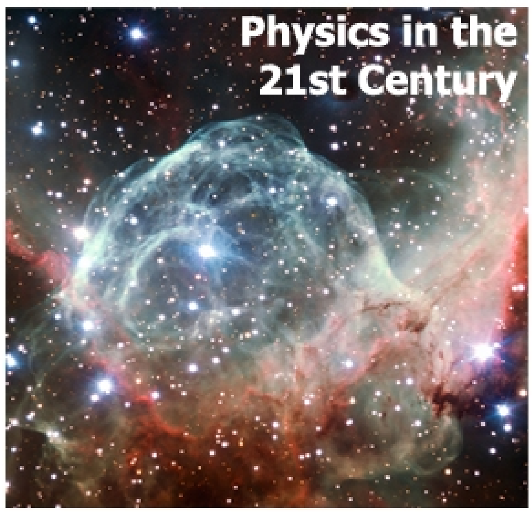
UC REAL Summer Programs 2014

Physics in the 21st Century



The aim of this course is to provide an overview of some of the hottest topics in Physics. The intention is not to cover the whole spectra, but to rather concentrate on three main areas in which significant research is being done at our University. Throughout the course some of the main concepts and latest results in Astronomy, Particle Physics and Nanophotonics will be reviewed by researchers from the Applied Physics Department of the Faculty of Science and of the Institute of Physics.

Program Director: Prof. Francisco Matorras, Dean of Sciences

Program Coordinator: Dr. Marcos López-Caniego

Timetable:

	Monday	Tuesday	Wednesday	Thursday	Friday
Week 1	Astro	Astro	Astro	Astro	-
Week 2	Astro	Astro	Astro	Astro	-
Week 3	Photonics	Photonics	Photonics	Photonics	Photonics
Week 4	HEP	HEP	HEP	HEP	-

Photonics Bibliography

- "Science at the nanoscale: An introductory text book" Ch.W. Shong; S.Ch. Haur; A.T.S. Wee. 2010, Pan Stanford Pub.
- "Nanotechnology: A gentle introduction to the next big idea" M. Ratner and D. Ratner. 2003, Prentice Hall.
- "Nanophotonics" P.N. Prasad. 2004, Wiley-Interscience.

Astronomy Bibliography

- “The Cosmic Century: A History of Astrophysics and Cosmology”, M. Longair, 2006, Cambridge Univ. Press
- “Astronomy” J.D. Fix, 2004, McGraw-Hill.
- “Astronomy: A physical perspective” M.L. Kutner, 2003, Cambridge University Press.
- “Cosmological inflation and large-scale structure” A.R. Liddle, D.H. Lyth, 2000, Cambridge University Press.
- “Theoretical Astrophysics, Volume 3: Galaxies and Cosmology” T. Padmanabhan, 2002, Cambridge University Press.
- “An introduction to Galaxies and Cosmology” Ed. M.H. Jones, R.J.A. Lambourne, 2004, Cambridge University Press.
- “An introduction to the Solar System” Ed. N. McBride, I. Gilmour, 2004, Cambridge University Press
- “An introduction to the Sun and Stars” Ed. S.F. Green, M.H. Jones, 2004, Cambridge University Press

HEP Biblography

- Detectors for Particle Radiation, second ed. K. Kleinknecht, 1999, Cambridge University Press.
- Particle Physics in the new millenium, 2003, Springer

Physics of the Universe: Modern Astronomy

This part of the course will guide the student through our knowledge of the Universe, when it was originated and how it has evolved to what we see now.

We will review the current cosmological model, from the origin of the Universe to the formation of galaxies and clusters of galaxies. We will introduce some key questions in modern cosmology: the Big-Bang and the inflationary paradigm, when did the first elements formed, how the most ancient light in the Universe (the cosmic microwave background) was originated and which is the information encoded in its anisotropies, what is the dark matter and its role in the structure formation, and what is behind dark energy and the accelerated expansion of the Universe. We will learn how to search for supermassive blackholes, and review the instrumentation used to explore the content and evolution of the Universe across the electromagnetic spectrum: from telescopes on the Earth to space observatories. Finally we will visit a nearby astronomical observatory to learn the basics of optical telescopes and observations.

Each day the lecture will be devoted to one topic. Preparatory material will be provided in advance. The format of the lectures will be as follows: first, the topic of the day will be presented in a comprehensive way, oriented towards a broad audience. Then, the instructor will open the students for active participation. Finally, the students will be asked to present one of the topics covered that day to the rest of the class. We will close the course with a panel session where students and instructors will discuss about a selection of topics covered in the course.

