GALILEAN SCHOOL COURSES CATALOG

CLASS OF NATURAL SCIENCES

ACADEMIC YEAR 2017-2018

Calculus

Teacher: Paolo Guiotto – UniPd – paolo.guiotto@unipd.it

Motivations.
The aim of the course is to introduce to mathematical modelling of biological systems through differential equations with particular emphasis both on modelling as well as on mathematical tools to discuss the qualitative behaviour of systems described in this way.

Targeted audience.
First year students.

Prerequisites.
No particular knowledge is required, the course is self-contained.

Syllabus.
1. Mathematical models – Malthus and logistic demographic models; multiple species models (prey-predator model and competition models); epidemic models (flu, smallpox, malaria).
2. Differential Calculus – infinitesimals, notions of derivative and main properties, elementary derivatives, rules of calculus, geometrical properties.
3. Calculus of primitives – notion of indefinite integral, elementary primitives, rules of calculus.
4. Differential equations – solution of the Malthus model, linear first order equations; solution of the logistic equation and discussion of the flu epidemic model; separable variables equations, the Cauchy problem and existence and uniqueness of solutions.
5. Systems of differential equations – existence and uniqueness, concepts of oriented orbit and phase portrait, first integrals, solution of the prey-predator model, equilibriums and their stability, linear systems, linearization theorem and local classification of equilibriums. Applications.

Teacher CV.
I've been a researcher of mathematical analysis at University of Padova since 1998. I taught courses of mathematical analysis and probability for degree students of mathematics, physics and engineering and for PhD students in pure and applied math. My collaboration with the Scuola Galileiana goes back to 2005. Along these years I've been tutor and teacher of courses of mathematical analysis and probability. In particular I teach the course of Calculus since 2012.
My scientific interests are in the field of analysis on infinite dimensional spaces with particular attention to measures on infinite dimensional space and stochastic partial differential equations.

Textbooks/bibliography
Lecture notes.

Complements of analysis

Teacher: Davide Vittone – UniPd – vittone@math.unipd.it

Motivations.
This course takes place in the first trimester of the first year; it requires only a minimal mathematical background. The aim is to cover topics that are related to, but not usually treated in, the standard first-year courses in Analysis.

Targeted audience.
First year students in Sciences or Engineering.

Syllabus.
Elementary set theory: Zermelo-Fraenkel axioms, cardinality, well-orderings, Zorn's lemma.
Complements of Analysis: inequalities (elementary and not: means, Holder, Minkowski, Jensen...) and convex functions (definition, derivatives, fine properties)
Elements of discrete dynamical systems: fixed points, attractive/repulsive fixed points, periodicity.

Teacher CV.
Born in 1980.
1999-2003 Student at the University of Pisa with fellowship from Scuola Normale Superiore.
2004-2006 PhD student at Scuola Normale Superiore. Advisor: prof. L. Ambrosio.
2007 Postdoc, University of Trento
2007-2014 Ricercatore (Assistant Professor) in Mathematical Analysis, University of Padova
2015-present Associate Professor in Mathematical Analysis, University of Padova
Research interests: Geometric Measure Theory and sub-Riemannian Geometry.

Textbooks/bibliography.
T. J. Jech, *Set Theory*
G. H. Hardy, J. E. Littlewood, G. Pólya, *Inequalities*
R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*

Introduction to probability models

Teacher: Alessandra Bianchi – UniPd – alessandra.bianchi@unipd.it

Motivations.
The aim of the course is to provide an introduction to elementary probability theory and its application to sciences. The typical environment will be that of discrete probability spaces that will be introduced in the first lectures together with some basic probability tools. By the construction and the analysis of suitable models, it will then be shown how probability can be applied to the study of phenomena in physics, computer science, engineering and social sciences. In turns, this will led to the discussion of some open problems of the field.

Targeted audience.
The course will be self-consistent and no specific mathematical knowledge is required. Logic and a scientific attitude are always helpful.

Syllabus.
First elements of probability theory: Discrete probability spaces; Combinatorics; Conditional probability; The Ising model in statistical mechanics: Definition and properties; Analysis of phase transitions in dimension 1 and 2; Discrete random variables: Discrete distributions, mean value, independence; Binomial and geometric distribution; Moments generating function; Applications to two common problems: The coupon collector problem; Shuffling a deck of cards; The symmetric random walk in one and higher dimensions: Definition and properties; Reflection principle and return probability at 0; Analysis of transience and recurrence; Electrical networks and random walk on graph: Elements of discrete potential theory; Harmonic functions and their probabilistic interpretation; Random walk on general graphs; Application to the gambler's ruin problem: probability of loss and win in a gambling game; Markov chains (theory): Definition and classification of Markov chains in finite space; Stationary distribution and ergodic theorem; Markov chains (examples and applications): Eherenfest model; Bernoulli-Laplace model; Galton-Watson branching process; Elements of Monte Carlo method: Definition of Monte Carlo Markov Chain (MCMC); examples and application to optimization problems.

Teacher CV.
Born on 31/12/1977
Education and positions

- July 2003 degree in Mathematics - University of Bologna
- April 2007 PhD degree in Mathematics - University of Roma Tre
- 2007-2009 postdoc fellow at the WIAS of Berlin (Germany)
- 2010- 2012 postdoc fellow at the Mathematics Dep. of Bologna
- Since May 2012 Assistant Professor ("Ricercatore") of Probability and Statistics at the Mathematics Dep. of Padova.

Research interests: probability and Statistical Mechanics, Metastability in Markovian processes, Stochastic dynamics and relaxation time, Interacting particle systems on random structures
She published 8 articles on international journals and gave around 30 talks to students and experts of the field. Teaching: 2010&2011&2012: Probability and statistics – University of Bologna; 2012&2013&2014: Statistics – University of Padova; 2014: Introduction to Probability models- Galilean School of Padova. Since 2012, responsible of the FIRB project "Stochastic Processes and Interacting Particle Systems".

