Euler-Heisenberg Lagrangian;
other examples.
- APPELQUIST-CARAZZONE DECOUPLING THEOREM.
- EQUIVALENT EFFECTIVE LAGRANGIANS;
independence of S-matrix elements on local field redefinitions.
- OPERATOR MIXING;
anomalous dimensions; examples;
- EFT DESCRIBING A BROKEN PHASE:
CCWZ construction; revisitation of the chiral Lagrangian;
other examples.
**Examination:** Discussion of selected topics from the program of the course, including resolution of problems.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081741/N0

## APPLIED ELECTRONICS

Master degree in **Physics**, Second semester
Lecturer: Piero Giubilato
Credits: 6 ECTS
**Short program:**
Part I. ELECTRONICS AND ANALOG INSTRUMENTATION
1. Review: Basic analog electronic
2. Review: Feedback
3. Operational Amplifiers (Real, Freq. Behavior)
- Linear and non-linear Applications
4. Generation of signals and oscillators
- Power supplies
- Voltage / current reference generators
- Oscillators
5. Noise and analog signal recovery
- Noise in electronic circuits (analogue) (noise and power spectrum, types of noise (thermal, shot, 1 / f), noise in devices (transistors, op.amp.), ENC calculation, feedback effect on noise)
- Low noise amplifiers (Radeka amplifier → charge amplifier, other front-end amplifiers → Noise in transimpedance ampli.)
- Analog Filters and Signal Recovery Techniques (Approximation and Implementation, Switched Capacitor Filters, Frequency/Time Domain Filters)
- Signal Recovery Techniques (shaping for "energy" or "timing" and optimum filters, Lock-in, signal media, matched filters, mixing)

PART II. DIGITAL ELECTRONICS, DIGITAL DEVICES, CONVERSION AD / DA
6. Inverters and logic port families (TTL, ECL, MOS, ...)
- Inverters and logic ports (logic port function, bipolar/MOS inverters, inverters and ports TTL, ECL, MOS)

- fundamental circuits (combinatorial and sequential operations, flip-flop multiplexers, adder, shift registers, memories)
7. Convert A/D and D/A
- Instruments (z-transform) and noise (quantization noise)
- Digital-to-Analogue (Nyquist rate converters, DAC based on Resistors / Capacitors / Current sources)
- Analogue-to-Digital (Nyquist rate converters, time accuracy, ADC Flash, two-step, interpolating, successive approximations, samplers)
- Some conversion circuits in detail (sample & hold, switched emitter followers, ...)
- Oversampling → sigma-delta
- Signal Processing and Digital Filtering Techniques
- Examples of measurements of time and space
8. Complements
- Microprocessors, Microcontrollers and FPGAs
- Data Bus
9. Digital Laboratory → Introduction to VHDL

**Examination:**
Oral exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081701/N0

## ASTROPARTICLE PHYSICS

Master degree in **Physics**, Second semester
Lecturer: Francesco D'Eramo
Credits: 6 ECTS
**Prerequisites:**
It is suggested to take the following courses in the first semester: Theoretical Physics, Theoretical Physics of Fundamental Interactions and General Relativity.
**Short program:**
1) Symmetries and Conserved Quantities in the Standard Model of Particle Physics
2) Particle Physics in the Expanding Universe
3) Energy Budget of our Universe
4) Big Bang Nucleosynthesis as a Probe for Physics Beyond the Standard Model
5) Particle Physics Models for Baryogenesis
6) Dark Matter Genesis in the Early Universe
7) Inflation and its Role in Dark Matter Genesis
8) Dark Matter Particle Candidates
9) Cosmic Rays
10) Experimental Searches for Dark Matter
11) Stars as Particle Physics Laboratories

**Examination:**
Oral exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081703/N0

## BIOLOGICAL PHYSICS

Master degree in **Physics**, Second semester
Lecturer: Mario Bortolozzi
Credits: 6 ECTS
**Prerequisites:**
The course will be held in English.
**Short program:**

Introduction: what is biophysics, top-down and bottom-up approaches.
The living cell: eukariotyc and prokaryotic cells, cell structure and function of its constituents, cell division.
The water: structure and chimical-physical properties, water-protein interaction, optical properties of water, pH and buffering systems, cell incubators.
Membranes and channels: conductance, cell equivalent circuit, Nernst potential, voltage-clamp technique, Hodgkin-Huxley model, neuronal action potential and its simulation, saltatory conduction and Schwann cell, patch-clamp, electrophysiology setup, derivation of cell electrical parameters, single channel current measurement, voltage-activated channel types and blockers, muscle and hair cell synapse, two-state channel model, three- and multi-state models, receptors, activation energies of a channel.
Diffusion: Fick's laws, diffusion from a point source, random walk and Monte Carlo approach, particle interaction with boundaries, random walk on a grid, numerical simulations of the diffusion process, discretization of the diffusive Laplacian, hydration shells, Kramer equation, electrical mobility, Nernst-Planck equation.
Permeability: partition coefficient, Goldman-Hodgkin-Kats equations, deviation from Ohm's law, ionic selectivity, single channel permeability, saturation, Eyring's theory, sodium and potassium channel models.
Chemical reactions: enzymatic reactions, Michaelis-Menten equation, SERCA and PMCA pumps, fluorescent dyes, calcium (Ca2+) dyes, configuration of a fluorescence microscope, relationship between dye fluorescence and Ca2+ concentration, photobleaching, ratiometric dyes, non-equilibrium conditions between Ca2+ and the dye, numerical simulations of Ca2+ dynamics, generation of a reaction-diffusion model and comparison with experiments, Ca2+ dynamics in the inner ear and in cardiac cells, modeling a complex geometry using meshes.
Molecular dynamics: DNA, RNA and proteins, the central dogma of biology, amino acids, folding and protein structures, simulation of protein dynamics, potential energy formula, computational algorithms, boundary conditions and examples of models.
Neural networks: machine learning, learning approaches, artificial neuron and schemes of neural networks, error backpropagation, artificial vision and speech recognition, cerebral organoids, Boltzmann machines.
**Examination:**
The final check is composed of a written and an oral part. The written exam consists of writing a report on a biological model solved by the student using a numerical simulation in Matlab. The oral exam consists of presenting by Power Point slides a recent scientific paper related to the course arguments.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081737/N0

## BIOPHOTONICS
Master degree in **Physics**, First semester
Lecturer: Fabio Mammano
Credits: 6 ECTS
**Prerequisites:**
Biological Physics
**Short program:**
Electromagnetic wave propagation: plane waves, spherical waves, phase velocity, irradiance, wave packets, group velocity, coherence length, interference.
Scalar diffraction theories: the Kirchhoff formulation, the Rayleigh-Somrnerfeld formulation, the Huygens-Fresnel principle.
Geometrical optics: Optical path length, the principle of Fermat, ideal imaging systems, matrix methods in paraxial imaging, cardinal points and planes.
Apertures and stops, image-forming instruments, brightness and illumination of images,

intensity fluctuations, detection noise.
The Debye integral representation of focused fields, irradiance distribution near focus (three-dimensional point spread function). Resolving power: the Rayleigh criterion. Minimum angular separation, visual acuity, phototransduction.
Transmitted light microscopy: angular spectrum of plane waves, diffraction gratings, abbe theory and resolution. Phase contrast, dark field, and differential interference contrast microscopy.
Fluorescence microscopy: molecular spectra, Jablonski diagram, Stokes' shift, life time and quantum efficiency, saturation of the excited state. Structure of the conventional fluorescence microscope.
Confocal microscopy: lateral resolution and axial resolution in the classical limit; optical sectioning and volume reconstruction; physical principles and applications of 2-photon excitation; advantages and disadvantages of different confocal systems.
Stimulated emission depletion (STED) nanoscopy and super-resolution.
Selected biophotonics applications: optical recording of changes in ion concentration. Optical sensors of Ca2+ ions, protons and other physiologically relevant ionic species. Imaging of Ca2+ at one and two wavelengths; local control of the concentration of Ca2+ and other active molecular species by UV photolysis of caged compounds; FRET, FRAP.
Intravital microscopy: biosensors, optochemogenetics, photodynamic therapy of cancer.
**Examination:**
Written and an oral exam. The written part concerns topics developed during the course. The oral exam consists in the presentation by the student of one or more original articles related to optical super-resolution techniques.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081799/N0

**COMPUTATIONAL METHODS IN MATERIAL SCIENCE (OFFERED IN THE MASTER DEGREE IN MATERIAL SCIENCE)**
Master degree in **Physics**, Second semester
Lecturer: Francesco Ancilotto
Credits: 6 ECTS
**Prerequisites:**
Elementary notions of quantum physics and solid state physics.
Fundamentals of thermodynamics: principles, thermodynamic potentials.
No prior knowledge of computer programming is required.
**Short program:**
Basic concepts of thermodynamics and classical statistical mechanics.
Classical Molecular Dynamics simulations; numerical integration of Newton equations.
Monte Carlo method; Metropolis algorithm.
Simulations in various statistical ensembles.
Common features of simulations methods: initial and boundary conditions; calculation of inter-particle interactions.
Calculation of thermodynamic and transport properties.
Intermolecular interactions: force-fields; atomistic and coarse grained models.
Variational methods for the solution of the Schrodinger equation.
Hartree and Hartree-Fock theory.
Elements of Density Functional Theory (DFT).
'First principles' simulations.
The different computational methods will be discussed in relation their application to topics of interest for material science (crystals, surfaces, soft matter, nanostructured materials).
In the computer exercises, students will carry out simple simulations, using open-source

software packages of current use in materials science, and will learn how to interpret and present the results of simulations.
**Examination:**
Oral examination in which the students will discuss written reports, on the results of three numerical simulations (Monte Carlo, Molecular Dynamics and DFT calculations).
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081717/N0

## COMPUTING COURSE (OFFERED IN THE MASTER DEGREE IN PHYSICS OF DATA – EXAM OF LABORATORY OF COMPUTATIONAL PHYSICS)

Master degree in **Physics**, First semester
Lecturer: Marco Zanetti
Credits: 6 ECTS
**Prerequisites:**
Even though not strictly required, the development of the class assumes the attendance of at least two physics laboratory classes during the bachelor degree
**Short program:**
- The working principles and logic schemes of a modern computer and its main components. Review of the available hardware solutions to face problems in various areas of scientific computing: parallel computing, cluster/cloud computing, distributed computing
- The python programming language, from the bases to the advance programming for scientific computing; review of the modern libraries for the data management and analysis (numpy, scipy, pandas, sciiti-learn, etc.)
- Monte Carlo methods for the simulation of physics phenomena
- Techniques to assess and extract the statistical features of a physics datasets and comparison with model predictions
- Visualisation and graphical representation of datasets and their properties

**Examination:**
To verify the proficiency of the students in the subjects covered by this course, the written reports on the lab experiences will be evaluated; such evaluation will have to be confirmed by an oral exam, during which the students will also be interviewed about what is thought during the lectures.
The oral exam will be split into two parts, each relevant to one of the two modules the class consists of.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/004PD/SCP9088156/N0

## COSMOLOGY OF THE EARLY UNIVERSE

Master degree in **Physics**, First semester
Lecturer: Nicola Bartolo
Credits: 6 ECTS
**Prerequisites:**
Generally the bases useful to attend this course are provided by the various courses within a given chosen curriculum.
**Short program:**
General introduction. The problem of the initial conditions: primordial density perturbations at the origin of the formation of the Large Scale Structure of the Universe.
- Short recall of the main problems of the standard cosmological model
- Inflationary cosmology in the Early Universe as a solution to the problems of the standard model

Modeling:
- Inflationary models: vacuum energy and the inflation field; dynamics of a scalar field in a

Friedman-Robertson-Walker Universe; possible realizations of the inflationary scenario
- Cosmological models of inflation and main features of the models within high-energy particle physics
- Observational predictions of the inflationary models: from the quantum perturbations in an expanding universe to the primordial density perturbations; generation of primordial gravitational waves and their observability (cosmological and interferometric probes).
Reheating phase and baryogengesis mechanisms
Delta-N and in-in formalisms for the study of cosmological perturbations. Example: primordial non-Gaussianity
Cosmological perturbations in General Relativity:
- scalar, vector and tensor perturbations
- gauge transformations
- Einstein equations linearly perturbed around the Robertson-Walker metric
Observational tests of the Early Universe
**Examination:**
Oral exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081761/N0

## EXPERIMENTAL SUBNUCLEAR PHYSICS

Master degree in **Physics**, First semester
Lecturer: Riccardo Brugnera
Credits: 6 ECTS
**Prerequisites:**
One assumes some prior knowledge: basic information regarding High Energy Physics and Quantum Electrodynamicscoming from the courses of Subnuclear Physics, Theoretical Physics and Theoretical physics of the fundamental interactions
**Short program:**
Quantum Chromodynamics
======================
QCD lagrangian, renormalization group equations, alpha_s as running coupling constant.
Dokhshitzer-Gribov-Altarelli-Parisi evolution equations. Structure functions.
Hadronization processes.
Electroweak Theory
==================
SU(2)XU(1) model, radiative corrections, physics at the Z0, interference and asymmetries at LEP, LEPII.
Goldstone model, Higgs mechanism, Higgs phenomenology, search for the Higgs boson.
Physics at the hadronic colliders: search and properties of the top quark and of the vector bosons
CKM Matrix
==========
Hierarchy of the parameters, different parametrization. Unitarity triangle. Example of measurement of some elements of the CKM matrix
CP violation and oscillations
==============================
Oscillation and CP violation in the neutral B system
CP violation in the mesons decays
Neutrinos oscillations: two flavours oscillations, three flavours oscillations, matter effect.
Solar neutrino oscillations and related experiments. Atmospheric neutrinos oscillations and related experiments. Log-baseline experiments.
**Examination:**

Oral
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081760/N0

## GENERAL RELATIVITY

Master degree in **Physics**, Second semester
Lecturer: Luca Martucci
Credits: 6 ECTS
**Prerequisites:**
Theoretical Physics is recommended.
**Short program:**
Riemannian geometry; Differential forms; the Principle of Equivalence; Einstein's field equation; the Schwarzschild solution, the Newtonian limit; experimental tests; Maximally symmetric spaces; Schwarzschild black holes; More on black holes (Penrose diagrams, charged and rotating black holes); black hole Thermodynamics.
**Examination:**
Questions on the topics presented during the course and solution of a simple problem.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081661/N0

## INTRODUCTION TO MANY BODY THEORY

Master degree in **Physics**, Second semester
Lecturer: Pierluigi Silvestrelli
Credits: 6 ECTS
**Prerequisites:**
Metodi Matematici
**Short program:**
Second-quantization formalism.
Single-particle and two-particle operators in second quantization.
Hamiltonian of Coulomb systems.
Two-point Green functions; expectation value of a single-particle operator, ground-state energy, Lehmann representation.
Adiabatic theorem and perturbative evaluation of the ground state.
Wick's theorem and Feynman diagrams for fermionic systems at T=0.
Self-energy, polarization diagrams (effective interaction), Dyson's equations.
Ground-state energy of the degenerate electron gas ("jellium" model) in the ring approximation (RPA).
Linear-response theory; applications:
screening of the electric charge (Friedel oscillations),
plasma oscillations, electronic scattering cross section for the inelastic electron scattering.
Interacting Bose systems at T=0.
Temperature Green's functions: Wick-Matsubara' theorem and Feynman diagrams.
**Examination:**
Oral exam and home-work exercises.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081699/N0

## INTRODUCTION TO NANOPHYSICS (OFFERED IN THE MASTER DEGREE IN MATERIAL SCIENCE)

Master degree in **Physics**, Second semester
Lecturer: Giovanni Mattei
Credits: 6 ECTS
**Prerequisites:**
Electromagnetism, Quantum Physics (particle in a box, quantum confinement), Solid State Physics (phononic and electronic structures of solids, thermal and optical properties)
**Short program:**
1) Fundamentals of NanoScience (MSc in Materials Science, 4 + 4 = 8 CFU)
MODULE A (4 CFU)
- Classification, characteristics and general properties of nanostructured materials: quantum confinement and electronic properties. Size Equations.
- Thermodynamic properties of nanostructured materials: thermodynamic size effect, nucleation (Gibbs-Thomson equation) and growth of nanostructures (Diffusion-Limited Aggregation and Ostwald Ripening regimes).
- Nanostructures embedded in solid matrices: ion implantation for the synthesis and processing of metallic nanostructures. Verification of the nucleation and growth models.
- Optical properties of nanostructured materials: (i) plasmonic properties of non-interacting metallic nanostructures (Mie theory and its extensions); (ii) interacting nanostructures
- Characterization techniques of nanostructures: transmission and scanning electron microscopy in transmission (TEM) and in scanning (SEM) mode.
MODULE B (4 CFU)
Overview of the preparation methods of nanostructures (both top-down and bottom-up, with particular emphasis on the latter). Structural aspects and energy of nanostructures and methods for their stabilization. Defects in nano dimensional materials. Solid with controlled porosity. Forms of nanoparticles: thermodynamics vs. kinetics. Core-shell nanoparticles. Self-assembly and self-organization. Colloidal method. Templating effect. Preparation of nanoparticles, nanowires, nanotubes, thin films. Self-assembled monolayers. Langmuir and Langmuir-Blodget films. Coherent, semi-coherent, epitaxial and pseudomorphic interfaces. Growth methods for ultrathin films: CVD, MBE, PVD, ALE and PLD methods.
Recall of the fundamental equations for electron and photon dynamics. Material properties for electron and photon confinement. Density of states for confined systems in one, two or three dimensions.
Properties of low dimensional carbon nanostructures: graphene and nanotubes. Tight binding approach for the description of their conduction, optical properties (absorption and emission) and Raman scattering (Kataura plots).
Models for the electron confinement in quantum dots in the weak and strong regime. Confinement of electrons in metallic nanoparticles and plasmonic properties. Froehlich conditions and far and near field optical properties. SERS effect with plasmonic nanostructures.
Hints on the confinement of photons in photonic crystals.
2) Introduction to NanoPhysics (MSc in PHYSICS, 4 + 2 = 6 CFU
The first 4 CFUs are the same as for MODULE A, previously described, which will be borrowed by the students of the 'Introduction to NanoPhysics' of the MSc Degree in Physics.
The remaining 2 CFUs address the following topics:
- Fundamental description of the dynamics of electrons and photons
- Confinement of electrons and photons in nanostructured or periodic materials:
- 2D and 3D photonic crystals;
- Meta-materials: (i) with hyperbolic dispersion and (ii) with negative refractive index;
- Practical laboratory activities: (i) synthesis of Au spherical nanoparticles in solution; (ii) measurement of their UV-VIS transmittance spectrum; (iii) simulation of the experimental spectra with the Mie theory; (iv) electron microscopy characterization.
**Examination:**

1) Fundamentals of NanoScience (MSc in Materials Science)
The exam is written (duration 2 h) with two open questions and a set of multiple-choice questions.
2) Introduction to NanoPhysics (MSc in PHYSICS)
The exam is written (duration 2 h) with an open question and an exercise with numerical applications of the learned topics.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081718/N0

## INTRODUCTION TO RADIATION DETECTORS

Master degree in **Physics**, Second semester
Lecturer: Roberto Stroili
Credits: 6 ECTS
**Prerequisites:**
Knowledge of electromagnetic phenomena, electromagnetic waves included.
Basic notions about special relativity and quantum mechanics.
**Short program:**
A. Description of the considered physical phenomena: introduction on the quantities measured in nuclear, high energy physics and astroparticle physics experiments. Charged particles energy loss. Bethe-Block formula, discussion and application to the particle detectors. Particle identification.
Multiple Coulomb scattering. Bremsstrahlung,radiation length, radiation spectrum.
Photon-matter interaction, absorption coefficient, photoelectric effect, Compton effect, pair production.
Cerenkov radiation. Mention of transition radiation. Nuclear interactions.
Scintillation in inorganic and organica materials. Energy loss in gases, diffusion, electric field effect, drift velocity, magnetic field effect. Energy loss in semiconductors.
B. Detector requirements based on the described effects: scintillation counters, Cerenkov counters, ionizing energy counters. Multiwire proportional chambers, drift chambers and TPC's. Limited streamer tubes, RPC's. Semiconductor detectors. Some mentions on trigger and readout electronics. Energy and momentum measurements. General structure of current particle detectors.
C. The particle accelerators. Electrostatic accelerators. Linear accelerators. The cyclotron. The syncrotron: transverse stability, weak focusing, betatron oscillations, transport matrices, strong focusing, quadrupoles and split roles. Hints on emittance, phase stability, syncrotron oscillations, phase diagrams, packet structure. Hints on syncrotron radiation. Storage rings: luminosity, antiproton storage, stocastic cooling.
**Examination:**
Oral.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081437/N0

## INTRODUCTION TO RESEARCH ACTIVITIES

Master degree in **Physics**, Second semester
Lecturer: Alberto Carnera
Credits: 6 ECTS
**Prerequisites:**
No specific prerequisite needed.
**Short program:**
The student will attend a summer stage for a total working time of about 150 hours in a research group either belonging to the Department or to associated laboratories or to an external approved structure.

A list of the proposed activities will be available on the site of the "Corso di Laurea Magistrale" by the end of the spring and the students will choose among the published proposals. The activity will be performed under the supervision of a tutor.

**Examination:**

Oral. Presentation and discussion of the results of the research activity.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081705/N0

## MATHEMATICAL PHYSICS (ALSO OFFERED FOR STUDENTS OF MASTER DEGREE IIN MATHEMATICS – EXAM OF HAMILTONIAN MECHANICS)

Master degree in **Physics**, Second semester
Lecturer: Paolo Rossi
Credits: 6 ECTS

**Prerequisites:**

Basics of algebra and differential geometry (the very basics of differential geometry will be recalled at the beginning of the course, if needed).
Basic knowledge of Hamiltonian mechanics and/or quantum mechanics would help putting the course content into context, but is not strictly needed.

**Short program:**

Hamiltonian systems in Poisson manifolds
(Poisson algebras, deformation theory, Poisson manifolds and their geometry,...).
Integrability
(reminder of Arnold-Liouville integrability, Lax representations, bihamiltonian structures,...).
Elements of quantization
(basic ideas of quantum mechanics, elements of deformation quantization, quantum mechanics in phase space,...).
Evolutionary Hamiltonian PDEs
(as infinite dimensional Hamiltonian systems, modern theory of integrable PDEs,...).

**Examination:**

To be decided depending also on the number of students, but probably either a relatively simple written exam granting access to an oral exposition in the form of a short seminar plus some questions, or a written exam containing both simple exercises and questions on theory.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7080817/N0

## MODELS OF THEORETICAL PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS OF DATA)

Master degree in **Physics**, First semester
Lecturer: Amos Maritan
Credits: 6 ECTS

**Prerequisites:**

Good knowledge of mathematical analysis, calculus, elementary quantum mechanics and basic physics.

**Short program:**

Introduction; "The Unreasonable Effectiveness of Mathematics in the Natural Sciences (Wigner 1959)"; Gaussian integrals Wick theorem
Perturbation theory connected contributions Steepest descent
Legendre transformation Characteristic/Generating functions of general probability distributions/measures
The Wiener integral geometric characteristics of Brownian paths and Hausdorff/fractal dimension
Brownian paths and polymer physics biopolymer elasticity. The random walk

generating function, the Gaussian field theory and coupled quantum harmonic oscillators
Levy walks violation of universality
Field theories as models of interacting systems
O(n) symmetric Phi^4– theory. The large n limit: Spherical (Berlin-Kac) model and 1/n expansion.
Perturbative expansion. Introduction to renormalization group techniques and universality.
Generalized diffusion and stochastic differential equations. The Feynman-Kac formula: diffusion with sinks and sources
Feynman path integrals and the quantum version of the Feynman-Kac formula.
Quantum mechanics (solvable model: free particle, harmonic oscillator)
Quantum vs stochastic phenomena: quantum tunneling and stochastic tunneling
Stochastic amplification and stochastic resonance
Non-perturbative methods: instantons
Diffusion in random media and anomalous diffusion
Quantum Mechanics in a random potential localization and random matrices
Statistical physics of random spin systems and the machine-learning problem
Random energy model, replica trick
Cavity method, Random Field Ising Model
**Examination:**
Final examination based on: Written and oral examination and weekly exercises proposed during the course
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP8083597/N0

**MULTIMESSENGER ASTROPHYSICS (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)**
Master degree in **Physics**, Second semester
Lecturer: Elisa Bernardini
Credits: 6 ECTS
**Prerequisites:**
This course is addressed to students with basic knowledge of elementary particles and their interactions and nuclear physics.
**Short program:**
The term "multi-messenger" is quite new and increasingly used in astronomy and astroparticle physics. It refers to combining information from different types of particles and waves to gain a deeper understanding of the astrophysical objects we observe in the sky.
Visible light only reveals a very small portion of the mysteries of the Universe. Astronomical observations are nowadays routinely performed with different telescopes across the electromagnetic spectrum, from radio waves through visible light, all the way to gamma-rays.
At the highest energies, the most violent processes in the Universe are at work. Whatever produces high energy gamma-rays, is expected to accelerate particles to energies that exceed the capabilities of man-made accelerators a billion times. Such particles can reach the Earth as cosmic rays, first discovered more than 100 years ago, still nowadays one of the most mysterious "messages" from our Universe.
Cosmic rays may interact in the vicinity or their sources or even along their way to Earth, to produce elusive particles called neutrinos and gamma-rays. While cosmic rays are deflected during their journey by intergalactic magnetic fields, neutrinos and photons, being neutral particles, keep memory of their source's direction. Their trajectory becomes thus crucial to unravel the origin of cosmic rays.
Neutrinos are extremely difficult to detect. Kubic-kilometer detectors are necessary to observe neutrinos at energies larger than few tens of GeV. The year 2013 witnessed the first

clear observation of neutrinos from distant astrophysical objects by the IceCube detector at the South Pole, opening a new observational window to the Universe.
The most extreme astrophysical objects, connected with the most violent phenomena in our Universe, are often associated with black holes or neutron stars. Whenever two such compact objects orbit around each other, they are expected to produce gravitational waves. The year 2015 witnessed the first direct observation of gravitational waves emitted by two merging black-holes (GW150914), measured by the LIGO detectors in the USA. The discovery was celebrated by the Nobel-prize for physics.
The year 2017 witness the triumph of multi-messenger astrophysics with the first identification of a source of cosmic neutrinos, the blazar TXS 0506+056, helped by the electromagnetic observations that followed the detection of a high energy neutrino (iceCube-170922A). This event happened just few days after another success of multi-messenger astrophysics: the detection of gravitational waves from two merging neutron stars (GW170817), followed by a burst of gamma-rays (GRB 170817A).
Both results greatly demonstrate the potential of multi-messenger astrophysics in observing and understanding the most extreme and mysterious phenomena in our Universe.
This course will illustrate its foundations.
**Examination:**
Oral examination.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081762/N0

## NUCLEAR ASTROPHYSICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)

Master degree in **Physics**, Second semester
Lecturer: Antonio Caaciolli
Credits: 6 ECTS
**Prerequisites:**
Elements of quantum mechanics and general physics
**Short program:**
Thermonuclear reactions.
Definition of nuclear cross section, astrophysical S-factor, reaction rate, and Gamow peak.
Nuclear burnings during hydrostatic and explosive stellar evolutionary phases.
Elements of stellar modelling.
Hydrogen burning: p-p chains, CNO, NeNa, MgAl cycles.
Helium burning: triple-alpha reaction and alpha + 12C.
Advanced nuclear burnings (C, Ne, O, Si).
Neutron-capture reactions (s and r: slow and rapid)
For each topic we provide an overview of the most relevant results in the recent literature.
How to determine the reaction rate for several cases (direct capture, narrow resonances, broad resonances)
How to perform a nuclear astrophysics experiment (every topic will be discussed with of existing experimental facilities and their most recent results)
The environmental background and how to shield it (passive and active shielding)
Underground experiment
Brief discussion on ion beam accelerators
Elements on detectors (gamma, neutrons, and charged particles)
Experimental measurements of the cross section (from the experimental yield to the S-factor)
Targets typology (gas, jet, and solid target). Target production techniques and how targets influence
the experimental measurements.
Brief discussion on indirect methods (Trojan Horse, ANC, …)

**Examination:**
Oral/written examination on all topics covered during the course.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081704/N0

## NUCLEAR PHYSICS (ALSO OFFERED FOR STUDENTS OF MASTER DEGREE COURSE IN PHYSICS OF DATA)

Master degree in **Physics**, First semester
Lecturer: Silvia Monica Lenzi
Credits: 6 ECTS
**Prerequisites:**
Quantum mechanics.
**Short program:**
Program of Nuclear Physics 2017/2018
First part: Nuclear Structure and Nuclear Models
- Introduction: The nucleus as a laboratory of Quantum Mechanics
- Symmetries and the Nuclear Force
- Experimental methods
- Theoretical Models:

1) Collective Models:
LDM, Fermi Gas and Density-Functional Models,
Surface vibrations, Rotating nuclei
2) Microscopic Models: Mean-field Models,
Interacting Shell Model
The Nilsson Model
Second part: Nuclear reactions
Introduction
- Nucleon-Nucleon Scattering
- Nuclear Reactions
- Interactions between heavy ions
- Direct nuclear reactions between heavy ions
- Multi-nucleon transfer reactions between heavy ions
- Compound nuclear reactions
- Fusion reactions below the Coulomb barrier
- Reactions of astrophysical interest

**Examination:**
The exam consists on an oral examination with eventual presentation of a research work on one of the several subjects proposed by the professors.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081658/N0

## OPTICS AND LASER PHYSICS (OFFERED IN THE MASTER DEGREE IN MATERIAL SCIENCE)

Master degree in **Physics**, First semester
Lecturer: Tiziana Cesca
Credits: 6 ECTS
**Prerequisites:**
Topics learned in basic courses of Mathematics and Physics.
**Short program:**
Classical optics:
- propagation of electromagnetic waves;
- polarization, birefringence, interference and diffraction;

- geometrical optics and matrix method; main optical instruments;
Lasers:
- the laser idea and proprieties of laser beams;
- absorption, spontaneous emission, stimulated emission;
- gain and population inversion;
- optical cavities and pumping;
- cw lasers;
- pulsed lasers: Q-switch and mode-locking;
- examples of main different laser types: gas lasers, solid-state lasers

Introduction to Quantum Optics:
- Photon statistics
- buching and antibuching;
- weak and strong coupling: Purcell effect and Rabi splitting.