Additional activities:

Visit to IFCA Supercomputing Cluster

Visit to the Cantabria Astronomical Observatory

Public evening session to observe the moon and planets at the IFCA observatory

Week 1

Day 1: Modern Astronomy. An overview.

The first lesson of the course will introduce, from a historical perspective, the development of Astrophysics and Cosmology. We will take a guided tour through the Universe: The Sun and the Solar System, stars and exoplanets, the interstellar medium, the Galaxy, galaxies, clusters and the Universe (special emphasis on topics not covered in detail during the rest of the course).

Day 2: Early Universe: Inflation, Primordial Nucleosynthesis and Cosmic Microwave Background.

This lesson will focus on the very early Universe. We will briefly introduce the basics of the Cosmological Principle, the Einstein theory of gravity, the inflation conjecture and the Friedmann equations that describe the expansion of the Universe. Together with the expansion of the Universe, we will introduce the other two observational phenomena that form the basic pillars of modern Cosmology: the primordial nucleosynthesis and the Cosmic Microwave Background.

Day 3: Dark ages and the reionization of the Universe: 21cm and first stars.

Following the formation of the Cosmic Microwave Background, the Universe underwent a period of *dark* expansion before the first stars and galaxies originated. During these poorly known *"dark ages",* the original tiny density fluctuations of the primordial soup collapsed under gravity, until they formed the seeds of the first galaxies and galaxy clusters. We will review these *dark ages*, that, for the first time, are beginning to be accessible to our radio telescopes via the observation of the redshifted 21-cm hydrogen line. Then we will study how the first stars formed, reionizing the surrounding medium, restarting the chemical evolution of the interstellar gas and shedding light into the darkness that until that moment filled up the Universe.

Day 4: Large Scale Structure. Dark Matter and Dark Energy.

This lesson illustrates the current content of energy and matter of the Universe. We will highlight the leading role played by the two species for which there is not a satisfactory explanation yet. On the one hand the Dark Matter, which governs the process associated to the large-scale structure formation and, on the other hand, the Dark Energy, responsible for the observable accelerated expansion of the Universe. We will review how different cosmological tests provide strong evidence for their existence, and summarize the experiments designed to probe their nature.

Week 2

Day 1: Galaxies

We will study the properties and contents of galaxies, and their Morphological and spectroscopic classification. We will explore the stellar populations and star formation activity across cosmic times using a multi-wavelength approach. Groups and clusters of galaxies. Mergers and interactions of galaxies: observations and simulations. Galaxy formation and evolution.

Day 2: Supermassive Black Holes (SMBH) and their host galaxies

In this lesson we will go through the various observational techniques used to discover actively accreting SMBH, Active Galactic Nuclei (AGN). We will explore the AGN census at different wavelengths, the observational evidences of the co-evolution of SMBH and their host galaxies and the cosmic history of SMBH mass growth and the formation and evolution of galaxies. In addition, we will study the mechanisms that trigger the star formation processes in AGN host galaxies and AGN feedback on the host galaxy.

Day 3: Astronomical Instruments and external visit to the Observatory

In this lesson we will review the main astronomical infrastructures available to researchers, from large optical telescopes and radio/sub-mm arrays on the surface of the Earth like the GTC, VLT, VLA or ALMA to space surveyors and observatories covering most of the electromagnetic spectrum like Planck, Herschel, XMM and Integral. We will also explore the Virtual Observatory and other existing databases with legacy catalogues and imagery of successful experiments and telescopes like Hubble or WMAP. We will visit the Cantabria Astronomical Observatory for a hands-on practical session with telescopes.

Day 4: Closing panel discussion with all the instructors and students.

Research projects:

- Polarization in the Cosmic Microwave Background
- Radio and sub-millimetre studies of extragalactic sources with Planck and Herschel
- Unveiling the dominant energy source of actively accreting SMBH at optical, infrared and X-ray wavelengths. Identification of the objects at different wavelengths;
- Study of the AGN spectral energy distributions (SEDs) to disentangle AGN and host galaxy emission. Stellar populations of AGN host galaxies.

Instructors:

Most Instructors will be members of the Institute of Physics. A sample of the scientific and teaching trajectory of some of them follows.

A. Alonso-Herrero obtained her Ph.D. in Astrophysics at the Universidad Complutense de Madrid in 1995. Between 1993 and 2003 she worked in the UK at the University of Oxford and University of Hertfordshire, and in the US at the University of Arizona on two different NASA projects. She is currently a staff scientist at the Spanish National Research Council. Her area of expertise is extragalactic astronomy and in particular, she studies star forming galaxies and actively accreting supermassive black holes in galaxies. She is mostly an observational astronomer and uses state-of-the-art infrared ground-based telescopes and satellites. She is member of the science team of one of the instruments that will work on board of the future James Webb Space Telescope.