Textbooks/bibliography.
1. F. Caravenna, P. Dai Pra. *Probabilità. Un primo corso attraverso modelli e applicazioni*, Springer (2013).
2. W. Feller. *An Introduction to Probability Theory and its Applications. I Volume*, Third edition, Wiley (1968).

For consultation:
3. P. G. Doyle, J.L. Snell*. Random walks and electric networks. Carus Mathematical Monographs, 22, Mathematical Association of America (1984). Available online.*
4. D. A. Levin, Y. Peres, E. L. Wilmer, *Markov Chains and Mixing Times*, American Mathematical Society, Providence, RI (2009). Available online. 5. O. Haggstrom. Finite Markov Chains and Algorithmic Applications. Cambridge University Press (2002). Available online.

Introduction to Thermodynamics

Teacher: Fulvio Baldovin – UniPd – fulvio.baldovin@unipd.it

Motivations.
Thermodynamics is a basic interdisciplinary subject which bridges over different areas of science, including physics, mathematics, chemistry, engineering, biology, and medicine. Although common to many bachelor curricula, time constraints and needs of focusing on practical application in the specific field tend to hinder the presentation of the simple, symmetric structure which underlies Thermodynamics. As a consequence, students may turn out to be confused about the meaning and use of different thermodynamic potentials and response functions.
Goal of the present course is to introduce the thermodynamics of simple systems. While keeping mathematical aspects at a level suitable for first-year undergraduate students, emphasis will be given to the equivalence of the entropy and energy representations, which through Legendre transformations generate all other potentials. Exemplifications and case of study from different fields will help the comprehension and application the formal structure.

Targeted audience.
The course targets the Natural Science Class of the Galilean School of the University of Padova, including students in physics, mathematics, chemistry, engineering, biology, and medicine. The ideal audience has supposedly been exposed to an introductory course of mathematical analysis in one variable, while a practical knowledge of partial derivatives and Legendre transformations will be offered within the course's lectures.

Syllabus.
- The temporal nature of macroscopic measurements
- The spatial nature of macroscopic measurements
- Summary of thermodynamic parameters
- The postulate of thermodynamic equilibrium
- Walls and constraints
- Measurability of the energy
- Quantitative definition of heat
- The basic problem of equilibrium thermodynamics
- The entropy postulates
- Partial derivatives and differentials
- Intensive parameters and equations of state
- Thermal, mechanical, and chemical equilibrium
- The Euler equation
- The Gibbs-Duhem relation
- Fundamental relation and equations of state
- The simple ideal gas
- The van der Waals ideal fluid
- The electromagnetic radiation
- The “rubber band”
- Second derivatives of the fundamental relation
- Possible, impossible, quasi-static, and reversible processes
- The maximum work theorem
- Engine, refrigerator, and heat pump performance
- The Carnot cycle
- Insight: thermal conductance and conductivity
- Power output and endoreversible engines
- The energy minimum principle
- Legendre transformations
- Thermodynamic potentials
- Massieu functions
- The minimum principles for the potentials
- The Helmholtz potential and the Laplace equation
- The Gibbs potential and chemical reactions
- Maxwell relations
- Reduction of derivatives

- Reconstruction of a fundamental equation from response functions
- Thermodynamic stability in the entropy representation
- Thermodynamic stability for the potentials
- Introduction to phase transitions
- The Clapeyron equation
- Unstable isotherms and first-order transititons
- General attributes of first-order phase transitions
- Thermodynamics in the neighborhood of the critical point

Teacher CV.
Fulvio Baldovin is Assistant Professor in Physics at the Physics and Astronomy Department of the University of Padova. He is author of about 45 original research articles in international journals. He has been teaching Statistical Mechanics for the Ph.D. degree in Physics, and Biological Physics for the Bachelor degree in Molecular Biology. He has been tutor in Theoretical Physics for the Galilean School of the University of Padova. He actively collaborates with complex systems groups at the Weizmann Institute in Israel and at the Universidad Nacional Autonoma de Mexico (UNAM).

Textbooks/bibliography.
H.B. Callen, *Thermodynamics and an introduction to Thermostatistics – Second Edition*, Wiley.
A number of problems and examples will be explicitly solved at the blackboard.

Measure theory

Teacher: Paolo Ciatti – UniPd – paolo.ciatti@unipd.it

Motivations.
The course is an introduction to the Lebesgue theory of integration in Euclidean spaces. The Lebesgue integral is nowadays a standard tool in the scientific literature. It is a flexible instrument allowing the proof of powerful theorems such as the celebrated Lebesgue dominated convergence theorem. Its wide diffusion is related to the completeness of the Lebesgue spaces of functions, a result of fundamental importance not only in mathematics, but also in quantum physics.

Targeted audience.
This lecture course is particularly directed to students in Mathematics, Physics and Engineering. However, students from other scientific disciplines may take advantage of a rigorous presentation of fundamental notions from measure theory which are often assumed to be known without providing a proof. A basic course in calculus would cover all necessary prerequisites.

Syllabus.
The exterior measure and the notion of measurable sets in Euclidean spaces. Measurable functions and definition of integrals for real or complex-valued functions. The monotone convergence theorem and the dominated convergence theorem. The space of integrable functions and the Riesz-Fischer theorem. The Fubini-Tonelli theorem. The Fourier inversion formula. The space of square integrable functions. An introduction to Hilbert spaces. Applications to Fourier series. The Fourier-Plancherel transform. Differentiation of the Lebesgue integral and the Hardy-Littlewood maximal function. Approximations to the identity and more general maximal functions.