**Examination:**
The exam is written and comprieses two exercizes and one open question.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081800/N0

## PHYSICS EDUCATION

Master degree in **Physics**, First semester
Lecturer: Ornella Pantano
Credits: 6 ECTS
**Prerequisites:**
Core knowledge of classic and modern physics.
**Short program:**
Physics teaching and learning: main topics and approaches in physics education research. Core ideas in physics, scientific practices and crosscutting concepts in natural sciences. Historical development of physics ideas that carry special significance for physics teaching and learning.
Different theoretical approaches to students' understanding of physics content and student difficulties, and their application in physics teaching. The role and importance of student interest, motivation and metacognition in learning physics. Student-centered approaches to physics teaching and learning.
The role of practical work and technologies in physics learning and teaching. Educational potential of out-of-school settings: benefits and opportunities offered by experiences outside the classroom.
Physics education research in different areas of physics, for example: mechanics, waves, optics, electromagnetism, relativity and quantum mechanics. Astronomy as a context in which proposing topics of classical and modern physics.
**Examination:**
The examination will consist of two parts:
(1) written assignments during the course (40%);
(2) a final written project at the end of the course on the development and implementation of an empirical study on a selected topic in physics (60%).
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP8084777/N0

## PHYSICS LABORATORY

Master degree in **Physics**, First semester
Lecturer: Francesco Recchia
Credits: 6 ECTS
**Prerequisites:**

Physics laboratory courses of the first three years.
**Short program:**
This course propose to the students some modern physics experiments that allow the approach to measurement techniques in use for the study of Fundamental Interactions, Matter and Astrophysics. Each student will carry out three experiments.
The experiments proposed are: 1) Cosmic Rays 2) Compton Scattering 3) Positronium decay 4) Gamma-ray imaging 5) Fast timing 6) Plasma Physics 7) X-ray fluorescence 8) Natural radioactivity and radon counting.
In the first five experiments the students will be trained to the use of scintillator for the detection of particles and gamma-rays and to the use of the relative electronics. Multiparameter events will be constructed exploiting timing coincidences between multiple detectors. The data will be analysed using the ROOT data analysis framework. In the Plasma Physics experiment the students will study the conditions that allow the formation of plasma starting from a small quantity of neutral gas. They will study the physical characterisations of the plasma by means of electronics measurements. The students will have to deal with vacuum and residual gas measurement techniques. The X-fluorescence and natural radioactivity experiments will be performed using high-resolution semiconductor detectors (Silicon and HPGe). They will train the students to spectroscopy techniques of the X and gamma radiation and to the relative analysis techniques.
**Examination:**
Written report by the group on the experiments performed. Individual interview with presentation of one of the experiments and possible short questions about the other two experiments. The presentation will concern the description of the physical phenomena, the experimental apparatus with the relative electronics and the data taking and analysis.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081617/N0

## PHYSICS OF COMPLEX SYSTEMS

Master degree in **Physics**, First semester
Lecturer: Antonio Trovato
Credits: 6 ECTS
**Prerequisites:**
Students are expected to already know the main concepts of equilibrium statistical mechanics, including phase transition, critical exponents and the renormalization group.
**Short program:**
Introduction to the physics of complexity and of emergent phenomena (general points of view of P.W. Anderson, N. Goldenfeld, L.P. Kadanoff, ...)
Brief overview of Brownian motion, stochastic differential equations and stochastic processes.
Statistical mechanics out of equilibrium: microscopic reversibility and macroscopic irreversibility.
Detailed balance in equilibrium. Linear response theory and transport phenomena.
Onsager reciprocity relations with examples (Seebeck and Peltier effects, etc.)
Fluctuation-response theorem, dynamic susceptibility and fluctuation-dissipation theorem.
Kramers-Kronig relations. Microscopic basis of Brownian motion.
Thermodynamics out of equilibrium at the micro- and nano-scales. Markovian description of non-equilibrium dynamics. Fluctuation theorems and work identities. Generalized detailed balance. Entropy production.
Out-of-equilibrium phase transitions. Directed percolation. Asymmetric simple exclusion and related processes, some basic results. Theory of large deviations. Molecular motors.
Applications of Gallavotti-Cohen theorem.
Stochastic dynamics of surfaces and interfaces: the Kardar-Parisi-Zhang equation.

Computational complexity and information theory. The random energy model and the random code ensemble. Complex energy landscapes and reweighting methods.
**Examination:**
Oral examination covering three or four of the topics chosen by the teacher among all those treated in the course. To each topic ample time is devoted to the exposition and to the discussion of possible connections with other parts of the program. This allows to ascertain how the student masters the subject.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081763/N0

## PHYSICS OF FLUIDS AND PLASMAS

Master degree in **Physics**, First semester
Lecturer: TO BE DEFINED
Credits: 6 ECTS
**Short program:**
The course presents, at an advanced level, some of the main subjects of the physics of fluids and plasmas.
During the course examples and applications from both astrophysics and controlled fusion will be presented.
Introduction
Fluids and plasmas in nature and laboratory. Characteristics and limitations of theories describing neutral fluids and plasmas. Non-collisional Boltzmann equation.
Neutral fluids
Collisional Boltzmann equation.
Moment equations and fluid dynamics derivation.
Ideal fluids; macroscopic derivation of fluid dynamics.
Viscuous flows.
Linear theory of waves and instabilities. Perturbative approach.
Turbulence in neutral fluids; Kolmogorov theory.
Plasmas
Basic properties of plasmas; plasmas in nature and laboratory.
Plasma orbit theory.
Dynamic of many charged particles.
Kinetic theory of plasmas, BBGKY hierarchy, Vlasov equation.
Two fluid model.
Collisionless processes in plasmas; Landau damping.
Collisional processes and the one-fluid model.
Diffusion and transport.
Basic magnetohydrodynamics; some simple examples of MHD instabilities.
Theory of magnetic topologies; magnetic reconnection; Sweet-Parker model. Magnetic helicity.
Dynamo theory. Parker's turbulent dynamo. Mean field magnetohydrodynamics.
**Examination:**
Oral exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081743/N0

## PHYSICS OF NUCLEAR FUSION AND PLASMA APPLICATIONS

Master degree in **Physics**, First semester
Lecturer: TO BE DEFINED
Credits: 6 ECTS
**Prerequisites:**

Knowledge of electromagnetism principles. A knowledge of the different plasma descriptions (kinetic, two-fluids, magnetohydrodynamics) is useful but not required, since essential notions will be provided during the course.

**Short program:**

First part: Nuclear fusion: main processes, cross sections, reactivity. Energy balance of a fusion reactor, break-even, ignition. Magnetic confinement and inertial confinement. Toroidal configurations for magnetic confinement. The tokamak configuration. Conceptual scheme of the reactor. MHD equilibria in cylindrical geometry, z-pinch, screw-pinch. MHD equilibria in toroidal geometry, flux functions, Grad-Shafranov equation. Safety factor, toroidal and poloidal beta. Tokamak operational limits: Hugill diagram, Greenwald limit, beta limit. Scaling laws for confinement time, L-mode and H-mode. Plasma heating: ohmic, with neutral beams, with radiofrequency. Outer region of the plasma, concepts of limiter and divertor. Formal analogy between magnetic field line trajectories and orbits of a Hamiltonian system. Alternative confinement schemes: stellarator and RFP. Status of fusion research: the ITER project. Safety and environmental impact of the fusion reactor.

Second part: Introduction to plasma applications. Methods of plasma formation. Planar diode model, Child-Langmuir law. Debye sheath, Bohm criterion, floating potential. Langmuir probe and its use to measure plasma properties. Double and triple probes. Radiofrequency discharges, capacitive and inductive coupling. Atmospheric pressure plasmas. Applications: "plasma medicine" applications, plasma propulsion for space applications.

**Examination:**

Oral exam

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081798/N0

## PHYSICS OF SEMICONDUCTORS (OFFERED IN THE MASTER DEGREE IN MATERIAL SCIENCE)

Master degree in **Physics**, First semester

Lecturer: Davide De Salvador

Credits: 6 ECTS

**Prerequisites:**

Mathematical prerequisites:

Continuous functions. Derivatives. Fundamental theorems of differential calculus. Relative and absolute maxima and minima. Exponential and logarithmic trigonometric functions. Study of a function. Definite integrals. Solid volumes of rotation. Taylor and Maclaurin series. Complex numbers. Exponential in the complex field. Differential equations. Linear differential equations of first order and second order. Functions of multiple variables. Limitations. Partial derivatives. Maximum and minimum relative. Saddle points. Double integrals in polar coordinates. Solid volumes. Triple integral. Vector differential calculus: flow of a vector field across a surface. Divergence of a field and divergence theorem.

Basic Physics Prerequisites

Coulomb's law. Electrostatic field. Electrostatic potential. Gauss's law. Poisson and Laplace equations. Capacity; ideal capacitor. Dielectric constant. Electrical currents and current density. Conservation of the charge. Ohm's law. Joule effect. Magnetic field; Lorentz force.

Quantum Physics Prerequisites :

Light quanta and photo-electric effect. Wave packs. The Heisenberg uncertainty principle. Shroedinger equation particle in a box. Quantum harmonic oscillator. Expectation values. Observables and operators. Quantum uncertainty and properties of eigenvalues. Square barrier tunnel effect. Penetration of the barrier. Particle in a three-dimensional box. Hydrogen atom and hydrogen atoms: fundamental state and excited states. Periodic table. Maxwell-Boltzmann distribution and density of states. Energy provision. Quantum statistics: Bose-Einstein and Fermi-Dirac distributions

Solid state physics Prerequisites
The crystalline structure of solids: the direct lattice and the reciprocal lattice. Phonons. The electrical conductivity of metals in the Drude model. Bloch's theorem.
**Short program:**
Review of the crystal structure of the main semiconductors. Elementary semiconductors , compounds and alloys.
Review of solid state basic concepts ( Bloch theorem , effective mass , concept of hole ) .
Origin and specificity of semiconductors band structure. The real bands (examples: GaAs , Si, Ge, AlGaAs ) .
The envelope function method for the calculation of quantum states generated by aperiodic potential.
The mechanism of doping. The carriers in a homogeneous semiconductor as a function of doping and temperature ( semic. non-degenerate, intrinsic, ionized , partially ionized , in saturation). The compensation by deep level.
The semiconductor non-homogeneous equilibrium. The case of the p-n junction .
Charge transport in semiconductors. Drift -diffusion equation. Intraband scattering phenomena and mobility in a semiconductor.
The mechanisms of generation and recombination in a semiconductor.
The equation of continuity. The case of the p-n junction under polarization.
The heterojunction joints metal / semiconductor , metal / oxide / semiconductor.
The quantum confinement in semiconductor quantum well , quantum wire , quantum dot .
LEDs , GaN based LED, photodetectors. Solid state laser architectures, quantum confinement effect on lasering. Photovoltaic cells. Different architectures and materials for photovoltaics. Efficiency. Mechanisms of loss of efficiency . Thin-film cells.
Produttive.Transistor bipolar and FET technologies . MOS structure.
Doping techniques. Ion implantation. Diffusion and defect .
Insulation, thermal oxidation.
Moore's Law and scaling. Issues and new materials.
**Examination:**
Oral exam. During the semester it will be possible to give a mid-term oral exam about the first part of the course concenrning on physical principle; at the end a second oral exam on the devices and processes will complete the final grade.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081797/N0

**PLANETARY ASTROPHYSICS (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)**
Master degree in **Physics**, Second semester
Lecturer: Francesco Marzari
Credits: 6 ECTS
**Prerequisites:**
Basic courses of the 3--year period.
**Short program:**
1) Dynamical and physical properties of planets and exoplanets.
2) Planetary formation from circumstellar disks, migration and planet-planet scattering. Short tutorial on fluid dynamics and tidal interaction between planets and disks.
3) Magnetic fields of the planets, origin and morphology.
4) Plasma motion in planetary fields, Van Allen Belts, magnetospheres and solar wind.
5) Tidal interaction planet-satellite and planet-star, lengthening of the terrestrial day and Moon outward drift.
6) Physics of planetary interiors, state and structure equations.
7) Non-gravitational forces acting on planetary precursors: Poyting-Robertson drag,

Yarkowski effect, gas drag.
7) Three-body problem: Lagrangian points (Trojan orbits), their stability, Hill's sphere and its applications (cataclysmic variables, asteroid satellites).
8) Secular perturbations in multiple planet systems.

**Examination:**

Oral exam

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2382/2017/003PD/SCP7081805/N0

## QUANTUM FIELD THEORY

Master degree in **Physics**, Second semester
Lecturer: Stefano Giusto
Credits: 6 ECTS

**Prerequisites:**

Relativistic quantum mechanics. Classical filed equations and canonical quantization of the scalar and fermionic fields. Basic QED.

**Short program:**

Path integrals in quantum mechanics and its generalization to relativistic quantum field theories. Correlation functions and their euclidean continuation. Relation between correlation functions and the S-matrix: the Lehmann-Symanzik-Zimmermann reduction formula. Equivalence of the path-integral and operator formalism.
Self-interacting scalar field theory: the perturbative expansion, functional derivation of the Feynman rules, generating functions and effective action. The fermionic path-integral. The definition of the path-integral for gauge theories: QED.
Divergences in quantum field theories. Dimensional regularization. Counterterms and renormalization. One-loop renormalization for the scalar field theory with quartic coupling and for QED. An introduction to renormalization at higher loops. The Renormalization Group: computation of the beta-function and of the anomalous dimension in scalar field theory and QED. The role of symmetries: Ward identities, gauge symmetries, the Ward-Takahashi identity in QED. Renormalization and the floating cut-off: an introduction to the Wilson-Polchinski equation.

**Examination:**

The examination is oral and it will consist of the discussion of one of the problems assigned during the course and of some general questions on the topics of the course, including the derivation of the main results.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2382/2017/004PD/SCP7081702/N0

## QUANTUM INFORMATION (OFFERED IN THE MASTER DEGREE IN PHYSICS OF DATA)

Master degree in **Physics**, First semester
Lecturer: Simone Montangero
Credits: 6 ECTS

**Prerequisites:**

Quantum mechanics and elements of programming.

**Short program:**

Basics in computational physics
1. Large matrix diagonalization
2. Numerical integration, optimizations, and solutions of PDE
3. Elements of Gnuplot, modern FORTRAN, python
4. Elements of object-oriented programming
5. Schrödinger equation (exact diagonalization, Split operator method, Suzuki-trotter decomposition, ...)

Basics of quantum information:
1. Density matrices and Liouville operators
2. Many-body Hamiltonians and states (Tensor products, Liouville representation, ...)
3. Entanglement measures
4. Entanglement in many-body quantum systems

Theory:
1. Numerical Renormalization Group
2. Density Matrix Renormalization group
3. Introduction to tensor networks
4. Tensor network properties
5. Symmetric tensor networks
6. Algorithms for tensor networks optimization
7. Exact solutions of benchmarking models

Applications:
1. Critical systems
2. Topological order and its characterization
3. Adiabatic quantum computation
4. Quantum annealing of classical hard problems
5. Kibble-Zurek mechanism
6. Optimal control of many-body quantum systems
7. Open quantum systems (quantum trajectories, MPDO, LPTN, ...)
8. Tensor networks for classical problems: regressions, classifications, and deep learning.

**Examination:**
The exam will be a final project composed of programming, data acquisition, and analysis, which will be discussed orally.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081801/N0

## RADIOACTIVITY AND NUCLEAR MEASUREMENTS

Master degree in **Physics**, Second semester
Lecturer: Marco Mazzocco
Credits: 6 ECTS
**Prerequisites:**
The student must have attended the courses of "Introduction of Nuclear Physics" and "Nuclear Physics"
**Short program:**
Radioactive decays. Summaries of the interaction of charged and neutral particles with matter in the energy range of nuclear physics and detection techniques.
Low energy nuclear energy: Ion accelerators: ion source, beam transport, magnetic analysis. Magnetic spectrometers, neutron detectors, charged particles and gamma radiation.
Dynamics of heavy ion reactions: the different types of nuclear reactions from elastic diffusion to complete fusion. Identification Techniques of Reaction Products, Detector Telescopes. Measurements of cross-section at energies around the Coulomb barrier. Angular distributions and excitation functions.
Gamma spectroscopy: energy calibration of gamma spectra, efficiency evaluation, activity computation. Angular distribution, multipolarity and polarization. Angular correlation and nuclear state description with statistical tensor. Average lifetime of excited states: electronic method, plunger, DSAM, Mossbauer.
Radioactive Beams: Production Methods "ISOL" and "IN-FLIGHT": Reactions with Secondary ISOL Beams: Coulombian excitation, nucleon transfer. Reactions with relativistic secondary beams: Coulombian and inelastic excitation, knock-out, charge exchange. Beta Decay: Measurements with Isol and In-flight beams, Total absorption spectrometry. Beta-delayed

neutron emission.
Nuclear astrophysics: Exploring the nuclear reactions in the stars and the synthesis of elements, Gamow peak, S-factor. Deriving the thermonuclear reaction rate. Dependence on the temperature of the nuclear reaction rate. Combustion cycles: Combustion of hydrogen through the p-p chain and the CNO cycle. Helium combustion with 3-alpha and alpha + C reactions. Advanced nuclear combustion reactions. Relevant cross section measurements: direct underground measurements, indirect Trojan-horse measures, etc.
Low radioactivity techniques: The problem of environmental radioactivity, a good shielding material, a screening of shielding materials (lead, iron, OFHC copper, mercury). The Rn as contaminant in low radioactivity measures. Intrinsic Detector Radioactivity. Effects of cosmic radiation.
Applications: Date with radionuclides. Radionuclides in nuclear medicine. The melting of light nuclei for energy production. About nuclear reactors. Mass spectrometry with accelerators for trace analysis. Non destructive analysis with neutron activation.
**Examination:**
Oral examination. The student will be asked some questions concerning the different topics presented during the lectures. It is also foreseen a detailed analysis of one of the arguments by the student.
**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/SC2382/001PD/SCP7081740/N0

**SOLID STATE PHYSICS (ALSO OFFERED FOR STUDENTS IN THE MASTER DEGREE IN PHYSICS OF DATA)**
Master degree in **Physics**, First semester
Lecturer: Francesco Ancilotto
Credits: 6 ECTS
**Prerequisites:**
Knowledge of elements of elementary quantum mechanics.
Knowledge of elements of elementary Statistical Mechanics (distribution functions, statistical ensembles, ensemmble averages, etc.)
**Short program:**
Chemical bonds in solids. The structure of crystals. Bravais lattices and bases. Simple crystal structures. Reciprocal lattice. Diffraction by periodic structures and experimental techniques. The Bragg law. Adiabatic approximation. Lattice dynamics. Harmonic approximation. The dynamical Matrix. Phonons. Monoatomic and diatomic linear chains. Spectroscopy of phonons. Thermal properties of crystals. Lattice specific heat. Anharmonic effects: thermal expansion, thermal conductivity of insulating materials. "Free" electrons model. Electronic specific heat. Electrostatic screening in a Fermi gas. Bloch theorem. Band structure. "Quasi-free" electron approximation. "tight binding" approximation. Examples of band structures. Transport phenomena. The Drude model. Hall effect in metals. Semiclassical model. The concept of "hole". Electrical and thermal conductivity in metals. Law of Wiedemann and Franz. Semiconductors. Cyclotron Resonance. Carriers concentration in intrinsic and extrinsic semiconductors. "Doping" and dopant states. Electron and hole mobility. Electrical conductivity in semiconductors. Hall effect in semiconductors. The Fermi surface in real metals. Superconductivity.
**Examination:**
Oral exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081660/N0

**STANDARD MODEL**

Master degree in **Physics**, Second semester
Lecturer: Paride Paradisi
Credits: 6 ECTS
**Prerequisites:**
Students should be familiar with the fundamental aspects of field theory, quantum electrodynamics and the calculation of amplitudes for physical processes through Feynman diagrams.
**Short program:**
Lagrangian construction summary for the Standard Model; Yukawa interactions and flavor physics; Aspects of the physics of the B meson; Mass terms for neutrinos, leptonic mixing and neutrino oscillations; Anomalies and the decay of the pion into two photons; Standard Model Precision Tests; Production and decay of the Higgs boson. The Standard Model as an effective theory and the hierarchy problem. Running of the Gauge coupling constants: Gauge coupling unification, asymptotic freedom and confinement. Grand unified theories.
**Examination:**
Oral examination.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081698/N0

**STATISTICAL MECHANICS (ALSO OFFERED FOR STUDENTS IN THE MASTER DEGREE IN PHYSICS OF DATA)**

Master degree in **Physics**, First semester
Lecturer: Enzo Orlandini
Credits: 6 ECTS
**Prerequisites:**
Statistical Mechanics (course given at the third year of the laurea triennale)
Thermodynamics
**Short program:**
In short the contents of the program can be summarised as follows:
Thermodynamics of phase transitions.
Critical points, order parameters and critical exponents. Phase transitions and spontaneous symmetry breaking.
Analytical tools to solve spins model in 1D, transfer matrix formalisms.
Mean field theories.
Ginzburg Landau theory.
Ginzburg criterium and upper critical dimension. Scaling theory and Kadanoff block spin argument.
Renormalisation group in real space. Universality.
Please note that some topics may vary
Spontaneous symmetry breaking for continuous symmetry. Goldstone's theorem.
**Examination:**
The verification of the acquired knowledge takes place through a common written test with 1-2 exercises to be solved analytically and 1-2 open questions on basic concepts. In this way we should be able to test the knowledge, the scientific vocabulary, the ability to synthesis and critical discussion acquired during the course.The second part of the exam will be oral and will be based on a discussion on the various topics discussed in class.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081659/N0

**STRUCTURE OF MATTER (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS OF DATA)**

Master degree in **Physics**, Second semester

Lecturer: Luca Salasnich
Credits: 6 ECTS
**Prerequisites:**
All the exams of the B.Sc. in Physics.
**Short program:**
1. Second quantization of the electromagnetic field.
Properties of the classical electromagnetic field in the vacuum.
Coulomb Gauge. Expansion in plane waves of the vector potential. Quantum oscillators and quantization of the electromagnetic field. Fock states and coherent states of the electromagnetic field. Electromagnetic field at finite temperature.
2. Electromagnetic transitions. An atom in the presence of the electromagnetic field. Fermi golden rule. Diple approximation.
Absorption, stimulated and spontaneus emission of radiation:
Einstein coefficients. Selection rules. Lifetime of atomic states and linewidths. Population inversion and laser light.
3. The Spin of the Electron. Klein-Gordon and Dirac equations. The Pauli equation and the spin. Dirac equation with a central potential. Relativistic hydrogen atom and fine splitting.
4. Many-body quantum systems. Identical particles. Bosons and Bose-Einstein condensation. Fermions and Pauli exclusion principle. Veriational principle. Hartree variational method for bosons and the Gross-Pitaevskii equation. Hartree-Fock variational method for fermions. Density functional theory:
theorems of Hoemberg-Kohn, density functional of Thomas-Fermi-Dirac-Von Weizsacker and density functional of Khom-Sham.
5. Second quantization of the Schrodinger field. Field operators for bosons and fermions. Fock and coherent states of the bosonic field operator. Schrodinger field at finite temperature. Matter field for interacting bosons and fermions. Bosons in a double-well potential and the two-site Bose-Hubbard model.
**Examination:**
Colloquium of about 30 minutes.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/002PD/SCP7081438/N0

## SUBNUCLEAR PHYSICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)

Master degree in **Physics**, Second semester
Lecturer: Donatella Lucchesi
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge on quantum mechanics, relativity, nuclear and subnuclear physics. Quantum field theory and Feynman graphs. Interaction of radiation and particles with matter.
**Short program:**
A brief reminder of basic concepts: symmetries, conservation laws, quantum numbers and elementary particle classification. Lifetime, resonances and Breit Wigner distribution.
QED: brief reminder of theoretical foundation, tree levels processes and loop diagrams. The running coupling constant. Experimental tests: success and open issues.
Weak interactions of leptons and quarks. Fermi constant(Gf), weak gauge bosons, relation between Gf and MW. Muon and tau decays: lepton universality. P,C violation in charged and weak currents. Nuclei, baryon and meson weak decays: "helicity suppression". Neutrino scattering. Spontaneous symmetry breaking and the Higgs boson. Measurements at LEP and at the LHC. Status and perspectives.
QCD. Hadron spectroscopy. ee annihilation to hadrons. Deep inelastic scattering of electrons and neutrinos; nucleon structure functions.

Hadron flavour Physics. The CKM matrix. Flavour oscillations and CP violation.
**Examination:**
A written test, including numerical execises and multi-answer questions. An oral test: the student can choose to discuss in detail the contents of a published article (and all the issues pertinent to it) among a set of those proposed during the lessons, or to be questioned on all the subjects discussed during the course.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081697/N0

## THEORETICAL PHYSICS

Master degree in **Physics**, First semester
Lecturer: Pierpaolo Mastrolia
Credits: 6 ECTS
**Prerequisites:**
Principle of Theoretical Physics
**Short program:**
Outline:
1. Quantum Electrodynamics: Feynman rules; scattering processes at tree-level: Rutherford scattering, Compton scattering, Bhabha scattering and Bremsstrahlung.
2. Basics of Radiative corrections and Renormalization.
3. Non-Abelian gauge theories. Lie Algebra, covariant derivatives, kinetic terms and self-interaction of gauge fields.
4. SU(3) gauge theory and Quantum Chromodynamics.
The color algebra.
Feynman rules and tree-level scattering amplitudes for gluons and quarks.
5. Introduction to the Weak interaction.
Fermi's theory: Feynman rules and the muon decay.
SU(2) x U(1) gauge theory and Electroweak unification.
6. Spontaneous symmetry breaking: breaking of a discrete symmetry; spontaneous breaking of global U(1) symmetry; Goldstone theorem; the Higgs mechanism.
7. Spontaneous symmetry breaking of SU(2)xU(1) and the Higgs doublet.
8. The Standard Model Lagrangean.
**Examination:**
Written and oral exam.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/004PD/SCP7081638/N0

## THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS OF DATA – EXAM OF THEORETICAL PHYSICS)

Master degree in **Physics**, First semester
Lecturer: Stefano Rigolin
Credits: 6 ECTS
**Prerequisites:**
Principle of Theoretical Physics
**Short program:**
Programme:
1. Quantum Elettrodynamics: Feynman rules, tree level processes ( Rutherford, Compton and Bhabha scattering, Bremsstrahlung).
2. Non Abelian gauge theories: non-Abelian gauge fields kinetic terms and selinteractions, covariant derivatives.
3. Quantum Crhomodynamics: The "colour" algebra, Feynman rules and scattering amplitudes

for gluons and quarks at tree level.
4. Electroweak gauge theory. The Fermi effective Lagrangian: Feynman rueles and muon decay. SU(2)xU(1) gauge theory and Electroweal unification.
5. Spontaneous symmetry breaking of a symemtry: the discrete and continuum cases. The Goldstone theorem and the Higgs mechanism.
6. Spontaneous symmetry breaking of the Electroweak symmetry.
7. The electroweak Lagrangian for one and three families.

**Examination:**
Written and oral exams.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/004PD/SCP7081657/N0

## THEORY OF STRONGLY CORRELATED SYSTEMS

Master degree in **Physics**, First semester
Lecturer: Luca Dell'Anna
Credits: 6 ECTS

**Prerequisites:**
Learning of some phenomena in condensed matter physics by means of the path integral approach

**Short program:**
Part 1: Introduction to the path integral
- Brief review of quantum mechanics for single particle and identical particles
- Second quantization: annihilation and creation operators
- Single-particle and double-particle operators
- Bosonic coherent states
- Grassmann algebra
- Fermionic coherent states
- Gaussian integrals with complex and grassmannian variables
- Feynmann integrals
- Patition function and imaginary time
- Equation of motion and stationary phase approximation
- Application of Feynman integrals for a double-well: instanton gas
- Functional integrals with coherent states
- Interacting particles: perturbation theory
- Functional integral for the electromagnetic field

Part 2: Applications
- Coulomb gas
* Perturbative approach
* Random Phase Approximation
* Functional integral method
- Non-interacting bosons: Bose-Einsten condensation
- Goldstone theorem
- Interacting bosons: Superfluidity
* Bogoliubov spectrum
* Landau criterion
* Action for the Goldstone mode
* Phenomenology
- Superconductivity
* Phenomenology and London equations
* Electron-phonon interaction
* Cooper problem
* BCS theory by functional approach: gap equation and critical temperature

* Ginzburg-Landau theory
* Action for the Goldstone mode
* Meissner effect and Higgs mechanism

**Examination:**
Oral examination
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2382/2017/001PD/SCP7081742/N0

**PHYSICS OF DATA**

**ADVANCED STATISTICS FOR PHYSICS ANALYSIS**

Master degree in **Physics Of Data**, Second semester
Lecturer: Alberto Garfagnini
Credits: 6 ECTS
**Prerequisites:**
None
**Short program:**
- review of basic concepts: probability, odds and rules, updating probabilites, uncertain numbers (probability functions)
- from Bernoulli trials to Poisson processes and related distributions
- Bernoulli theorem and Central Limit Theorem
- Inference of the Bernoulli p; inference of lambda of the Poisson distribution. Inference of the Gaussian mu. Simultaneous inference of mu and sigma from a sample: general ideas and asymptotic results (large sample size).
- fits as special case of parametric inference
- Monte Carlo methods: rejecion sampling, inversion of cumulative distributions, importance sampling. Metropolis algorithm as example of Markov Chain Monte Carlo. Simulated annealing
- the R framework and language for applied statistics.

**Examination:**
A project will be assigned to students consisting in the statistical analysis of a physics dataset. The final exam will consist of the discussion of the project, its quality will determine the overall evaluation
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082557/N0

**ASTRO-STATISTICS AND COSMOLOGY**

Master degree in **Physics Of Data**, First semester
Lecturer: Michele Liguori
Credits: 6 ECTS
**Prerequisites:**
Probability and statistics: definition of probability, probability distributions, mean value, variance and covariance, Bayes Theorem, basics of statistical estimation theory, maximum likelihood, confidence intervals, hypthesis testing.
Cosmology: Hubble law, Robertson-Walker metric, Friedmann-Robertson-Walker equations. Cosmological perturbations: Jeans instability, power spectrum, growth factor.
**Short program:**
Bayes theorem and bayesian probability. Choice of prior. Bayesian inference and Monte Carlo Markov Chain (MCMC): Metropolis-Hastings, Gibbs and Hamiltonian sampling. Joint likelihood. Parameter marginalization. Bayesian evidence: model selection and comparison, information criteria. Fisher matrix for experimental design and forecasting.
Applications: power spectrum estimation in cosmological datasets (Cosmic Microwave Background and Large Scale Structure), MCMC for cosmological parameter estimation, component separation, Gravitational Wave data analysis, Fisher matrix forecasting for future

cosmological surveys.
Parts of the program might undergo changes, according to the composition and the competences of the class.