X. Barcons received the Master in Physics from the University of Barcelona in 1981 and the PhD from the University of Cantabria in 1985. He was teaching assistant (1981-87) and Associate Professor (1987-93) at the University of Cantabria. He was postdoctoral researcher at the Institute of Astronomy, Cambridge (UK) in 1986/87, where he returned in 1997 as sabbatical visitor. In 1993 he was appointed Senior Research Scientist of CSIC (Spanish Council for Scientific Research), and in 2002 he was promoted to Research Professor. He has been working for over 25 years in X-ray astronomy, largely on Active Galactic Nuclei and Surveys. He has served in ESA's Astronomy Working Group (2002-04) and Space Science Advisory Committee (2004-06), and participated in a number of space science projects, most notably XMM-Newton (where he currently chairs the user's group) and the proposed next European X-ray Observatory (XEUS/IXO/Athena/Athena+) where he has continuously served in the Study/Coordination teams, and often chaired the Science Working Group.

D. Herranz received the B.S. degree in 1995 from the Universidad Complutense de Madrid, Madrid, Spain, and the Ph.D. degree in astrophysics from Universidad de Cantabria, Santander, Spain, in 2002. He was a CMBNET Postdoctoral Fellow at the Istituto di Scienza e Tecnologie dell'Informazione "A. Faedo" (CNR), Pisa, Italy, from 2002 to 2004. He is currently at the Instituto de Física de Cantabria, Santander, Spain, as Associate Professor. His research interests are in the areas of cosmic microwave background astronomy and extragalactic point source statistics as well as the application of statistical signal processing to astronomical data, including blind source separation, linear and non-linear data filtering, and statistical modeling of heavy-tailed processes.

P. Vielva received the degree in physics in 1998 and the Ph.D. degree in 2003, both from the Universidad de Cantabria, Santander, Spain. In 2004, he was a postdoctoral researcher at the Collège de France/APC, Paris. In 2006, he was a visiting researcher at the Cavendish Laboratory of the University of Cambridge, U.K. He is currently a Ramón y Cajal Researcher at the Instituto de Física de Cantabria. His field of research is cosmology, especially the development and application of statistical and signal processing tools for the study of the CMB and the large scale structure of the Universe. He is a Planck scientist of the European Space Agency Planck mission and an associated researcher of the QUIJOTE and J-PAS experiments.

Nanophotonics in everyday life

The purpose of this course is to introduce the general physical background of the interaction of electromagnetic radiation with matter at the nanoscale level. For this, we will explain how a nanostructure scatters and absorbs an electromagnetic wave through the application of the Mie theory. These effects will be shown and carefully analyzed by focusing mainly on Plasmonics, a recent and very active branch of Nanophotonics whose objective is the study of "plasmonic resonances" in metallic nanostructures. In this part, we will analyze the Physics of "plasmons", collective oscillations of the electronic plasma at nanometric dimensions. Depending on the shape, size and optical properties of the nanostructure, as well as the spectral range of the incident radiation, different effects can be obtained as a consequence of the localization of the electromagnetic radiation at dimensions smaller than the incident wavelength and also the local enhancement of the electromagnetic field in the proximities of the nanostructure.

The high interest in research on Plasmonics is based on the richness and multi-disciplinary character of its applications in medicine, material analysis (surface enhanced spectroscopic techniques - SERS and equivalent-), material engineering (metamaterials), optical communications and computing, microscopy, energy storing (solar cells), etc. The course finishes with an exhaustive presentation and analysis of all these applications.

Week 3

Day 1: Fundamentals of Nanophotonics

This first talk will be focused on the basic theory of electromagnetic optics, starting from the description of light as a wave. Some basic concepts on the interaction of electromagnetic radiation with matter will lead us to the understanding of some particular waves that propagate in conducting surfaces, i.e. surface plasmons. This survey will end with the particular case of localized plasmon resonances, occurring in small metal nano-particles, a very peculiar system with relevance in science and technology.

Day 2: Practical session

Some aspects of light-matter interaction (absorption, scattering and transmission) will be proposed for simulation in the computer by the student, conducted by a room supervisor. For this purpose, free software will be used. In order to understand the processes taking place in these particles, other more complex simulations on near-field and plasmonic resonances in nanoparticles will be shown, using finite elements based methods (DDA, FDTD, COMSOL)

Day 3: Research topics and multidisciplinary applications

A group of specific topics with relevance in research, related to either near- and far-field effects, will be described: Hot-spots, nanoantennas, nanosensors, SERS, Near-field Microscopy, metamaterials and others. In all cases emphasis will be put on the applied aspects, like the biomedical applications, the solar cell efficiency, etc.

