Annex 2 - Documento di progettazione iniziale e in itinere

Name of the PhD Programme	
English name	Physics and Astrophysics
Coordinator	Sergio Luigi Cacciatori
Administrative Department	Department of Science and High Technology - DiSAT
Website	https://www.uninsubria.it/formazione/offerta-formativa/fisica-e-astrofisica-xl
Scientific Area	02- Physical Sciences
Scientific Disciplinary Sectors	FIS/01, FIS/02, FIS/03, FIS/04, FIS/05, FIS/07
Research Topics	The topics covered concern several areas of current interest, including: field theories, quantum gravity, statistical physics, non-linear and complex systems, quantum technologies, quantum transport and thermodynamics, condensed matter physics, ultrafast non-linear optics, light scattering by nanoparticles and quantum optics, biophysics, elementary particle physics, photodetectors and their applications, medical physics, data science, exoplanets, extragalactic astrophysics, cosmology, gravitational waves, numerical methods for the simulation of astrophysical systems, the study of time-variable astrophysical phenomena, and the study of big data in astrophysics through machine learning and artificial intelligence techniques.
Curricula	No
Main Language of instruction	English
Duration	3 years
Agreements for double/joint degree, etc.	No
Type	Non-associated
Date of approval by the Department Council	

1 – Programme design

The aim of the program is to develop the skills, operational autonomy, and critical analysis capabilities that are the foundation of basic and applied research. The Department of Science and High Technology, where the proposing research groups operate, has modern, specialized, and well-equipped laboratories where cutting-edge research is conducted. Experimental investigations are supported by leading theoretical groups. Doctoral students can therefore engage in high-profile activities in a competitive, international context. At the same time, they can develop their profile as "industrial researchers," working in synergy with high-profile partner companies. To this end, the program includes specific courses for doctoral students in Physics and Astrophysics, covering various areas of current research interest, such as artificial intelligence, quantum technologies, and general relativity. Research activities will be developed in collaboration with tutors selected from the faculty, as well as by encouraging collaboration with scientists from national and international universities and scientific institutes. Seminars will also be organized on topics such as big data, machine learning, and biophysics, as well as courses related to improving English language skills and written and oral scientific communication, intellectual property, and the valorization of research results. Attendance at at least one international school will also be required (such as, but not limited to, the local Lake Como School, the E. Fermi School in Varenna, and schools organized by ICTP and CECAM). For advanced computer science training, given the diverse skills required by various research fields, it is considered most appropriate to propose that students participate in thematic schools, such as the CERN School of Computing or CINECA courses. The choice of specific courses and other training activities is subject to approval by the Academic Board, which will take into account the individual students' learning needs, including their thesis project.

2 – Consultazioni con le parti interessate

The stakeholder consultation for the Doctoral Programs is inspired by the ongoing updating of doctoral programs to reflect the scientific and higher education profiles expressed by the job market, with a strong focus on innovation. To this end, an Advisory Committee has been established, involving experts from academia, research institutions, schools, industry, and the workplace. Its members are:

Sergio Luigi Cacciatori, Coordinator of the PhD Program in Physics and Astrophysics, Professor of the College, representative for the Theoretical Physics sector

Alessia Allevi, President of the Bachelor's and Master's Degree Programs in Physics, Professor of the College, representative for the Experimental Physics sector

Giovanni Bazzoni, President of the Bachelor's and Master's Degree Programs in Mathematics

Giuliano Benenti, Professor of the College, representative for the Theoretical Physics sector

Brunella Gerla, President of the Bachelor's and Master's Degree Programs in Computer Science

Alessandro Lupi, Professor of the College, representative for the Astrophysics sector

Romualdo Santoro, Professor of the College, representative for the Particle Physics sector

Roberto Della Ceca, Director of INAF - Brera Astronomical Observatory

Monica Bollani, Researcher at CNR - Institute of Photonics and Nanotechnology

Daniele Faccio, Professor at the University of Glasgow

Fabrizio Favale, Einstein High School, Milan

Gueorgui Mihaylov, Principal Data Scientist at Haleon Group, London

Francesco Caponio, Nuclear Instruments, Lambrugo

Ferrante Enriques, Partner and Head of Information Systems at Zanichelli Editore SPA