**Examination:**

The exam is comprised of three phases.

1) Resolution of assigned homework during the course, eventually to undertake in group.
2) Written examination, structured in 1 or 2 exercises - where the concepts discussed in class are applied - and theoretical questions.
3) Optional: oral examination with discussion of the course topics.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082722/N0

**COMPUTATIONAL NEUROSCIENCE (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA – EXAM OF NEURAL NETWORKS AND DEEP LEARNING)**

Master degree in **Physics Of Data**, First semester
Lecturer: Alberto Testolin
Credits: 6 ECTS

**Prerequisites:**

The course relies on preliminary knowledge of mathematical analysis, linear algebra and probability theory. Familiarity with machine learning concepts is desired, though not mandatory. Python programming skills are required.

**Short program:**

1. Introduction: computational and mathematical modeling of neural systems; basics of neuroscience; levels of analysis in system neuroscience.
2. Single-neuron modeling: morphology, neuro-electronics, principles of synaptic transmission; integrate-and-fire models; the Hodgkin-Huxley model.
3. Principles of neural encoding: recording neuronal responses; spike trains, firing rates, local field potentials; tuning functions and receptive fields; efficient encoding principles and information compression.
4. Network modeling: neural network architectures; localistic, distributed, and sparse representations; examples from the visual system.
5. Learning, memory and plasticity: synaptic plasticity in biological systems (Hebb rule, LTP, LTD, STDP); synaptic plasticity in artificial neural networks and overview of machine learning basics.
6. Supervised learning: perceptron, delta rule, error backpropagation.
7. Supervised deep learning: advanced optimization methods for training multi-layer networks; convolutional architectures; transfer learning and multi-task learning.
8. Recurrent neural networks: backpropagation through time, long short-term memory networks.
9. Unsupervised learning: competitive networks; self-organizing maps; associative memories and Hopfield networks; autoencoders and Boltzmann machines.
10. Unsupervised deep learning: hierarchical generative models; generative adversarial networks.
11. Reinforcement learning: exploration-exploitation dilemma; temporal-difference learning; conditioning and dopamine circuits; deep reinforcement learning.
12. Case studies from neurocognitive modeling: visual perception; space coding; semantic cognition; complementary learning systems; hippocampus and experience replay.
13. Large-scale brain organization: structural and functional properties of brain networks; neuronal oscillations and spontaneous brain activity; neuromorphic hardware.

**Examination:**

Evaluation of knowledge and abilities acquired will consist on an individual project assignment, which will be discussed during the oral exam. The project will require a software implementation of one or more computational models and analyses discussed during the course, along with a short essay in which the student will describe and discuss the project results. The oral exam will also include general theoretical questions related to the course content.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082718/N0

**COSMOLOGY (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY – EXAM OF THEORETICAL COSMOLOGY)**

Master degree in **Physics Of Data**, Second semester
Lecturer: Sabino Matarrese
Credits: 6 ECTS

**Prerequisites:**

Fundamentals of Cosmology and Astrophysics

**Short program:**

General introduction

• Derivation of the Friedmann eqs. from Einstein's eqs. (after a very synthetic introduction to the latter), assuming the Robertson-Walker line-element.

The Cosmic Microwave Background (CMB) Radiation

• Boltzmann eq. and hydrogen recombination: beyond Saha equation
• The Boltzmann eq. in the perturbed universe: the photon distribution function
• The collision term
• Boltzmann eq. for photons in the linear approximation
• Boltzmann eq. for cold dark matter (CDM) in the linear approximation
• Boltzmann eq. for baryons in the linear approx.
• Evolution eq. for the photon brightness function
• Linearly perturbed Einstein's equations (scalar modes)
• Initial conditions
• Super-horizon evolution
• Acoustic oscillations and tight coupling
• Free-streaming – role of the visibility function
• Evolution of gravitazional potential and Silk damping
• Temperature anisotropy multipoles
• Angular power-spectrum of the temperature anisotropy
• Sachs-Wolfe effect
• Small angular scales: acoustic peaks and their dependence on cosmological parameters

The gravitational instability

• Gravitational instability in the expanding Universe
• Boltzmann eq. for a system of collisionless particles and the fluid limit
• The Zel'dovich approximation
• The adhesion approximation
• Solution of the 3D Burgers equation
• Approach based on the Schroedinger equation.

Statistical methods in cosmology

• The ergodic and the "fair sample" hypotheses
• N-point correlation functions
• Power-spectrum and Wiener-Khintchine theorem
• Low-pass filtering techniques
• Up-crossing regions and peaks of the density fluctuation field
• Gaussian and non-Gaussian random fields
• The path-integral approach to cosmological fluctuation fields**Examination:**

The exam of this course can be made in two alternative ways:
1. Oral interview on the main topics analyzed during the course.
2. (only for the students who attended the classes) Short written dissertation on a topic discussed during the course, to be agreed with the lecturer. The dissertation should contain a detailed of the chosen subject, based upon one or a few review articles (and or some cosmology textbook chapters).
The content of this dissertation, to be discussed with the professor is expected to show how much the student has
become acquainted with the main concepts presented in the lectures.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCN1035989/N0

## DIGITAL SIGNAL PROCESSING (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA)

Master degree in **Physics Of Data**, First semester
Lecturer: Tomaso Erseghe
Credits: 6 ECTS
**Prerequisites:**
This course has the following prerequisites: fundamentals of signals and systems, knowledge on Fourier analysis, and basics of Computer Programming in any language which is appropriate for signal analysis (e.g., MatLab, Python, C, Java). Moreover: 1. for the DIGITAL SIGNAL PROCESSING module: Laplace and/or Z transforms; 2. for the E-HEALTH module: fundamentals of telecommunications and of network protocols; any further knowledge or previous experience on telemedicine and biological signals acquisition or processing is also useful.
**Short program:**
The module will cover the following topics:
1. Shift-invariant discrete time linear systems; Systems defined by linear constant coefficient difference equations; Z-transform and its properties.
2. Discrete Fourier Transform (DFT): definition, properties and usage in practical contexts; FFT algorithms; fast convolution algorithms.
3. Design of linear phase FIR filters: windowed Fourier series technique; frequency sampling method; minimization of the Chebyschev norm (Remez algorithm).
4. IIR filter design using the bilinear transformation method; Butterworth, Chebyschev and Cauer filters; frequency transformations.
5. Multirate linear systems: interpolation and decimation; Efficient realizations; Examples of application.
**Examination:**
The course has the following methods of examination:
DIGITAL SIGNAL PROCESSING module:
The grading of the expected knowledge and skills is based on two contributions: 1. a closed book WRITTEN EXAM, where the student must solve four problems, needed to verify that a good knowledge of the theoretical aspects and of the fundamental characteristics of the various digital signal processing systems analyzed during the course has been acquired; 2. the development of a simple HOMEWORK consisting in a computer simulation project using Matlab, to check the ability of the student to apply the theoretical concepts to a practical implementation. Each student must write a short report describing the methodologies used to solve the assigned homework and the obtained results.
E-HEALTH module:
For ATTENDING STUDENTS the verification of the expected knowledge and skills is carried out with: 1. an ORAL EXAM (individual assessment) with few questions to test the knowledge of the whole course program; 2. a simple PROJECT (5-6 pages) on a selected topic to be agreed

with the teacher; the project is presented in about 15 minutes (using slides) during the oral exam; 3. a two-pages report at the end of each LAB EXPERIENCE. Projects and lab experiences are carried out either individually or in pairs at the discretion of the teacher.
For NON-ATTENDING STUDENTS the verification of the expected knowledge and skills is carried out with: 1. an ORAL EXAM (individual assessment) with few questions to test the knowledge of the whole course program; 2. a more complex PROJECT on a selected topic to be agreed with the teacher; the project requires both a theoretical part and a Matlab-based part in order to test the abilities developed by the attending students during laboratories; the project is presented in about 15 minutes (using slides) during the oral exam.
The final grade of the course is expressed as a combination of the judgments in the two modules (50%+50%).
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082710/N0

**GAME THEORY (OFFERED IN THE MASTER DEGREE IN COMPUTER ENGINEERING)**
Master degree in **Physics Of Data**, First semester
Lecturer: Leonardo Badia
Credits: 6 ECTS
**Prerequisites:**
A course, even a basic one, on probability theory.
**Short program:**
Basic concepts of game theory
Utility, market, discount factor
Static games in normal form
Dominance, Nash equilibrium
Efficiency, price of anarchy
Zero-sum games, minmax games
Mixed strategies, mixed equilibria
Nash theorem, minmax theorem
The tragedy of the commons
Dynamic games
Strategy and subgames
Backward utility
Stackelberg equilibria
Repeated games and cooperation
Dynamic duopolies, collusion
Cooperation, pricing
Imperfect/incomplete information
Bayesian games, signaling, beliefs
Revelation principle
Axiomatic game theory
Fictitious play
Best response dynamics
Distributed optimization
Algorithmic game theory
Computation, complexity, and completeness of equilibria
Auctions, bargaining
First-price and second-price auctions
VCG principle
Cooperative games: the core, the Shapley value
Resource allocation
Utilities, choices, and paradoxes

Potential games, coordination
Bio-inspired algorithms
Evolutionary games
Cognitive networks
Selfish routing
Game-theory enabled multiple-input systems

**Examination:**

For the students of engineering programs with regular attendance to the course (differently from other kinds of students), the exam involves the development of a project in 1-3 person groups, on course-related topics applied to ICT. This is agreed half-way through the course together with the lecturer.

For all the students, in any event the exam also includes a mandatory open-book written test, containing four problems of game theory focusing on different topics of the course. Every exercise involves three questions.

For engineering students with regular attendance to the course, the written test is limited to solving three exercises out of four. For the other students (non-engineering students or students without regular attendance), the written test involves all of the four exercises.

If the written test is sufficient, non-engineering students or students without regular attendance can directly finalize the passing score. Engineering students with regular attendance instead discuss their project with an oral exam after the written test. Oral exams are scheduled in the same day of written tests (even though students can decide to give the two parts on separate days). Both the written test and the oral exam must be sufficient to pass.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP7079401/N0

## GENERAL RELATIVITY (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)

Master degree in **Physics Of Data**, First semester
Lecturer: Marco Peloso
Credits: 6 ECTS

**Prerequisites:**

Knowledge of Special Relativity

**Short program:**

1. Preliminaries

Lorentz transformations and addition of velocities in special relativity. The geometry of flat spacetime. Time dilatation, length contraction, and the relativity of simultaneity. Four-vectors and special relativistic kinematics. Special relativistic dynamics and the energy-momentum tensor. Variational principle for Newtonian mechanics and for a free motion in special relativity. Light rays and Doppler shift. Observers and Observations.

2. Space, Time, and Gravity in Newtonian Physics.

Inertial frames. The principle of relativity. Newtonian Gravity. Gravitational and Inertial Mass.

3. Gravity as Geometry

The equivalence principle. Clocks in a gravitational field and gravitational redshift. Coordinates, line element, and the metric. Light cones and world lines. Length, area, volume computations. Vectors in curved spacetime. Hypersurfaces. Newtonian gravity in spacetime terms (weak field approximation).

4. The Einstein equations

Parallel transport and curvature. Covariant derivative, Riemann, Ricci, and Einstein tensor. The source of curvature. Einstein equations and weak field approximation.

5. Geodesics

The geodesic equation. Symmetries and Killing vectors. Local inertial frames and freely falling

frames.
6. Schwarzschild Geometry
Gravitational redshift. Particle orbits: the precession of the perihelion. Light ray orbits: the deflection and time delay of light. Solar system tests of general relativity.
7. Horizons and Coordinate Systems
Minkowski spacetime in Rindler coordinates. Schwarzschild black-holes. Eddington-Finkelstein, and Kruskal-Szekeres coordinates, Kruskal and Penrose diagrams.
8. Rotations and Kerr Geometry
Geodetic precession around a non-rotating, and a slowly rotating body. Kerr metric and the ergosphere.
9. Cosmology
FLRW geometry. Spatial curvature. Evolution in presence of matter, radiation, and a cosmological constant. Cosmological redshift. Luminosity and angular distance.
10. Gravitational waves (if time permits)
**Examination:**
Questions on the topics presented during the course and solution of a simple / medium problem.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2490/2019/000ZZ/SCP7081661/N0

## INFORMATION THEORY AND COMPUTATION (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS – EXAM OF QUANTUM INFORMATION)

Master degree in **Physics Of Data**, First semester
Lecturer: Simone Montangero
Credits: 6 ECTS
**Prerequisites:**
Quantum mechanics and elements of programming.
**Short program:**
Basics in computational physics
1. Large matrix diagonalization
2. Numerical integration, optimizations, and solutions of PDE
3. Elements of Gnuplot, modern FORTRAN, python
4. Elements of object-oriented programming
5. Schrödinger equation (exact diagonalization, Split operator method, Suzuki-trotter decomposition, ...)
Basics of quantum information:
1. Density matrices and Liouville operators
2. Many-body Hamiltonians and states (Tensor products, Liouville representation, ...)
3. Entanglement measures
4. Entanglement in many-body quantum systems
Theory:
1. Numerical Renormalization Group
2. Density Matrix Renormalization group
3. Introduction to tensor networks
4. Tensor network properties
5. Symmetric tensor networks
6. Algorithms for tensor networks optimization
7. Exact solutions of benchmarking models
Applications:
1. Critical systems
2. Topological order and its characterization
3. Adiabatic quantum computation

4. Quantum annealing of classical hard problems
5. Kibble-Zurek mechanism
6. Optimal control of many-body quantum systems
7. Open quantum systems (quantum trajectories, MPDO, LPTN, ...)
8. Tensor networks for classical problems: regressions, classifications, and deep learning.

**Examination:**
The exam will be a final project composed of programming, data acquisition, and analysis, which will be discussed orally.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082709/N0

## LABORATORY OF COMPUTATIONAL PHYSICS (C.I.)

Master degree in **Physics of Data**, Annual
Credits: 12 ECTS
***Modules of the integrated course unit:***
- LABORATORY OF COMPUTATIONAL PHYSICS (MOD. A)
- LABORATORY OF COMPUTATIONAL PHYSICS (MOD. B)

***Common characteristics of the Integrated Course unit:***
**Prerequisites:**
Even though not strictly required, the development of the class assumes the attendance of at least two physics laboratory classes during the bachelor degree
**Examination:**
To verify the proficiency of the students in the subjects covered by this course, the written reports on the lab experiences will be evaluated; such evaluation will have to be confirmed by an oral exam, during which the students will also be interviewed about what is thought during the lectures.
The oral exam will be split into two parts, each relevant to one of the two modules the class consists of.

**LABORATORY OF COMPUTATIONAL PHYSICS (MOD. A)**
***Specific characteristics of the Module***
Lecturer: Marco Zanetti
**Short program:**
- The working principles and logic schemes of a modern computer and its main components. Review of the available hardware solutions to face problems in various areas of scientific computing: parallel computing, cluster/cloud computing, distributed computing
- The python programming language, from the bases to the advance programming for scientific computing; review of the modern libraries for the data management and analysis (numpy, scipy, pandas, sciiti-learn, etc.)
- Monte Carlo methods for the simulation of physics phenomena
- Techniques to assess and extract the statistical features of a physics datasets and comparison with model predictions
- Visualisation and graphical representation of datasets and their properties

**LABORATORY OF COMPUTATIONAL PHYSICS (MOD. B)**
***Specific characteristics of the Module***
Lecturer: Marco Baiesi
**Short program:**
1. Introduction. Bias-Variance decomposition
2. Gradient descent methods
3. Linear regression: Ridge and LASSO
4. Logistic regression
5. Combining models: bagging, boosting, and random forests
6. Feed-forward deep neural networks: basics

7. Deep neural networks: regularization
8. Deep neural networks: examples
9. Clustering
10. Energy-based models
11. Restricted Boltzmann machines
12. Concluding examples

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082524/N0

## LIFE DATA EPIDEMIOLOGY

Master degree in **Physics Of Data**, First semester
Lecturer: Leonardo Badia
Credits: 6 ECTS

**Prerequisites:**
The course requires some previous knowledge on:
- Probability theory.
- Differential equations.

**Short program:**
Epidemics: motivation and applications (both to life sciences and ICT)
Epidemics through compartmental models
Solutions of epidemic models through differential equations
Demography and equilibria
Extended models and complex contagions
Time-variable trends and temporal networks
Network epidemics
Metapopulation for spatial diffusion
Data-driven models and integration in computational epidemology
Epidemiology data: surveillance, problems, and biases
Statistical and mechanical methods
Maximum likelihood fit
Public health scenarios: analysis and forecasts

**Examination:**
The exam will consist of two parts.
1) an individual written exam with exercises on mathematical evaluations and practical applications of concepts explained during the course
2) a (group) project developed throughout the course and discussed after the written exam
The two parts of the exam can be sustained separately, although it is advised that the students perform them together (typically, exam sessions will have both parts in the order above)

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082719/N0

## MACHINE LEARNING

Master degree in **Physics Of Data**, First semester
Lecturer: Pietro Zanuttigh
Credits: 6 ECTS

**Prerequisites:**
Basic knowledge of Mathematics, Probability Theory, Statistics, Linear Algebra, Algorithms and basic Programming skills.

**Short program:**
Motivation; components of the learning problem and applications of Machine Learning. Supervised and unsupervised learning.
PART I: Supervised Learning

1. Introduction: Data, Classes of models, Losses.
2. Probabilistic models and assumptions on the data. The regression function. Regression and Classification.
3. When is a model good? Model complexity, bias variance tradeoff/generalization (VC dimension, generalization error).
4. Models for Regression: Linear Regression (scalar and multivariate), subset selection, linear-in-the-parameters models, regularization.
5. Classes of nonlinear models: Sigmoids, Neural Networks.
6. Kernel Methods: SVM.
7. Models for Classification: Logistic Regression, Neural Networks, Perceptron, Naïve Bayes Classifier, SVM, Deep Learning.
8. Validation and Model Selection: Generalization Error, Bias-Variance Tradeoff, Cross Validation. Model complexity determination.
PART II: Unsupervised learning
1. Cluster analysis: K-means Clustering, Mixtures of Gaussians and the EM estimation.
2. Dimensionality reduction: Principal Component Analysis (PCA).

**Examination:**
The evaluation of the acquired skills and knowledge will be performed using two contributions:
1. A written exam without the book, where the student must solve few problems, with the aim of verifying the acquisition of the main ingredients of a learning problem and of the main machine learning tools, the analytical ability to use these tools and the ability to interpret the typical results of a practical machine learning problem.
2. Computer simulations (optional) with the aim of acquiring the practical competences for using machine learning tools. These simulations, to be performed at home, allow to verify the ability of practically exploiting the acquired theoretical concepts. The student will have to provide a brief document explaining the employed methodologies used to solve the assigned problem together with the obtained results.
The final grade will be based on the written test with a bonus up to 3 point for the students who will hand in also the lab assignments.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082660/N0

## MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (C.I.)

Master degree in **Physics of Data**, Annual
Credits: 12 ECTS

***Modules of the integrated course unit:***
- MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. A)
- MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. B)

***Common characteristics of the Integrated Course unit:***

**Prerequisites:**
Elements of analysis and algebra.
General physics.
Statistics.
Basic programming elements.

**Examination:**
Development of a project assigned at the end of the course. Presentation and discussion of the project, questions on the material presented in class.

**MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. A)**

***Specific characteristics of the Module***
Lecturer: Gianmaria Collazuol

**Short program:**

PART I - Electronics for real-time data management systems
1) Data Sources
- signal generation in sensors/detectors
- early (analog) data processing (amplificaton, filtering, ...)
- digitization (A/D, ADC, TDC, ...)
- timing, sync and control signals distribution systems
2) Data Transport
- Data Transport Architectures
- Physical layers for data streams
- Interconnections and buses
3) Real Time Data Processing
- Digital ports and logics
- Storage units - Memories
- Processing units - focusing on FPGA
- Parallel data streams
4) Real Time Data Filtering and System Control
- Trigger generation and distribution
- Transducers and System Control
PART II - Hands-on Laboratory of data management with FPGA
1) Introduction to FPGA and intro to the ARTY A7 board
2) FPGA Programming framework, Simulation and Test-Bench
3) Combinational Logic Circuits
4) Sequential Logic Circuits
5) Virtual Input Output and Integrated Logic Analyzer
6) Arithmetic Operations
- case study: DAC/ADC and FIR Filter
7) Finite State Machines
8) Memories
9) Buses and Protocols
- case study: SPI interface for accessing Flash memory
- case study: IPBUS - communication FPGA-PC via Ethernet interface
NOTE - Examples and Case studies will be chosen in various fields: from High Energy Physics to Astro-particle and Space Physics Systems on satellites; from Nuclear Imaging Medicine to Low-Latency Market Data Feed Processing; from Biomedical and Neuro Sciences to Gravitational Wave Physics.

**MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. B)**

***Specific characteristics of the Module***

Lecturer: Donatella Lucchesi

**Short program:**

Part 1) Distributed computing
Distributed Computing systems and the Grid paradigm
Computing Models
Dask principles
Setup of a cluster with Dask
Data movement and analysis on dask cluster
Machine learning on a dask cluster
Part 2) Data Management
Data Workflows in scientific computing
Storage Models
Data management components:
-Name Servers and databases
-Data Access protocols

-Reliability
-Availability
-Access Control and Security
-Cryptography
Authentication, Authorization, Accounting
Scalability
-Cloud storage
-Block storage
Analytics
Data Replication
Data Caching
Monitoring, Alarms
Quota
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082533/N0

## MODELS OF THEORETICAL PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)

Master degree in **Physics Of Data**, First semester
Lecturer: Amos Maritan
Credits: 6 ECTS
**Prerequisites:**
Good knowledge of mathematical analysis, calculus, elementary quantum mechanics and basic physics.
**Short program:**
Introduction; "The Unreasonable Effectiveness of Mathematics in the Natural Sciences (Wigner 1959)"; Gaussian integrals Wick theorem
Perturbation theory connected contributions Steepest descent
Legendre transformation Characteristic/Generating functions of general probability distributions/measures
The Wiener integral geometric characteristics of Brownian paths and Hausdorff/fractal dimension
Brownian paths and polymer physics biopolymer elasticity. The random walk generating function, the Gaussian field theory and coupled quantum harmonic oscillators
Levy walks violation of universality
Field theories as models of interacting systems
O(n) symmetric Phi^4– theory. The large n limit: Spherical (Berlin-Kac) model and 1/n expansion.
Perturbative expansion. Introduction to renormalization group techniques and universality.
Generalized diffusion and stochastic differential equations. The Feynman-Kac formula: diffusion with sinks and sources
Feynman path integrals and the quantum version of the Feynman-Kac formula.
Quantum mechanics (solvable model: free particle, harmonic oscillator)
Quantum vs stochastic phenomena: quantum tunneling and stochastic tunneling
Stochastic amplification and stochastic resonance
Non-perturbative methods: instantons
Diffusion in random media and anomalous diffusion
Quantum Mechanics in a random potential localization and random matrices
Statistical physics of random spin systems and the machine-learning problem
Random energy model, replica trick
Cavity method, Random Field Ising Model
**Examination:**

Final examination based on: Written and oral examination and weekly exercises proposed during the course

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8083597/N0

## NETWORK MODELLING (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA – EXAM OF STHOCASTIC PROCESSES)

Master degree in **Physics Of Data**, Second semester

Lecturer: Michele Zorzi

Credits: 6 ECTS

**Prerequisites:**

The course requires preliminary knowledge of: Mathematical Analysis, Probability, random variables and random processes, networks and protocols. For the examples treated, a basic course in networks and protocols is useful (through not required).

**Short program:**

1. Review of probability and random processes
2. Markov chains: definitions and main results
3. Markov chains: asymptotic behavior
4. Study of multi-access systems and their stability properties
5. Poisson processes: definitions and main results
6. Renewal processes: definitions and main results, asymptotic behavior
7. Renewal reward, regenerative, and semi-Markov processes
8. Exercises and examples of applications

A detailed list of the topics covered during the course, with specific reference to chapters and pages of the texts, is available on the course website through the e-learning platform.

**Examination:**

The assessment of the knowledge and skills acquired is carried out by means of a written test divided into two parts.

Part A, with a duration of 90 minutes and open-book, consists of eleven numerical questions grouped into four exercises. Each question has a value of three points.

Part B, with a duration of 60 minutes and closed-book, consists of three theoretical questions (typically proofs of theorems seen in class). Each question has a value of eleven points.

If the student scores at least 15 points in part A and the average score of part A and part B is at least 18, the latter can be accepted as the final grade. If the score in part A is less than 15 or the average of the two tests is less than 18, the exam is not passed.

Even if the final exam can be passed by a successful written exam (in two parts), the student can always ask to take an oral exam if he/she wants to improve the grade. In no case can the oral exam replace the written test.

Examples of exams are available on the elearning platform course website, and are extensively covered in class.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082659/N0

## NETWORK SCIENCE (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA)

Master degree in **Physics Of Data**, First semester

Lecturer: Tomaso Erseghe

Credits: 6 ECTS

**Prerequisites:**

This course has the following prerequisites: knowledge in Probability Theory, and Computer Programming in any language which is appropriate for network analysis (e.g., MatLab, Python, C, Java, Linux). Moreover: 1. for the INTERNET module: to be familiar with the most basic networking and communication concepts and terms (ISO/OSI model, packet-based networks, routing); 2. for the NETWORK SCIENCE module: knowledge in Calculus and Linear Algebra; any further knowledge of networking processes in economics, biology, telecommunications, semantics, etc. might be useful.

**Short program:**

The module will cover the following topics:

1. Network models - Basic network properties: graphs, adjacency matrix, degree distribution, connectivity; Erdos-Renyi model; Random graphs with general degree distribution; Power laws and scale free networks; Small world phenomena; Hubs; Network generation and expansion; Barabasi-Albert model; Preferential attachment; Evolving networks; Assortativity; Robustness.
2. Ranking - Hubs and authorities; PageRank: teleportation, topic specific ranking, proximity measures, trust rank; Speeding up by quadratic interpolation.
3. Community detection - Dendrograms; Girvan Newman method and betweenness; Modularity optimization; Spectral clustering; Other clustering algorithms; Core-periphery model for overlapping communities; Clique percolation method; Cluster affiliation model and BigCLAM.
4. Miscellaneous aspects - Link prediction; Applications scenarios

**Examination:**

The course has the following methods of examination:

INTERNET module:

The final exam will be the same for both ATTENDING and NON-ATTENDING students since it does not rely on in-class activities. The exam consists of two parts, namely: 1. a WRITTEN EXAM at the computer, 2. a LAB TEST. Students will be offered four attempts to pass the written and the lab tests. During in-class lectures, the students may be offered to participate to some (in class or at home) activities, such as peer-reviewing of other students' reports, participating in-class discussion and taking part to problem-solving competitions. The active participation to such initiatives may bring a few extra points (up to 3) to the students.

NETWORK SCIENCE module:

The verification of the expected knowledge and skills is carried out with the DEVELOPMENT OF A PROJECT aimed at verifying the ability to apply theory in interdisciplinary contexts, and which requires: the choice, the collection of data, and the analysis of a different network for each student; computer implementation (in any programming language known to the student) of the algorithms required for the analysis; the drafting of an essay. The project is foreseen in two ways: 1. for ATTENDING students in which the students are guided towards intermediate project objectives (HOMEWORKS) coherently with the development of the lessons, and complete the project at the end of the course; 2. for NON-ATTENDING students, in which the development of the project takes place in a single solution and is discussed in an oral exam in one of the four institutional dates. A bonus of up to 3 points is available for attending students that take part to an INTERDISCIPLINARY PROJECT with social science students attending the twin course on SOCIAL NETWORK ANALYSIS.

The final grade is expressed as a combination of the judgments in the two modules (50%+50%).

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082723/N0

**NUCLEAR PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)**

Master degree in **Physics Of Data**, First semester

Lecturer: Silvia Monica Lenzi

Credits: 6 ECTS

**Prerequisites:**

Quantum mechanics

**Short program:**
Program of Nuclear Physics 2017/2018
First part: Nuclear Structure and Nuclear Models
• Introduction: The nucleus as a laboratory of Quantum Mechanics
• Symmetries and the Nuclear Force
• Experimental methods
• Theoretical Models:
1) Collective Models:
LDM, Fermi Gas and Density-Functional Models,
Surface vibrations, Rotating nuclei
2) Microscopic Models: Mean-field Models,
Interacting Shell Model
The Nilsson Model
Second part: Nuclear reactions
Introduction
• Nucleon-Nucleon Scattering
• Nuclear Reactions
• Interactions between heavy ions
• Direct nuclear reactions between heavy ions
• Multi-nucleon transfer reactions between heavy ions
• Compound nuclear reactions
• Fusion reactions below the Coulomb barrier
• Reactions of astrophysical interest
**Examination:**
The exam consists on an oral examination with eventual presentation of a research work on one of the several subjects proposed by the professors.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP7081658/N0

## QUANTITATIVE LIFE SCIENCE

Master degree in **Physics Of Data**, First semester
Lecturer: TO BE DEFINED
Credits: 6 ECTS
**Prerequisites:**
Basics of Stochastic processes. Thermodynamics of phase transitions.
If you never attended the class “Statistical Mechanics” or “Models of Theoretical Physics” we suggest also to follow the first 3 CFU of this exam
**Short program:**
The program can be summarized as follow
Theoretical Neuroscience
- Basics in Neuroscience
- Neural circuits & structure and function of brain networks
- Wilson Cowan models
- Stochastic whole brain models
- Mean field approaches
- Criticality in the brain
- Controllability in brain networks
2. Statistical Mechanics of Ecological Systems
- Neutral theory and emergent patterns in ecology
- Dynamical Evolution of Ecosystems
- Upscaling and Downscaling biodiversity
- Species Interaction Networks

- Consumer-Resource Models
3. Physical Models in Biology
- Virus Dynamics
- Bacterial Genetics
- Molecular Population Dynamics
- Gene expressions
- Criticality in gene-regulation networks
- Robustness and Adaptability in Living Systems.