Teacher CV.
Paolo Ciatti. Undergraduate Education: Laurea in Fisica, Università di Torino,1990. Thesis directed by Prof. Tullio Regge. Graduate Education: PhD in Mathematics, Politecnico di Torino,1995. Thesis directed by Prof. Fulvio Ricci. Academic Positions: Junior Researcher, University of New South Wales (Sydney),1996-1997. Ricercatore, Università di Padova, 1998-2008. Professore Associato, Università di Padova, 2008-present. Adjoint Professor, Dalhousie University (Halifax, Nova Scotia), 2013-present.

Textbooks/bibliography.
Folland, Gerald B. *Real analysis. Modern techniques and their applications*. Second edition. John Wiley & Sons, Inc., New York, 1999.
Royden, H. L. *Real analysis.* Third edition. Macmillan Publishing Company, New York, 1988.

Interaction Networks in Living Systems

Subtitle: *Emergent Universal Patterns in Living Systems*

Teachers: Marco Formentin – UniPd – marco.formentin@unipd.it
Amos Maritan – UniPd – amos.maritan@unipd.it

Motivations.
Living systems are characterized by the emergence of recurrent dynamical patterns. Such patterns are deemed to be universal in the sense they are due to few common key mechanisms, independent of the details of the specific system. This belief justifies investigation through mathematical models able to grasp fundamental features while disregarding inessential complications. Aims of this the course are: 1) to stimulate a scientific attitude when facing a wide variety of natural phenomena without prejudice; 2) to be able to identify some of the key characteristics responsible for the emergence of a phenomenon; 3) to provide general tools/models, both analytical and numerical, which are fundamental for the development of appropriate models for the phenomenon to be understood.

Targeted audience.
This course can be held in the second or later year. It could be of interest to all students of the Galilean School. Prerequisites: The two courses of “Calculus” and “Probability” in the first year of the GS.

Syllabus.

I Part
1) Emergence of regular patterns in interactive human dynamics: a) waiting times for written communication b) mobility and migration patterns c) stylized facts of financial markets. Simple mathematical models of a), b) and c).
2) Synchronization. Example of synchronization in physics, chemistry and life sciences. Population of globally coupled oscillators. The Kuramoto model: from disorder to synchronization.
3) Random walk on networks: recurrent vs. transient random walk. Electrical networks and random walk. Exploring complex networks through random walk statistics.

II Part
1) Network theory: Deterministic and random networks; Erdos- Renyi networks; Degree distribution; Percolation; Barabasi-Albert model; Small World.
2) Transportation networks: Fractal river basin: Body mass – metabolism scaling; Tree geometry and forests
3) Species interaction networks: Dynamical stability of large and complex interacting systems (with a brief introduction to the random matrix theory); complexity-stability paradox; Emergence of nested interaction networks in mutualistic systems.

Bibliography:
A-L. Barabasi, *Lampi*, Einaudi, 2011
A-L. Barabasi, *La scienza delle reti*, Einaudi, 2004
M. Formentin, A. Lovison, A. Maritan, and G. Zanzotto, *Hidden scaling patterns and universality in written communication,* Phys. Rev. E 90, 012817, 2015
F. Simini, M. C. González, A. Maritan and A-L. Barabási, *A universal model of mobility and migration patterns*. Nature 484, 96–100, 2012
S.H. Strogatz, *From Kuramoto to Crawford: exploring the onset of synchronization in populations of coupled oscillators*, Physica D: Nonlinear Phenomena 143.1 (2000): 1-20.
P. G. Doyle, J.L. Snell, *Random walks and electric networks. Carus Mathematical Monographs*, 22, Mathematical Association of America (1984). Available online.
M.E.J. Newman, *Network: an introduction*, Oxford University press (2010). Only few chapters.
R. M. May, *Stability and complexity in model ecosystems*, Princeton University press (2001).
West, Bruce J. *Nature’s Patterns and the Fractional Calculus*. Vol. 2. Walter de Gruyter GmbH & Co KG, 2017.

Teachers CV.
Marco Formentin is a researcher in Probability and Mathematical Statistics at the Department of Mathematics of the University of Padova. His research interests are mainly concerned with stochastic models for systems of many interacting components with strong interests for applications in complex systems in ecology and interactive human activity.

Amos Maritan is professor of Statistical Physics at the Department of Physics and Astronomy of the University of Padova. His main fields of interest are the equilibrium and non-equilibrium statistical mechanics, complex systems, renormalization group, dynamics of interfaces, polymer and bio-polymer physics, physics of ecosystems, criticality in living systems. More at: http://www.pd.infn.it/~maritan/index.html

Fluidynamics

Teacher: Roberto Turolla – UniPd – turolla@pd.infn.it

Motivations.
Fluids and their motions play a central role in many areas of physics, engineering, biology and physiology, from the scale of living cells to astronomical ones. Fluids are complex systems, the dynamics of which was (partly) understood only during the last century. The course aims at providing the basics of fluid mechanics, i.e. the dynamics of liquids, presenting at the same time a number of examples and applications.

Targeted audience.
Second year students in physics, mathematics, chemistry and engineering. The course is also suited for students in life sciences with a sufficient mathematical background (only elementary notions of calculus and vector analysis are required).