Valentina Riva, Head of Strategists at Mercuria Energy Trading, Geneva

Riccardo Bosisio, Strategy and Corporate Development Director at Candriam, Paris

Elonora Rubino, Product & Process Change Manager at Quanta System SpA, Samarate

Antonella Pugliese, Ferraris High School, Varese

Stefano Carsi, Nuclear Instruments, Lambrugo

Giosuè Saibene, representing the PhD students of the XXXIX cycle

Matteo Onate, representing the PhD students of the XL cycle

Sofia Mangiacavalli, representing the PhD students of the XLI cycle

3 – Teaching Staff

Indicare la composizione del Collegio (come da scheda di Accreditamento)

n.	Surname	Name	Ateneo	Department/ Structure	Role	Qualification	Competition Sector	CUN Area	SSD
1.	*ALLEVI*	*Alessia*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Associato (L. 240/10)*	*02/B1*	*02*	*FIS/01*
2.	*BENENTI*	*Giuliano*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Ordinario (L. 240/10)*	*02/B2*	*02*	*FIS/03*
3.	*CACCIA*	*Massimo Luigi Maria*	*INSUBRIA*	*Science and High*	*COMPONENTE*	*Professore Ordinario*	*02/A1*		*FIS/01*

				Technology				*02*	
4.	*CACCIATORI*	*Sergio Luigi*	*INSUBRIA*	*Science and High Technology*	*Coordinatore*	*Professore Associato (L. 240/10)*	*02/A2*	*02*	*FIS/02*
5.	*CASPANI*	*Lucia*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Associato confermato*	*02/B1*	*02*	*FIS/03*
6.	*CLERICI*	*Matteo*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Associato confermato*	*02/B1*	*02*	*FIS/03*
7.	*GINELLI*	*Francesco Giulio*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Associato confermato*	*02/A2*	*02*	*FIS/02*
8.	*HAARDT*	*Francesco*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Ordinario (L. 240/10)*	*02/C1*	*02*	*FIS/05*
9.	*LAMPERTI*	*Marco*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Ricercatore a t.d. - t.pieno (art. 24 c.3-b L. 240/10)*	*02/D1*	*07*	*FIS/05*
10.	*LUPI*	*Alessandro*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Associato (L. 240/10)*	*02/C1*	*02*	*FIS/05*
11.	*NARDO*	*Luca*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Associato (L. 240/10)*	*02/D1*	*02*	*FIS/07*
12.	*PAROLA*	*Alberto*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Ordinario*	*02/B2*	*02*	*FIS/03*
13.	*PIATTELLA*	*Oliver Fabio*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Associato (L. 240/10)*	*02/A2*	*02*	*FIS/02*
14.	*PRATI*	*Franco*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Associato confermato*	*02/B2*	*02*	*FIS/03*
15.	*PREST*	*Michela*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Ordinario (L. 240/10)*	*02/A1*	*02*	*FIS/04*
16.	*SANTORO*	*Romualdo*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Associato (L. 240/10)*	*02/A1*	*02*	*FIS/01*
17.	*SORMANI*	*Mattia Carlo*	*INSUBRIA*	*Science and High Technology*	*COMPONENTE*	*Professore Associato confermato*	*02/C1*	*02*	*FIS/05*
n.	**Surname**	**Name**	**Ateneo**	**Department/ Structure**	**Role**	**Qualification**	**Competition Sector**	**CUN Area**	**SSD**

n.	**Surname**	**Name**	**Type of Institution:**	**Institution**	**Country**	**Qualification**	**SSD**	**Competition Sector**	**CUN Area**
1.	*BONDANI*	*Maria*	*Institution of Research (VQR)*	*National Council of Research*	*Italy*	*First Researcher*	*FIS/01*	*02/B1*	*02*
2.	*CACCIANIGA*	*Alessandro*	*Institution of Research (VQR)*	*National Institute of Astrophysics*	*Italy*	*First Researcher*	*FIS/05*	*02/C1*	*02*
3.	*COVINO*	*Stefano*	*Institution of Research (VQR)*	*National Institute of Astrophysics*	*Italy*	*Research Director*	*FIS/05*	*02/C1*	*02*
4.	*JEDRKIEWICZ*	*Ottavia*	*Institution of Research (VQR)*	*National Council of Research*	*Italy*	*First Researcher*	*FIS/03*	*02/B1*	*02*
5.	*LANDONI*	*Marco*	*Institution of Research (VQR)*	*National Institute of Astrophysics*	*Italy*	*Researcher*	*FIS/05*	*02/C1*	*02*
6.	*NAVA*	*Lara*	*Institution of Research (VQR)*	*National Institute of Astrophysics*	*Italy*	*First Researcher*	*FIS/05*	*02/C1*	*02*
7.	SCODEGGIO	Marco	*Institution of Research (VQR)*	*National Institute of Astrophysics*	*Italy*	*First Researcher*	*FIS/05*	*02/C1*	*02*

La composizione e qualificazione del Collegio dei Docenti deve essere oggetto di divulgazione pubblica (web), anche mediante pubblicazione del CV dei docenti.