Please note that some topics may vary.

**Examination:**

The first part of the verification of the acquired knowledge will evaluated be through homework exercises (to do in groups) and the participation of the students in the class discussions The second part will takes place through, a common written test with 1-2 exercises to be solved and open questions to test the knowledge on basic concepts, the scientific vocabulary, the ability to synthesis and critical discussion acquired during the course. The third facultative part of the exam will be oral and will be based on a discussion on the various topics discussed during the course.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082720/N0

## RELATIVISTIC ASTROPHYSICS (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)

Master degree in **Physics Of Data**, Second semester
Lecturer: Giacomo Ciani
Credits: 6 ECTS

**Prerequisites:**

Basic knowledge of general relativity is suggested, but not mandatory.

**Short program:**

Elements of general relativity. Gravitational waves (GW) in linearized theory; TT-gauge and detector frame; interaction with free falling masses and rigid bodies.

Generation of GW. Quadrupole and post-newtonian approximations. Energy and momentum loss by gravitational wave emission. Examples of GW sources: stable and coalescing binary systems, rotating rigid bodies, extreme mass-ratio inspirals.

GW detection. Hulse-Taylor system. Fundamentals of stochastic signals and noise theory. Resonant bars detectors. Modern GW interferometers: basic principle, noise sources, fundamental and technical limitations. Future GW experiments. Elements of data analysis.

Astronomy and science with gravitational waves. Current observations of black hole and neutron star mergers. Tests of general relativity. Astrophysical implications. Multi-messenger astronomy.

**Examination:**

Oral examination aimed at verifying the conceptual understanding of the topics presented and the ability to correctly approach and analyze specific problems related to GW theory and detection.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP7081738/N0

## SOLID STATE PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)

Master degree in **Physics Of Data**, First semester
Lecturer: Francesco Ancilotto
Credits: 6 ECTS

**Prerequisites:**

Knowledge of elements of elementary quantum mechanics.
Knowledge of elements of elementary Statistical Mechanics (distribution functions, statistical ensembles, ensemmble averages, etc.)
**Short program:**
Chemical bonds in solids;
The structure of crystals;
Bravais lattices and bases;
Simple crystal structures;
Reciprocal lattice;
Diffraction by periodic structures and experimental techniques;
The Bragg law;
Adiabatic approximation;
Lattice dynamics;
Harmonic approximation,
The dynamical Matrix;
phonons;
Monoatomic and diatomic linear chains;
Spectroscopy of phonons;
Thermal properties of crystals;
Lattice specific heat;
Anharmonic effects: thermal expansion, thermal conductivity of insulating materials;
"free" electrons model;
Electronic specific heat;
electrostatic screening in a Fermi gas.;
Bloch theorem;
Band structure;
"quasi-free" electron approximation;
"tight binding" approximation;
Examples of band structures;
Transport phenomena;
The Drude model;
Hall effect in metals;
Semiclassical model;
The concept of "hole";
Electrical and thermal conductivity in metals;
Law of Wiedemann and Franz;
Semiconductors;
Cyclotron Resonance;
Carriers concentration in intrinsic and extrinsic semiconductors;
"Doping" and dopant states;
electron and hole mobility;
Electrical conductivity in semiconductors;
Hall effect in semiconductors;
The Fermi surface in real metals.
Superconductivity.
**Examination:**
Oral exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP7081660/N0

## STATISTICAL MECHANICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)

Master degree in **Physics Of Data**, First semester
Lecturer: Enzo Orlandini
Credits: 6 ECTS

**Prerequisites:**
Statistical Mechanics (course given at the third year of the laurea triennale)
Thermodynamics

**Short program:**
In short the contents of the program can be summarised as follows:
Thermodynamics of phase transitions.
Critical points, order parameters and critical exponents. Phase transitions and spontaneous symmetry breaking.
Analytical tools to solve spins model in 1D, transfer matrix formalisms.
Mean field theories.
Ginzburg Landau theory.
Ginzburg criterium and upper critical dimension. Scaling theory and Kadanoff block spin argument.
Renormalisation group in real space. Universality.
Please note that some topics may vary
Spontaneous symmetry breaking for continuous symmetry. Goldstone's theorem.

**Examination:**
The verification of the acquired knowledge takes place through a common written test with 1-2 exercises to be solved analytically and 1-2 open questions on basic concepts. In this way we should be able to test the knowledge, the scientific vocabulary, the ability to synthesis and critical discussion acquired during the course.The second part of the exam will be oral and will be based on a discussion on the various topics discussed in class.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP7081659/N0

## STATISTICAL MECHANICS OF COMPLEX SYSTEMS (OFFERED IN THE MASTER DEGREE IN MATHEMATICAL ENGINEERING)

Master degree in **Physics Of Data**, Second semester
Lecturer: Amos Maritan
Credits: 6 ECTS

**Prerequisites:**
Good knowledge of mathematical analysis, calculus and basic physics.
For "Physics of Data" students the course has 6 CFU. However, if they are not adequately trained in statistical mechanics, they are encouraged to follow all 9 credits

**Short program:**
The program can be summarized as follows
Statistical mechanics and Entropy
Ising model
Diffusion Processes
Complex networks.
Principle of maximum entropy and inference
Montecarlo simulations
Dynamics of and on networks.
Percolation on networks.
Neural networks

**Examination:**
The first part of the verification of the acquired knowledge will evaluate the homework exercises and the participation of the students in the class discussions The second part will

takes place through, a common written test with 1-2 exercises to be solved and open questions to test the knowledge on basic concepts, the scientific vocabulary, the ability to synthesis and critical discussion acquired during the course. The third part is oral, optional and it will be based on a discussion on the various topics of the course.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP8082536/N0

## STRUCTURE OF MATTER (OFFERED IN THE MASTER DEGREE IN PHYSICS)

Master degree in **Physics Of Data**, Second semester
Lecturer: Luca Salasnich
Credits: 6 ECTS

**Prerequisites:**
All the exams of the B.Sc. in Physics.

**Short program:**
1. Second quantization of the electromagnetic field.
Properties of the classical electromagnetic field in the vacuum.
Coulomb Gauge. Expansion in plane waves of the vector potential. Quantum oscillators and quantization of the electromagnetic field. Fock states and coherent states of the electromagnetic field. Electromagnetic field at finite temperature.
2. Electromagnetic transitions. An atom in the presence of the electromagnetic field. Fermi golden rule. Diple approximation.
Absorption, stimulated and spontaneus emission of radiation:
Einstein coefficients. Selection rules. Lifetime of atomic states and linewidths. Population inversion and laser light.
3. The Spin of the Electron. Klein-Gordon and Dirac equations. The Pauli equation and the spin. Dirac equation with a central potential. Relativistic hydrogen atom and fine splitting.
4. Many-body quantum systems. Identical particles. Bosons and Bose-Einstein condensation. Fermions and Pauli exclusion principle. Veriational principle. Hartree variational method for bosons and the Gross-Pitaevskii equation. Hartree-Fock variational method for fermions. Density functional theory:
theorems of Hoemberg-Kohn, density functional of Thomas-Fermi-Dirac-Von Weizsacker and density functional of Khom-Sham.
5. Second quantization of the Schrodinger field. Field operators for bosons and fermions. Fock and coherent states of the bosonic field operator. Schrodinger field at finite temperature. Matter field for interacting bosons and fermions. Bosons in a double-well potential and the two-site Bose-Hubbard model.

**Examination:**
Colloquium of about 30 minutes.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP7081438/N0

## SUBNUCLEAR PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)

Master degree in **Physics Of Data**, Second semester
Lecturer: Donatella Lucchesi
Credits: 6 ECTS

**Prerequisites:**
Basic knowledge on quantum mechanics, relativity, nuclear and subnuclear physics. Quantum field theory and Feynman graphs. Interaction of radiation and particles with matter.

**Short program:**
A brief reminder of basic concepts: symmetries, conservation laws, quantum numbers and elementary particle classification. Lifetime, resonances and Breit Wigner distribution.
QED: brief reminder of theoretical foundation, tree levels processes and loop diagrams. The

running coupling constant. Experimental tests: success and open issues.
Weak interactions of leptons and quarks. Fermi constant(Gf), weak gauge bosons, relation between Gf and MW. Muon and tau decays: lepton universality. P,C violation in charged and weak currents. Nuclei, baryon and meson weak decays: "helicity suppression". Neutrino scattering. Spontaneous symmetry breaking and the Higgs boson. Measurements at LEP and at the LHC. Status and perspectives.
QCD. Hadron spectroscopy. ee annihilation to hadrons. Deep inelastic scattering of electrons and neutrinos; nucleon structure functions.
Hadron flavour Physics. The CKM matrix. Flavour oscillations and CP violation.

**Examination:**

A written test, including numerical execises and multi-answer questions. An oral test: the student can choose to discuss in detail the contents of a published article (and all the issues pertinent to it) among a set of those proposed during the lessons, or to be questioned on all the subjects discussed during the course.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP7081697/N0

**THE PHYSICAL UNIVERSE (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY – EXAM OF FUNDAMENTALS OF ASTROPHYSICS AND COSMOLOGY)**

Master degree in **Physics Of Data**, First semester
Lecturer: Sabino Matarrese
Credits: 6 ECTS

**Prerequisites:**

Fundamental concepts of quantum mechanics and special relativity

**Short program:**

Fundamental concepts of galactic and extra-galactic astrophysics
• The classification of galaxies
• Statistical properties of the galaxy population
• Groups and clusters of galaxies
Fundamental concepts of Cosmology
* Main components of the Universe. Observational evidence for the existence of dark matter and dark energy.
* Expanding Universe and Cosmological Principle.
* Robertson-Walker line-element. Geometrical properties.
* Hubble constant and deceleration parameter.
* Distances in Cosmology; redshift and Hubble law (low-redshift approximation).
* Derivation of Friedmann equations (dust case); Newtonian and relativistic contributions
* Friedmann models.
* Cosmological constant: Einstein's static solution and de Sitter solution. Dynamical dark energy
* Cosmological solutions for the spatially flat case. Universe models with non- zero spatial curvature.
• Exact treatment of the Hubble law.
Thermal history and early Universe
* Number density, energy density and pressure of a system of particles in thermodynamic equilibrium.
* Entropy conservation in a comoving volume.
* Time-temperature relation in the Early Universe.
* Shortcomings of the standard cosmological model: horizon, flatness problems, etc.
* Inflation in the Early Universe: solution of the horizon and flatness problems.
• Kinematics and dynamics of inflation; the "inflaton".
• Old, new and chaotic inflation; slow-roll dynamics (basic account).

* Baryon asymmetry in the Universe (basic account)
• Primordial nucleosynthesis of light elements.
* Hydrogen recombination: Saha equation. Matter-radiation decoupling. Cosmic Microwave background.
* General definition of decoupling.
Dark matter: general properties
* Boltzmann equation in Cosmology and cosmic relics.
* Hot/Cold/Warm Dark matter: definition, present abundance and general cosmological properties.
Elements of stellar astrophysics
* Gravitational contraction and conditions for hydrostatic equilibrium.
* Adiabatic index and equilibrium.
* Conditions for gravitational collapse.
* Jeans theory of gravitational instability.
* Contraction of a protostar.
* Star formation and degenerate electron gas.
* The Sun: general properties, radiative diffusion, thermonuclear fusion.
* Stellar nucleosynthesis.
* Stellar cycles.
* Hertzsprung-Russell diagram.
* Basics of stellar structure. Clayton model: Minimum mass of a star; maximum mass for a Main-Sequence star.
* End-points of stellar evolution: white dwarfs, neutron stars, Chandrasekhar mass, black holes.
The formation of cosmic structures
* Linear evolution of perturbations in the expanding Universe (basic principles).
* Spherical collapse of a cosmic proto-structure.
* Mass-function of cosmic structures: Press-Schechter theory.

**Examination:**
Oral interview.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP7081677/N0

**THEORETICAL PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)**
Master degree in **Physics Of Data**, First semester
Lecturer: Pierpaolo Mastrolia
Credits: 6 ECTS
**Prerequisites:**
Principle of Theoretical Physics
**Short program:**
Outline:
1. Quantum Electrodynamics: Feynman rules; scattering processes at tree-level: Rutherford scattering, Compton scattering, Bhabha scattering and Bremsstrahlung.
2. Basics of Radiative corrections and Renormalization.
3. Non-Abelian gauge theories. Lie Algebra, covariant derivatives, kinetic terms and self-interaction of gauge fields.
4. SU(3) gauge theory and Quantum Chromodynamics.
The color algebra.
Feynman rules and tree-level scattering amplitudes for gluons and quarks.
5. Introduction to the Weak interaction.
Fermi's theory: Feynman rules and the muon decay.
SU(2) x U(1) gauge theory and Electroweak unification.

6. Spontaneous symmetry breaking: breaking of a discrete symmetry; spontaneous breaking of global U(1) symmetry; Goldstone theorem; the Higgs mechanism.
7. Spontaneous symmetry breaking of SU(2)xU(1) and the Higgs doublet.
8. The Standard Model Lagrangean.

**Examination:**
Written and oral exams

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP7081638/N0

**THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS (OFFERED IN THE MASTER DEGREE IN PHYSICS)**

Master degree in **Physics Of Data**, First semester
Lecturer: Stefano Rigolin
Credits: 6 ECTS

**Prerequisites:**
Principle of Theoretical Physics

**Short program:**
Programme:
1. Quantum Elettrodynamics: Feynman rules, tree level processes ( Rutherford, Compton and Bhabha scattering, Bremsstrahlung).
2. Non Abelian gauge theories: non-Abelian gauge fields kinetic terms and selinteractions, covariant derivatives.
3. Quantum Crhomodynamics: The "colour" algebra, Feynman rules and scattering amplitudes for gluons and quarks at tree level.
4. Electroweak gauge theory. The Fermi effective Lagrangian: Feynman rueles and muon decay. SU(2)xU(1) gauge theory and Electroweal unification.
5. Spontaneous symmetry breaking of a symemtry: the discrete and continuum cases. The Goldstone theorem and the Higgs mechanism.
6. Spontaneous symmetry breaking of the Electroweak symmetry.
7. The electroweak Lagrangian for one and three families.

**Examination:**
Written and oral exams

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC2443/2018/000ZZ/SCP7081657/N0

**FIRST CYCLE DEGREES WITH SOME COURSE UNITS HELD IN ENGLISH:**

**ASTRONOMY**

**ASTROPHYSICS 2**

Degree in **Astronomy**, Second Semester
Lecturer: Paola Marigo
Credits: 6 ECTS

**Prerequisites:**

Elements of plane trigonometry, derivatives, integrals, basic knowledge of physics.
Preparatory courses: Astronomy I and Astronomy II (mod. A) of the Bachelor in Astronomy.

**Short program:**

1) Introduction and overview. Observational constraints, the H-R diagram, mass-luminosity and mass-radius relations, stellar populations and abundances.
2) Hydrostatics, energetics and timescales. Derivation of three of the structure equations (mass, momentum and energy conservation). Hydrostatic and thermal equilibrium. Derivation of the virial theorem and its consequences for stellar evolution. Derivation of the characteristic timescales of stellar evolution.
3) Equation of state (EoS). Local Thermodynamical equilibrium. General derivation of n, U, P from statistical mechanics. Limiting cases: ideal gas, degeneracy. Mixture of gas and radiation. Adiabatic processes. Ionization (Saha equation, consequences for thermodynamic properties).
4) Energy transport in stellar interiors. The 4th equation of stellar structure: the energy transport equation. Diffusion approximation for radiation transport. The radiative temperature gradient. Opacity. Eddington luminosity. Convection: Derivation of stability criteria (Schwarzschild, Ledoux). Convective energy transport: order-of-magnitude derivation. Mixing-length theory.
5) Nuclear reactions. Nuclear energy generation (binding energy). Derivation of thermonuclear reaction rates (cross sections, tunnel effect, Gamow peak). Temperature dependence of reaction rates .Nuclear burning cycles: H-burning by pp-chain and CNO-cycle. He burning by 3-alpha and alpha+C reactions. Advanced burning reactions.
6) Stellar evolution equations. Overview, time/space derivatives, limiting cases. Boundary conditions and their effect on stellar structure. How to obtain solutions.
7) Simple stellar models. Polytropic models. Homology relations: principles, derivations, application to contraction and the main sequence. Stability of stars: derivation of simplified criteria for dynamical and secular stability.
8) Schematic evolution from the virial theorem (VT). Evolution of the stellar centre combining the VT and the EoS: evolution tracks in terms of (P, rho) and (T, rho). Evolution towards degeneracy or not. The Chandrasekhar mass, low-mass vs massive stars. Critical ignition masses, brown dwarfs, nuclear burning cycles.
9) Detailed evolution: towards and on the main sequence. Simple derivation of Hayashi line, pre-MS evolution tracks properties of the ZAMS: M-L and M-R relations, occurrence of convection zones evolution across the MS band: structural changes, low-mass vs high-mass, effects of overshooting.
10) Post-MS evolution. The Schoenberg-Chandrasekhar limit, the mirror principle. H-shell burning: Hertzsprung-gap, red giant branch, first dredge-up. He-burning: horizontal branch, loops, Cepheids. RGB mass loss.
11. Late evolution of low- and intermediate-mass stars.
The Asymptotic Giant Branch: thermal pulses, 2nd/3rd dredge-up, mass loss, nucleosynthesis. White dwarfs: structure, non-ideal effects, derivation of simple cooling theory.
12) Pre-SN evolution of massive stars. Importance of mass loss across the HRD (O stars, RSG, LBV and WR stars). Modern evolution tracks. Advanced evolution of the core: nuclear burning cycles and neutrino losses, acceleration of core evolution. Pre-SN structure

13) Explosions and remnants of massive stars. Evolution of the core towards collapse: Fe-disintegration, electron captures, role of neutrinos supernovae. Observed properties and relation to massive star evolution. Limiting masses for neutron star and black hole formation, dependence on mass loss and metallicity.**Examination**:
Oral and/or written examination with open questions on all the topics covered during the course.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1160/2008/000ZZ/SCM0014352/N0

**BIOLOGY**
**Molecular Biology**
Degree in **Biology**, First Semester
Lecturer: Maria Eugenia Soriano Garcia - Cuerva
Credits: 7 ECTS
**Prerequisites:**
Biochemistry Cell Biology
**Short program:**
THE ORIGIN OF THE MOLECULAR BIOLOGY
The nature of genetic material, the double helix, the central dogma

DNA STRUCTURE AND TOPOLOGY
DNA structures (A, B, Z): chemical structure, parameters, stability, alternative local conformations: cruciforms, hairpins, triple helix, unpaired structures, curvature.
DNA topology: Fuller equation and parameters.

TOPOISOMERASES
Function, types, and mechanisms of action.

RNA STRUCTURE
Chemical structure and topology
Chemical modifications, secondary and tertiary structures
Conformation-function correlation

THE GENETIC CODE
Deciphering, structure, and evolution.
Reading and ORF phases.
Amber and Ochre mutants.

ORGANIZATION OF GENETIC MATERIAL
Viruses, bacteria and eukaryotic DNA
Packaging levels
The nucleosome: components, assembly, and post-translational modifications. Distribution and positioning during replication and transcription.
Chromatin: structure, conformation, and functionality. Centromeres and Telomeres
Atypical organizations

ORGANIZATION OF GENETIC INFORMATION
In prokaryotes: operons
In eukaryotes: coding and non-coding regions
Genetic profiles

DNA REPLICATION.
Proposed models
Origin of replication: identification and regulation
Mechanism and phases of the replication process.
Replication machinery
Telomeres and nucleosomal DNA (epigenetics)
The faithfulness of DNA replication

TRANSCRIPTION IN PROCARIOTS.
Transcription unit, RNA polymerase and Phases
Promoters
Closed and open complex: sigma and abortion phase factors.
Extension and termination rho-dependent and independent
Regulation of transcription: Operons classification
Lactose and tryptophan operons

FAGO LAMBDA
Regulation of the lytic and lysogenic cycle

TRANSCRIPTION IN EUKARYOTES.
RNA polymerase phases I, II and III: Characteristics, differences, and functions.
Promoters and transcription factors.
Complex mediator.
Regulation of transcription: Activators, co-activators and silencers. Distal and proximal sites.
Chromatin remodeling and methylation. Genetic imprinting

RNA MATURATION.
Eukaryotes: splicing, categories of introns, splicing mechanisms, Self-splicing;
Catalytic RNA, evolutionary implications; enzymes with RNA components and proteins; small nuclear RNAs.

TRANSLATION.
Ribosomal RNA and tRNA; ribosomes; protein synthesis; starting and elongation factors.
Ribosome as a molecular machine.
Modifications of mRNA: polyadenylation and CAP. Problem of eukaryotic regulation as a combinatorial system. Examples of regulation at the level of chromatin modifiers: I'RNA as a regulator, siRNA, miRNA,snRNA.

TECHNIQUES:
Agarose gel electrophoresis
Southern blot
Cloning: restriction enzymes, plasmids and ligases
Polymerase Chain reaction (PCR)
Sequencing techniques
Silencing: siRNA
Acrylamide gel and western blot electrophoresis

LABORATORY ACTIVITY
Analysis of a transposon in the human genome. extraction of DNA from saliva and amplification of the locus PV 92 and study of the polymorphism.
**Examination**:
Oral or written with open questions and or multiple choice

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1165/2008/000ZZ/SCP4068096/N0

## Evolutionary Biology

Degree in **Biology**, Second Semester
Lecturer: Andrea Augusto Pilastro
Credits: 10 ECTS

**Prerequisites:**
Formal Genetics and basic Molecular Biology are fundamental prerequisits. Basic knowledge in Mathematics and Informatics, Zoology, Botany and Developmental biology would also be useful.

**Short program:**
the course is given in English.

This is an integrated course, which consists of two parts (Evolutionary Biology and Population Genetics) held by different teachers.

Evolutionary Biology
This part of the course is an introduction to the evolutionary biology. The teacher will present the main selective and ecological processes which are responsible for adaptive (and non-adaptive) evolutionary changes. Students will be guided to integrate their knowledge of the genetic mechanisms responsible for the expression of phenotypic traits (including their plasticity) into an evolutionary framework.
1. An introduction to evolution
2. The history of life
How does evolution lead to the tree of life?
Understanding phylogenies
Homologies and analogies
Important events in the history of life
3. Mechanisms of adaptive evolution
Descent with modification
Mechanisms of change
Genetic variation
Sex and genetic shuffling
Natural selection
Sexual selection
Artificial selection
Adaptation
Misconceptions about natural selection
Coevolution
4. Microevolution
Detecting contemporary microevolutionary change
Mechanisms of microevolution (directional, stabilizing and disruptive selection)
5. Speciation
Defining a species
Defining speciation
Causes of speciation
Reproductive isolation
Evidence for speciation
6. Macroevolution
Patterns in macroevolution
7. The big questions in evolutionary biology

The pace of evolution
The maintenance of genetic variation

Population Genetics
The general theme of this part of the course is the origin, maintenance and meaning of genetic variability. The study of population genetics provides the necessary tools for the comprehension of the genetic mechanisms which are the driving force of biological evolution.
1. Genetic variability in populations;
2. How is genetic variability organized?
3. The Hardy-Weinberg principle;
4. Recombination, linkage and linkage disequilibrium;
5. The structure of natural populations;
6. The origins of genetic variability;
7. Random genetic drift;
8. An introduction to coalescence theory;
9. Inbreeding and non-random breeding;
10. Population subdivision and genetic flow;
11. Darwinian selection;
12. The molecular basis of population genetics;
13. The Neutral Theory and molecular evolution.
**Examination**:
Evolutionary Biology
The final exam will be written, with multiple choice questions, but oral examination available upon request.

Population Genetics
The final exam will be written, with multiple choice questions, short answers and problems involving the analysis and interpretation of mock experimental data.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1165/2008/000ZZ/SCP3053524/N0

**MATHEMATICS**
**DISCRETE MATHEMATICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA – EXAM OF GRAPH THEORY)**
Degree in **Mathematics**, Second Semester
Lecturer: Michelangelo Conforti
Credits: 6 ECTS
**Prerequisites:**
basic knowledge of mathematics (including proof techniques, basic combinatorics etc.)
**Short program:**
Undirected graphs: Basic Definitions: walks, paths, cuts, connectivity. Classes of graphs: Bipartite, complete, k-regular, hypercubes.
Trees: Definitions, basic properties, fundamental cycles, minimum spanning tree: Kruskal's algorithm.
Bipartite Matchings: Definitions, alternating-augmenting paths. Hall's theorem, Konig's theorem, stable matchings.
General Matchings: Tutte's theorem, Berge's formula, Gallai's identities.
Directed Graphs: Basic definitions and properties. Strong connectivity, strongly connected components, acyclic digraphs, Tournaments, Hamiltonian paths and cycles in tournaments, Gallai-Milgram theorem, comparability graphs.
Connectivity: Edge and vertex connectivity, 3 Menger theorems, ear decompositions.
Graph Coloring: Edge-Chromatic number, Vizing's theorem, Chromatic number.

Planarity. Plane drawings and dual graphs, Euler's formula, colorability of planar graphs, Kuratowski theorem , Tait's theorem.
Traversability. Hamiltonian and Eulerian Graphs.
**Examination**:
Written exam.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1159/2008/000ZZ/SC04105572/N0

**PHYSICAL-MATHEMATICAL MODELS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN MATHEMATICAL ENGINEERING – EXAM OF CONTINUUM MECHANICS)**

Degree in **Mathematics**, First Semester
Lecturer: Marco Favaretti
Credits: 6 ECTS
**Prerequisites:**
Pr.: Calculus, elementary algebra and geometry, and a first course in Mathematical Physics.
**Short program:**
1. Kinematics of Continuous systems, spatial and material representation.
2. Mass conservation principle. Balance and Conservation laws
3. Cauchy tetrahedron theorem.
4. Principle of virtual works in continuum mechanics. Balance law and the first cardinal equation.
5. Material description of the stress tensor.Work-Energy Theorem. Constitutive equations and the principle of material indifference.
6. Ideal elastic fluids. Navier-Stokes, Vorticity.
7. Hagen-Poiseuille flow, plane motion of Navier-Stokes fluids, Bernoulli Theorem.
8. Elementary Meteorology: Cyclones and Anticyclones.
9. Variational formulation of classical field theories: hyper-elasticity and linear elasticity.
10. Principles of thermodynamics. Legendre transformation and thermodynamic potentials. First principle of thermodynamics for continuum systems. Balance laws and the first principle. The second principle in the Clausius-Duhem formulation. Balance laws and the second principle. Theorem of Clausius-Duhem. Thermoelastic materials.
11. Wave propagation. The method of characteristics: linear and quasi-linear theories. Singularities. Nonlinear theory and the Hamilton-Jacobi equation. Wave propagation in systems of conservation laws. Weak discontinuities, Hugoniot-Hadamard. Sound speed. High frequency asymptotic waves. Shock waves. Rankine-Hugoniot.
12. Fourier series and applications.
**Examination**:
Written exam.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1159/2008/000ZZ/SC01111314/N0

## SECOND CYCLE DEGREES WITH SOME COURSE UNITS HELD IN ENGLISH:

### CHEMISTRY

### CHEMISTRY OF ORGANIC MATERIALS

Master degree in **Chemistry**, Second semester
Lecturer: Enzo Menna
Credits: 6 ECTS

**Prerequisites:**
General Organic Chemistry.

**Short program:**
The course program covers main application fields for advanced organic materials.
Each application will be discussed with regard to:
- theoretical bases required to understand how the material works
- different chemical classes of materials
- different kind of structures (polymers, oligomers, molecules, supramolecular systems and nanostructures)
- synthesis and characterization of structures
- structure-property relationships (e.g. effect of the substituent, of the supramolecular organization, ...)
- device fabrication techniques (e.g. thin layer deposition, self assembly of systems, ...)
- example of application both at research and commercial level.

According to such scheme, the following topics will be considered in particular:
- Fullerenes, nanotubes and other carbon nanostructures
- Organic photovoltaic devices
- Organic electroluminescent materials (OLED)
- Supramolecular polymers
- Self assembled layers of organic molecules
- Organic molecules for non-linear optics
- Advanced biomimetic materials: dry adhesives (gecko effect) and self healing materials.
- Structural organic materials: main classes of plastic and engineering polymers, their application, synthesis and properties.

**Examination**:
Oral exam. The student can choose either English or Italian language. During 20-30 minutes, the student will be asked to expose briefly and rigorously some topics and to make connections among involved topics.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1169/2018/000ZZ/SCP9087639/N0

### CHEMISTRY OF ORGANIC MATERIALS

Master degree in **Chemistry**, Second semester
Lecturer: Enzo Menna
Credits: 6 ECTS

**Prerequisites:**
General Organic Chemistry.

**Short program:**
The course program covers main application fields for advanced organic materials.
Each application will be discussed with regard to:
- theoretical bases required to understand how the material works
- different chemical classes of materials
- different kind of structures (polymers, oligomers, molecules, supramolecular systems and nanostructures)

- synthesis and characterization of structures
- structure-property relationships (e.g. effect of the substituent, of the supramolecular organization, ...)
- device fabrication techniques (e.g. thin layer deposition, self assembly of systems, ...)
- example of application both at research and commercial level.

According to such scheme, the following topics will be considered in particular:
- Fullerenes, nanotubes and other carbon nanostructures
- Organic photovoltaic devices
- Organic electroluminescent materials (OLED)
- Supramolecular polymers
- Self assembled layers of organic molecules
- Organic molecules for non-linear optics
- Advanced biomimetic materials: dry adhesives (gecko effect) and self healing materials.
- Structural organic materials: main classes of plastic and engineering polymers, their application, synthesis and properties.