Syllabus.
Basic properties of fluids: pressure, density, viscosity. Newtonian and non-Newtonian fluids (interlude: how it is possible to walk on a liquid).
Conservation laws and equations of motion. The control volume and the Reynolds transport equation. The conservation of mass, the equations of momentum and energy. The Euler and Bernoulli equations.
Dimensional analysis and the similarity principle. The basic adimensional groups in fluidynamics: force and pressure coefficients, the Reynolds, Froude, Rossby and Mach numbers. Adimensional form of the equations of motion and the role of "numbers" in their analysis. Geometrical and dynamical similarity.
Ideal flows. Two-dimensional flow of an inìviscid fluid. Stream function and streamlines. The velocity potential and Laplace equation. Superposition principle. Circulation. Ideal flow past a cylinder. Magnus effect. Lift: why do planes fly?
The stress tensor. Stresses in an incompressible fluid. The Navier-Stokes equations. Applications to one-dimensional flows: Poiseuille flow, fluid sheet on an inclined plane. Internal laminar flows. Flow in a conduct: critical Reynolds number and the entrance length, Poiseuille law. Flow between two plane-parallel plates: the Couette flow. Lubrication. The boundary layer for a plane surface, Blasius solution. The boundary layer for a curved surface. Viscous flow past a sphere (Stokes flow) and a cylinder. Geostrophic flows and the Ekman boudary layer.

Teacher CV.
Roberto Turolla got his Master degree in Physics at the University of Padova, attended a PhD programme at the International School for Advanced Studies in Trieste and is presently full professor at the Department of Physics and Astronomy, University of Padova. Since 2007 he holds a Honorary Professorship at Mullard Space Science Laboratory, University College London (UK).
Research interests: astrophysics of compact objects (black holes and neutron stars). In particular, his expertise is in astrophysical radiative transfer under strong field (gravitational and magnetic) conditions and in the interpretation of X-ray/optical/radio data from collapsed stars in terms of physical models. Such an activity is sustained by several international collaborations with different institutions, both in Europe and the US. He published more than 190 papers on international refereed journals. He teaches General Physics for the bachelor degree in Astronomy and Relativistic Astrophysics for the master degree in Physics.

Textbooks/bibliography.
J.F. Kreider *Principles of Fluid Mechanics, Allyn & Bacon*
Notes of the lectures (in pdf format)

Materials for Biomedical Applications

Teacher: Nicola Elvassore – UniPd – nicola.elvassore@unipd.it

Motivations.
The aim of the course is to introduce the principles of design and development of biomaterials and micro- and nano-technology used in connection to biological systems, including biotechnology and biomedical engineering. An overview of quantitative description and analysis at molecular scale of interactions between biological systems and biomaterials will be provided.

Targeted audience. Second year students.

Prerequisites.
No particular knowledge is required, the course is self-contained.

Syllabus.
1. Principles of biological engineering: quantitative description of biological systems including thermodynamics and mass transport.
2. Molecular interactions between bio- and synthetic molecules and surfaces.
3. Processing approaches for materials and application of state-of-the-art materials science, including 3D printing.
4. Biomaterials controls cell function; overview of biomaterials induced biological functions, including biochemical cues, mechano-transduction, 3D cell niche and microenvironment design.
5. Applications in regenerative medicine, tissue engineering, drug delivery, vaccines, and cell-guiding surfaces.

Teacher CV.
Dr. Nicola Elvassore is Associate Professor at the Department of Industrial Engineering at University of Padova, Italy and Principal Investigator at the Venetian Institute of Molecular Medicine, Padova, Italy. Honorary Professor, Faculty of Pop Health Sciences, Centre for Stem Cells & Regenerative Medicine, University College London, UK. Distinguished Professor-in-Residency at Shanghai Institute of Advanced Immunochemistry (SIAIS), ShanghaiTech University, Shanghai, China.
He focuses on the area of stem cell engineering. He is constantly developing micro-technologies to investigate, decipher and dissected the extrinsic networks of endogenous signals that are self-established during cellular reprogramming and programming. He applies engineering principles to control the 3D self-arrangement ability of pluripotent stem cell toward tissues or organs to model human disease and predict patient-specific pathological outcomes. His publication list includes over 90 papers published as articles in peer-review journals including publications in Nature, Nature Methods and Cell.

Textbooks/bibliography
Lecture notes.

Algebra

Teacher: Giovanna Carnovale – UniPd – carnoval@math.unipd.it

Motivations.
When studying a natural phenomenon it is crucial to understand its symmetries. Group theory formalizes the study of symmetries and the family of Coxeter groups, on which we are going to focus, include the most ubiquitous groups of symmetries: the groups of permutations of a finite set. Coxeter groups are groups generated by reflections and they have important connections with the theory of Lie algebras and Lie groups, which, in turn, have many applications, for instance, in physics.

Targeted audience.
The course is meant for third year students but could be followed by any student with basic knowledge of linear algebra.

Prerequisites.
Basic knowledge of linear algebra.

Syllabus.
Equivalence relations and congruences, basic notions of group theory: group, subgroup, homomorphisms, isomorphisms, cosets, normal subgroups, homomorphism theorem, direct products. Presentation of a group by generators and relations, Coxeter groups and Coxeter graphs. Representations. The geometric representation of a Coxeter group. The length function and its geometric interpretation. Roots. Bruhat order. Classification of finite Coxeter groups. Affine Coxeter groups. Crystallographic groups. Polynomial invariants. Connections with Lie theory.

Teacher CV.
I have obtained my degree cum laude in Roma La Sapienza, writing my dissertation in Utrecht, with an Erasmus fellowship. I took a Master Class in the Netherlands on Algebraic Lie theory and hypergeometric functions, and a PhD in Utrecht on quantum groups. I have been post-doc in Cergy-Pontoise, Paris VI, Antwerp and Roma Tor Vergata. Since 2001 I work for the University of Padova, where I became associate professor in 2015. I have collaborated with the Scuola Galieiana by teaching classes, tutoring students and co-directing Tesi Galileiane. My research area is Algebra, with focus on Lie theory.