4 – Description of the training and research project

The focus area is the Physical Sciences, which are divided into the Physics and Astrophysics curricula.
Regarding the Physics curriculum, teaching and research activities cover various areas of current interest, including field theories, quantum gravity, statistical physics, nonlinear and complex systems, quantum technologies, quantum transport and thermodynamics, condensed matter physics, ultrafast nonlinear optics, light scattering by nanoparticles and quantum optics, biophysics, elementary particle physics, photodetectors and their applications, medical physics, and data science.

Regarding the Astrophysics curriculum, teaching and research activities, carried out in close collaboration with the National Institute for Astrophysics, concern various areas of current interest, including exoplanets, extragalactic astrophysics, cosmology, gravitational waves, numerical methods for simulating astrophysical systems, the study of time-varying astrophysical phenomena, and the study of big data in astrophysics using machine learning and artificial intelligence techniques.

Educational Objective
The primary objective of the Doctorate is to develop the skills, operational autonomy, and critical analysis capabilities that are the foundation of basic and applied research. The Department of Science and High Technology, where the proposing research groups operate, has modern, specialized, and well-equipped laboratories where cutting-edge research is conducted. Experimental investigations are supported by leading theoretical groups. Doctorate students can therefore engage in high-profile activities in a competitive, international context. At the same time, they can develop their profile as "industrial researchers," working in synergy with high-profile partner companies. Graduates of the Doctorate in Physics demonstrate strong operational and intellectual autonomy, are accustomed to collaborative research in highly competitive international contexts, and have developed a systemic approach to problem solving. Depending on the research context, these general characteristics are associated with advanced expertise in the quantitative analysis of large amounts of data, knowledge of cutting-edge technologies, and/or advanced mathematical methods. Consequently, while academic and industrial research remains the primary professional development context, individuals qualified by a PhD in Physics can aspire to career paths in the research departments of banks and financial institutions, in the R&D departments of high-tech companies, and in technology consulting firms. Finally, it should be emphasized that teaching in schools represents an important career opportunity.

Core Educational Activities
The training program primarily requires the acquisition of 60 hours of academic credits to be chosen from the following internal courses, each lasting 20 hours, within the curriculum, according to a learning plan approved by the Teaching Committee. Following consultation with the Advisory Committee, the curriculum may be expanded based on the availability of faculty to cover the courses recommended by the Committee members (see the attached extract from the minutes of the meeting with the Advisory Committee).
Among these, the course "Scientific Communication" by journalist Davide Re is guaranteed and is currently being planned.

Relativistic astrophysics (Luigi Foschini, I e II anno)
Short summary:
- Classical Relativity (Galilean)
- Special Relativity (Minkowski spacetime, beaming, superluminal motion)
- General Relativity (tensors)
- Equations of the Gravitational Field and solutions of astrophysical interest (black holes, cosmology, gravitational waves)

- Radiative Processes (bremsstrahlung, synchrotron, Compton scattering)
- Accretion onto compact objects (types of accretion disk, corona and X-ray emission lines)
- Outflows: winds and relativistic jets
- Instruments and Data Analysis for high-energy astrophysics (hardware, software, calibration)
- Hands-on examples of X-ray data analysis (data of *Neil Gehrels Swift Observatory*).

Lecture notes will be available at due time (currently under revision).

Feynman path integrals (Phil Ratcliffe, I e II anno)

This short lecture series provides a very brief introduction to the Feynman Path Integral approach to quantisation, which represents a completely original and alternative axiomatic basis for quantum theories. While developed within the framework of non-relativistic quantum mechanics, the method is of particular importance (for its clarity and simplicity) in second or field quantisation. However, it finds useful applications in many other areas, as diverse as statistical mechanics and even, for example, financial analysis. Being limited to eight hours of front-on lectures, little attention is paid to mathematical rigour. In other words, a description of the physical basis and significance will be provided, together with some of the interesting applications of the technique of relevance to physics.

Quantum Technologies (Alessia Allevi, Giuliano Benenti, Maria Bondani, I anno)

The second quantum revolution is unfolding now, exploiting the enormous advancements in our ability to detect and manipulate single quantum objects and triggering the development of the different quantum technologies. The course, after a preliminary introduction to the principles of quantum information, is intended to give an introduction to the different quantum technologies for computing, simulation, communication, metrology, and machine learning, including quantum optics laboratory demonstration of quantum information protocols.