**Examination**:
Oral exam. The student can choose either English or Italian language. During 20-30 minutes, the student will be asked to expose briefly and rigorously some topics and to make connections among involved topics.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1169/2018/000ZZ/SCN1036077/N0

## MAGNETIC SPECTROSCOPIES

Master degree in **Chemistry**, Second semester
Lecturer: Lorenzo Franco
Credits: 6 ECTS

**Prerequisites:**
Physics and quantum chemistry basics.

**Short program:**
Introduction to electromagnetic field and radiation-matter interactions. Classical and quantum mechanical description of spin and magnetic moments. Nuclear and electron spin properties. Spin Hamiltonians. Bloch equation, spin relaxation and density matrix description of magnetic resonance. Pulsed and Fourier Transform techniques in magnetic resonance (FID, spin-echoes etc.). Product operator formalism. Zeeman interaction. Nuclear and electronic magnetic interaction. Electron Paramagnetic Resonance. Isotropic and anisotropic interactions. EPR spectra in liquid and solid phase (single crystal, disordered solids). Zero Field Splitting. Advanced EPR techniques: ENDOR, ODMR, Time-resolved EPR, Multifrequency EPR, Pulsed EPR.

**Examination**: Oral examination.

**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/SC1169/000ZZ/SCP9087644/N0

## OPTICAL PROPERTIES OF MOLECULAR SYSTEMS

Master degree in **Chemistry**, Second semester
Lecturer: Elisabetta Collini
Credits: 6 ECTS

**Prerequisites:**
Knowledge of the subjects taught in the basic and advanced classes of physical chemistry.

**Short program:**
1. Electromagnetic fields

2. Dielectric properties of materials and molecules
3. Time dependent perturbation theory of spectroscopy
4. Absorption, emission and scattering
5. Vibrational spectroscopy of polyatomic molecules
6. Electronic and vibronic transitions: absorption and emission
7. Time resolved spectroscopy for the study of the dynamics and photophysics of molecular systems
8. Photohysics and photochemistry of molecular aggregate systems
8.a Frenkel excitons
8.b Non radiative processes: energy transfer processes
9. Elements of non linear optical spectroscopy in the time and in the frequency domain.

**Examination**:
Final oral exam
**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/SC1169/000ZZ/SCP9087642/N0

## PHYSICAL CHEMISTRY OF FLUIDS

Master degree in **Chemistry**, First semester
Lecturer: Alberta Ferrarini
Credits: 6 ECTS
**Prerequisites:**
Concept of mathematics: power series expansion, derivatives, integrals.
Termodynamics: principles, thermodynamic potentials and their properties.
Quantum mechanics: Schroedinger equation, wavefunction, model of particle in a box.
**Short program:**
The first part of the course will introduce concepts and methods of statistical themodinamics (distribution functions, partition functions and thermodynamic properties). These will be used to examine fluctuations on the microscopic and molecular scale, intermolecular correlations and thermodynamic properties of simple liquids.
In the second part of the course, the concepts and methods developed in the first part will be applied to topics such as:
- Colloids and dispersed/supramolecular systems: effective interactions (van der Waals and entropic forces, Poisson-Boltzmann theory, DLVO theory), tuning of attractive interactions (phase diagrams of colloids and of protein solutions).
- Polymers: conformational and elastic properties of polymers (freely-jointed and worm-like chain models) and their experimental determination (measure of shape fluctuations and stretching of single polymers); liquid-liquid phase separation (Flory-Huggins theory); coil-globule transition.
- Anisotropic systems: liquid crystals, lipid membranes.
The course includes also some mention of experimental methods for the investigation of the structure and order of fluids, in particular scattering and microscopy techniques and single molecule experiments.
**Examination**:
Oral exam with at least three open questions, which allow students to use the concepts and methods acquired in the two parts of the course.
**More information:**
https://en.didattica.unipd.it/off/2018/LM/SC/SC1169/000ZZ/SCP9087658/N0

## PHYSICAL CHEMISTRY OF THE SOLID STATE AND OF MATERIALS

Master degree in **Chemistry**, Second semester
Lecturer: Camilla Ferrante
Credits: 6 ECTS

**Prerequisites:**
The student should be familiar with concepts and notions of classical physics (mechanics, dynamics and electromagnetism). A knowledge of elements of quantum mechanics, thermodynamics and spectroscopy is also required (at the level of a bachelor or first degree in chemistry) as well as the knowledge of intermolecular forces which are part of the program of Physical Chemistry IV.
**Short program:**
1. Basics. Classification of solids
2. Structure and Symmetry in Crystals
3. Local order in fluids and amorphous solids
4. Polymers
5. Lattice dynamics
6. Phonons and thermal properties
7. Electrons in crystals
8. Metals and semiconductors
9. Physical properties of crystals. General principles
10. Dielectric and optical properties of insulators
11. Magnetic materials
12. Devices based on inorganic and organic semiconductors.

**Examination**:
Oral exam whereby the student should report and explain one or more argument discussed in the lectures. Aim of the exam is to verify the knowledge acquired by the student and her/his ability to elaborate on them.
**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/SC1169/000ZZ/SCP9087640/N0

## PRINCIPLES AND APPLICATIONS OF ORGANOMETALLIC CHEMISTRY

Master degree in **Chemistry**, First semester
Lecturer: Andrea Biffis
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge in chemistry imparted in the undergraduate courses in Chemistry or Industrial Chemistry.
**Short program:**
Introduction
Organometallic compounds: definition. Historical overview. General properties and preparation methods. Organometallic compounds in the periodic table: trends.
Organometallic compounds of the main group elements
The preparation methods, the properties and the applications of the most important organometallic compounds of the main group metals, of the group 12 metals and of boron will be illustrated.
Organometallic compounds of the transition metals
The preparation methods, the properties and the applications of the most important classes organometallic compounds of the transition metals, such as compounds containing sigma M-C bonds, metal carbonyls, metal carbenes, metal olefin and metal alkyne complexes, allyl, polenyl and polyene complexes will be illustrated. Special attention will be given to applications in organometallic synthesis and catalysis
**Examination**:
Oral examination.
**More information:**
https://en.didattica.unipd.it/off/2018/LM/SC/SC1169/000ZZ/SCP9087645/N0

## PROTEIN STRUCTURE AND DYNAMICS

Master degree in **Chemistry**, First semester
Lecturer: Massimo Bellanda
Credits: 6 ECTS

**Prerequisites:**
Basic knowledge of physical-chemistry and biochemistry

**Short program:**
1. Basic concepts in NMR: introduction to nuclear spin physics, chemical shift, scalar coupling.
2. Relaxation, dipolar coupling, nuclear Overhauser effect (NOE).
3. Practical aspects in the acquisition of NMR spectra: principal components of NMR spectrometer, acquisition and processing of NMR signals, preparation of samples suitable for the NMR analysis.
4. Principle of FT-NMR; Producat Operator formalism to describe NMR experiments.
3. Homonuclear 2D NMR experiments (COSY, TOCSY, NOESY).
6. Heteronuclear correlation spectroscopy: INEPT, HSQC and HMQC experiment.
7. Triple resonance NMR experiments for the study of proteins.
8. Use of NMR data for the structural characterization of peptides and proteins: secondary structure from NMR parameters, high resolution tertiary fold from NOE data. Structure validation.
9. Spin relaxation measurments to evaluate protein dynamics
10.Strategies to study large proteins: TROSY experiments and deuteration.
11. Residual Dipolar Couplings in structural biology.
12. Protein-and protein-ligands interactions by NMR.
13. Production of recombinant labeled proteins.

**Examination**:
Oral questions with the option to define with the lecturer a specific topic or a case study to discuss at the beginning of the exam.

**More information:**
https://en.didattica.unipd.it/off/2018/LM/SC/SC1169/000ZZ/SCP9087646/N0

## THEORETICAL CHEMISTRY

Master degree in **Chemistry**, Second semester
Lecturer: Diego Frezzato
Credits: 6 ECTS

**Prerequisites:**
Basic knowledge in chemistry, physics and mathematics.

**Short program:**
1. Description of molecular stochastic dynamics: theory of stochastic processes, Fokker-Planck equation, stochastic differential equations; tools for the numerical solution; correlation functions and spectral densities; stochastic chemical kinetics.
2. Laws of transformation under rotation: change of representation of scalar, vector and tensor properties under rotation of the reference frame; rotation of scalar fields; rotational stochastic dynamics.
3. Linear response theory: response of a classical system to weak perturbations.
4. Open quantum system dynamics: response theory, Master Equation, formal treatment of spectroscopic observables.
5. Stochastic Thermodynamics: work fluctuation theorems and applications.

**Examination**:
Oral examination, with the possibility to analyse a specific problem and discuss a brief report on it.

**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/SC1169/000ZZ/SCP9087641/N0

**COMPUTER SCIENCE**

## ADVANCED TOPICS IN COMPUTER SCIENCE

Master degree in **Computer Science**, Annual
Lecturers: prof. A. Abate, prof. R. Meyer, prof. H. Reijers.
Credits: 6 ECTS
**Prerequisites:**
No prerequisites.
**Short program:**
The course consists of series of lectures, illustrating advanced topics in computer science with the support of international experts. More precisely, the themes will be the following:
- "Modern Automated Formal Verification"
Prof. Alessandro Abate, University of Oxford, UK
http://www.cs.ox.ac.uk/people/alessandro.abate/home.html
- "Analysis of Memory Models"
Prof. Roland Meyer, University of Braunschweig, Germany
https://www.tcs.cs.tu-bs.de/group/meyer/home.html
- "Business Process Management & Analytics"
Hajo Reijers, Utrecht University, Netherlands
https://www.win.tue.nl/~hreijers
**Examination:**
The student will deepen some chosen theme. A discussion in the form of a seminar or the development of a related project will then be used to asses to what extent the student masters the subject.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP6076301/N0

## BIG DATA COMPUTING

Master degree in **Computer Science**, Second semester
Lecturer: Andrea Alberto Pietracaprina
Credits: 6 ECTS
**Prerequisites:**
The course has the following prerequisites: competences regarding the desing and analysis of algorithms and data structures, knowledge of fundamental notions of probability and statistics, and programming skills in Java or Python.
**Short program:**
The course will cover the following topics:
Introduction to the Big Data phenomenon
Programming frameworks: MapReduce/Hadoop, Spark
Clustering
Association Analysis
Graph Analytics (metriche di centralità, scale-free/Power-law graphs, fenomeno dello small world, uncertain graphs)
Similarity and diversity search
**Examination:**
The exam consists of a number of programming homeworks, assigned approximately every 2-3 weeks and to be carried out in groups of 3-4 students, and of an individual written test comprising both theory questions and exercises.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP7079297/N0

## BIOINFORMATICS

Master degree in **Computer Science**, First semester
Lecturer: Mauro Conti
Credits: 6 ECTS
**Prerequisites:**
There are no particular prerequisites other than what it is expected from a master student in informatics.However, a basic knowledge of genetics and molecular biology will help in the understanding of the biological motivations of bioinformatics.
The course is in English, therefore the students should have a reasonable command of spoken and written English.
**Short program:**
This is a six credits course: five credits will be from lessons while one credit will be from practical activities, either the implementation and of some algorithm or the in-depth investigation of the literature on given arguments.
The lessons are divided in three main parts.
The first part is an extensive introduction on Biology presented as a scientific field centered on Information. The mechanisms that facilitate the transmission and evolution of biological information is used to introduce some biological problems that require computational approaches and bioinformatics tools.
The second part of the course describes the main algorithms used for the alignment of biological sequences, including those designed for "next generation sequencing". The algorithms used for de novo genomic assembly are also described.
Finally, the third part of the course covers several aspects of bioinformatics related to functional genomics, such as the analysis of transcription, gene prediction and annotation, the search of patterns and motifs and the prediction of protein structures. The role of Bioinformatics in individual genomic analysis and personalized medicine is also discussed.
**Examination:**
The exam will be articulated into three parts: 1) a practical session in which the student must describe a project of data analysis, that must be submitted at least two days before the date of the exam, 2) a quiz session on Moodle, that will take place at the beginning of the exam day, 3) an oral discussion in which the student must describe his/her project and answer questions on the topics of the course. A continuous process of assessment will be carried out throughout the course, to verify the level of understanding of the students.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SC06100856/N0

## COMPUTER AND NETWORK SECURITY

Master degree in **Computer Science**, First semester
Lecturer: Giorgio Valle
Credits: 6 ECTS
**Prerequisites:**
No strict prerequisites on previous exams.
However, it is suggested to have basic knowledge of networking, cryptography, and distributed systems (typically acquired in BSc degrees in Computer Science).
**Short program:**
Theory: RFID security, captcha, untrusted storage, smartphone security, attacks on smartphone, password protection, distributed Denial of Service attacks, deep learning, behavioural biometrics, VoIP security, secure content delivery, anonymous communications, keyloggers detection, anonymity in WSN, botnet detection, trusted HW, security of RFID ePassports, node replication attack in WSN, secure data aggregation in WSN, privacy issues in social networks, Google Android smartphone security, electronic voting, P2P botNet detection, taint mechanisms, browser security, privacy of location based services, Named Data Networking security, Named Data Networking privacy, cloud security, anonymity in wireless

network, smartphone user profiling, SSL security issues in Android, circumvent censorship, secure messaging, operational technology security, cyber-physical systems security Laboratory: advanced security tools, including: traffic analysis with machine learning tools, data inference, Android security tools, advanced analysis of malware systems and advanced persistent threat; web security; social network analysis tools, trusted platform modules.

**Examination:**

Project with written essay + oral exam.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP6076342/N0

## CRYPTOGRAPHY (OFFERED IN THE MASTER DEGREE IN MATHEMATICS)

Master degree in **Computer Science**, First semester
Lecturer: Alessandro Languasco
Credits: 6 ECTS

**Prerequisites:**

The topics of the following courses: Algebra (congruences, groups and cyclic groups, finite fields), Calculus (differential and integral calculus, numerical series) both for the BA in Mathematics.

**Short program:**

First Part: Basic theoretical facts: Modular arithmetic. Prime numbers. Little Fermat theorem. Chinese remainder theorem. Finite fields: order of an element and primitive roots. Pseudoprimality tests. Agrawal-Kayal-Saxena's test. RSA method: first description, attacks. Rabin's method and its connection with the integer factorization. Discrete logarithm methods. How to compute the discrete log in a finite field. Elementary factorization methods. Some remarks on Pomerance's quadratic sieve.

Second Part: Protocols and algorithms. Fundamental crypto algorithms. Symmetric methods (historical ones, DES, AES) . Asymmetric methods. Attacks. Digital signature. Pseudorandom generators (remarks). Key exchange, Key exchange in three steps, secret splitting, secret sharing, secret broadcasting, timestamping. Signatures with RSA and discrete log.

**Examination**:

Written exam

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SC04111836/N0

## DATA MINING

Master degree in **Computer Science**, Second semester
Lecturer: Annamaria Guolo
Credits: 6 ECTS

**Prerequisites:**

Basic knowledge of Computer science, Databases. Basic knowledge of Probability and Statistics is useful although not essential.

**Short program:**

- Introduction to the course: Data analysis as a tool for decision support. Motivations and context for data mining.
- Simple linear and multiple linear regression model: estimation, confidence intervals, hypothesis test, p-value, prediction, model selection, residual analysis, spurious correlation, multicollinearity
- Classification methods: logistic regression, linear discriminant analysis and extensions
- Model selection criteria: cross-validation, adjusted R2, AIC, BIC, automatic selection
- Regularisation: ridge regression and lasso
- Principal components regression

- Semiparametric regression: regression splines, smoothing splines, generalized additive models

**Examination**:

The examination is composed by two parts.

1) The first part is a written examination (1 hour) about linear regression models and it includes questions with multiple choices and exercises. The exercises regard the analysis of a real dataset, including numerical evaluations, interpretation of results from R and comments on graphical outputs. The first part of the examination will take place after the middle of the course.

During the written examination the use of a pocket calculator is allowed.

2) The second part is a practical examination carried out in laboratory (2 hours and 30 minutes) and it is constituted by the analysis of a real data set using R. The student is required to write a report describing the data analysis performed, including the most relevant graphical analyses and model estimation and an appropriate interpretation of the results.

During the practical examination students are allowed to bring with them and consult a copy of the textbook, the slides of the course, the laboratory notes.

The final evaluation will be the mean of the results from the two parts.

Students who do not take the first assessment in the middle of the course will have a written examination immediately after the practical final examination.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SC01111799/N0

## DEEP LEARNING

Master degree in **Computer Science**, Second semester

Lecturer: Alessandro Sperduti

Credits: 6 ECTS

**Prerequisites:**

It is advisable to have the basic knowledge related to Probability, Programming, and Algorithms.

**Short program:**

The topics covered in the course are as follows:

- Introduction to the course contents;
- Deep Feedforward Networks;
- Regularization for Deep Learning;
- Optimization for training Deep Models;
- Basic concepts for Convolutional Neural Networks;
- Recurrent Neural Networks for sequence modelling;
- Autoencoder
- Deep Generative Models;
- TensorFlow.

**Examination**:

The student must pass a written exam. In addition, the student must develop a notebook agreed with the teacher.

**More information:**

https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP9087561/N0

## FUNCTIONAL LANGUAGES

Master degree in **Computer Science**, First semester

Lecturer: Gilberto Filè

Credits: 6 ECTS

**Prerequisites:**

Imperative and object oriented programmino
**Short program:**
The course introduced the functional language Haskell. In particular the following aspects are studied:
Pattern matching.
Curryfied and higher-order functions.
Type inference: what it is and how it is done.
I/O.
Parametric polymorphism.
Lazy evaluation.
Functors, applied functors and monads.
Run-time support.
Parsing with Monads
**Examination**:
The exam has a written and an oral part. The written part counts for 80% of the final grade and concerns the concepts and exercises studied during the course. The oral part is a discussion about the project that consists of a parser for a functional language.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP6076299/N0

**GAME THEORY**
Master degree in **Computer Science**, First semester
Lecturer: Gilberto Filè
Credits: 6 ECTS
**Prerequisites:**
A course, even a basic one, on probability theory.
**Short program:**
Basic concepts of game theory
Utility, market, discount factor
Static games in normal form
Dominance, Nash equilibrium
Efficiency, price of anarchy
Zero-sum games, minmax games
Mixed strategies, mixed equilibria
Nash theorem, minmax theorem
The tragedy of the commons

Dynamic games
Strategy and subgames
Backward utility
Stackelberg equilibria
Repeated games and cooperation
Dynamic duopolies, collusion
Cooperation, pricing
Imperfect/incomplete information
Bayesian games, signaling, beliefs
Revelation principle

Axiomatic game theory
Fictitious play
Best response dynamics
Distributed optimization

Algorithmic game theory
Computation, complexity, and completeness of equilibria
Auctions, bargaining
First-price and second-price auctions
VCG principle
Cooperative games: the core, the Shapley value

Resource allocation
Utilities, choices, and paradoxes
Potential games, coordination
Bio-inspired algorithms
Evolutionary games
Cognitive networks
Selfish routing
Game-theory enabled multiple-input systems

**Examination**:
For the students of engineering programs with regular attendance to the course (differently from other kinds of students), the exam involves the development of a project in 1-3 person groups, on course-related topics applied to ICT. This is agreed half-way through the course together with the lecturer.

For all the students, in any event the exam also includes a mandatory open-book written test, containing four problems of game theory focusing on different topics of the course. Every exercise involves three questions.

For engineering students with regular attendance to the course, the written test is limited to solving three exercises out of four. For the other students (non-engineering students or students without regular attendance), the written test involves all of the four exercises.

If the written test is sufficient, non-engineering students or students without regular attendance can directly finalize the passing score. Engineering students with regular attendance instead discuss their project with an oral exam after the written test. Oral exams are scheduled in the same day of written tests (even though students can decide to give the two parts on separate days). Both the written test and the oral exam must be sufficient to pass.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP7079401/N0

## MATHEMATICAL MODELS AND NUMERICAL METHODS FOR BIG DATA (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN DATA SCIENCE)

Master degree in **Computer Science**, First semester
Lecturer: DA DEFINIRE
Credits: 6 ECTS

**Prerequisites:**
Background on Matrix Theory: Type of matrices: Diagonal, Symmetric, Normal, Positive De nite; Matrix canonical forms: Diagonal, Schur; Matrix spectrum: Kernel, Range, Eigenvalues, Eigenvectors and Eigenspaces Matrix Factorizations: LU, Cholesky, QR, SVD

**Short program:**
Numerical methods for large linear systems
◦ Jacobi and Gauss-Seidel methods ◦ Subspace projection (Krylov) methods ◦ Arnoldi method for linear systems (FOM) ◦ (Optional) Sketches of GMRES ◦ Preconditioning: Sparse and incomplete matrix factorizations

Numerical methods for large eigenvalue problems
◦ The power method ◦ Subspace Iterations ◦ Krylov-type methods: Arnoldi (and sketches of Lanczos + Non-Hermitian Lanczos) ◦ (Optional) Sketches of their block implementation ◦ Singular values VS Eigenvalues ◦ Best rank-k approximation
Large scale numerical optimization
◦ Steepest descent and Newton's methods ◦ Quasi Newton methods: BFGS ◦ Stochastic steepest descent ◦ Sketches of inexact Newton methods ◦ Sketches Limited memory quasi Newton method
Network centrality
◦ Perron-Frobenius theorem ◦ Centrality based on eigenvectors (HITS and Pagerank◦) Centrality based on matrix functions
Data and network clustering
◦ K-Means algorithm◦ Principal component analysis and dimensionality reduction ◦ Laplacian matrices, Cheeger constant, nodal domains◦ Spectral em bedding ◦ (Optional) Lovasz extension, exact relaxations, nonlinear power method (sketches)
Supervised learning
◦ Linear regression ◦ Logistic regression ◦ Multiclass classi cation ◦ (Optional) Neural networks (sketches)

**Examination**:
Written exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP7079406/N0

## METHODS AND MODELS FOR COMBINATORIAL OPTIMIZATION

Master degree in **Computer Science**, First semester
Lecturer: Luigi De Giovanni
Credits: 6 ECTS
**Prerequisites:**
Basic notions of Operations Research, Linear Programming, and computer programming.
**Short program:**
1. Advanced linear programming and duality with applications: primal-dual simplex, column generation, applications to network
optimization.
2. Advanced methods for Integer Linear Programming (ILP): Branch & Bound and relaxation techniques, alternative ILP formulations,
cutting planes method and Branch & Cut, application to relevant examples (Traveling Salesman Problem, location, network design etc.).
3. Meta-heuristics for combinatorial optimization: local search based, evolutionary algorithms.
4. Application of graph modeling and optimization.
5. Labs: optimization software packages and libraries.

**Examination**:
Oral examination about course contents and exercises on the application of optimization methods to solve realistic problems. Each student may chose to present a short project concerning a case study about models and exact/heuristic solution methods for a realistic application of combinatorial optimization.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SC01122975/N0

## PROCESS MINING (OFFERED IN THE MASTER DEGREE IN DATA SCIENCE)

Master degree in **Computer Science**, First semester
Lecturer: DA DEFINIRE

Credits: 6 ECTS
**Prerequisites:**
Basic notions of algorithms, data structures and programming.
**Short program:**
The course will cover the topics listed below:

1. MODELING AND ANALISYS: THE BPMN PERSPECTIVE
- Process Identification
- Essential and Advanced Process Modeling in BPMN
- Qualitative Analysis
- Quantitative Analysis
- Process redesign

2. MODELING AND ANALISYS: THE PETRI NET PERSPECTIVE
- An introduction to Petri Nets
- Petri nets and colored petri nets
- Simulation based analysis
- Reachability and coverability analysis
- Process modeling and analysis with PN

3. PROCESS MINING
- Data & Process mining
- Getting the data: the construction of event logs
- An introduction to Process discovery
- Advanced process discovery
- Conformance checking - replay based
- Conformance checking - logic based
- Mining additional perspectives
- Typical use cases, e.g., medical processes

4. DECLARATIVE APPROACHES
- Declarative approaches and Declare
- Declarative process mining (discovery in Declare) and hybrid approaches

5. PREDICTIVE PROCESS MONITORING
- Basic Predictive Process Monitoring techniques
- Advanced Predictive Process Monitoring techniques

**Examination**:
Written exam and project. The project is due and has to be discussed by the end of the course.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP7079235/N0

## STRUCTURAL BIOINFORMATICS

Master degree in **Computer Science**, Second semester
Lecturer: Damiano Piovesan
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge of optimization methods and machine learning. Python programming language.
**Short program:**
The course consists of two parts:
1) Introduction to living matter (2 credits):

1.1) Introduction to organic chemistry, weak interactions and energy
1.2) Structure and function of DNA and proteins
1.3) Lipids, membranes and cellular transport
1.4) Experimental methods for structure determination
2) Computational Biochemistry (4 credits):
2.1) Biological Databases
2.2) Software libraries and concepts for sequence alignments and database searches
2.3) Sequence - structure relationship in proteins and structural classification
2.4) Methods for the prediction of protein structure from sequence, the CASP experiment
2.5) Methods for the prediction of protein function and interactions, the CAFA experiment
2.6) Non-globular proteins, disorder and structural repeats

**Examination**:
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis)
1) Written test of the biochemistry concepts (ca. 30%)
2) Software project (ca. 40%)
3) Project presentation and critical evaluation (ca. 30%)

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP7079278/N0

## VISION AND COGNITIVE SERVICES

Master degree in **Computer Science**, Second semester
Lecturer: Lamberto Ballan
Credits: 6 ECTS

**Prerequisites:**
The student should have basic knowledge of programming and algorithms. It is also advisable to be familiar with basic concepts in probability and analysis of multivariate functions.

**Short program:**
The course will cover the topics listed below:
- Introduction:
From human cognition to machine intelligence and cognitive systems; brief intro to artificial intelligence, cognitive computing and machine learning; the AI revolution: current trends and applications, major challenges.
- Cognitive Services:
Basic concepts; Language, Speech, and Vision services; major providers and APIs (IBM Watson, AWS, Google Cloud); enabling technologies.
- Machine Learning and applications:
Classification; intro to deep learning and representation learning; training and testing; evaluation measures; algorithm bias.
- Early Vision and Image Processing:
Machine perception; image formation, sampling, filtering and linear operators; image gradients, edges, corners; designing effective visual features (SIFT and gradient based features); image matching.
- Visual Recognition and beyond:
"Teaching computers to see": bag-of-features, spatial pyramids and pooling; representation learning in computer vision, convolutional neural networks; R-CNN and segmentation; image captioning, multi-modal scenarios and beyond the fully-supervised learning paradigm.
- Hands-on Practicals:
What's in the box? How to build a visual recognition pipeline; using cognitive services for image recognition/understanding; combining different services and modalities.

**Examination**:

The student is expected to develop, in agreement with the teacher, a small applicative project. In addition, the student must submit a written report on the project, addressing in a critical fashion all the issues dealt with during its development. During the exam students are asked to present and discuss their project and answer to a few questions about the topics addressed in class.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP9087563/N0

**WIRELESS NETWORKS**
Master degree in **Computer Science**, First semester
Lecturer: Claudio Enrico Palazzi
Credits: 6 ECTS
**Prerequisites:**
Computer Networks.
**Short program:**
Introduction to Wireless Networks.
Wireless network issues: error and collision losses, fairness and transmission delays, handoffs.
MAC layer standards: 802.11 a/b/g/n/p/s
Transport protocols in wireless environments: TCP Vegas, TCP Westwood, TCP Hybla, CUBIC.
Ad hoc networks and routing protocols: MANET, VANET, DSDV, AODV, DSR.
Applications and services on mobile networks.
**Examination**:
Students are evaluated through individual/team projects and oral finals focused on all the topics discussed in class.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1176/2014/000ZZ/SCP6076377/N0

**EVOLUTIONARY BIOLOGY**
**ETHOLOGY**
Master degree in **Evolutionary Biology**, First semester
Lecturer: Andrea Augusto Pilastro
Credits: 6 ECTS
**Prerequisites:**
Good knowledge in evolutionary biology, ecology, genetics, and zoology (advanced undergraduate course level)
**Short program:**
Main topics will regard the link between animal behavior ecology and evolution, the development and control of behaviour: genes environment and neural mechanisms, the evolution of animal signals, adaptive responses to predators, foraging behaviour and optimality models, reproductive behaviour: male and female tactics, mating systems, parental care, sperm competition and sexual selection, sexual conflict, social behavior, kin selection.
**Examination**:
Written test (multiple choice questions, open questions)
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1179/2018/000ZZ/SCN1031442/N0

**EVOLUTION AND CONSERVATION**
Master degree in **Evolutionary Biology**, First semester
Lecturer: Andrea Augusto Pilastro
Credits: 6 ECTS
**Prerequisites**:

Good knowledge in evolutionary biology, ecology, genetics, zoology and botany (advanced undergraduate course level)
**Short program:**
Lectures will be in English.
While evolutionary biology has important theoretical and practical implications in conservation, it has often been neglected. The reason for this probably originates from the mistaken belief that evolution acts too slowly to be relevant on an ecological time scale. In this course we will combine the fields of evolutionary and conservation biology to emphasize the importance of evolutionary theories in conservation programs. This course will therefore focus on genetic and evolutionary applications to the problems of conservation, while reflecting the diversity of concerns that are relevant to conservation biology. Particular emphasis will be put on themes like measures of phylogenetic diversity and uniqueness, population genetic structure of natural and managed populations including the identification of `evolutionary significant units' and `management units' for conservation, assessment of levels of genetic variation within species and populations, assessments of the effect of sexual selection mate choice and reproductive strategy on population conservation, forensic applications, methods for maximising genetic diversity during captive breeding programs and re-introduction schemes, effect of anthropogenic factors on evolutionary adaptation to local changes in the environment.
**Examination**:
Evaluation based on written exam. Oral test possible if required by the student (please contact the teacher in advance).
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1179/2018/000ZZ/SCO2043741/N0

**PHILOSOPHY OF BIOLOGICAL SCIENCES**
Master degree in **Evolutionary Biology**, First semester
Lecturer: Dietelmo Pievani
Credits: 8 ECTS
**Prerequisites**:
Prior knowledge needed for the classes in Philosophy of Biological Sciences is that normally provided for students at the third year of the first degree (mainly in Biology, but not only). Particularly, the basic understanding of Evolutionary Biology, in its fundamental principles and processes, is required. Students should also have sufficient and basic capacities for argumentation and expression, enabling them to defend a thesis and grasp the contents of a scientific debate, actively participating in the discussion of case-studies. The classes (in English) are primarily intended for students from the Department of Biology, but the involvement of students from other careers, such as particularly Philosophy and History, is not precluded. The construction of a heterogeneous class of students every year is indeed an asset, given the interactive teaching provided in the classes. Class attendance is mandatory due to the interactive nature of lessons.
**Short program:**
The course aims at deepening the fundamental concepts, principles and analytical methods of the philosophy of biology, according to current International debates, namely: types of explanation and inferences in biological sciences; notions of theory, hypothesis, empirical basis, model, falsifiability, parsimony, prediction; biological terminology; biological ontology; selection of models and probability; research protocols; logic of scientific discovery in life sciences; scientific controversies; defensive and argumentative strategies. These general objectives are addressed through critical discussion of case-studies - both historical and taken from primary scientific literature - in particular about Evolutionary Biology and the structure of evolutionary theory.
The general themes in philosophy of life science will also be developed through the analysis of

the logic of scientific discovery in Charles Darwin's work, extrapolated from his unpublished private texts, such as the Notebooks of Transmutation, and the working papers that led to the peculiar argumentative structure of the Origin of Species in its six editions. Darwin's thoughts, assumptions and insights, in their typical theoretical pluralism, will become another starting point to discuss evolutionary issues debated in the scientific literature today. Among the others:
- Notions of "species";
- Tempo and mode of speciation (gradualism and punctuationism);
- Variation and inheritance;
- Genetics and epigenetics;
- Evolution, ecology and biogeography;
- Functional factors and structural factors (adaptations and constraints) in evolutionary change;
- Common descent (Tree Thinking) and natural selection;
- Explanatory power of selective mechanisms;
- Units of evolution and levels of selection (the debate about the evolution of altruism);
- Relationships between ontogeny and phylogeny;
- The role of "chance" in evolution;
- Teleology and contingency;
- Darwin's risky predictions;
- Extended Evolutionary Synthesis.