Textbook/bibliography.
Artin, *Algebra*, Bollati Boringhieri
Humphreys, *Reflection groups and Coxeter groups*, Cambridge University Press
Bourbaki, *Lie groups and Lie algebras*, Chapters IV, V, VI, Springer

General Relativity

Teacher: Kurt Lechner – UniPd – kurt.lechner@unipd.it

Motivations.
The course is aimed to furnish the mathematical and physical foundations of the theory of General Relativity, the theory describing classical Gravity in compatibility with Einstein's Relativity Principle. The theory is constructed considering as basic physical cornerstone the Equivalence Principle, and by translating it in the mathematical paradigm of General Covariance. Differential Geometry arises as a compelling consequence of physical observations, not as a "dogma" of mathematical prejudices. After the construction of the theory, the comparison between the predictions of General Relativity and historical as well as recent experiments will play a central role in the second part of the course, with a particular focus on gravitational waves. The connection between the more speculative phenomenon of black holes and the related mathematical solutions of Einstein's equations will also be established.

Targeted audience.
The course is targeted for students possessing basic knowledges of classical electrodynamics, especially Maxwell's equations and their basic solutions, and the theory of Special Relativity formulated in the manifestly covariant tensor formalism.

Syllabus.
Introduction. Foundations of special relativity. Gravity against the other fundamental interactions. The postulates of special relativity and the tensor calculus.
A relativistic theory of Gravitation. Equivalence principle. Metric tensor, affine connection, geodesics. Newtonian limit and gravitational red-shift. The principle of General Covariance.
Elements of Differential Geometry. Differentiable manifolds and diffeomorphism invariance. Tensors. Pseudo-Riemannian manifolds. Affine connection and covariant differentiation. Curvature and Riemann tensor.
Physical systems in an external gravitational field. The minimal coupling to gravity. Electrodynamics in an external gravitational field. Conservation of electric charge and fourmomentum in a curved space-time.
Einstein's equations. Derivation of Einstein's equations. Cosmological constant. The energymomentum tensor of the gravitational field. Postulates of General Relativity: local and global causality.
Schwarzschild solution. Spherical solutions of Einstein's equations. Classical experimental tests of General Relativity.
Black holes. Global analysis of geodesics in the Schwarzschild metric. Qualitative analysis of geodesics. Event horizon and Kruskal metric. Hawking radiation.
Gravitational waves. Solutions of Einstein's equations in the weak field limit. Plane waves. Energy radiated by oscillating bodies. The decay of the period of the binary pulsar PSR 1913+16 as indirect evidence of the existence of gravitational waves. Direct detection of gravitational waves by the LIGO interferometer.
Brief introduction to the Cosmological Standard Model. Basic elements.
Formal developments. The least-action principle in General Relativity. The Einstein-Hilbert action for the gravitational field.

Teacher CV.
Born: 15/05/1962 (Brixen, Italy)
Education:
- Laurea in Physics, University of Padua (1986, November).
- Magister Philosophiae, International School for Advanced Studies, Trieste, (1989, October).
- Doctor Philosophiae, International School for Advanced Studies, Trieste, (1990, April).

Academic positions and duties:
- Researcher for Theoretical Physics, Dept. of Physics, Univ. of Padua (1990-2004).
- Associate Professor for Theoretical Physics, Dept. of Physics and Astronomy, Univ. of Padua (since 2004).
- Member of the Dept.'s council (2003).
- Member of the Teaching Committee of the Dept. of. Physics (since 2004)
- Member of commettees for permanent research positions in Theoretical Physics at the Universities of Milano (2000), and Cagliari (2002).

Teaching and tutor activities:
- Courses on "General Physics I and II", "Relativity'', "Thermodynamics", "Electromagnetic fields", "Theoretical Physics", "Mathematical Methods for Physics" at the Faculties of Sciences and Engineering and the "Scuola Galileiana di Studi Superiori".
- Tutor for the students of the "Scuola Galileiana di Studi Superiori" (2006-2011).

Research fields:
Superstring-theory and M-theory. Supergravity theories. Anyons and Chern-Simons theories. Quantum Anomaly cancellation. Spin-statistics connection, covariance and duality in field-, brane- and string-theory. Radiation reaction and self-interaction for charges, dyons and p-branes. Classical electrodynamics of massless charges.
Author of about 50 publications on international journals. Link:
http://www.slac.stanford.edu/spires/find/hep/www?rawcmd=FIND+A+LECHNER
Book author: "Elettrodinamica Classica", 570 pg, Springer-Verlag, Milano, 2014.

Textbooks/bibliography.

1) S. Weinberg, "*Gravitation and Cosmology*", Wiley, New York, 1972.
2) S.W. Hawking and G.F.R. Ellis, "*The large scale structure of space-time*", Cambridge University Press, London, 1973.
3) M. Gasperini, "*Relativita' Generale e Teoria della Gravitazione*", Springer-Verlag, Milano, 2010.

Complements of Electrodynamics

Teachers:
Massimo Passera – Istituto Nazionale di Fisica Nucleare, Sezione di Padova – passera@pd.infn.it
Marco Zanetti – UniPd – marco.zanetti@unipd.it

Motivations: The aim of the course is to introduce selected advanced topics in classical electrodynamics.

Targeted audience: third year students.

Syllabus: Review of Maxwell equations; Plane electromagnetic waves and wave propagation; Radiating systems, multipole fields and radiation; Scattering and diffraction; Scattering of charged particles; Dynamics of relativistic particles and electromagnetic fields; Radiation by moving charges; Particle accelerators; Betatrons; Synchrotrons; Optical interferometry; Generation and detection of electromagnetic radiation.

Teachers CV.
Massimo Passera: Degree in Physics at University of Torino, Italy; Ph.D. at New York University, New York, USA; Postoctoral Fellow at the Institut for Theoretical Physics, University of Bern, Switzerland, at the Department of Theoretical Physics, University of Valencia, Spain, and at the Dipartimento di Fisica, University of Padova, Italy. Senior Researcher of the Istituto Nazionale di Fisica Nucleare, Sezione di Padova, Italy.