Introduction to non equilibrium statistical physics (Francesco Ginelli, II anno)

Classical statistical mechanics describes system at thermodynamic equilibrium. However, a wide range of natural systems, ranging from climate to virtually all living matter, are kept out of equilibrium by external driving and/or fluxes of energy which is constantly absorbed and dissipated through the system.

This course introduces some of the concepts employed in the study of macroscopic systems away from their state of thermodynamic equilibrium, mainly covering kinetic theory, stochastic processes and linear response. These constitute the principles to describe systems slightly perturbed out of equilibrium. Other selected topics may include active matter, pattern formation and systems with absorbing states.

Non-Newtonian aspects of general relativity (Sergio Cacciatori, II anno)

This is a 20-hour course, where some specific aspects of the general relativistic dynamics will be discussed, compared to the analogous mechanisms in Newtonian gravity, when allowed. The main arguments included in the course are:

-Einstein equations and their comparison with Newtonian gravity: time dependence, non-harmonicity tensorial character, non-linearity.

-Gravitational waves: generation and detection; weak and strong gravitational waves, effective one body formalism.

-Dragging effects and weak and strong gravitomagnetism, with applications to the motion of massive bodies and galaxies

However, modifications on the program can be considered on demand, to adapt the details of the lessons to the specific needs of the students.

Complements of theoretical physics (Sergio Cacciatori, I anno)

This is a 20-hour course, with the aim of presenting some advanced topics in theoretical physics, related with the physics of the standard model and/or general aspects of theoretical physics. The main arguments proposed by the course are:

-Symmetries in quantum field theory: Lie groups, spontaneous symmetry breaking of global

symmetries and local symmetries, symmetries in path integral formalism, anomalies.
-Feynman integrals in classical and quantum theories. Methods of computation of the Feynman integrals and related twisted cohomology.
-The geometry of the Standard Model of Particles and possible extensions to grand unification models.
According to the interests of the participating students, it is possible to consider a short introduction to all such arguments, or to develop more deeply one of them if needed.

Theory of Cosmological Perturbations (Oliver Piattella, I anno)
Perturbations about the FLRW metric and the problem of the gauge; the scalar-vector-tensor decomposition; Einstein equations and Boltzmann equations for perturbations; primordial modes: adiabaticity and isocurvature initial conditions; the inflationary paradigm; solutions for the evolution of perturbations; the matter power spectrum and the CMB power spectra.

Basics and applications of FPGAs (Alessia Allevi, Andrea Abba, Stefano Carsi, Marco Lamperti, I anno)
The use of FPGA systems is motivated by their ability to provide fast, deterministic, and real-time processing of signals. The course begins with an introduction to FPGA systems, explaining what they are, what they are used for, the available alternatives, and how they are programmed (2 hours). It then focuses on the use of Sci-Compiler, a dedicated software, to program a digital charge integration system, including hands-on sessions using personal computers and an evaluation board provided by the instructors (14 hours). Finally, a laboratory use case is presented involving a 14-bit digitizer for acquiring signals from a pair of silicon photomultipliers used in the characterization of quantum light (4 hours).

Numerical methods for astrophysics (Alessandro Lupi, I anno)
The course "Numerical methods for astrophysics" is meant to introduce state-of-the-art numerical modelling techniques employed in astrophysics and will cover 20 hours. In detail, the following topics will be covered:
- Newtonian dynamics and the N-body problem (grid-based vs particle-based methods)
- Advanced techniques for computational hydrodynamics: adaptive mesh refinement vs moving-mesh vs mesh-free methods, advantages and limitations
- High performance computing: code development and optimization

Time series analysis for astrophysicists (Stefano Covino, I e II anno)
Time series are ubiquitous in astrophysics. This course is aimed at providing PhD students the main capabilities to extract physical information with state-of-the-art statistical inferences from the available datasets. We will refer to real science cases developed in the astrophysical literature, yet the discussed methodologies could be of definite interest to anyone involved in quantitative analysis of data in a temporal (or spatial) sequence in any field of modern physics, economy, engineering and social sciences.
At the end of the course students will be able to:
•carry out analysis of any statistical problem in a full Bayesian framework
• properly model time series to derive meaningful statistical inferences about stationarity,
• short and long-term memory behavior;
• deal with data irregular spaced and/or affected by correlated noise
• apply big-data techniques to carry out the analyses of typical large datasets obtained by modern astrophysical facilities.
More specifically the main topics of the course are:
• Time (and spatial) variability in astrophysics
• Time- domain analysis and auto-regressive processes
• Irregular sampling, Lomb Scargle periodograms
• Case studies: ANG variability
• Advanced topics: non-parametric analysis
• Matching filter

