Ph.D. courses 2022-2023:

1) "**Topological quantum matter and information**": Prof. María Belén Paredes Ariza (IFT)
- Abstract: I will give an introduction to the theory of topological matter and anyons, and to the theory of topological quantum information and computation. I will discuss the following subjects: quantum braiding statistics and anyons, topological order, topological quantum codes, fractional quantum Hall systems, topological qubits and topological protection, topological quantum computation. I will introduce these concepts both at a mathematical level and at a physical level, discussing physical systems in which topological order and anyons can arise.
- Timetable: September 22, 27, 29. 14:00 – 15:30 hs.; October 4. 14:00 – 15:30 hs.; May 23, 25, 30. 14:00 – 15:30 hs.; June 1. 14:00 – 15:30 hs.

2) "**Holography and Quantum Information**": Prof. Juan Felipe Pedraza Avella (IFT)
- Abstract: This minicourse will provide a modern perspective on the emergence of spacetime in holography and quantum gravity using ideas borrowed from quantum information. The course will be split into two parts. The first part will introduce the necessary background on AdS/CFT and then focus on probing bulk gravitational physics using measures of quantum entanglement. The second part of the course will explore other useful information-theoretic tools such as computational complexity, quantum chaos, and quantum teleportation. Throughout the course, the aim will be to apply these concepts to understand the physics of black holes, wormholes, and other relevant gravitational backgrounds.
- Timetable: October 3, 6, 10, 13. 9:30 – 11:00 hs.; October 24, 27, 31. 9:30 – 11:00 hs.; November 3. 9:30 – 11:00 hs.

3) "**Theory and phenomenology of multi-Higgs SM extensions**": Prof. Emanuele A. Bagnaschi (CERN)
- Abstract: We discuss the theory and phenomenology of multi-Higgs extensions of the Standard Model, with specific attention to supersymmetric ones. The course will cover material ranging from theoretical aspects to experimental analyses at the LHC and future colliders.
- Timetable: October 28. 9:00 – 11:00 hs.; October 31. 11:30 – 13:30 hs.; November 2, 3. 11:30 – 13:30 hs.; November 4. 9:00 – 11:00 hs.

4) "**Effective field Theory in Particle Physics**": Prof. Ben Grinstein (Universidad de California San Diego, UCSD)
- Abstract: The course is an introduction to Effective Field Theory in particle physics, with an emphasis on the applications to weak interactions and grand unification, but includes also brief discussion of wilsonian effective action, SMEFT and Heavy Quanrk Effective Theory (HQET).
- Topics to be covered: Why do we need EFT? Challenges of EFT. Appelquist Carazzone Theorem. GUTs. RGE. Renormalization of composite operators. Operator anomalous dimensions: explicit computations. Operator mixing and their RGE. Using symmetries and equations of motion (EOM) to constrain mixing of operators. Prove Equations of Motion in elements. Wilsonian EFT and relation to renormalziation in QFT (minimalistic). HQET.
- Timetable: November 8, 10, 11, 14, 15, 16, 17, 28, 29, 30. 16:00 – 18:00 hs.; December 1, 2. 16:00 – 18:00 hs.

5) **<u>"Introduction to Form"</u>**: Prof. Jos Vermasseren (NIKHEF)
- <u>Abstract</u>: Form is a program for the fast symbolic manipulation of very big formula's. It is being used for many of the big perturbative calculations in field theory, but also in some mathematical calculations it has been able to obtain results that could not be obtained by other means.
The first three sessions make the attendants familiar with the underlying philosophy and basic commands and explain a few fundamentals about how to make fast programs. This will be followed by three actual research problems in the fields of gravity, Euler characteristics and integration by part reductions respectively.
- <u>Timetable</u>: November 8, 10, 15, 17, 22, 24. 11:00 – 13:00 hs.