Textbooks/bibliography:
J. D. Jackson, Classical electrodynamics, Wiley, NY, 1999 (3rd ed.);
A. Zangwill, Modern Electrodynamics, Cambridge University Press, 2013;
Lecture notes.

A journey into drug discovery

Teachers:
Part 1: Stefano Moro – UniPd – stefano.moro@unipd.it
Part 2: Giovanni Marzaro – UniPd – giovanni.marzaro@unipd.it
Part 3: Adriana Chilin – UniPd – adriana.chilin@unipd.it
Part 4: Barbara Gatto – UniPd – barbara.gatto@unipd.it

Motivations.
The aim of the course is I) to introduce the process of drug discovery (basic methodologies of rational drug design, production and evaluation) both for natural and synthetic and biotechnological drugs, and II) to understand how the structure of a compound is responsible for its therapeutic properties.

Targeted audience.
Third year students of the Natural Science Class. Students of other classes are welcome.

Prerequisites.
Basic knowledge of chemistry and biology.

Syllabus.
Part 1: Computer-aided Drug Discovery (Stefano Moro)
Time-independent methodologies in the identification and optimization of drug candidates: structures and properties similarity, pharmacophore hypothesis, molecular docking, virtual screening.
Time-independent methodologies in the identification and optimization of drug candidates: molecular dynamics (MD), free energy perturbation (FEP).
Part 2 and 3: Drug synthesis and SAR (Giovanni Marzaro and Adriana Chilin)
Basic concept in organic synthesis, how to plan a drug synthesis (from retrosynthetic analysis to chemoinformatic tools), how to carry out a drug synthesis (from lab scale to full plant scale), lessons learned from kinase inhibitors, case studies about structure-activity relationships.
Part 4: Biotechnological drugs (Barbara Gatto)
Pharmaceutical Biotechnology: market and development of red biotech. Molecular Biotechnology. Expression methods and criteria for the expression system choice. Production and downstream processing of Biotech Therapeutics. Legal requirements and normative for biotechnological drugs (EMA, FDA). Biosimilars, biobetters and orphan drugs. Immunogenicity, aggregation and glycosylation. Monoclonal Antibodies in clinical use.

Teachers CV.
Stefano Moro. Degree in Chemistry and Pharmaceutical Technology, PhD in Chemistry. Professor of Medicinal Chemistry at DSF (University of Padova) and PI of the Moleculat Modeling Section (MMS, mms.dsfarm.unipd.it). Research area: ligand- and structure-based ligand identification and optimization, molecular dynamics applications in drug discovery, chemoinformatics.
Giovanni Marzaro. Degree in Chemistry and Pharmaceutical Technology, PhD in Pharmaceutical Sciences. Tenure track researcher in Medicinal Chemistry at DSF (University of Padova). Research area: synthesis and characterization of bioactive compounds in the field of cancer treatment and cystic fibrosis therapy. Area of expertise: Organic synthesis and MAOS, Flash Chromatography, HPLC, IR, NMR, MS.
Adriana Chilin. Degree in Chemistry and Pharmaceutical Technology, PhD in Pharmaceutical Sciences. Associate professor in Medicinal Chemistry at DSF (University of Padova). Research area: synthesis and characterization of bioactive compounds in the field of cancer treatment and cystic fibrosis therapy. Area of expertise: Organic synthesis and MAOS, Flash Chromatography, HPLC, IR, NMR, MS.
Barbara Gatto. Degree in Chemistry and Pharmaceutical Technology, PhD in Pharmaceutical Sciences. Post-doctoral fellow at Johns Hopkins University Medical School, Baltimore, USA and Robert Wood Johnson Medical School, UMDNJ, NJ, USA, and Genzentrum der LMU, München. Associate Professor of Medicinal Chemistry at DSF (University of Padova) where she teaches medicinal chemistry and pharmaceutical biotechnologies.

Textbooks/bibliography
Lecture notes.

Introduction to String Theory

Teacher: Stefano Giusto – UniPd – stefano.giusto@unipd.it

Motivations.
String theory represents a significant theoretical extension of quantum field theory, with deep implications for both physics and mathematics. String theory unifies in a consistent framework quantum mechanics and general relativity and provides the most promising theoretical scheme for a unified theory of fundamental interactions. At the same time string theory probably represents the richest and most complex mathematical object that has emerged from physics, having multiple connections with differential and algebraic geometry, topology, representation theory and infinite-dimensional analysis. The goal of this course is to provide a basic introduction to the classical and quantum aspects of string theory, clarifying those aspects that are essential to grasp its fundamental physical content.

Targeted audience.
First and second year master students in physics. The course is suited also for third year students in physics and students in mathematics with some familiarity with quantum mechanics.
Knowledge of classical physics and basic special relativity will be required. The essential notions of quantum mechanics relevant for the extension to string theory will be briefly reviewed.

Syllabus.
Reminders of special relativity, electromagnetism, gravitation and their generalization to space-times with extra dimensions.
The classical relativistic bosonic string: Nambu-Goto and Polyakov actions, equations of motion, boundary conditions for open strings, mode expansion, conserved currents, gauge invariance and constraints. The relativistic string in the light-cone gauge.
Lightning review of quantum mechanics: quantization of the relativistic particle and the harmonic oscillator.
Quantization of the relativistic bosonic string: covariant and light-cone quantizations; open strings and the dynamics of D-branes; the spectrum of closed strings and the emergence of gravity.
Compactification and T-duality. String amplitudes.
A qualitative overview of the superstring, low energy effective actions (supergravity) and applications to the study of black holes.