• Case study: LIGO/Virgo gravitational wave signals
• Big-data machine learning and intelligent systems for time- series analysis
• Case studies: spatial variability /CMB, large scale structure)

QFT on curved spacetimes (Ugo Moschella, I e II anno)
The course is intended as a short introduction to Quantum Field Theory on curved spacetimes. In doing this I will also discuss some topics in General Quantum Field Theory that are not always taught in standard QFT courses. Topics that will be covered are: 1) Quantization. CCR and CAR algebras. Representations of the commutation rules. The Stone-Von Neumann theorem and its failure.
2) Quantization of fields. Canonical quantization of the Klein Gordon field in Minkowski spacetime. Commutators. Propagators. Two-point functions. Quantum fields as distributions. N-point functions. Reconstruction theorem.
3) The spectral condition and its consequences.
4) KMS equilibrium states. Bogoliubov transformations. Generalized Bogoliubov transformations. The Unruh effect
5) Canonical Quantization of fields in curved spacetimes. General formalism. The Local Hadamard condition. The microlocal spectrum condition. Renormalization. The Casimir effect.
6) Examples. Expanding universes. Bogoliubov transformations. Particle creation by expansion.
7) Thermal equilibrium states. The Hawking effect.
8) Quantum field theory on the de Sitter spacetime. De Sitter invariant vacua. Preferred vacuum. The thermal interpretation. Massless Fields. Applications. Instabilities.
9) Quantum field theory on the anti de Sitter spacetime. The AdS-CFT correspondence.

Textbooks
N.D. Birrell, P. C. W. Davies. *Quantum Fields Curved Space*. Cambridge University Press (1982)
S. A. Fulling. *Aspects of quantum field theory in curved space-time.* Cambridge University Press (1989)
R.M. Wald. *Quantum field theory in curved space-time and black hole thermodynamics.* Chicago U. (1995)

Astrochemistry (Alessandro Lupi, I anno)
- Introduction to Astrochemistry.
- The interstellar medium: physical conditions, regions and different components.
- Radiative and collisional excitation processes.
- Basic processes in Astrochemistry.
- Gas-phase processes.
- Photochemistry: ionisation and dissociation.
- Cosmic rays.
- Solids in the interstellar medium.
- Thermal processes.
- Case study: Chemistry in molecular clouds (the molecular factory).

Probing Vibrational Modes with Light: Principles and Practice of Raman Spectroscopy (Marco Lamperti, I e II anno)
This laboratory course provides a self-contained introduction to Raman spectroscopy, combining theoretical foundations with hands-on laboratory sessions. The course follows a research-driven approach: after a theoretical introduction and a laboratory session covering instrument usage and data analysis on predefined samples, the students will work on designing and carrying over a final experiment. The exam will consist in live discussion of the results during the final project.
Program summary:
Theoretical foundations (3 lessons, 2h each)
-Physical principles of Raman scattering: classical and quantum description of light-matter

interaction, vibrational selection rules, spectral interpretation
-Instrumentation of a dispersive Raman spectrometer: light sources, optical components, detector physics, noise sources and signal-to-noise optimization

Laboratory sessions (2 lessons, 4h each)
-Overview of the setup, instrument operation, spectral acquisition and processing
-Molecular vibrations in pharmaceutical solids (e.g. paracetamol, caffeine): spectral assignment and polymorphism
-Phonons in inorganic materials (TiO_2, graphene if available): phase identification and layer characterization
-Overview of advanced techniques (FT-Raman, UV resonance Raman, Raman imaging) as a perspective module, expandable depending on student's interests

Final project (3 lessons, 2+3+3h)
-Discussion of proposals with the teacher and design of the experiment
-Investigation of the research question using Raman spectroscopy and possibly other techniques (such as infrared and UV-VIS spectroscopy)
-Depending on the outcomes, there is the possibility of extending the collaboration beyond the course with the goal of contributing to an original research publication

Laser-Driven Radiation Sources: Science, Technology and Applications (Matteo Clerici, I e II anno)
This short course introduces students to the technological aspects and applications of laser-driven sources of radiation, one of the most active areas of research in laser physics today. The course begins with a brief introduction to ultrafast lasers, followed by an overview of the science, technology, impact, and applications of state-of-the-art secondary sources. These include parametric amplifiers (mid-infrared sources), optical rectification or photoconductive switching (THz sources), and non-perturbative light-matter interactions (high-order harmonic generation).