**Examination**:
Examination is oral and aims at the evaluation of both scientific and philosophical skills acquired, through open-ended questions and requests for argumentation and comparison of different theses and models. The examination (in Italian or in English) is divided into a common part and a monographic part. The common part includes textbooks, books and articles that provide a general overview of the contents of the discipline. The examination also provides the monographic choice, by the students, of one of the cases discussed during the classes, on which a specific study with further bibliography (usually two chapters of books or additional papers) is required. Attendance is mandatory, due to the teaching by interactive methods and case-studies. Students unable to attend a percentage of classes (anyway no more than 50%) have to agree the attendance with the teacher.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1179/2018/000ZZ/SCP3054388/N0

**GEOLOGY AND TECHNICAL GEOLOGY**

**APPLIED GEOCHEMISTRY**

Master degree in **Geology and technical Geology** , First semester
Lecturer: Christine Marie Meyzen
Credits: 6 ECTS

**Prerequisites:**
All students must have a solid understanding of basic principles in chemistry, geology, mineralogy, igneous and metamorphic petrology.

**Short program:**
Isotope geochemistry plays an increasingly important role in a wide variety of geological, environmental, medical, forensic and archeological investigations. Isotope methods allow to determine the age of the Earth, reconstruct the climate of the past, detect adulterated foods and beverages, detect and monitor the progress of diseases in human and explain the formation of the chemical elements in the universe. This course is designed to provide an introduction to the principles and applications of isotope geochemistry. Systems discussed include the classic radiogenic systems (Rb-Sr, Sm-Nd, Lu-Hf and U-Th-Pb), traditional stable isotope systems (e.g. H and O) and extinct radioactivities. Applications as chronometers or

tracers will be focused on a wide range of topics ranging from processes and timescales relevant to the formation of the planet and solar system, the evolution of the Earth system to environmental issues.
COURSE CONTENT:
1.Introduction
2.Nuclear physics and nuclear stability
3.Radioactivity
4.Nucleosynthesis: when, where and how chemical elements are formed?
5.Principles of stable isotope geochemistry
6.Mass-balance calculations
7.Tracing the hydrologic cycle with stable isotopes
8.Radioactive decay and geochronometry
9.The Rb-Sr method
10.The Sm-Nd method
11.The Lu-Hf method
12.The U-Pb, Th-Pb and Pb-Pb methods
**Examination**:
Course learning goals will be assessed by written examinations.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP5070181/N0

## APPLIED PETROGRAPHY
Master degree in **Geology and technical Geology** , First semester
Lecturer: Claudio Mazzoli
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge in petrology, geochemistry and mineralogy
**Short program:**
This course examines in depth application aspects of petrography with reference to the following arguments: physical-chemical properties and decay of natural ornamental and dimension stones; traditional ceramic materials; hydraulic and non-hydraulic binders; applications to archaeometry.
In particular, the course deals with the application of petrographic methods to the study of ornamental and dimension stones, ceramic materials and artificial building materials. This course is therefore organised in the following parts:
1. Ornamental and dimension stones: quarrying activity, properties, durability; ageing and quality control for dimension stones; physical-mechanical properties; determination of compressive, flexural, tensile and shear strength; abrasion resistance, water absorption, etc. Decay of stone, description of alteration. Stone restoration: cleaning, strengthening, waterproofing.
2. Ceramic materials: traditional ceramic materials and archaeometric investigations. Reference groups, recognition of the source area for the raw materials or the production.
3. Non-hydraulic and hydraulic binders: mortar, plaster, gypsum, cement, aggregate, pigments.
4. Analytical methods for archaeometry and age determination in artefacts.
**Examination**:
Oral test.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP3051232/N0

## APPLIED SEDIMENTARY GEOLOGY
Master degree in **Geology and technical Geology**, First semester

Lecturer: Massimiliano Ghinassi
Credits: 6 ECTS
**Prerequisites:**
asic concepts of geology (structural geology, geodynamic settings, lithology (different types of rocks) and geomorphology (geomorphic configuration of the main depositional environments). Complete view of the main geological processes and main basics of geology, geomorphology, sedimentary geology and paleontology. Comprehensive knowledge of sedimentology (depositional dynamics and stratal architecture of different depositional environments), lithology and sedimentary petrography (sedimentary rocks and sediments, optical microscope analyses), paleoecology and biostratigraphy (fossil determination and biostratigraphic meaning), carbonate petrography and geochemistry (biomineralizations, geochemetry of stable isotopes)
**Short program:**
The course will be based on a multidisciplinary approach and will be developed on the analyses of data collected in the frame of a 3-days excursion, which will be held within the first two weeks of the course.
Content of the course will be as follows:
Introduction to the main geomorphological, geological and stratigraphic features of the selected study area (credits 0.25)
Introduction to the research program (goal of the study and schedule) and summary of the main research methodologies (credits 0.5)
Field activities and data collection (credit 1)
Sedimentology (credit 1): facies analyses and reconstruction of depositional dynamics, architectural analyses and definition of 3D sedimentary bodies, summary
Sedimentary petrography (credit 1): sediment characterization, provenance analyses, summary
Paleoecology and biostratigraphy (credit 1): determination of fossil content, biostratigraphy and ecobiostratigraphy, paleoenvironmental reconstruction, summary
Carbonate petrography and geochemistry (credit 1): biomineralizations, sclerochronology, trace elements and stable isotope geochemistry, summary
Integration of the acquired datasets and final summary (credits 0.25)
**Examination**:
Witten test. The test will be based on interpretation and elaboration (written report) of specific datasets, which will be provided consistently with the topics of the course.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP8083422/N0

## BASIN ANALYSIS

Master degree in **Geology and technical Geology**, Second semester
Lecturer: Massimiliano Zattin
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge of some courses of the first semester (Applied geophysics, Micropaleontology, Applied geochemistry)
**Short program:**
1) The foundations of sedimentary basins; classification and plate tectonics.
2) Basins due to lithospheric stretching: rifts and passive margins.
3) Basins due to lithospheric flexure: foredeep, foreland, buckling.
4) Dynamic topography.
5) Strike-slip and pull-apart basins.
6) Subsidence and thermal history.
7) Appication to petroleum industry.

8) Seismic reflection basics.
9) Geometric characterization of seismic reflectors and seismic facies; seismic surfaces; seismic sequences and units.
10) Seismic interpretation of rifting, passive margin and foreland settings.
11) Sequence stratigraphy applied to seismic interpretation.

**Examination**:
The exam is divided into two parts. Evaluation of the first one (chapters 1-7, see below) is provided by a written examination with open questions. Chapters 8-11 are evaluated through a practical test (i.e. interpretation of a seismic line). The student is asked to give a geological interpretation that includes the main deformation events and the type of sedimentary basin.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP3051165/N0

## CARBONATE SEDIMENTOLOGY

Master degree in **Geology and technical Geology**, First semester
Lecturer: Nereo Preto
Credits: 6 ECTS

**Prerequisites:**
Knowledges of sedimentary geology and clastic sedimentology; base notions of chemistry. Having taken, or being taking "Sedimentology" is recommended.

**Short program:**
- Te carbon cycle in the oceans, and some notions of physical oceanography;
- the precipitation of carbonates as a chemical and biological process;
- origin of carbonate platforms and deep-water carbonates;
- types of carbonate platforms, their depositional architectures, and their dynamic stratigraphy;
- diagenesis of carbonates and reconstruction of diagenetic histories;
- dolomitization processes;
- sequence stratigraphy of carbonates.

**Examination**:
The marking is based on two documents: a mid-term report based on class excercises and a final exam.
The report is the interpretation of a carbonate depositional system, presented as a idealized geological cross section of a carbonate platform, which is being studied during the course.
The final exam is a written test, which requires to answer briefly, with a short text or with geological sketches, to open questions.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP5070180/N0

## GEOLOGY AND EXPLORATION OF PLANETARY BODIES

Master degree in **Geology and technical Geology**, First semester
Lecturer: Matteo Massironi
Credits: 6 ECTS

**Prerequisites:**

**Short program:**
Course contents:
- Physical parameters of the terrestrial planets
- Impact cratering
- Crate Chronology- Classification of the Meteorites
- Moon: topography, internal structure, tectonic and cratering features, basin related tectonism, surface deposits and geological units, origin and evolution, water on the Moon
- Mercury: physiographic provinces and geological units, internal structure, tectonic and

volcanic features, cratering, surface composition and volatiles, origin and evolution.
- Venus: topography, tectonism and volcanism, evolution.
- Mars: topography, internal structure, tectonism and volcanism, water and water related morphologies, surface evolution.
- Geology, structure and composition of comets and asteroids
- Geology of the Medicean satellites
- Planetary space mission and related payloads

**Examination**:
Oral examination will be related to the geology of the solar system bodies, space missions and payload dedicated to the explorations of planetary bodies

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP8085501/N0

## MICROPALEONTOLOGY

Master degree in **Geology and technical Geology**, First semester
Lecturer: Claudia Agnini
Credits: 6 ECTS

**Prerequisites:**
Basic of Stratigraphy and Paleontology

**Short program:**
The course can be subdivided in three main parts:
- History of micropaleontology and its position in the context of the geological sciences. Its developments and the importance of deep-sea drilling projects. (0.5 CFU)
- "Pure" micropaleontology. An overview of the various microfossil groups of botanical and zoological origin, that are widely used both in academic research and oil and gas industry, by presenting their morphology, taxonomy, mode of life, environments and stratigraphic distribution. In this context, preparation- and research techniques of main microfossil groups and their geological importance in terms of dating, correlation, facies interpretation, paleoenviromental and paleoclimaticreconstruction is introduced to the students. (3.5 CFU)
- practical microscope exercitations on micropaleontological samples which contain the main microfossil groups presented in the general theoretical part (e.g., calcareous nannofossils, foraminifera, radiolarians, diatoms, ….). A daily field excursion is also proposed (2 CFU).

**Examination**:
The knowledge acquired during the course is checked by means of
-a practical test in which the students analyse a micropaleontological sample.
-an oral examination during which the concepts, the scientific terminology, the syntesis ability and the critical spririt are evaluated.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP7077717/N0

## MORPHODYNAMICS OF LAGOONS, DELTAS AND ESTUARIES UNDER CLIMATE CHANGE

Master degree in **Geology and technical Geology**, First semester
Lecturer: Andrea D'Alpaos
Credits: 6 ECTS

**Prerequisites:**
Basic mathematics and physics (Calculus 1 and 2, Experimental Physics).

**Short program:**
- Morphodynamics and biogemorphodynamics. Short introduction to coastal systems and to their morphodynamic evolution in response to physical and biological forcings (0.5 credits).
- Relative sea level and its variations. Tides, waves, currrents, and sediment transport processes in shallow water systems (1.5 credits)..
- Morphology and evolution of lagoons, deltas, and estuaries (2.5 credits).

- A case study: The Venice Lagoon and its morphological evolution during the past centuries. Will Venice survive? (0.5 credits).
- General effects of a rising sea level. Natural and anthropogenic forcings. Effects of a changing climate. Effects on lagoons, deltas, and estuaries (1.0 credit).

**Examination**:
Written and oral exam.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP3051173/N0

## NUMERICAL MODELING IN GEOSCIENCES

Master degree in **Geology and technical Geology**, First semester
Lecturer: Manuele Faccenda
Credits: 6 ECTS

**Prerequisites:**
Basic knowledge of mathematics, physics and MatLab (provided during the Laurea Triennale)

**Short program:**
1. Mathematical basis for partial differential equations (derivatives, gradient, divergency, laplacian operator)
2. Rock physical properties (viscosity, elastic moduli, cohesion and friction coefficient, density, thermal conductivity and diffusivity, heat capacity)
3. Thermal, chemical, hillslope and fluid overpressure diffusion equations
4. Stress, strain and strain rate tensors and constitutive relationships.
5. Visco-elasto-plastic deformation
6. Conservation of mass
7. Conservation of momentum
8. Conservation of energy
9. Numerical method: finite difference with particle-in-cell (mixed Eulerian-Lagrangian scheme)
10. Solution of systems of equation with iterative (Gauss-Siedel) ir direct (Gauss elimination) methods.

**Examination:**
Oral and practical test.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP4065499/N0

## PETROLEUM GEOLOGY

Master degree in **Geology and technical Geology**, Second semester
Lecturer: Massimiliano Zattin
Credits: 6 ECTS

**Prerequisites:**
Basic knowledge of some courses of the first semester (Sedimentology, Applied geophysics, Micropaleontology, Applied geochemistry)

**Short program:**
The course will delivery the key-concepts of petroleum geology and is integrated by seminars on specific topics (to be defined during the semester).
- The origin of petroluem; physico-chemical properties of hydrocarbons (0.5 CFU)
- The source rock, maturity of organic matter and petroleum migration (1 CFU)
- The seal rock (0.5 CFU)
- Reservoir geology, stratigraphic traps, structural traps (2 CFU)
- Main exploration and production techniques (1 CFU)
- Hydrocarbon reserves in Italy and in the World (1 CFU)

**Examination**:
Written examination with essay questions.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP3051098/N0

## PETROLOGY

Master degree in **Geology and technical Geology**, First semester
Lecturer: Bernardo Cesare
Credits: 6 ECTS
**Prerequisites:**
In order to take full advantage of the course and be able to fully follow the classes the student will already have basic knowledge of petrography, geochemistry and mineralogy, as well as of english.
**Short program:**
Focusing on the metapelitic system, and through extensive practice at the microscopic laboratory, the course will provide deep insight into the main aspects of metamorphic petrology, such as:
-metamorphic classification;
-equilibrium assemblages; metamorphic facies;
-chemographies and other graphical representations;
-metamorphic reactions and equilibria;
-thermodynamics applied to phase equilibria modelling;
-role of fluids in metamorphism, fluid inclusions;
-geothermobarometry and phase equilibria calculations;
-metamorphism of pelites;
-contact metamorphism; crustal anatexis;
-microstructures of anatectic rocks;
-melt inclusions in migmatites and granulites.
**Examination**:
The acquired knowledges and skills will be assessed through an oral examination in english
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP8085500/N0

## SEDIMENTOLOGY

Master degree in **Geology and technical Geology**, Second semester
Lecturer: Massimiliano Ghinassi
Credits: 6 ECTS
**Prerequisites:**
Basic concepts of geology (structural geology, geodynamic settings, lithology (different types of rocks) and geomorphology (geomorphic configuration of the main depositional environments)
Basic knowledge concerning sedimentology (textural features of the main types of sediments and sedimentary rocks) and stratigraphy (temporal and spatial variability of depositional systems)
**Short program:**
Introduction to Sedimentology (credits: 0.2)
- facies and facies associations
- textural features of sediments, stratal geometries and terminology
Sediment transport/deposition and post-depositional modifications (credits: 1.8)
- tractional transport from unidirectional currents
- tractional transport from oscillatory currents
- mass transport

- soft-sediment deformations
- icnofossils

Depositional environment (credits: 2.5)
- continental depositional environments (alluvial fan, fluvial, lacustrine, eolian)
- coastal depositional environment (wave-dominated coasts, deltas, tidal flats/lagoons )
- deep marine depositional environment (turbidites, conturites)

Sequence stratigraphy (credits: 0.5)
- base level and accommodation space
- systems tracts
- sequences
- incised valleys
- non-marine sequence stratigraphy

**Examination**:
The knowledge concerning the three main topics (processes of sediment transport, depositional environment, sequence stratigraphy) treated during the course will be evaluated. Skill of students in describing and interpret specific deposits or sedimentary succession will be evaluated. The syntax and clarity of the written text will be also considered.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1180/2009/000ZZ/SCP3051016/N0

**INDUSTRIAL BIOTECHNOLOGY**

**ENVIRONMENTAL BIOTECHNOLOGY AND BIOENERGY PRODUCTION**

Master degree in **Industrial Biotechnology**, First semester
Lecturer: Fiorella Lo Schiavo
Credits: 8 ECTS

**Prerequisites:**
No specific prerequisites. Students should have a general background in basics of plant biology and biotechnology

**Short program:**
Environmental Biotechnology:
Responses of Plants To Abiotic Stresses: Stresses involving water deficit, osmotic stress and its role in tolerance to drought and salinity, impact of water deficit and salinity on transport across plant membranes. Freezing stress. Flooding and oxygen deficit. Oxidative stress. Heat/Cold stress.
Plant responses to mineral toxicity: Molecular Physiology of mineral nutrients, acquisition, transport and utilization. Aluminium toxicity, heavy metal ion toxicity (Cd+2, Hg2+, Pb2+).
Phytoremediation approaches to remove soil/water contaminants.
Biotechnologies for Energy production:
Introduction: current energy sources and the necessity of renewable fuels.
Production of bioethanol from ligno-cellulosic biomasses.
Production of biodiesel from oleaginous crops.
Algae as biofuels producers. Evaluation of advantages and disadvantages with respect to plants.
Hydrogen production from algae and bacteria.
The biotechnological challenges for biofuels production: the optimization of conversion of solar into chemical energy.
Examples of genetic engineering for biofuels.
Exploitation of unicellular algae for wastewater treatment and bioremediation.

**Examination:**
the evaluation consists of two parts:
1. presentation and critical analysis of some recent scientific papers.
2. written test on the class contents.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1731/2014/000ZZ/SCO2044108/N0

## ENVIRONMENTAL BIOTECHNOLOGY AND PHYTOREMEDIATION

Master degree in **Industrial Biotechnology**, Second semester
Lecturer: Elide Formentin
Credits: 6 ECTS
**Prerequisites:**
None
**Short program:**
Plant biotechnologies:
- Introduction to environmental stresses with focus on abiotic stresses.
- Introduction to the mechanisms of water and solutes transport through biological membranes.
- Responses of plants to environmental stresses: specifically, the topics of water stress and oxidative stress at the molecular level will be addressed.
- Molecular physiology of mineral nutrients, their absorption, transport and use.
- Toxicity of pollutants and plant responses.
- Genetic improvement for the use of plants for phytoremediation and cultivation in marginal soils.

Phytoremediation:
- Use of plants to decontaminate soil and water by containing, degrading or removing the contaminant.
- Examples of application of phytoremediation techniques.

**Examination:**
The exam is divided into two parts:
1. presentation and critical analysis of some literature works.
2. written exam on the course contents.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1731/2014/000ZZ/SCP9088066/N0

## GENETIC TOXICOLOGY AND ENVIRONMENTAL CHEMISTRY

Master degree in **Industrial Biotechnology**, Second semester
Lecturer: Paola Venier
Credits: 6 ECTS
**Prerequisites:**
Essentials of general, inorganic and organic Chemistry, Biology and Genetics
**Short program**
The following contents will be expanded or reduced according to the student's skills and interests.
Part A (CHIM).
Chemico-physical properties and main descriptors in environmental chemistry. Evaluation of the pollutant distribution in air, water and soil. How chemical speciation affects the distribution of chemicals in the environment and their toxicity. Examples and model study cases (1.25 CFU).
Macro and micro-pollutants of the environment: organic compounds, metals, emerging contaminants. Radionuclides, sources of radioactive contamination. European regulatory aspects. Risk evaluation and management of the main pollutants (1.25 CFU).
Methods for determining main chemical parameters and contaminants. Examples of pollutants and case studies (0.5 CFU).
Part B (BIO).

Variety of toxic agents and possible adverse effects at different levels of biological organization. Toxicokinetics and toxicodynamics (in general). Biological targets, exposure measurements, effect and susceptibility. Dose-response with/without threshold, hormesis. Hazard, risk, harm. Safety/precautionary symbols and regulations. Criteria for the identification of toxic agents, with particular attention to genetic and reproductive toxicity (1.25 CFU).
Effects and responses induced by non-ionizing and ionizing radiations. Dose units. Adaptive response, bystander effect, radio-resistance in cancer cells and in extremophilic microbes. Effects and responses induced by chemical compounds: examples related to pesticides, metals/metalloids, animal/plant toxins (1.25 CFU).
Microbe-mediated bioremediation strategies (0.5 CFU).**Examination:**
The exam will be a verbal interview on Part A (CHIM, 3 CFU) and Part B (BIO, 3 CFU). For Part B, the student will also debate a topic (toxic agent, biological process in terms of function/dysfunction, investigation method) agreed with the teacher during the course and based on the scientific literature. Effective reporting of biotechnological aspects will be positively evaluated.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1731/2014/000ZZ/SCP9088037/N0

## IMMUNOLOGICAL BIOTECHNOLOGY

Master degree in **Industrial Biotechnology**, First semester
Lecturer: Emanuele Papini
Credits: 8 ECTS
**Prerequisites:**
The student must have a good preparation in general Immunology
**Short program:**
- Classic Vaccinology
- Main problems in the development of a vaccine.
- production of recombinant vaccines
- Microbial, animal and plant models for vaccine production.
- Reverse vaccinology: genome based antigen individuation (in silico). Production, quality control.

Main vaccines in pediatric prevention in Italy.
Adjuvants - Mucosal adjuvants - micro-nanosized new generation adjuvants.
- Use of dendritic cells in therapy: perspectives.

Practical part:
Evaluation in vitro of adjuvancy in human dendritic cells. Isolation of monocytes fromm blood, thier differentiation into Dendritic Cells (DCs). Stimulation of DCs with various adjuvants and analysis of cell activation by Elisa (TNFa) and flow cytometry (CD86, CD11), RT-PCR (tnfa gene transcription). Aultologous/heterologous T lymphocytes proliferation and characterisation of their immunological competence by FACS.
**Examination**:
Oral examination plus evaluation of a laboratory activity written report
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1731/2014/000ZZ/SCO2044105/N0

## NANOBIOTECHNOLOGY

Master degree in **Industrial Biotechnology**, First semester
Lecturer: Alessandro Moretto
Credits: 8 ECTS
**Prerequisites:**

Basic background in chemistry and organic chemistry acquired in the previous fundamental courses. Basic knowledge about formation and properties of nanoparticles. Basic background in anatomy/physiology, cell biology and protein biochemistry.
Previous attendance of the "Nanosystems" course (previous semester) is suggested.

**Short program:**

I. Introductory lessons that summarize the general features of nanoassembled systems; these lessons are meant to go over the main contents of the course "Nanosystems", for the benefit of those students who followed it; at the same time, they are meant to provide a basis for those student who do not have it. Outline of the essential features of nano-structured systems. The ideal nanostructure: components. Modified "natural" nanostructures (bacterial Outer Membrane Vescicles, viruses). Engineered nanoparticles: inorganic (silica, gold), organic (nanoformulations, polymers), liposomes and lipidic nanoparticles, quantum dots. Derivatization with small organic molecules (conjugation, orthogonal bioconjugation), with proteins or antibodies for specific cell targeting.

II. Lectures on nano-biomedicine and nanotoxicology. Physio-structural features of living organisms that come primarily into play in the interaction with nanomaterials.

Blood circulation, endothelial cells, renal filter. Reticuloendothelial system (RES): tissue-resident macrophages. Professional phagocytes: PMN, monocytes-macrophages, APCs. Accessibility to tissues and systems: physiological and pathological endothelial permeability (in chronic inflammation, and neoplasms); Permeabilisation Retention Effect (lymphatic system); "Shrines": blood-brain barrier: structure and its alteration. Cellular and humoral responses to nano-materials, toxicology and pharmacokinetic aspects. The chemical basis of the interaction between nanomaterials and biomolecules: multivalency and cooperativity. Acute cytotoxic cell damage. Toxic mechanisms, principles, measurements. Current knowledge on the toxicity of inorganic (silica, gold) and organic (microgels, liposomes, nanotubes, polymers) nanostructures. Uptake-clearance, endocytosis and phagocytosis. Opsonization: plasma opsonins. Complement. Concept of protein crown. Concept of stealth property (or "invisibility") of a nano-structure. PEGylation. Proinflammatory, pro-immune, pro-coagulant activities: cytokines induction, radicals production, leukocyte and endothelial activation. Complement and coagulation cascades induced by macroscopic or nanoscopic bio-materials. Immune reaction. In vitro measurements. Biodegradation and elimination from the body (kidney, bile).

III. Bio-active (transported) portion and applications: drugs, immunostimulants, DNA. Direct action of the nanomaterial, photoactivation, magnetic field activation. Applications: fluorescent biomarking of tissues and cells, in vivo imaging, diagnosis. Drug and gene delivery. Vaccines. Immunological adjuvants. Detection of pathogens. Detection of proteins. Probing the structure of DNA. Tissue engineering.

Hyperthermal therapies. Separation and purification of biological molecules and cells. Contrast agents in magnetic resonance imaging (MRI). Phagokinetic studies.

IV. Laboratory. The practical part will be introduced by preparatory lectures. It will consist of the synthesis of nanosystems, among which will be nanoparticles (both organic and inorganic/metallic) coated with organic (charged) ligands; liposomes (some fluorophoric molecules will be incapsulated and released by appropriate stimuli); hydrogels based on amino acids and peptides. These nanosystems will be characterized using spectroscopic techniques, such as UV-vis, fluorescence, and dinamic light scattering. Next, the student will test the biocompatibility of the nanosystems produced in biological a-cellular (plasma) or cellular (stabilized human cell lines) models. Examples of possible characterization are: blood coagulation tests, complement activation, citotoxicity, cellular uptake.**Examination**:

The evaluation will be partly based on a written report on the experimental part, which will have to be turned in by the end of the course, and on an oral exam. The oral exam consists in an open-answer questions on topics covered both in the practical and in the theoretical part

of the course.
The time allotted to the discussion of the topics proposed is 40 minutes.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1731/2014/000ZZ/SCO2044101/N0

## NANOSYSTEMS

Master degree in **Industrial Biotechnology**, Second semester
Lecturer: Sabrina Antonello
Credits: 6 ECTS
**Prerequisites:**
B.Sc. level knowledge of Physical Chemistry and Organic Chemistry.
**Short program:**
Part A: Physical chemistry and characterization of nanosystems.
Nanoscale dimension and quantum size confinement.
Intermolecular forces: electrostatic forces, dispersion forces, hydrogen bonds.
Physical Chemistry of interfaces.
Thermodynamics of self-assembly and self-organization.
Amphiphilic molecules: thermodynamics for aggregation of micelles, bilayers, vesicles, biological membranes.
Self-assembled monolayers and Langmuir-Blodgett films.
Electron and charge transfers.
Electrochemical techniques.
Scanning probe microscopies.
Optical, electronic microscopies and other surface characterization methods.
Part B. Preparation, properties and application of nanosystems.
Bottom-up approaches to nanosystems production.
General concepts of solution synthesis: La Mer description of nucleation and growth process, Ostwald ripening, sintering.
Steric and electrostatic stabilization of nanosystems (DLVO theory, Z-potential, stealth behavior).
Aggregates of amphiphilic molecules and peptides.
Polymeric nanoparticles and dendrimers.
Stimuli-responsive nanosystems.
Carbon nanostructures (nanotubes, fullerenes, graphene).
Metal nanoparticles, nanoshells, nanorods and nanoclusters.
Plasmon resonance in metal nanostructures and surface enhanced Raman spectroscopy (SERS).
Semiconductive nanoparticles: quantum dots.
Oxides nanoparticles : silica, titania.
Magnetic nanoparticles.
**Examination**:
Written exam based on a series of tests, to be taken during the semester, and one final, to be taken on the first official date. Each test consists usually in four open questions that could require to draw graphs, report equations and make simple calculations.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1731/2014/000ZZ/SCP9088035/N0

# INDUSTRIAL CHEMISTRY

## ANALYTICAL CHEMISTRY OF INDUSTRIAL PROCESSES

Master degree in **Industrial Chemistry**, Second semester
Lecturer: Marco Frasconi
Credits: 6 ECTS

**Prerequisites:**
Knowledge of instrumental analysis: molecular spectroscopy (UV-Vis and infrared spectroscopies), electroanalytical chemistry (potentiometry and voltammetry), gas-chromatography and high-performance liquid chromatography.
**Short program:**
1) Introduction to Process Analytical Chemistry.
2) Sampling for analytical purposes. Process sampling systems.
3) Data domains and signal elaboration. Sources of noise in instrumental analysis and signal-to-noise optimization strategies.
4) Principles of chemical sensors. Types, preparation and properties of sensors for in-line analytical applications.
5) Electrochemical sensors. Potentiometry and ion-selective electrodes. Ion-sensitive field-effect transistors (ISFET). High-temperature potentiometric oxygen sensor in combustion process monitoring. Amperometric sensors and biosensors. Applications of electrochemical sensors in bioprocess monitoring and control.
6) Conductometric sensors. Resistive and capacitive gas sensors. Impedance humidity sensors.
7) Optical sensors. Optical fibers as a basis for optical sensors. Design of selective optical sensors.
8) Automated methods of analysis. Flow injection analysis and applications in industrial biotechnology.
9) On-line chromatographic techniques. Process gas-chromatography (GC) and liquid-chromatography. Multidimensional chromatography. Applications of GC and multidimensional GC in the petrochemical industry. On-line liquid chromatography for protein characterization in continuous bioprocessing.
10) Optical spectroscopy for process analyses. Infrared and Raman spectroscopy: instrumentation design and sampling interface. Practical examples of IR and Raman analytical applications in the pharmaceutical industry.
**Examination:**
The exam consists of a written assay, on a focused topic on process analytical control, and an oral exam with the presentation and discussion of the assay, follow by two questions on the core topics of the course. The final mark is calculated from the assessment marks of the written assay and oral exam.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1170/2015/000ZZ/SCP9087648/N0

## BIOPOLYMERS
Master degree in **Industrial Chemistry**, First semester
Lecturer: Stefano Mammi
Credits: 6 ECTS
**Prerequisites:**
None beyond the requisites for admission to the Master's course.
**Short program:**
The program is divided into the following points:
1) Polypeptides and protein macromolecules.
Chemistry and stereochemistry of peptide residues. Concepts of primary, secondary, tertiary and quaternary structure. Sequencing and synthesis of polypeptides. Description of various types of ordered conformations of polypeptide chains. Outline of predictive methods of secondary and tertiary structures. Conformational analysis and forces that determine the structure of peptides and proteins.
2) Polynucleotides
Chemistry and stereochemistry of nucleotides. Typical properties of purine and pyrimidine

bases and their derivatives. Primary, secondary, tertiary and quaternary structures of nucleic acids. Structural differences between DNA and RNA. Conformational analysis and forces that determine the structure of nucleic acids. Sequencing and chemical synthesis of oligonucleotides.
3) Industrial production of proteins
PCR. Main molecular biology techniques for the production of proteins. Industrial applications.
4) Polysaccharides
Chemistry and stereochemistry of structural units of polysaccharides. Structures of monosaccharides, disaccharides, homopolysaccharides, heteropolysaccharides. Mention of the structure of some peptidoglycan.
5) Industrial Biopolymers
Biomass. Concept of Biorefineries. Production of energy and chemicals from biomass. Modified polysaccharides in the food industry.
Modified polysaccharides and plastics: blends of starch and synthetic polymers, acidic polysaccharides, cellulose, chitin, chitosan.
Development and production of polymers from renewable sources. Derivatives of vegetable oils. Polyhydroxyalkanoates. PLA. Protein derivatives.
Biocompatible polymers. Hyaluronic acid and derivatives. Polymeric biomaterials.
6) Analytical techniques for the study of the structural properties of biopolymers.
Characterization and separation of biopolymers on the basis of their hydrodynamic properties: ultracentrifugation, electrophoresis, light scattering, size exclusion chromatography.
Spectroscopy applied to the study of biopolymers: UV-Vis, circular dichroism, IR, fluorescence, MS.