Teacher CV.
Associate professor at the University of Padua.
Ph. D. in Physics: U. Genoa, 1999.
Academic Positions:
- Post-doc, Harvard University, USA, 1999;
- Research contract, U. Lecce, Italy, 2000;
- Research contract, U. Genoa, Italy, 2000-03;
- Post-doc, The Ohio State University, USA, 2003-06;
- Post-doc, U. Toronto, Canada, 2006-07;
- Post-doc, IPhT, Saclay, France, 2007-09;
- Post-doc, LPTHE, Paris 6, France, 2009-10;
- Researcher, U. Genoa, Italy, 2010-11.

Teaching:
- Theoretical Physics (Teaching assistant), U. Genoa, 2000-2003;
- Theoretical Relativistic Physics (Teaching assistant), U. Padua, 2010-11;
- String Theory, Ph. D. in Physics, U. Padua, 2011-12, 2015-17 and Scuola Galileiana, 2014-15;
- Electromagnetic Fields, U. Padua, 2011-2017;
- Quantum Physics for astronomers, U. Padua, 2015-2017;
- Physics for computer science, engineers and pharmacists, U. Padua, 2014-17.

Research topics:
My main research interest is in String Theory and in particular I am trying to provide a microscopic understanding of the thermodynamic properties of black holes.

Textbooks/bibliography
B. Zwiebach, "*A First Course in String Theory*"
D. Tong, "*Lectures on String Theory*"

Dynamical Foundations of Statistical Mechanics

Teacher: Antonio Ponno – UniPd – ponno@math.unipd.it

Motivations:
Statistical mechanics is that "fundamental" part of theoretical physics that explains the laws of thermodynamics in terms of the microscopic properties of a given physical system. Such an explanation is of probabilistic character: a few particular probability distributions, depending on the given interactions between the elementary constituents of the system and on the specific parameters under control, are assigned on the space of the states of the system. Aim of this course is to treat the problem of the dynamical foundations of statistical mechanics, i.e. the explanation of the basic laws of statistical mechanics in terms of the actual dynamics of the elementary constituents of physical systems. As strange as it can appear, after more than 150 years of theories and results, such a problem remains, at present, partially unsolved.

Targeted audience:
The course is directed, in particular, to students in Mathematics, Physics and Chemistry, but the topic may be of some interest to other students of the Natural Sciences Class, depending on their personal interests or attitudes. Prerequisites are: basic notions of integral and differential calculus, of general physics, and of differential equations. The course may be certainly attended by students from the second-third year of the Degree in Mathematics and Physics on.

Syllabus:
-Introduction: what is statistical mechanics.
- Early kinetic theories: Clausius theory of gasses, virial theorem and its relevance to astrophysics; the unsolved problem of founding the statistical mechanics of star - clusters.
- Modern kinetic theory of gasses: BBGKY hierarchy, Boltzmann equation and H-theorem: the first "proof" of approach to equilibrium. Poincaré recurrence and the related, apparent, conceptual paradoxes.
- The point of view of mechanics: breakdown of integrability, Poincaré-Fermi theorem and the birth of ergodic theory. The early conjecture of Fermi. KAM theorem and its apparent implications.
- The modern approach to statistical mechanics: priveleged probability measures on the phase space of the system. Properties and equivalence of the two main canonical measures; fluctuations and correlations. Role of the thermodynamic limit: statistical behavior of large size, linear particle chains.
- Dynamical justification I: systems with a stochastic (gaussian) thermostat. From Langevin to Fokker-Planck equations. Gibbs measure as a global attractor.
- Dynamical justification II: ergodic theory. Characterization of ergodic and mixing systems. Poincaré recurrence revisited: Kac theorem on the first return time.
- The Fermi-Pasta-Ulam problem.

Teacher (short) CV:
"Laurea" in Physics: Rome, 1998. PhD in Physics: Padova, 2002. Postdoc position in Mathematical Physics: Milano, 2002-2006. Researcher in Mathematical Physics: Padova, 2006-2014. Associate Professor in Mathematical Physics: Padova: 2014-present. Research periods abroad in France, Brazil and Germany.

Textbooks/Bibliography:
Lectures notes of the teacher and references therein.

Investigating Brain Neuronal Networks

Teacher: Stefano Vassanelli – UniPd – stefano.vassanelli@unipd.it

Motivations

Neuroscience is taking a leap into the era where technological advances in neuronal networks recording and stimulation allow fundamental questions on brain computation to be addressed. Macroscale brain circuits, and their underlying neuronal microcircuits, can be measured at an ever increasing resolution and their activity stimulated down to the level of single neurons. Successful strategies for understanding brain computation rely on merging such technologies with information theory approaches to extract information from measured signals that is relevant to brain processing and to identify fundamental rules that can be implemented in brain-inspired computing systems.

Target audience

The course is typically interdisciplinary and all students of the class in Natural Sciences are encouraged to attend. During the lectures, we will attempt to establish 'a common language', and to foster interaction between students across different disciplines.

Prerequisites

Strong interest in the experimental and theoretical investigation of principles of brain information processing

Syllabus

1. The neuron and the fundamental mechanisms of neuronal excitability and signaling: membrane conductances and ionic channels; the generation of the action potential and its propagation; the dendritic tree and its role in neuronal processing; the synapse, the mechanisms of neuron-to-neuron signal transmission and plasticity rules.
2. Measuring brain neuronal networks spanning from the micro to the macro scale: electrophysiological and imaging methods to measure neuronal networks in vitro and in vivo. The toolbox for neuronal stimulation.
3. Basic principles of neuronal coding: computing with spiking neurons (rate and phase coding), putative roles of neuronal synchronization and network oscillations, exctracting relevant information from measured neuronal population signals.