6) **<u>"Effective Chiral Lagrangian"</u>**: Prof. Stefano Rigolin (Padova University)
- <u>Abstract</u>:
- The linear sigma model and its symmetries. To introduce the notation we will discuss the simplest examples of linear sigma model, namely the ones for a U(1)-singlet and SU(2)-doublet (i.e. SO(4)) complex scalar field. Application: the SM custodial symmetry. Representation invariance of the linear sigma model.
- Spontaneous symmetry breaking of the linear sigma model. pi+pi scattering and check of representation invariance. Coupling the sigma model with fermion and fermion masses. Application: QCD at low energy (optional)
- The non-linear sigma model as an effective field theory. The SO(4)/S0(3) effective Lagrangian. Integrating out the "radial" degree of freedom (equation of motion approach). Higher order operators as expansion in momenta.
- The chiral effective Lagrangian. Leading and Next to Leading Order operators. Application to the SU(2)_L x SU(2)_R/ SU(2)_V symmetry breaking case. Introducing Gauge interactions to the chiral effective Lagrangian. Explicit Symmetry breaking terms.
- Optional: CCWZ formalism and/or Axion Chiral Lagrangian
- <u>Timetable</u>: November 21, 22, 23, 24, 25.
January 30, 31.
February 1, 2, 3.
16:00 – 18:00 hs.

7) **<u>"Experimental Neutrino Physics with Large Devices"</u>**: Prof. Luis Labarga (UAM)
- <u>Abstract</u>: Experimental neutrino physics is a major source of breakthrough Scientific results: the well stablished massive nature of the neutrinos that is not compatible with the current Standard Model of Fundamental Interactions, and the serious hints for a non-cero CP violation in the leptonic sector that is eagerly expected to shed light to the fundamental predominance of mass against anti-mass are most important examples.
In addition, those large neutrino underground detectors are serving as powerful neutrino telescopes that provide measurements critical to the development of fundamental cosmology and astrophysics. Supernova SN1987, and Galactic or extra Galactic high energy neutrino fluxes are most important examples.
This Course deals with the main large neutrino experiments: past, current, and future. The basics of their techniques, their above key measurements and others, their differences and complementarity, will be explained and discussed. The lecturer will try to convince the audience about the need (relative to other HEP experiments) of the next generation of devices that will hopefully provide new, fundamental steps in our knowledge of Nature.
- <u>Timetable</u>: December 13, 14, 15. 10:30 – 12:00 hs.; January 17, 18. 10:30 – 12:00 hs.

8) "**Exactly solvable models in low-dimensional many-body physics**": Prof. Germán Sierra Rodero (IFT UAM-CSIC)
- Abstract: In Statistical Mechanics and Condensed Matter Physics there are models that can be solved exactly in low dimensions . They have played a central role in understanding phase transitions, magnetism, superconductors, bose gases, etc. In this course we shall review some of these models like Heisenberg, Ising, Hubbard, Lieb-Liniger, Richardson-Gaudin, etc.
- Bibliography:
    * Field Theory Methods and Quantum Critical Phemonena, I. Affleck, in Les Houches, 1988. North-Holland.
    * Statistical Field Theory: An Introduction to the Exactly Solved Models in Statistical Physics, G. Mussardo, Oxford University Press.
    * Quantum Groups in 2 dimensional Physics, C. Gómez, M. Ruíz-Altaba, G. Sierra, Cambridge University Press.
- Timetable: February 7, 14, 21, 28. 11:00 to 13:00 hs.; March 7, 14, 21, 28. 11:00 to 13:00 hs.