Day 4: Laboratory session

In this session, the students will be shown some experiments based on the interaction of nanoparticles with light. These may include a microscopy-based spectometer analyzing localized resonances, colloidal effects of gold nanoparticles and others. (Handling of the instrumentation by the students will be subjected to the number of students and the risk for the equipment).

Day 5: External visit

We propose a trip in which the students may visit some place connected with the topics of the week. For instance, we plan to visit a Spanish company in which the work in research and development is oriented to nanotechnology, aiming to new products that implement some optical properties of nanoparticles.

Instructors

Most Instructors will be members of the Optics Group of the Department of Applied Physics. A sample of the scientific and teaching trajectory of some of them follows.

Dr. Fernando Moreno is Professor of Optics at the University of Cantabria since 1993. He received his Ph.D. in Physics from the University of Zaragoza in 1982, conducting research on the *Stark effect in plasmas* by *sub-Doppler laser techniques*. Between 1982 and until 1993 he made research in *photon statistics* and related techniques applied to the determination of sizes and shapes of macromolecules in solution using light scattering methods. After a stay as a guest researcher at the Royal Signals and Radar Establishment (Great Malvern, UK) in 1990, he opened a new line of research in *light scattering by particles and particle surfaces*, emphasizing the resolution of the *inverse problem*. After spending a year in the Department of Physics at the University of California San Diego (USA, 1996), this line of research was extended to the nanometer range. This formed the backbone of his research work in *Plasmonics and Nano-Optics*. He has published over 120 articles and is co-author of four patents with members of the Army Research Laboratory in Maryland (Washington, USA). He has been director of various research projects both public (National Research Plan, CDTI, NATO, The Royal Society, USAITCA, etc.) and private companies. From the latter, new applied research lines have emerged in Color, Phosphor Materials (construction industry and textiles) and Physiological Optics (LASIK). He co-founded the Spin-off *FOTOGLASS* (*www.fotoglass.es*) dedicated to research and development in Optical Materials and holds a patent (ES2364256). He is Senior Member of Optical Society of America, member of the European Optical Society, the Electromagnetics Academy (USA) and the Spanish Society of Optics. Of the latter, he is Chairman of the Education Committee.

Dr. Francisco González is full professor of Optics in the Department of Applied Physics of the University of Cantabria since 2002. In 1984, he got his PhD degree in Physics in the University of Cantabria, working in *the analysis of luminous signals with deterministic profile by using photon counting techniques*. Between 1980 and 2002 he made research in *Photon Correlation Spectroscopy* and its applications in the measurement of size and shape of macromolecules in solution through light scattering techniques, in *light scattering by random rough surfaces and surfaces with microparticles*. Recently he being working in plasmonics research, dealing with illuminated metallic nanoparticles isolated or located on substrates. Furthermore, he has focused the research on the electromagnetic behaviour of nanodielectric particles with high refractive index. He has published over 110 articles in scientific journals and 10 book chapters. He has headed national research projects in both public and private sectors. In the latter, *Colour* and *Physiological Optics* have been the main research topics. *Phosphorescent materials* made of glass have also been developed and commercialized for safety signing purposes through a spin-off created by other colleagues and himself. He has been Supervisor of seven PhD presented during the last 15 years. He is habitual *reviewer* of journals published by the IOP, OSA, APS, Elsevier, etc.

Dr. Jose Mª Saiz is a permanent lecturer of Optics in the Department of Applied Physics of the University of Cantabria (UC) since 2003. He obtained his Physics degree in Zaragoza, in 1988 and his PhD degree in Physics in the University of Cantabria in 1993, with a Thesis on the scattering of surfaces with particles. Since then, and after a post-doctoral stay in the ORC (Optoelectronic Research Centre, Southampton, UK) he held different positions with contracts for either research and lecturing activities in the Departments of Modern Physics and Applied Physics of the UC. His interests are strongly linked to the main lines of research of the Group of Optics of the UC, and from the past to our days the main one has been light scattering (and backscattering) from structured surfaces and volumes. This includes a variety of micro- to nano-structures, materials and configurations, with emphasis on different aspects like particle-sizing, multiple scattering, defect characterization, or localized plasmon resonance analysis. It also has involved different methodological approaches (angle-dependence, integration, statistic analysis of fluctuations, polarization, etc) and computational techniques (Ray-tracing, integral methods like the Extinction Theorem, Discrete Dipole Approximation, etc). Other past activities include the study of gain and lasing thresholds in ion-implanted waveguides, and collaborations in product or software developments in fields like refractive aspects of the eye, color characterization or saturation effects in phosphorescent emission in order to meet safety requirements. He has published over 70 articles in scientific journals. He is co-author of 4 international patents and two pending Spanish patents.