**Examination:**
The exam is oral and consists in a discussion over the properties, the production, the experiments and the instrumental techniques to study one of the classes of biopolymers described in the lectures.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1170/2015/000ZZ/SCL1001864/N0

**MARINE BIOLOGY**
**BIODIVERSITY AND BEHAVIOR**
Master degree in **Marine Biology**, First semester
Lecturer: Matteo Griggio
Credits: 8 ECTS

**Prerequisites:**
To successfully follow this course, it is desirable that the student has taken courses in ecology, and in particular in marine ecology, at different levels (population, community).

**Short program:**
Biodiversity: the concept of biodiversity, the diversity of organisms and the ecological systems in which they live. The key role of evolution in shaping biodiversity. Ecological pressures on the morphology and behaviour of marine species. Morphological and behavioural adaptations to different marine habitats (pelagic, benthic, abyssal, intertidal). Biodiversity as the web of complex interrelationships between organisms, the contribution of the study of animal behaviour to understanding the concept of biodiversity. The study of reproductive behaviour, parental care, mimicry and social life, using the most modern concepts of behavioural ecology. Anthropic pressures on marine species and marine habitats. Anthropic impacts on marine species behaviour.

**Examination**:
The evaluation is a written test consisting of three open questions.

**More information:**
https://en.didattica.unipd.it/didattica/2019/IF0360/2013/000ZZ/SCO2046334/N0

## MOLECULAR ECOLOGY AND DEMOGRAPHY OF MARINE ORGANISMS

Master degree in **Marine Biology**, First semester
Lecturer: Chiara Papetti
Credits: 7 ECTS
**Prerequisites:**
Basic knowledge of Ecology, Population Genetics, Botany, Zoology and Statistics.
The course will be held in English, hence an understanding of written and spoken English is required.
**Short program:**
Basics of population ecology: exponential growth curves and discrete logistics. Review of population genetics: factors that determine genetic variability.
Characteristics of marine organisms and their demographic effects. Stochastic models. Models structured by age. Recruitment.
Characteristics of marine organisms and their effects at the genetic level. Effective population size. Environment and distribution of polymorphisms on a geographical and evolutionary scale.
Types of molecular markers: mitochondrial markers, microsatellites, AFLP, SNPs. Laboratory methodologies.
Types of data produced by molecular markers and associated analyzes. Analysis at individual population level. Comparison between populations. Choice of markers in relation to the biological problem. Identification of individuals by genetic markers, marking and recapture with genetic methods, estimation of the historical size of the population, estimation of geographical differentiation, identification of stocks and mixed stock assessment. During the course, examples and case studies will be presented in order to expand on some of the main themes, pointing out the sampling design, the methods and markers used, the characteristics of the species analyzed and the data analysis. During the course, a molecular ecology laboratory will be proposed during which the main basic molecular biology techniques (e.g. DNA extraction, PCR, sequencing / genotpying) will be applied to the solution of an ecological problem. The data will be analyzed with the main molecular analysis software. The results of this laboratory and the biological problem will provide the starting background for the development of a group project.
**Examination**:
The exam entails two parts: written test with open questions and multiple choice quizes (half of the written exam focuses on aspects of demography and population dynamics and the second part will address knowldge and abilities on the rest of the program) and a group project. The group project will allow to evaluate the ability to propose and describe a biological problem, to plan the execution of a project and to choose and apply a method that is suitable for achieving the project objectives. The group project will be based on the results and experience of the laboratory. This part is worth 10 points while the written assignment is worth 20 points (10 points for demography and population dynamics and 10 points for the rest of the program). All group members will get the same score for group work. The written exam will allow to evaluate the theoretical knowledge. The date of presentation of the group projects will be chosen by mutual agreement with the students, indicatively at the end of the semester or before the first official exam. The written exam will take place during the pre-scheduled exam sessions as published on the exams' calendar. Easter egg: if you read this syllabus send me a picture of your favorite animal or plant by email.
Some changes to the evaluation plan and to the course general approaches may be agreed on with students. The exam grade is given by the sum of the scores obtained in all the parts. Details on the structure of the exam, subdivision of the scores between each part will be

illustrated again during the first lessons and, upon request, also later. The exam rules will be made available also via moodle (descriptive slides).
To facilitate understanding of the examination procedures and evaluation criteria, a simulation will take place during the course with some of the possible exam questions.
**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/IF0360/000ZZ/SCN1032607/N0

**MATERIALS SCIENCE**

**COMPUTATIONAL METHODS IN MATERIALS SCIENCE (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS)**

Master degree in **Materials Science**, Second semester
Lecturer: Francesco Ancillotto
Credits: 6 ECTS
**Prerequisites:**
Elementary notions of quantum physics and solid state physics.
Fundamentals of thermodynamics: principles, thermodynamic potentials.
No prior knowledge of computer programming is required.
**Short Program:**
Basic concepts of thermodynamics and classical statistical mechanics.
Classical Molecular Dynamics simulations; numerical integration of Newton equations.
Monte Carlo method; Metropolis algorithm.
Simulations in various statistical ensembles.
Common features of simulations methods: initial and boundary conditions; calculation of inter-particle interactions.
Calculation of thermodynamic and transport properties.
Intermolecular interactions: force-fields; atomistic and coarse grained models.
Variational methods for the solution of the Schrodinger equation.
Hartree and Hartree-Fock theory.
Elements of Density Functional Theory (DFT).
'First principles' simulations.
The different computational methods will be discussed in relation their application to topics of interest for material science (crystals, surfaces, soft matter, nanostructured materials).
In the computer exercises, students will carry out simple simulations, using open-source software packages of current use in materials science, and will learn how to interpret and present the results of simulations.
**Examination**:
Oral examination in which the students will discuss written reports, on the results of three numerical simulations (Monte Carlo, Molecular Dynamics and DFT calculations).
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1174/2015/000ZZ/SCP7081717/N0

**FUNDAMENTALS OF NANOSCIENCE (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS – EXAM OF INTRODUCTION TO NANOPHYSICS)**

Master degree in **Materials Science**, Second semester
Lecturer: Giovanni Mattei
Credits: 8 ECTS
**Prerequisites:**
Electromagnetism, Quantum Physics (particle in a box, quantum confinement), Solid State Physics (phononic and electronic structures of solids, thermal and optical properties)
**Short Program:**
1) Fundamentals of NanoScience (MSc in Materials Science, 4 + 4 = 8 CFU)
MODULE A (4 CFU)

- Classification, characteristics and general properties of nanostructured materials: quantum confinement and electronic properties. Size Equations.
- Thermodynamic properties of nanostructured materials: thermodynamic size effect, nucleation (Gibbs-Thomson equation) and growth of nanostructures (Diffusion-Limited Aggregation and Ostwald Ripening regimes).
- Nanostructures embedded in solid matrices: ion implantation for the synthesis and processing of metallic nanostructures. Verification of the nucleation and growth models.
- Optical properties of nanostructured materials: (i) plasmonic properties of non-interacting metallic nanostructures (Mie theory and its extensions); (ii) interacting nanostructures
- Characterization techniques of nanostructures: transmission and scanning electron microscopy in transmission (TEM) and in scanning (SEM) mode.

MODULE B (4 CFU)

Overview of the preparation methods of nanostructures (both top-down and bottom-up, with particular emphasis on the latter). Structural aspects and energy of nanostructures and methods for their stabilization. Defects in nano dimensional materials. Solid with controlled porosity. Forms of nanoparticles: thermodynamics vs. kinetics. Core-shell nanoparticles. Self-assembly and self-organization. Colloidal method. Templating effect. Preparation of nanoparticles, nanowires, nanotubes, thin films. Self-assembled monolayers. Langmuir and Langmuir-Blodget films. Coherent, semi-coherent, epitaxial and pseudomorphic interfaces. Growth methods for ultrathin films: CVD, MBE, PVD, ALE and PLD methods.

Recall of the fundamental equations for electron and photon dynamics. Material properties for electron and photon confinement. Density of states for confined systems in one, two or three dimensions.

Properties of low dimensional carbon nanostructures: graphene and nanotubes. Tight binding approach for the description of their conduction, optical properties (absorption and emission) and Raman scattering (Kataura plots).

Models for the electron confinement in quantum dots in the weak and strong regime.

Confinement of electrons in metallic nanoparticles and plasmonic properties. Froehlich conditions and far and near field optical properties. SERS effect with plasmonic nanostructures.

Hints on the confinement of photons in photonic crystals.

2) Introduction to NanoPhysics (MSc in PHYSICS, 4 + 2 = 6 CFU

The first 4 CFUs are the same as for MODULE A, previously described, which will be borrowed by the students of the 'Introduction to NanoPhysics' of the MSc Degree in Physics.

The remaining 2 CFUs address the following topics:
- Fundamental description of the dynamics of electrons and photons
- Confinement of electrons and photons in nanostructured or periodic materials:
- 2D and 3D photonic crystals;
- Meta-materials: (i) with hyperbolic dispersion and (ii) with negative refractive index;
- Practical laboratory activities: (i) synthesis of Au spherical nanoparticles in solution; (ii) measurement of their UV-VIS transmittance spectrum; (iii) simulation of the experimental spectra with the Mie theory; (iv) electron microscopy characterization.**Examination**:

1) Fundamentals of NanoScience (MSc in Materials Science)

The exam is written (duration 2 h) with two open questions and a set of multiple-choice questions.

2) Introduction to NanoPhysics (MSc in PHYSICS)

The exam is written (duration 2 h) with an open question and an exercise with numerical applications of the learned topics.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1174/2015/000ZZ/SCP9087651/N0

**NANOFABRICATION**

Master degree in **Materials Science**, First semester
Lecturer: Filippo Romanato
Credits: 6 ECTS
**Prerequisites:**
Single-cycle degree.
**Short program:**
Many of the impressive technical and scientific progress of the last two decades and 'based on the ability' to control individual chemical and physical phenomena at the level of a few nanometers that 'the scale of size which occurs most natural phenomena. This control and 'was obtained by developing systems and processes of micro and nano fabrication for the realization of devices (also referred to as lab-on-chip) capable of exchanging signals (detection and implementation) systems with the size of few nanometers coining, in fact The definition of nanotechnology.
The course will discuss the process of miniaturization of the devices and the how the scale reduction can change or generate many (new) phenomena that distinguish the operation of nanodevices. We will present the main technologies for nanofabrication and we will show examples of application for the construction of devices and experiments at nanoscience. After a general distinction between processes top-down and bottom-up, we will explained the technology of lithography (UV, electronic, X-ray, ion imprinting, interference etc.), the processes of deposition (plasma assisted, or chemical vapor phase, sol-gel, etc.) and etching in the gas (reactive ion etching, milling) or liquid (chemical etching) phase. We will review manufacturing technology of electronic devices based on silicon.
The course is orinted to students in view of their thesis also looking at the broad correlation between physical, chemical, bio-chemical phenomena involved in the creation of nanostructures and nanodevices. The course covers issues of industrial nanotecnotecnology research.
The course is complemented by visits in nanofabrication laboratory in Trieste at the laboratories of the CNR nanofabrication at the synchrotron Elettra. During these visits they will have practical demonstrations of lithographic processes during the course in the classroom.
Syllabus: Nanofabrication:
Program
Nanofabrication: general concepts
Types of lithographs: Top down and bootom-up
Mask - mask less lithography parallel serial
Types of processes sotrattivi
Process development
The role of nanofabrication in production processes
The methodological approach of nanofabrication: interdisciplinary thematic.
Lithographs and Device Types
Diffractive optics,
Microfluidics,
Electronic devices, lab-on-chip, etc.
Lithographs 2D and 3D
Resolutions vs. throughput
Lithographs tridimensioni
Combinations of lithographs
FIB (Focused ion beam)
Resist less
Mask less lithography
First type of lithography
Resist

Introduction to resist: ownership 'and lithographic process
types of resist
Processes on the resist
Spinning
Baking
Dose and development
Contrast, resolution,
Litographic sensibility
Photochemical Quantum efficiency
Plasma etching resistance
Electron beam lithography
Electron sources
Vector scan
Beam blanking
Interaction with electron beam
Energy dependence
Proximity effects - dose correlation
Resolution limit
Exposure time
Stitching
Overlay
Single LEVEL- multi levels
Examples
Generality 'on lithographic techniques parallel
Replica of pattern
Masks
Molds
UV lithography
UV lithography proximity '
UV lithography far field
Optical lithography
General principles
Diffraction
Interference Lithography
Principle of 'interference
Mode '
Property '
X-ray lithography
LTX proximity '
X-ray lithography far field
Deep X-ray
Next generation Deep EUV
Alignment and exposure
Several step processes
Nanoimprinting
**Examination**:
Oral exam, presentation of the work and assessment of the main concepts of nano lithography.
A depth study of a topic will presented after a written report preparation.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1174/2015/000ZZ/SCL1000406/N0

## OPTICS AND LASER PHYSICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS)

Master degree in **Materials Science**, First semester
Lecturer: Tiziana Cesca
Credits: 6 ECTS
**Prerequisites:**
Topics learned in basic courses of Mathematics and Physics.
**Short program:**
Classical optics:
- propagation of electromagnetic waves;
- polarization, birefringence, interference and diffraction;
- geometrical optics and matrix method; main optical instruments;

Lasers:
- the laser idea and proprieties of laser beams;
- absorption, spontaneous emission, stimulated emission;
- gain and population inversion;
- optical cavities and pumping;
- cw lasers;
- pulsed lasers: Q-switch and mode-locking;
- examples of main different laser types: gas lasers, solid-state lasers

Introduction to Quantum Optics:
- Photon statistics
- buching and antibuching;
- weak and strong coupling: Purcell effect and Rabi splitting.

**Examination**:
The exam is written and comprieses two exercizes and one open question.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1174/2015/000ZZ/SCN1037878/N0

## OPTICS OF MATERIALS

Master degree in **Materials Science**, First semester
Lecturer: Moreno Meneghetti
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge of electromagnetic wave propagation and of quantum mechanics.
**Short program:**
Optical susceptibility. Models for the description of the linear and non linear optical susceptibility of materials. Propagation of electromagnetic waves in linear and non linear media. Quantum theory of the optical susceptibility. Spectroscopic techniques for the measurements of linear and non linear properties of materials. Second order properties of non linear materials. Non linear index of refraction dependent processes. Multiphoton absorptions. Raman scattering and SERS spectroscopy of nanostructured materials.
**Examination**:
Examination will be an oral test.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1174/2015/000ZZ/SCP3050267/N0

## ORGANIC FUNCTIONAL MATERIALS

Master degree in **Materials Science**, First semester
Lecturer: Miriam Mba Blazquez
Credits: 6 ECTS
**Prerequisites:**

Organic Chemistry courses of the 1st cycle Degree:
nomenclature of organic molecules, organic functional groups
electrofile and nucleofile
basicity and acidity
addition reactions (alkenes)
nucleophilic substitution (alcohols, halogenated compounds)
Electrophilic aromatic substitution (reactions of aromatic compounds)
Pericyclic reactions
**Short program:**
1. Carbon nanostructures: Synthesis, properties, characterization and applications of fullerenes, carbon nanotubes, graphene
2. Semiconducting organic polymers: synthesis, properties, characterization, electronic structure, charge generation and transport, bandgap engeneering
3. Small organic molecules for organic electronics
4. Organic light emitting diodes (OLEDS), organic solar cells (OSCs) and organic field effect transistors (OFET)
5. Supramolecular materials
**Examination**:
Written exam.
six questions
two hours time
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1174/2015/000ZZ/SCP9087652/N0

**PHYSIC AND TECHNOLOGY OF SEMICONDUCTORS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS)**
Master degree in **Materials Science**, First semester
Lecturer: Davide De Salvador
Credits: 8 ECTS
**Prerequisites:**
Mathematical prerequisites:
Continuous functions. Derivatives. Fundamental theorems of differential calculus. Relative and absolute maxima and minima. Exponential and logarithmic trigonometric functions. Study of a function. Definite integrals. Solid volumes of rotation. Taylor and Maclaurin series. Complex numbers. Exponential in the complex field. Differential equations. Linear differential equations of first order and second order. Functions of multiple variables. Limitations. Partial derivatives. Maximum and minimum relative. Saddle points. Double integrals in polar coordinates. Solid volumes. Triple integral. Vector differential calculus: flow of a vector field across a surface. Divergence of a field and divergence theorem.

Basic Physics Prerequisites
Coulomb's law. Electrostatic field. Electrostatic potential. Gauss's law. Poisson and Laplace equations. Capacity; ideal capacitor. Dielectric constant. Electrical currents and current density. Conservation of the charge. Ohm's law. Joule effect. Magnetic field; Lorentz force.
Quantum Physics Prerequisites :
Light quanta and photo-electric effect. Wave packs. The Heisenberg uncertainty principle. Shroedinger equation particle in a box. Quantum harmonic oscillator. Expectation values. Observables and operators. Quantum uncertainty and properties of eigenvalues. Square barrier tunnel effect. Penetration of the barrier. Particle in a three-dimensional box. Hydrogen atom and hydrogen atoms: fundamental state and excited states. Periodic table. Maxwell-Boltzmann distribution and density of states. Energy provision. Quantum statistics: Bose-Einstein and Fermi-Dirac distributions

Solid state physics Prerequisites
The crystalline structure of solids: the direct lattice and the reciprocal lattice. Phonons. The electrical conductivity of metals in the Drude model. Bloch's theorem.
**Short program:**
Review of the crystal structure of the main semiconductors. Elementary semiconductors , compounds and alloys.
Review of solid state basic concepts ( Bloch theorem , effective mass , concept of hole ) .
Origin and specificity of semiconductors band structure. The real bands (examples: GaAs , Si, Ge, AlGaAs ) .
The envelope function method for the calculation of quantum states generated by aperiodic potential.
The mechanism of doping. The carriers in a homogeneous semiconductor as a function of doping and temperature ( semic. non-degenerate, intrinsic, ionized , partially ionized , in saturation). The compensation by deep level.
The semiconductor non-homogeneous equilibrium. The case of the p-n junction .
Charge transport in semiconductors. Drift -diffusion equation. Intraband scattering phenomena and mobility in a semiconductor.
The mechanisms of generation and recombination in a semiconductor.
The equation of continuity. The case of the p-n junction under polarization.
The heterojunction joints metal / semiconductor , metal / oxide / semiconductor.
The quantum confinement in semiconductor quantum well , quantum wire , quantum dot .
LEDs , GaN based LED, photodetectors. Solid state laser architectures, quantum confinement effect on lasering. Photovoltaic cells. Different architectures and materials for photovoltaics. Efficiency. Mechanisms of loss of efficiency . Thin-film cells.
Produttive.Transistor bipolar and FET technologies . MOS structure.
Doping techniques. Ion implantation. Diffusion and defect .
Insulation, thermal oxidation.
Moore's Law and scaling. Issues and new materials.
**Examination**:
Oral exam. During the semester it will be possible to give a mid-term oral exam about the first part of the course concenrning on physical principle; at the end a second oral exam on the devices and processes will complete the final grade.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1174/2015/000ZZ/SCP9087650/N0

## SUPERCONDUCTING MATERIALS

Master degree in **Materials Science**, Second semester
Lecturer: TO BE DEFINED
Credits: 6 ECTS
**Prerequisites:**
Solid State Physics
**Short program:**
BASIC PRINCIPLES OF SUPERCONDUCTIVITY
Electrical conduction in normal metals. Phenomenology of superconducting materials. The two-fluid model. London electrodynamics. First and second type superconductors. Thermodynamics of the superconducting transition. Bose condensation. Microscopic theory of superconductivity. The superconducting ground state. Quasiparticle excitations. Radiofrequency superconductivity.
SUPERCONDUCTING MATERIALS
Superconductivity in transition metals and Matthias' empirical rules. B1 and A15 Compounds, the particular case of MgB2 and high Tc superconducting materials. Synthesis and surface treatments in superconducting materials, both thin film and bulk. Characterization of

superconducting properties. Materials and applications in mixed phase and Meissner phase.
APPLICATIONS OF SUPERCONDUCTIVITY
Overview of different superconducting materials applications, with particular focus on: superconducting magnets, superconducting motors, radiofrequency cavities, SQUID and current transport.

**Examination**:
The evaluation exam on the knowledge and expected skills is based on an oral discussion (of about half an hour), in which open questions on the arguments of the course will be submitted.

**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/SC1174/000ZZ/SCP9087678/N0

**MATHEMATICS**

## ADVANCED ANALYSIS

Master degree in **Mathematics**, First semester
Lecturer: Giovanni Colombo
Credits: 8 ECTS

**Prerequisites:**
Basic real and functional analysis

**Short program:**
Fixed point theorems by Brouwer and Schauder, with applications; the hairy ball theorem.
Gateaux and Fréchet differentiability. The differential of the norm in L^p spaces.
Ekeland variational principle with some applications (Banach fixed point theorem; local inveribility of smooth functions in infinite dimensional spaces). Further applications to PDE and control theory.
An introduction to Convex analysis: regularity of convex functions; subdifferential and normal vectors to convex sets; the convex conjugate; convex minimization problems and variational inequalities.
An introduction to the mathematical Control Theory. Closedness of the set of trajectories under convexity assumptions; existence of optimal controls for minimum problems. Set separation and cone (non-)transversality as basic tools for abstract constrained minimization.
Optimal Control.
Nonlinear ordinary differential equations and transport of vectors and co-vectors.
Necessary conditions for constrained minima. Pontryagin Maximum principle.
Families of vector fields and controllability of control systems. An introduction to Rashewskii-Chow Theorem.

**Examination:**
An oral exam on the topics covered by the course, that may include doing some simple exercises.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SCP6076557/N0

## ALGEBRAIC GEOMETRY 1

Master degree in **Mathematics**, Second semester
Lecturer: Orsola Tommasi
Credits: 8 ECTS

**Prerequisites:**
Many results are based on results from commutative algebra. Basic knowledge of commutative algebra (corresponding to roughly the first half of the commutative algebra course) is recommended.

**Short program:**
This course is intended as a foundational course in algebraic geometry, starting from the basics of the subject and progressing to more avanced techniques such as the study of sheaves and schemes.
Contents:
Affine varieties.
The Zariski topology.
The sheaf of regular functions on a variety.
Morphisms of varieties.
Projective varieties.
Dimension of a variety.
Introduction to schemes.

**Examination:**
Written exam, possibly taking homework assignments into account.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SC02119737/N0

## ALGEBRAIC GEOMETRY 2

Master degree in **Mathematics**, First semester
Lecturer: Carla Novelli
Credits: 6 ECTS
**Prerequisites:**
Basics on topology and commutative algebra.
**Short program:**
Introduction to affine and projective varieties.
Morphisms, rational maps and birational maps.
Singularities and resolution of singularities. Blow-ups.
Introduction to sheaves and cohomology.
Rational curves and divisors on varieties.
Ampleness and cones of curves.
Extremal rays and extremal contractions.
Surfaces: Cone Theorem, birational classification and Minimal Model Program.
Higher dimensional varieties: Cone Theorem, Contraction Theorem, Extremal Rays, contractions associated with extremal rays, introduction to Minimal Model Program and Minimal Models.
**Examination:**
Seminar.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/001PD/SC02120637/N0

## COMMUTATIVE ALGEBRA

Master degree in **Mathematics**, First semester
Lecturer: Remke Nanne Kloosterman
Credits: 8 ECTS
**Prerequisites:**
Basic notions of algebra (groups, rings, ideals, fields, quotients, etc.), as acquired in the "Algebra 1" course.
**Short program:**
Commutative rings with unit, ideals, homomorphisms, quotient rings. Fields, integral domains, zero divisors, nilpotent elements. Prime ideals and maximal ideals. Local rings and their characterization. Operations on ideals (sum, intersection, product). Extension and contraction of ideals w.r.t. homomorphisms. Annihilator, radical ideal, nilradical and Jacobson radical of a ring. Direct product of rings.
Modules, submodules and their operations (sums, intersection). Annihilator of a module. Direct sums and direct products of modules. Exact sequences of modules, snake lemma. Projective and injective modules. Finitely generated and finitely presented modules, free modules. Cayley-Hamilton theorem and Nakayama's lemma.
Tensor product and its properties. Extension of scalars for modules. Algebras over a ring and their tensor product. Adjunction and exactness of the Hom and tensor product functors. Flat modules. Kahler differentials
Rings of fractions and localisation. Exactness of localisation. of rings and modules. Local properties.
Integral elements, integral extension of rings and integral closure. Going Up, Going Down and geometric translation. Valuation rings. Overview of completions.
Chain conditions, Artinian and Noetherian rings and modules. Hilbert's basis theorem. Normalization Lemma and Nullstellensatz.

Discrete valuation rings. Fractional ideals and invertible modules. Cartier and Weil divisors, Picard group, cycle map. Dedekind domains and their extensions. Decomposition of ideals, inertia, ramification.
Krull dimension, height of a prime ideal. Principal ideal theorem. Characterisation of factorial domains. Regular local rings. Finiteness of dimension for local noetherian rings.
**Examination**:
Written exam.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SCP3050935/N0

## CALCULUS OF VARIATIONS

Master degree in **Mathematics**, Second semester
Lecturer: Roberto Monti
Credits: 8 ECTS
**Prerequisites:**
The Analysis 1 and 2 and the Real Analysis corse
**Short program:**
Introduction to the classical formalism of the Calculus of Variations: indirect methods, first variation, Euler-Lagrange equations, applications.
First direct methods, working in spaces of Lipschitz functions, via a priori gradient estimates.
Modern direct methods: introduction to Sobolev spaces and their use in minimization problems. Tonelli's theorem and the XX problem of Hilbert.
Introduction to currents.
Introduction to optimal transportation
Plateau problem
**Examination**:
Homeworks and oral exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SCP3050978/N0

## CRYPTOGRAPHY (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COMPUTER SCIENCE)

Master degree in **Mathematics**, First semester
Lecturer: Alessandro Languasco
Credits: 6 ECTS
**Prerequisites:**
The topics of the following courses: Algebra (congruences, groups and cyclic groups, finite fields), Calculus (differential and integral calculus, numerical series) both for the BA in Mathematics.
**Short program:**
First Part: Basic theoretical facts: Modular arithmetic. Prime numbers. Little Fermat theorem. Chinese remainder theorem. Finite fields: order of an element and primitive roots. Pseudoprimality tests. Agrawal-Kayal-Saxena's test. RSA method: first description, attacks. Rabin's method and its connection with the integer factorization. Discrete logarithm methods. How to compute the discrete log in a finite field. Elementary factorization methods. Some remarks on Pomerance's quadratic sieve.
Second Part: Protocols and algorithms. Fundamental crypto algorithms. Symmetric methods (historical ones, DES, AES) . Asymmetric methods. Attacks. Digital signature. Pseudorandom generators (remarks). Key exchange, Key exchange in three steps, secret splitting, secret sharing, secret broadcasting, timestamping. Signatures with RSA and discrete log.
**Examination:**
Written exam.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/001PD/SC04111836/N0

**FUNCTIONS THEORY**
Master degree in **Mathematics**, First semester
Lecturer: Davide Vittone
Credits: 8 ECTS
**Prerequisites:**
Besides the courses of Analysis 1 and 2, the courses of Real Analysis and Functional Analysis 1
**Short program:**
Between brackets we denote topics that might be skipped or exposed without proofs according to time availability and/or audience interests.
THEORY OF DISTRIBUTIONS
Definitions, derivatives in the sense of distributions, order of a distribution, compactly supported distributions, convolutions, tempered distributions, Fourier transform, applications.
SOBOLEV SPACES
Definition and elementary properties, approximation theorems, boundary trace and extension results, Sobolev-Gagliardo-Nirenberg, Poincaré and Morrey inequalities, compactness theorems, [capacity and fine properties of Sobolev functions].
ELEMENTS OF GEOMETRIC MEASURE THEORY
Recap of some measure theoretical tools, covering theorems and differentiation of measures, Hausdorff measure and dimension, Lipschitz functions and Rademacher theorem, rectifiable sets, approximate tangent space, [area and coarea formulae].
FUNCTIONS WITH BOUNDED VARIATION
Definition, approximation and compactness results, [trace and extension theorems], coarea formula, sets with finite perimeter, [isoperimetric inequalities, reduced boundary and structure theorem for sets with finite perimeter, fine properties and decommposability of the derivative of a BV function]
**Examination:**
Home exercises (one exercise sheet for each of the four parts of the course), according to which a mark will be proposed to the student. An oral examination is optional.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SCP3050963/N0

**FUNCTIONS OF SEVERALCOMPLEX VARIABLES**
Master degree in **Mathematics**, First semester
Lecturer: Luca Baracco
Credits: 6 ECTS
**Prerequisites:**
Integral and differential calculus in several variables.
**Short program:**
1. Real and complex differentials
2. Cauchy formula on polydiscs
3. Subharmonic functions
4. Separate analytic functions
5. Analytic functions and convergent power series
6. Levi form and H. Lewy's extension theorem
7. Logarithmic Superharmonicity, Continuity principle, Propagation of holomorphic extendibility
8. Domains of holomorphy end pseudoconvex domains
9. L2 estimates and Neumann problem

**Examination**:
Oral exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SCN1037792/N0

## HAMILTONIAN MECHANICS (OFFERED IN THE MASTER DEGREE IN PHYSICS – EXAM OF MATHEMATICAL PHYSICS)

Master degree in **Mathematics**, Second semester
Lecturer: Paolo Rossi
Credits: 6 ECTS
**Prerequisites:**
Basics of algebra and differential geometry (the very basics of differential geometry will be recalled at the beginning of the course, if needed).
Basic knowledge of Hamiltonian mechanics and/or quantum mechanics would help putting the course content into context, but is not strictly needed.
**Short program:**
Hamiltonian systems in Poisson manifolds
(Poisson algebras, deformation theory, Poisson manifolds and their geometry,...).
Integrability
(reminder of Arnold-Liouville integrability, Lax representations, bihamiltonian structures,...).
Elements of quantization
(basic ideas of quantum mechanics, elements of deformation quantization, quantum mechanics in phase space,...).
Evolutionary Hamiltonian PDEs
(as infinite dimensional Hamiltonian systems, modern theory of integrable PDEs,...).
**Examination**:
To be decided depending also on the number of students, but probably either a relatively simple written exam granting access to an oral exposition in the form of a short seminar plus some questions, or a written exam containing both simple exercises and questions on theory.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SCL1000251/N0

## HARMONIC ANALYSIS

Master degree in **Mathematics**, Second semester
Lecturer: Massimo Lanza De Cristoforis
Credits: 6 ECTS
**Prerequisites:**
Analysis courses of the first two years, and preferably the following courses
Real Analysis
Mathematical Methods
Functional Analysis 1
and the basic properties of harmonic functions, which will be anyway brushed up.
**Short program:**
Preliminaries on function spaces
Integral operators with weakly singular and singular kernel
Applications to the analysis of potentials
Elements of potential theory
Applications to boundary value problems for harmonic functions.
**Examination**:
Partial tests and final oral exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SCL1001879/N0

## HOMOLOGY AND COHOMOLOGY

Master degree in **Mathematics**, Second semester
Lecturer: Bruno Chiarellotto
Credits: 6 ECTS

**Prerequisites:**
We expect the student knows that it is possible to associate some invariants (fundamental group..), basic commutative algebra.