Fundamentals and Applications of Optical Metrology (Lucia Caspani, I e II anno)
This short course introduces students to the basic concepts of optical metrology and provides an overview of the current state-of-the-art for some of its most advanced and widespread applications. The course begins with an introduction to the theoretical aspects of optical metrology and the physical mechanisms underpinning its applications. It then analyzes examples of transformative metrological applications, such as interferometry (empowering the observation of phenomena like gravitational waves), spectroscopy (e.g., time-resolved spectroscopy with unparalleled sensitivity), and dual-comb spectroscopy (used e.g., astrophysical observations).

Advanced Concepts of Light-matter interaction and their applications (Ottavia Jedrkiewicz, I e II anno)
This short course introduces students to the basic concepts of light-matter interactions and their applications. It begins with an introduction to laser physics and the different regimes of light-matter interaction driven by intense laser fields. The course then focuses on key applications of lasers, such as micromachining (cutting, drilling, and machining of transparent materials), medical applications (e.g., eye surgery), and applications to astrophysics (spectroscopy and interferometry).

Selected topics in astrophysical fluid dynamics (Mattia Sormani, I e II anno)
Argomenti trattati (un sottoinsieme di)
- Fundamentals of hydrodynamics: continuity and Euler equations, equation of state, conservation of mass/momentum/energy, viscosity and thermal conduction, Lagrangian vs Eulerian views, vorticity equation, Kelvin circulation theorem, rotating frames, radiative heating & cooling, Reynolds number
- Fundamentals of magneto-hydrodynamics: MHD equations, induction equation, magnetic pressure and tension, magnetic flux freezing, magnetic fields amplification.

- Hydrostatic equilibrium: polytropic and isothermal spheres, polytropic and isothermal slabs, application: Chandrasekhar upper mass limit for white dwarfs
- Spherical steady flows: Parker solar wind and Bondi spherical accretion
- Waves: sound waves, water waves, group velocity, analogy between shallow water theory and gas dynamics, MHD waves (Alfvén waves, fast and slow waves), internal gravity waves
- Shocks: steepening of sound waves and the formation of shocks, 1D jump conditions at discontinuity (Rankine-Hugoniot conditions), Mach number, MHD shocks, shock thickness in the presence of viscosity
- Spherical blast waves: strong explosion in uniform atmosphere, Sedov-Taylor self-similar solution, application: supernovae
- Instabilities: Kelvin-Helmholtz instability, Thermal instability, Rayleigh instability, rotational instability and Rayleigh criterion, magneto-rotational instability, Jeans instability
- Gravity: Legendre expansion, Gauss's Law, Poisson equation, Tidal forces, Virial theorem. Applications: calculation of moon tides, stability of satellites in orbit around the Earth
- Elements of turbulence, Kolmogorov's theory
- Rotating equilibria and thick discs: barotropic equilibria and Taylor-Proudman theorem, baroclinic equilibria, Solberg-Hoiland stability criterion
- Accretion discs: inviscid thin disc, viscous evolution of a thin disc and spreading of a thin ring, steady-state viscous thin discs, angular momentum transport, Shakura-Sunyaev alpha-disc "standard" model, emitted spectrum, the Eddington limit, angular momentum transport in discs
- Effects of rotation on waves, epicyclic frequency and Lindblad resonances, density waves in discs, Toomre instability, Papaloizou-Pringle instability

Other educational activities

Seminars

Seminars by visitors from the Department of High Technology are planned on various topics of current interest, such as data science, big data, machine learning, artificial intelligence, quantum technologies, and biophysics. The detailed seminar program will be established during the meetings of the Faculty of Science and Technology and will take advantage of the opportunity to attract visitors through our University's visiting professor program or through other available funds.

Course on "The exploitation way: from curiosity driven research to the market"

Research is essentially curiosity driven and aimed to extend our knowledge of natural and social phenomena. However, quite often research results, together with the technology and know-how developed to achieve them, do have a value for society at large with a potential impact that can be disruptive. But exploitation is not an easy game: the industrial and research communities are driven by different principles and targets, speak a different language and yet today there is a soft reciprocal mistrust, often preventing to establish links that can lead to win-win situations.
Through the lectures, advantages of respectful collaborations will be analyzed, together with schemes ranging from contract to collaborative research to end up with company creation. The question of intellectual property protection will also be addressed, comparing patenting, full unbound disclosure, open software and open hardware approaches.