Teacher CV

Stefano Vassanelli graduated cum Laude in Medicine at the University of Padova and his doctoral thesis was awarded with the "Casati" price from the "Accademia Nationale dei Lincei". After completing a PhD in molecular biology and pathology he did his postdoctoral studies first at the Oregon Graduate Institute of Science and Technology, Dpt. of Biochemistry, (Portland. Oregon, USA), and then at the Max-Planck Institute for Biochemistry, Dpt. Membrane and Neurophysics (Martinsried, Germany) specializing on brain-chip interfaces and on the investigation of neuronal networks in the rat brain. Since 2001 he is leading the Neurochip laboratory at the University of Padova. At present SV is associate professor in the Dept. of Biomedical Sciences of the University of Padova and teaches physiology to students of the medicine, bioengineering and pharmaceutical sciences curricula.

Textbooks/bibliography

Lectures notes

Kandel, E. R., Schwartz, J. H., Jessell, T. M., Siegelbaum, S. A. & Hudspeth, A. J. *Principles of Neural Science, Fifth Edition*. (McGraw-Hill Professional, 2012).

Vassanelli, S. Multielectrode and Multitransistor Arrays for In Vivo Recording. in *Nanotechnology and Neuroscience: Nano-electronic, Photonic and Mechanical Neuronal Interfacing* (eds. Vittorio, M. D., Martiradonna, L. & Assad, J.) 239–267 (Springer New York, 2014)

Quian Quiroga, R. & Panzeri, S. Extracting information from neuronal populations: information theory and decoding approaches. *Nature Reviews Neuroscience* **10,** 173–185 (2009).

Topics in complex geometry

Teachers: Ugo Bruzzo – SISSA – bruzzo@sissa.it; Jacopo Stoppa – SISSA – jstoppa@sissa.it

Motivations
Methods involving "complex variables" have played a central role in both Mathematics and Physics for a very long time and continue to flourish in present day research (e.g. the development of the mathematical aspects of topological field theories; a full theoretical understanding of Einstein metrics on compact complex manifolds). Our aim is to introduce Mathematics and Physics students to some of the complex algebraic and differential geometry needed to access current research. We will focus on a more explicit and tractable case of manifolds enjoying a very large symmetry group: complex toric manifolds.

Targeted audience
Mathematics/Physics students.

Syllabus

Module 1
Toric algebraic geometry: fans, toric varieties and their basic properties. Resolutions of singularities. Divisors and line bundles on toric varieties.

Module 2
Complex differential geometry of toric manifolds: complex and symplectic local coordinates. The global structure. Kähler metrics on toric manifolds. Algebraic metrics and asymptotics. Extremal metrics. Toric Fano manifolds. Einstein metrics and the Wang-Zhu theorem.

Instructors' CV
Ugo Bruzzo is full professor of Geometry at SISSA. In the past he was associate professor at the University of Genoa, and held visiting positions at the University of Pennsylvania in Philadelphia, Universidad de Salamanca and others. He is interested in the geometry of moduli spaces of sheaves and their applications in mathematical physics, Higgs bundles, and toric geometry.

Jacopo Stoppa is a full professor of Geometry at SISSA. Previously he held positions at the Max Planck Institute for Mathematics, Bonn; Trinity College, Cambridge, and Università di Pavia. He is the recipient of a Starting Grant of the European Research Council. His research interests revolve around the concept of stability in algebraic geometry, with applications to complex differential geometry (canonical Kähler metrics) and enumerative theories (Donaldson-Thomas invariants).

Textbooks/bibliography

Module 1:
W. Fulton, *Introduction to Toric Varieties*
D.Cox, J. Little, H. Schenck, *Toric Geometry*
Lecture notes available at http://people.sissa.it/~bruzzo/notes/toric.pdf

Module 2:
lecture notes, expanding on the paper of S. K. Donaldson "*Kähler geometry on toric manifolds, and some other manifolds with large symmetry*", freely available at https://arxiv.org/abs/0803.0985.

Data Analysis and Machine Learning

Subtitle: *Machine Learning Crash Course*

Teacher: Lorenzo Rosasco – UniGe – lorenzo.rosasco@unige.it,
Marco Zanetti – UniPD – marco.zanetti@unipd.it

Motivations. Machine Learning is a key to develop intelligent systems and analyze data in science and engineering. Machine Learning engines enable intelligent technologies such as Siri, Kinect or Google self driving car, to name a few. At the same time, Machine Learning methods help deciphering the information in our DNA and make sense of the flood of information gathered on the web, forming the basis of a new “Science of Data” . This course provides an introduction to the fundamental methods at the core of modern Machine Learning. It covers theoretical foundations as well as essential algorithms. Classes on theoretical and algorithmic aspects are complemented by practical lab sessions.

Syllabus.
Elements of statical learning theory. Supervised learning: regression and classification .Model selection and Bias Variance trade-off. Nearest Neighbors and local methods. Regularization for parametric and nonparametric models. Kernel methods and Gaussian processes. Dimensionality reductions and principal components analysis. Variable selection and sparsity. Neural networks and sparsity.

Teacher CV.
Lorenzo Rosasco is associate professor at University of Genova and Visiting professor at the Massachusetts Institute of Technology (MIT). He is also a researcher at the Italian Technological Institute (IIT), where he coordinates the joint IIT-MIT Laboratory for Computational and Statistical Learning. He received his PhD in 2006 from the University of Genova, after being a visiting student at the Center for Biological and Computational Learning at MIT, the Toyota Technological Institute at Chicago (TTI-Chicago) and the Johann Radon Institute for Computational and Applied Mathematics. Between 2006 a and 2009 he has been a postdoctoral fellow at the Center for Biological and Computational Learning at MIT. His research focuses on
theory and algorithms for machine learning.

Textbooks/bibliography

1. L. Rosasco. *Introductory Machine Learning Notes*. (provided)

T. Hastie, R. Tibshirani and J. Friedman. *The Elements of Statistical Learning*. 2nd Ed., Springer, 2009.