The Large Hadron collider: the quest for the Higgs Boson and more

In this part of the course, the basic concepts of particle physics will be described, with a significant emphasis on the recent results provided by the Large Hadron collider. In particular, special time will be devoted to the experimental and theoretical aspects behind the recent announcements about the Higgs Boson discovery.

Research in particle physics had impressive growth during the past decade, both on the theoretical models and, mainly, on the experimental sides. The so-called Standard Model of Particle Physics provides a very solid mathematical model explaining the whole set of experimental observations in the subatomic world, including those affecting the evolution of the “Young Universe”. It also proved its solidness with risky predictions that were later experimentally prove (one such is the well-known case of the Higgs Boson). The evolution of the field was possible also due to the tremendous effort in technology reproducing in accelerators conditions that are not commonly present in nature currently and in detectors capable to register the passage and properties of the tiny particles produced. The course will attempt to show the importance of these two aspects of the research, its connection and the historical evolution.

The theoretical aspects will be treated in seminars, without deepening into the mathematical aspects, combined with debate sessions. Experimental issues will also be treated in seminars, complemented with demonstrations in the laboratories and hands-on session analyzing real collider data on a computer. Depending on the availability, debate sessions with scientists at CERN (European Centre for Particle Physics) through videoconferences will be performed.

Week 4

Day 1: The standard model of particle physics

Particle Physics, a brief historical overview, experiments and theoretical break-throughs that lead to our current understanding of the subatomic world. The standard model of particle physics. elementary particles and fundamental interactions. The Higgs boson and the Higgs field.

Day 2. Experimental techniques in particle physics

Particle accelerators: need, historical evolution and basic principles. The large hadron collider. Principles for particle detection and major technologies. Dissection of a LHC experiment. Computing for Particle Physics.

Day 3. Analysis at a collider

Data analysis at LHC: how to interpret a collision. Trigger, reconstruction and selection. Hands-on LHC data. An example in more depth: the Higgs boson discovery

Day 4. The LHC and beyond

Major physics results at the LHC. Precision measurement of the SM: b-quark and top-quark physics, electroweak and QCD measurements. Search for new physics: Supersymmetry and exotic models. Review of the main open questions in particle physics. Theoretical and experimental prospects.

Research projects:

- LHC data analysis

Instructors

Most Instructors will be members of the Institute of Physics and the Department of Modern Physics Optics. A sample of the scientific and teaching trajectory of some of them follows.

Teresa Rodrigo is full Professor and member of the Institute of Physics (IFCA, Instituto de Física de Cantabria, CSIC-Univ. Cantabria). She has a wide experience in experimental particle physics, has participated in most of the hadron colliders in the world during the last 3 decades. She worked in UA1, the experiment that discovered the W and Z bosons, participated in the top-quark discovery at the CDF experiment, where she also contributed in many other aspects. She has participated actively in the design, construction and physic exploitation of CMS, one of the LHC detectors. She was responsible for the construction of one of the subdetectors. During the last two years she was the chairwoman of the collaboration board of this experiment, when she played a leading role in the Higgs boson discovery.

Francisco Matorras is full Professor and member of the Institute of Physics (IFCA, Instituto de Física de Cantabria, CSIC-Univ. Cantabria). He has also participated in the development and operation of CMS. In this experiment, he is member of the publication committee for top-quark physics, he is responsible for one of the data-analysis computer centers and one of the representatives in the computing resource board. Formerly he participated in an electro-positron collider, leading different physics groups (tau physics and Higgs searches). He is also now the Dean of the Faculty of Science.

Alberto Ruiz is full Professor and member of the Institute of Physics (IFCA, Instituto de Física de Cantabria, CSIC-Univ. Cantabria). He is presently the Director of the Doctoral School of the UC**,** Coordinator of the National Thematic Network for Future Linear Colliders and Spanish delegate in the International Particle Physics Outreach Group (IPPOG). He has been involved in several experiments and scientific policy committees. His research has been linked to heavy flavor and tau lepton physics and Higgs searches at LEP, Tevatron and LHC, as well as R&D for future linear colliders.