Course on "Scientific Communication: Written and Oral"

Correctly communicating one's own result is an essential skill that every young scientist need to learn. This may range from writing a PhD dissertation or a paper for peer-review to giving a talk at a conference.
In this brief soft skills course, we will review the essential of written and oral communications from a practicing physicist standpoint. In particular, we will discuss how to frame your results in the wider context of existing research, how to describe correctly your results and/or present your data, how to adapt your talk to the kind of audience you are facing and related issues. The course consists in frontal lectures, talks exercises and assignments.

English language course for doctoral students

This course is optional and open to all doctoral students who wish to attend.

The course will focus on improving and consolidating the four fundamental language skills (listening, reading, speaking, and writing) and will provide participants with useful strategies for a possible certification exam (B2 FIRST – Cambridge Assessment English, Level B2 of the Common European Framework of Reference for Languages, CEFR). Lessons will be complemented by a blended English language learning program using the MacMillan English Campus (MEC) software platform. This includes listening and reading comprehension, pronunciation, and grammar exercises tailored to the individual doctoral students' level and designed to gradually acquire the skills necessary to reach the B2 level required for potential certification. Additional language support is also available from the new university language center (CLA).

Italian or foreign doctoral students are exempt from the certification exam if they:

• have attended, for the entire duration of their degree program, at least one year of college in countries where English is the language of instruction;

• have completed at least one year of mobility during their degree program, studying in English;

• have spent at least six months abroad during their doctoral program in countries where the official language is not Italian;

• have obtained a university degree, in Italy or abroad, at the end of a second-level program taught entirely in English;

• have obtained:

- a degree in Foreign Languages and Literatures, Modern Foreign Languages and Literatures, Translators, Interpreters, Translation, and Interpreting (English only), completed in at least three-year courses, in accordance with the regulations prior to Ministerial Decree 509/1999;
- a degree under the Ministerial Decree 509/1999 in classes L-11 Modern Languages and Cultures or L-3 Linguistic Mediation Sciences, whose study plan included a three-year English language course;
- a degree under the Ministerial Decree 270/2004 system in classes L-11 Modern Languages and Cultures and L-12 Linguistic Mediation, whose study plan included a three-year English language course.

Self-certification or verification of exemptions is verified by the PhD program board. The School's secretariat records the positive or negative evaluation of exemptions for the purpose of updating students' records on Esse3.

Doctoral Schools

Attendance at at least one international school will also be required (such as, but not limited to, the local Lake Como School, the E. Fermi School in Varenna, and schools organized by ICTP and CECAM).

Computer Science Course

For advanced computer science training, given the diverse skills required by various research fields, it is considered most appropriate to encourage students to participate in thematic schools, such as the CERN School of Computing or CINECA courses. The choice of specific courses and other training activities is subject to approval by the Teaching Board, which will take into account the individual students' learning needs, including their thesis project.

Research Training Activities

Regarding research, in addition to possible collaboration with tutors' research activities, students will be encouraged to participate in international schools, workshops, and conferences. This will be done both for the experiential purpose of presenting their research and for the purpose of establishing collaborative approaches with researchers and colleagues from institutions outside their own university, both nationally and internationally.

Additionally, meetings will be organized with companies potentially interested in hiring physicists and astrophysicists, aimed at fostering both potential collaboration during the doctoral program and potential career opportunities upon completion.
Visits to foreign institutions for a total of at least two months over the three-year period, visits to other laboratories, and involvement in industrial and applied research activities, possibly with the co-supervision of company personnel, will also be encouraged.

Interdisciplinary, Multidisciplinary, and Transdisciplinary
Doctoral students will be asked to include in their study plan, in addition to specific choices relevant to their research project, a multidisciplinary component. This may consist of choosing one of the courses not directly related to their specific field, and/or the addition of courses taken at other universities or international schools, on topics complementary to their research, following approval and recognition by the faculty.
To the same end, seminars and mini-courses will be organized by invited external instructors on interdisciplinary topics. Periodic seminar series will also be organized by the students of the school, aimed at disseminating their research activities to other areas and, conversely, at learning how to apply their research experience to other fields. These will include so-called cross-disciplinary seminars, in which doctoral students will be asked to present to their colleagues, in a manner that everyone can understand, research topics that cut across their own field, preferably chosen to demonstrate the applicability of their expertise to other fields. Where possible, collaboration with colleagues and researchers from other scientific fields will also be encouraged.