**Short program:**
Starting from the basic definition of the algebraic topology we will introduce the definition of homology and cohomology for a topological space. Singular, simplicial, cellular, relative, excisin, mayer-vietoris. Tor and Ext: universal coefficients theorem. Cup and cap product: teh ring structure on the cohomology of a projective space. Poincare' duality.

**Examination:**
Taylored on the basis of the students attitudes: oral and homeworks.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SC02111817/N0

## INTRODUCTION TO GROUP THEORY

Master degree in **Mathematics**, First semester
Lecturer: Andrea Lucchini
Credits: 8 ECTS

**Prerequisites:**
Basic knowedges in general algebra

**Short program:**
General introduction to group theory: actions of groups, solvable and nilpotent groups, finitely presented groups. A short history of the classification of finite simple groups. Topological groups. Profinite groups (characterizations, profinite completion, countable based profinite groups, arithmetical properties, subgroups of finite index in profinite groups, Galois groups of infinite dimensional extension). Probabilistic methods in group theory.

**Examination:**
Oral. The candidate will be asked to present the most important arguments presented in the course, proving the more significant results and solving some related exercise.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/001PD/SC03111814/N0

## INTRODUCTION TO PARTIAL DIFFERENTIAL EQUATIONS

Master degree in **Mathematics**, First semester
Lecturer: Francesco Rossi
Credits: 8 ECTS

**Prerequisites:**
Differential and integral calculus.
Elementary theory of ordinary differential equations.
Basic theory of complex analysis (functions of complex variables, holomorphic and analytic functions).

**Short program:**
Didactic plan:
- First order PDEs: transport equation with constant coefficients, conservation laws (classical and weak solutions, Rankine-Hugoniot conditions, Riemann problem).
- Wave equation: existence of solutions, D'alembert formnula, method of spherical means, Duhamel's principle, uniqueness, finite speed of propagation.
- Laplace equation: fundamental solution, harmonic functions and main properties, mean

value formulas, Liouville's Theorem, Harnack's inequality, maximum principle. Poisson equation. Green's function and Poisson's representation formula of solutions. Basic notions of the theory of distributions.
Weak solutions of Laplace equations on bounded domains are harmonic functions.
- Heat equation: fundamental solution, existence of solutions for the Cauchy problem and representation formula. Uniqueness and stability of solutions. Mean value formulas, maximum principle, Hopf's maximum principle.

**Examination:**
The exam consists of a final oral examination on the topics treated in class. There will be both theoretical questions and the discussion of some exercise to solve.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SCP3050960/N0

## INTRODUCTION TO RING THEORY

Master degree in **Mathematics**, First semester
Lecturer: Alberto Facchini
Credits: 8 ECTS

**Prerequisites:**
Courses of "Algebra 1" and "Algebra 2". That is, standard undergraduate Algebra.

**Short program:**
Rings. Categories, functors. Modules and their homomorphisms, bimodules, submodules and quotients. Natural transformations. Sets of generators, maximal submodules, free modules and IBN rings, exact sequences, projective modules, tensor product of modules, projective modules over Z. Subcategories. Simple modules, semisimple modules, noetherian modules, artinian modules, modules of finite composition length. Semisimple artinian rings, artinian rings, the Jacobson radical, local rings, injective modules, projective covers, injective envelopes.

**Examination:**
Oral examination and/or evaluation of the exercises solved by the studnts during the course.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SC03111812/N0

## NUMBERS THEORY 1

Master degree in **Mathematics**, Second semester
Lecturer: Francesco Baldassarri
Credits: 8 ECTS

**Prerequisites:**
A standard Basic Algebra course; basic Linear Algebra; a basic course of Calculus; a short course in Galois Theory would be most useful; some familiarity with the theory of analytic functions of one complex variable would be useful.

**Short program:**
1. Basic algebra of commutative groups and rings.
2. Factorization of elements and ideals
3. Dedekind domains
4. Algebraic number fields. Cyclotomic and quadratic fields.
5. Rings of integers. Factorization properties.
6. Finite extensions, decomposition, ramification. Hilbert decomposition theory.
7. Frobenius automorphism, Artin map;
8. Quadratic and cyclotomic fields. Quadratic reciprocity law. Gauss sums.
9. An introduction to Class Field Theory (from Kato-Kurokawa-Saito Vol. 2, Chap. 5)
10. Minkowski Theory (finiteness of class number and the unit theorem).
11. Dirichlet series, zeta function, special values and class number formula.

The whole material is to be found in the single textbook: Daniel A. Marcus "Number Theory", Springer-Verlag. The essential part of the program consists of Chapters 1 to 5, with those exercises which are used in the body of the textbook.
Chapters 6 and 7 are required to get a higher grade. The lengthy real-analytic proofs in Chapters 5/6/7 are not essential. A good understanding of the complex-analytic strategy is necessary.
We recommend, for cultural reasons, reading through the two volumes of Kato-Kurokawa-Saito, possibly without studying proofs.
**Examination:**
We will propose the preparation of 1 or 2 written reports during the course. These are supposed to check the step-by-step understanding of the topics presented and the interest of the students in the subject. The exam will be concluded by a final report on a topic chosen by the teacher that the student will prepare individually at home.

Students will be offered to present one topic agreed with the teacher in a 45 minutes lecture during the course. A final oral examination is reserved for those who aim at top grades.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/001PD/SCP4063857/N0

## NUMBER THEORY 2

Master degree in **Mathematics**, Second semester
Lecturer: Adrian Iovita
Credits: 6 ECTS
**Prerequisites:**
Number Theory 1.
**Short program:**
The course will develop the theory of local fields following J.-P. Serre's book: Local fields.
We will study: valuation rings, completions of valuation rings, complete discrete valuation fields of mixed charatcteristic and their fnite extensions, the ramification filtration of the the Galois group of a finite, Galois extesnion of a local field.
As an application we will study p-adic modular forms.i
**Examination**:
Homework exercices will be handed in weekly, there will be a midterm exam and written final.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/001PD/SC01120636/N0

## REPRESENTATION THEORY OF GROUPS

Master degree in **Mathematics**, Second semester
Lecturer: TO BE DEFINED
Credits: 6 ECTS
**Prerequisites:**
Basic notions of linear algebra and group theory.
**Short Program:**
Representations. Irreducible representations. Maschke's theorem. Orthogonality of characters. Induced representations. Frobenius reciprocity. Rappresentazioni Indotte, formual di Mackey. Reciprocita' di Frobenius. Frobenius-Scur Indicator. Compact groups. Linear algebraic groups and their Lie algebras. Solvable, nilpotent and semisimple Lie algebras. Cartan's criterion. Killing form. Weyl's theorem. Root space decomposition. Root systems. Classification of semisimple Lie algebras. Universal enveloping algebras. Finite dimensional irreducible representations of a semisimple Lie algebra.

**Examination:**
Written exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/001PD/SC01120635/N0

## RINGS AND MODULES

Master degree in **Mathematics**, Second semester
Lecturer: Silvana Bazzoni
Credits: 6 ECTS
**Prerequisites:**
Notions from the Algebra courses of the first two years of the degree in Mathematics and basic notions on module theory over arbitrary rings.
**Short program:**
Additive and Abelian categories. Functor categories. Freyd-Mitchell embedding theorem. Pull-back and push-out. Limits and colimits. Adjoint functors. Categories of chain complexes and the homotopy category. Foundamental Theorem in homology. Left and right derived functors. The functors Tor, flatness and purity. The funtors Ext and Yoneda extensions. Flat, projective and injective dimensions of modules and their characterization in terms of derived functors. Applications to the global dimension of rings and Hilbert's syzygies Theorem.
**Examination:**
Written exam consisting in answering to questions from the theory and in solving exercises. Discussion of the composition and possible oral exam.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/001PD/SCL1001443/N0

## SYMPLECTIC MECHANICS

Master degree in **Mathematics**, First semester
Lecturer: Franco Cardin
Credits: 6 ECTS
**Prerequisites:**
Elementary Calculus and Geometry
**Short program:**
Essential of Differential Geometry and Exterior Differential Calculus.
Cohomology.
Riemannian manifolds:
Existence of metrics, Whitney theorem.
Symplectic Geometry:
Symplectic manifolds.
Introduction and developments of Hamiltonian Mechanics on symplectic manifolds.
Local and global parameterization of the Lagrangian submanifolds and their generating functions. Theorem of Maslov-H\"ormander.
Hamilton-Jacobi equation, its geometrical solutions and links to the Calculus of Variations. Conjugate points theory in calculus of variations.
Relative cohomology and Lusternik-Schnirelman theory. Introduction to Symplectic Topology: existence and classification of critical points of functions and applications to generating functions of Lagrangian submanifolds.
The min-max solution of Hamilton-Jacobi equation. Symplectic Topology by Viterbo: towards the solution of the Arnol'd conjecture. Morse theory.
**Examination**:
Written.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/001PD/SC02119743/N0

## STOCASTIC METHODS FOR FINANCE

Master degree in **Mathematics**, Second semester
Lecturer: Martino Grasselli
Credits: 7 ECTS
**Prerequisites:**
Stochastic analysis
**Short program:**
The pricing problem in the binomial models
Risk neutral pricing in the discrete time world
European and American options in the binomial model.
Arbitrage and risk neutral pricing in continuous time.
Pricing of contingent claims in continuous time: the Black&Scholes formula.
Black&Sholes via PDE and via Girsanov.
Hedging and completeness in the Black&Scholes framework.
Feynman-Kac formula and risk neutral pricing in continuous time.
Pur Call parity, dividends and static vs dynamic hedging.
The Greeks and the Delta-Gamma hedging. Delta-Gamma-Vega neutral portfolios.
Barrier options pricing in the Black&Scholes model.
Quanto option pricing in the Black&Scholes model.
Multi asset markets, pricing and hedging.
Exchange options pricing in the multi-asset Black&Scholes model.
Incomplete markets: quadratic hedging.
Smile and skew stylized facts.
Beyond the Black&Scholes model: stochastic volatility.
The Heston model.
Bonds and interest rates. Pre-crisis and multiple-curve frameworks.
Short rate models, Vasicek, CIR, Hull-White models, affine models.
Cap&Floor pricing in the short rate approaches.
Change of numeraire and Forward Risk Neutral measure.
**Examination:**
Final examination based on: Written and oral examination.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/010PD/SC03111823/N0

## TOPOLOGY 2

Master degree in **Mathematics**, First semester
Lecturer: Andrea D'Agnolo
Credits: 6 ECTS
**Short program:**
Algebraic Topology is usually approached via the study of the fundamental group and of homology, defined using chain complexes, whereas, here, the accent is put on the language of categories and sheaves, with particular attention to locally constant sheaves.
Sheaves on topological spaces were invented by Jean Leray as a tool to deduce global properties from local ones. This tool turned out to be extremely powerful, and applies to many areas of Mathematics, from Algebraic Geometry to Quantum Field Theory.
On a topological space, the functor associating to a sheaf the space of its global sections is left exact, but not right exact in general. The derived functors are cohomology groups that encode the obstructions to pass from local to global. The cohomology groups of the constant sheaf are

topological (and even homotopical) invariants of the space, and we shall explain how to calculate them in various situations.
**Examination**:
Traditional
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1172/2011/001PD/SC03111819/N0

**NATURAL SCIENCE**
**ANTHROPOLOGY**
Master degree in **Evolutionary Biology**, Second semester
Lecturer: TO BE DEFINED
Credits: 6 ECTS
**Prerequisites:**
Prior knowledge needed for the classes in Anthropology is that normally provided for students at the final class of the first degree in Natural Sciences. Particularly, the basic understanding of Genetics, Statistics, Phylogeny, and Evolutionary Biology in their fundamental principles and processes, is required. Students should also have sufficient and basic capacities for argumentation and expression, enabling them to defend a thesis and grasp the contents of a scientific debate, actively participating in the discussion of case-studies. No prior knowledge is requested about specific contents in Population Genetics and Genomics.
**Short program:**
The course aims at deepening the fundamental concepts, principles and analytical methods of Molecular Anthropology within a broader international context. Particularly:
- early phases of human evolution with an overview on the available fossil remains (8h);
- genetic characterization of archaic humans (Neanderthals and Denisova) (4h);
- human expansions out of Africa and interactions with pre-existing archaic humans (4h);
- evidences of adaptive introgressions (genetic advantages derived from archaic genetic material) (2h);
- peopling of the continents (Eurasia, America, Oceania) (6h);
- dating of the divergence between various modern human populations (4h);
- genetic adaptation to the diverse environments encountered inside and outside of Africa (4h);
- how structured is the genetic diversity of our species (4h);
- demographic growth and expansion/admixture events following technological revolutions (i.e. Neolithic) (4h);
- patrilinear (Y chromosome) and matrilinear (mtDNA) perspectives on the diversification of modern populations (2h);
- brief overview on the DNA sequencing and genotyping techniques and analyses ;
- introduction to the ground-breaking consequences of ancient DNA (aDNA) in the field of Molecular Anthropology;
- succint exploration of satellite topics introduced by the students themselves through Journal Clubs on recently published articles (6h)

These general objectives are addressed through critical discussion of case-studies taken from primary scientific literature on Molecular Anthropology.
**Examination**:
Examination is oral and aims at evaluating the scientific skills acquired, through open-ended questions and requests for argumentation and comparison of different theses and models. The suggested reference books are meant to provide a general basis of knowledge which must be integrated with the material examined during the lectures as well as with the most recent scientific papers in the field of Molecular Anthropology (introduced during the lectures). If chosen by the candidate, the exam may start with the discussion of a specific scientific paper among the ones suggested by the teacher, followed by a discussion and additional questions

on various topics from the lectures. Attendance is strongly recommended, due to the teaching by interactive methods and case-studies. Students unable to attend a sizeable number of classes must get in touch with the teacher before to discuss an adequate examination mode.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1178/2014/000ZZ/SCP8085142/N0

**ENVIRONMENTAL IMPACT ASSESSMENT**
Master degree in **Evolutionary Biology**, First semester
Lecturer: Massimo De Marchi
Credits: 6 ECTS
**Prerequisites:**
Ecology and environmental law
**Short program:**
-The role and need for evaluation
-Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA): regulations, procedures, case studies, European and International comparisons
-Art. 6 of Habitat directive and assessment of implications on Natura 2000 sites: procedures and case studies
-Social Impact Assessment and interaction with environmental assessment: key case studies
-Ecosystem services approach in environmental assessment
-GIS techniques and Multi Criteria Models for environmental assessments
-Accounting methods for environmental good and services: Contingent Evaluation, Cost/Benefits Analysis
-The management of participation inside environmental assessment procedures
**Examination**:
Working group evaluation report plus oral examination
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1178/2014/000ZZ/SCP4063900/N0

**ENVIRONMENTAL MINERALOGY**
Master degree in **Evolutionary Biology**, Second semester
Lecturer: Gilberto Artioli
Credits: 8 ECTS
**Prerequisites:**
Basic chemistry and chemical thermodynamics. Essentials of mineralogy and geology.
**Short program:**
Natural solid materials: basic concepts of mineralogy and crystal-chemistry.
Natural processes. Introduction on the distribution of the chemical elements on the Earth's crust, on the geological processes, on the geochemical cycles. Processes and fluid-solid interactions at the mineral surfaces. Experimental techniques to study materials surfaces.
Case studies:
(1) Hazardous minerals in nature and in working places:
asbestos, free silica. Environmental monitoring, assessment, mineral quantification, disposal.
(2) Microporous materials and inclusion compounds: clays, zeolites, clathrates, gas hydrates. Crystal structure, crystal chemistry, absorption properties, ionic exchange properties, catalysis. Their use in environmental, agricultural, and industrial applications.
(3) Mineral dust. Origin, characterization. Implications for the palaeoclimatic and environmental reconstructions of the investigations of mineral dust entrapped in polar ice and ocean sediments.
(4) Metals and the environment. Dispersion and re-mobilization of toxic elements during mineral deposits exploitation and industrial transformation of raw resources. Acid mine drainage. The case of arsenic dispersion: inorganic vs bio-controlled processes.

(5) Binders and cements. Their use in history and in present societies as building materials. Environmental applications in solidification and inertization processes of wastes and polluted soils.
(6) Rare Earth Elements. REE cycle and natural resources. Their role in technological products, recovery from e-waste.
**Examination**:
(1) mid-term presentation on an analytical technique selected by the teacher. The student will summarize: (a) the fundamentals of the technique, (b) the instrumental configuration, (c) the resulting information, (d) describe one application with environmental implications.
(2) The student will deliver a final presentation on a topic with environmental implications agreed with the teacher. The student will present: (a) the scientific problem, (b) the data available in the literature, with critical discussion, (c) the prospected actions for a better definition or solution of the problem.**ore information:**
https://en.didattica.unipd.it/didattica/2019/SC1178/2014/000ZZ/SCP4065427/N0

**SANITARY BIOLOGY**
**APPLIED STATISTICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN MOLECULAR BIOLOGY)**
Master degree in **Sanitary Biology**, First semester
Lecturer: Alessandra Rosalba Brazzale
Credits: 6 ECTS
**Prerequisites:**
The style is informal and only minimal mathematical notation will be used. There is no real prerequisite except elementary algebra. However, a previous introductory course in statistics is recommended.
**Short program:**
- General ideas. From the research problem to probabilistic models. Sampling. Observational and experimental studies. Statistical tests: hypotheses, p-values and their interpretation, types of error, power. The problem of multiple comparisons/tests. Confidence intervals.
- Elementary methods. Inference on a proportion and comparison of two proportions. Student's t: one sample, two samples, paired data. Large sample inference. Nonparametric methods: Wilcoxon (one and two samples) and Kruskal-Wallis tests. Correlation coefficient.
- Advanced methods. One-way and two-way analysis of variance. Regression analysis: linear and logistic model. Exploring multivariate data: principal components and cluster analysis.
**Examination**:
Written exam. Students are required to answer a number of questions concerning the statistical analysis of a real data set.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1177/2008/000ZZ/SCN1028731/N0

**BIOCHEMISTRY OF DISEASES**
Master degree in **Sanitary Biology**, First semester
Lecturer: Luca Scorrano
Credits: 8 ECTS
**Prerequisites:**
Biochemistry, Physiology and Pathology.
**Short program:**
1. Introduction to the course
2. Mechanisms of protein homeostasis
3. Mechanisms of cellular ion homeostasis
4. Mechanisms of redox homeostasis and cellular bioenergetics
5. Biochemical mechanisms of reversible cellular damage

a. atrophy
b. hypertrophy
c. Metaplasia (EMT)
6. Biochemical mechanisms of irreversible cellular damage
a. apoptosis
b. necrosis
c. necroptosis
d. Autosis
7. Biochemical mechanisms of senescence and aging
8. Biochemical mechanisms of cell transformation and oncogenesis
9. Role of biochemistry in mitochondrial disease
These topics will be covered in specific workshops, Journal Clubs, lectures held by the teacher and by ad-hoc invited international experts.
Tutorials
Laboratory tutorials on biochemical assays of cell death and autophagy and on the analysis of mitochondrial dysfunction.
**Examination**:
Evaluation of the overall active participation to classes and tutorials (30%)
Evaluation of the lab report (30%)
Evaluation of the final public presentation (40%)
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1177/2008/000ZZ/SCP5073118/N0

**HUMAN PHYSIOLOGY**
Master degree in **Sanitary Biology**, First semester
Lecturer: Luigi Bubacco
Credits: 9 ECTS
**Prerequisites:**
The class requires previous knowledge of basic Biochemistry, cell Biology and General Physiology
**Short program:**
The Central Nervous System (8 hours)
Neurons: Cellular and Network organization and Properties,
Efferent Division: (10 hours) Autonomic and Somatic Motor Control. Sensory Physiology.
Muscles physiology (8 hours) Control of Body Movement
Cardiovascular Physiology (10 hours) Blood Flow and the Control of Blood Pressure and functional properties of Blood
Respiratory Physiology (8 hours) Mechanics of Breathing. Gas Exchange and Transport
The Kidneys (8 hours) Fluid and Electrolyte Balance
Digestion (8 hours) Energy Balance and Metabolism.
Endocrine Control of Growth and Metabolism (8 hours)
Reproduction and Development (8 hours)
**Examination**:
Written exam, four questions to be answered in two hours.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SC1177/2008/000ZZ/SCN1032657/N0

**STATISTICAL SCIENCES**
**ANALYSIS OF INVESTMENT PROJECT**
Master degree in **Statistical Sciences**, First Semester
Lecturer: Michele Moretto
Credits: 9 ECTS

**Prerequisites:**
Microeconomics and Mathematics of Financial Markets.
Mathematics of Financial Derivatives,
Elements of (Stochastic) Dynamic Optimization
**Short program:**
Part A: Introduction
1)Capital Budgetin
2)The Contingent Claim Analysis (CCA)
3)Real Options
4)Simple Examples
- Managerial flexibility
- Forest resources
- Weather derivatives
- Scale production → Call option
- Land use → Put option
Part B: Tools
5)Continuous stochastic processes and Ito's Lemma
6)Stochastic Dynamic Programming (SDP)
7)Valuation of the Option to Wait to Invest
8)Optimal investment rule using CCA
9)Optimal investment rule using SDP
10)Black and Scholes - Merton formula
11)The Beta for Options
12)Interactions among Multiple Real Options
-Moothballing - Option to Shut Dow and Restart
-Optimal Scrapping - Operating Option
-Abandonment value - Option to Exit
-Set Aside - Option to Switch
Part C: Investment Theory Under Uncertainty
13)Value of a Firm as a sum of Operation Options
-Sequential Investment – Compound Options
-Two Stage Projects
-The Central Planner Decision
-A Competitive Industry
14) Strategic Investment, Real Options and Games
- The Preemption game
- War of Attrition game
- The Value of Learning
- Sequential Games: A Supply Chain Example
- Principal Agent in Continuous Time
- Procurement and Auctions
Part D: Case Studies
15) Possible Applications
**Examination:**
Group work with a presentation of a short essay for those who attend up 80% of the lessons
Otherwise written exam
**More information:**
https://en.didattica.unipd.it/didattica/2019/SS1736/2014/000ZZ/SCP9087340/N0

**COMPUTATIONAL FINANCE**
Master degree in **Statistical Sciences**, First Semester
Lecturer: Massimiliano Caporin

Credits: 9 ECTS
**Prerequisites:**
Not strinctly necessary but kindly suggested.
1) Basic elements of statistics for financial applications.
2) Basic elements of mathematical finance.
3) Basic knowledge of microeconomics and macroeconomics, knowledge of the Markowitz model, knowledge of the Capital Asset Pricing Model (CAPM).
The prerequisites at point 3) correspond to the content of the course of Economics of Financial Market taugth in the three-year degree in Statistica per l'Economia e l'Impresa.
**Short program:**
1. The Matlab suite: introduction and coding.
2. Basic Asset Allocation: Markowitz with and without the risk free; Markowitz under standard constraints.
3. Advanced Asset Allocation: Risk Budgeting; non-linear and cardinality constraints; penalization methods in the asset allocation framework;the Michaud approach for resampling; Black-Litterman model; Chow-Kritzman model.
4. Backtesting and performance evaluation.
**Examination**:
The exam will be given in the form of a group homework. Each group (a team), will receive, at a beginning of the course (groups will be formed within the first two weeks of lectures), a list of tasks pointing at computational finance questions. Each team will have to coordinate activities, inducing team members to interact. During the exam session, each team will show results in the form of a presentation. Each team member must have full knowledge of the presentation and of the analyses performed by the team and of the main findings.
**More information:**
https://en.didattica.unipd.it/didattica/2019/SS1736/2014/000ZZ/SCP4063078/N0

**THEORY AND METHODS FOR INFERENCE**
Master degree in **Statistical Sciences**, Second Semester
Lecturer: Alessandra Salvan
Credits: 9 ECTS
**Prerequisites:**
First year Masters courses of the Department of Statistical Sciences, especially Probability Theory and Statistics (Advanced).
**Short program:**
- Statistical models and uncertainty in inference. Statistical models. Paradigms of inference: the Bayesian and frequentist paradigms. Prior specification. Model specification (data variability). Levels of model specification. Problems of distribution (variability of statistics). Simulation. Asymptotic approximations and delta method.
- Generating functions, moment approximations, transformations. Moments, cumulants and their generating functions. Generating functions of sums of independent random variables. Edgeworth and Cornish-Fisher expansions. Notations $O_p(\cdot)$ and $o_p(\cdot)$. Approximations of moments and transformations. Laplace approximation.
- Likelihood: observed and expected quantities, exact properties. Dominated statistical models. Sufficiency. Likelihood: observed quantities. Examples: a two-parameter model, grouped data,
censored data, sequential sampling, Markov chains, Poisson processes. Likelihood and sufficiency. Invariance properties. Expected likelihood quantities and exact sampling properties.
Reparameterizations.
- Likelihood inference: first-order asymptotics. Likelihood inference procedures. Consistency of the maximum likelihood estimator. Asymptotic distribution of the maximum likelihood

estimator. Asymptotic distribution of the log-likelihood ratio: simple null hypothesis, likelihood confidence regions, asymptotically equivalent forms, non-null asymptotic distributions, composite null hypothesis (nuisance parameters), profile likelihood, asymptotically equivalent forms and one-sided versions, testing constraints on the components of the parameter. Non-regular models.
- Bayesian Inference. Non-informative priors. Inference based on the posterior distribution. Point estimation and credibility regions. Hypothesis testing and the Bayes factor. Linear models.
- Likelihood and Bayesian inference: numerical and graphical aspects in R. Scalar and vector parameter examples. EM algorithm.
- Estimating equations and pseudolikelihoods. Misspecification. Estimating equations. Quasi likelihood. Composite likelihood. Empirical likelihood.
- Data and model reduction by marginalization and conditioning. Distribution constant statistics. Completeness. Ancillary statistics. Data and model reduction with nuisance parameters:
lack of information with nuisance parameters, pseudo-likelihoods. Marginal likelihood. Conditional likelihood. Profile and integrated likelihoods.
- The frequency-decision paradigm. Statistical decision problems. Optimality in estimation: Cram´er-Rao lower bound, asymptoticefficiency, Godambe efficiency, Rao-Blackwell-Lehmann-Scheffe theorem. Optimal tests: Neyman-Pearson lemma, composite hypotheses: families with monotone likelihood ratio, locally most powerful tests, two-sided alternatives, other constraint criteria. Optimal confidence regions.
- Exponential families, Exponential dispersion families, Generalized linear models.
Exponential families of order 1. Mean value mapping and variance function. Multiparameter exponential
families. Marginal and conditional distributions. Sufficiency and completeness. Likelihood and exponential families: likelihood quantities, conditional likelihood, profile likelihood and mixed parameterization. Procedures with finite sample optimality properties. First-order asymptotic theory. Exponential dispersion families. Generalized linear models.
- Group families. Groups of transformations. Orbits and maximal invariants. Simple group families and conditional inference. Composite group families and marginal inference.

**Examination**:
1/3 homework, 1/3 final written exam, 1/3 written and oral presentation rewiewing one or two recent research papers.

**More information:**
https://en.didattica.unipd.it/didattica/2019/SS1736/2014/000ZZ/SCP4063246/N0