9) "**Dark matter in compact stars**": Prof. Marina Cermeno Gavilan (IFT)
- Abstract: Dark Matter (DM) constitutes most of the matter in the presently accepted cosmological model for our Universe. However, despite the substantial progress on both theoretical and experimental fronts, its nature remains unknown. Some well-motivated DM candidates are difficult to test with conventional searches, encouraging the exploration of new strategies. The extreme conditions (high density and compactness) in the interior of compact stars, such as neutron stars (NSs) and white dwarfs (WDs), could allow them to gravitationally accrete a massive DM component, provided the interaction strength between the luminous and dark sectors is at current experimental level of sensitivity. Moreover, NSs and WDs can be present in environments with a DM density higher than the local one, which further contributes to making them better DM accretors. The existence of DM inside these objects could therefore provide novel indirect DM signatures. In this course I will review the importance of searching for DM around dense stars. I will briefly introduce the need for DM and I will present the properties of NSs and Wds. I will calculate the DM capture rate in stars and I will show how this rate can be enhanced when DM particles are accreted into compact stars. After this, I will analyse different signatures that could be observed due to the presence of DM in these compact objects.
- Timetable: February 13, 15, 20. 16:00 – 18:00 hs.

10) "**Julia for Scientists**": Profs. Juan José Gómez-Cadenas, Andrew Laing & Alberto Ramos
- Abstract: This course targets PhD students that perform numerical simulations/computations in their research. We will address different computational problems in the areas of dynamical systems, algorithms and linear algebra and solve them using the Julia language. The course does not requires any previous knowledge of the language, since the main characteristics and advantages of the Julia language will be explained during the course. However having experience with *another* programming language (python, FORTRAN, C, ...) will be useful. The main objectives of the course is to learn how to write efficient and reproducible data analysis tools useful for the scientific community.
IMPORTANT: A list or prerequisites and instructions to install the software are available in: https://github.com/andLaing/JuliaForScientists
- Timetable: March 13, 15, 16, 17. 11:00 to 13:00 hs.; March 13, 14, 15, 16, 17. 16:00 to 18:00 hs.

11) "**Introduction to indirect searches for dark matter**": Prof. Viviana Gammaldi (UAM)
- Abstract: In this introductory course I will present the fundamentals of indirect searches for dark matter. I will introduce both astrophysical and astroparticles aspects of this research field, within a phenomenological approach. I will explain in detail the main ingredients of the carrier equation, discussing related uncertainty, as well as both theoretical and experimental limitations.
- Timetable: March 21, 23. 16:00 to 18:00 hs.

12) "**Introduction to Collider Phenomenology**": Prof. Jose Miguel No (UAM)
- Abstract: In this introductory course we will present the basics of phenomenology at collider experiments. We will review the key ingredients for analyses at hadron at lepton colliders, discuss the most-widely used elements for BSM studies in the phenomenologist's toolbox (Feynrules, MadGraph, Pythia, Delphes) and explore "real-life" collider studies in Higgs, dark matter and long-lived-particle searches at the LHC.
- Timetable: April 12, 14, 19, 21, 26, 28. 10:00 – 11:30 hs.; May 3, 5, 10, 12. 10:00 – 11:30 hs.

13) "**Quantum Field Theory Anomalies in Condensed Matter Physics**": Prof. Karl Landsteiner (IFT UAM-CSIC)
- Abstract: Anomalies belong to the most emblematic properties of quantum field theories. When a symmetry present in the classical theory cannot be realized in the quantum theory we speak of an anomaly. Traditionally they are associated to high energy and particle physics. In the recent years they have however become a cornerstone of condensed matter physics.
In this course I'll try to
- give a pedagogical introduction to anomalies
- discuss different methods to calculate them
- demystify and give physical interpretations of "consistent" and "covariant" anomalies
- review how anomalies induce dissipationless transport
- show how anomalies classify topological states of matter
- Timetable: May 4, 9, 11, 16, 18, 22. 10:30 to 12:00 hs.

14) "**Experimental approaches to search for new physics**": Prof. Elías López Asamar (UAM)
- Abstract: This course will offer an overview of the different experimental efforts that might lead us to discover new physics effects. After a brief introduction on the theoretical and experimental reasons that motivate the existence of new physics (day 1), the course will give a summary of the current research activity in the areas listed below, along with the respective constraints and standing discrepancies. In each case, a set of references will be also provided, in order to allow students to learn further in their areas of interest.
- Timetable: March 23, 27, 30. 11:00 – 13:00 hs.