Criteria for Selecting Academic Supervisors and Company Co-Supervisors
The selection of supervisors must be tailored to the research activity of each doctoral student. For this reason, the research activity of the individual project is first evaluated by the members of the Faculty of Medicine, who select, possibly through a direct interview with the interested student, the most experienced in the relevant research field. The selected supervisor may then use his or her expertise to select, if necessary, a co-supervisor within the same university or at any recognized national or international institution or company, chosen from among the leading experts available. The final selection of supervisors will then be submitted to the Doctoral Faculty of Medicine for approval.

The training project will be published in a dedicated section of the University website.

5 – Resources

The Department of Science and High Technology, where the proposing research groups operate, has modern, specialized, and well-equipped laboratories where cutting-edge research is conducted. Experimental investigations are supported by leading theoretical groups, as evidenced by the high scientific productivity and intense international collaboration. Doctoral students can therefore engage in high-profile activities in a competitive, international context. At the same time, they can develop their skills as "industrial researchers," working in synergy with high-profile partner companies.

ANNEX:

EXTRACT FROM THE MINUTES OF THE CONSULTATION OF 13.04.2026 DOCTOR OF RESEARCH IN PHYSICS AND ASTROPHYSICS

………..

Fabrizio Favale, Liceo Scientifico Einstein, Milano:

"………..

-The courses seem to me to be unbalanced toward theoretical training aspects... I think some more experimental courses would be desirable.

-I suggest a mini-course on managing logistics and the administrative-legal aspects of research in Italy and abroad. (Expenditure planning, funding research, stakeholders, presentation of national and international projects) Years ago, ERC representatives highlighted the shortcomings of Italian projects, not so much in terms of innovative scientific-technical content, but in terms of formal, organizational, and legal aspects and in terms of formal correctness with respect to the requirements of the calls for proposals.

Riccardo Bosisio, Strategy and Corporate Development Director at Candriam, Parigi:

"………..

the impression is that there is a certain imbalance between theoretical physics and astrophysics.

……….. It seems that some areas are significantly more represented than others. I don't know if this is a problem: I'll just leave it up to you to decide whether it's worth reviewing the way these areas are divided, without altering the curriculum.

………..

Ferrante Enriques, Partner and IT Manager at Zanichelli Editore SPA:

"………..

A physicist's education at an Italian university already prepares them for entry into the current world of work: It provides the flexibility and problem-solving skills that are highly valued in companies, yet very rare. A well-trained physicist who knows nothing about how a company works will always be preferable to a mediocre one with a good understanding of the professional field. Therefore, any additional courses or changes in the teaching structure should not detract from this distinctive and unique quality.

That said:

- Numerical methods, data science, and artificial intelligence applied to physics. I imagine that, like all professions, physics could also benefit from the help of AI tools (in the broadest sense). If I've read correctly, much of the research in biophysics, such as on the structure of proteins, is now conducted using neural networks. But you've probably already thought of that.

- Computer science, especially in the areas that might be of interest to a physicist or that a physicist lacks: models, algorithms, software architecture, and business information technology.

- Basics of business administration.

- Not a real course, but a career guidance service. What jobs are available outside of research for a physicist?

I'd add a point regarding guidance: obviously, it's not a course, but it could also be meetings with professionals from various fields. In that case, I'd be happy to discuss IT in the workplace (rather than publishing, which is a bit of a niche).

Monica Bollani, CNR researcher – Institute of Photonics and Nanotechnologies:

"A possible suggestion for further activity is the following:

A training laboratory or methodological workshop for the following activity:

The activity aims to provide doctoral students with advanced training in the principles, methods, and practices of scientific project design in the European context, with particular reference to the preparation of competitive research proposals under the main European Union funding programs. The training program will explore the constituent elements of a scientific proposal—from the state of the art and the formulation of research objectives, to the definition of the methodology, work plan, scientific and socioeconomic impact aspects, as well as dissemination strategies, exploitation of results, and project management. The activity will integrate theoretical framework sessions with applied seminars, critical analysis of case studies, and guided exercises, in order to develop advanced skills in doctoral students in scientific project writing, building research partnerships, and interpreting the evaluation criteria adopted at the European level.

……..

Alessia Allevi suggests that one way to overcome the difficulty of organizing experimental courses could be to bring together like-minded people in companies who are willing to organize a joint course, thus avoiding having to ask for a heavy teaching load from people who cannot be paid. Courses of this kind could also be of interdisciplinary or cross-disciplinary interest.

……..

Finally, he suggests that Davide Re (journalist, deputy head of the cultural section of Avvenire, expert in the subject, and university assistant in the chairs of Law and Ethics of Information and Communication of the Criminal Process in History, within the Department of Human Sciences and Innovation for the Territory, at the University of Insubria) could be asked to teach a course in scientific communication.

……..