COURSE DATA

Data Subject	
Code	34270
Name	Relativity and cosmology
Cycle	Grade
ECTS Credits	4.5
Academic year	2023 - 2024

Study (s)

Degree	Center	Acad. year	Period
1105 - Degree in Physics	Faculty of Physics	4	Second term

Subject-matter

Degree	Subject-matter	Character
1105 - Degree in Physics	16 - Complements of Physics	Optional

Coordination

Name	Department
FONT RODA, JOSE ANTONIO	16 - Astronomy and Astrophysics

SUMMARY

The course Relativity and Cosmology, a 4.5 credits, optional subject offered in the second half of the fourth year of the Physics Degree, is an introduction to the theory of space-time in the presence of gravitation, that is, to Einstein's theory of gravitation, also known as the theory of general relativity (GR). The basic language of this theory is Riemannian geometry (curved spaces). Therefore, this course will also present an introduction to the basic notions of curved spaces. The study of GR can be continued in the Advanced Physics Master's program.

GR is necessary in various disciplines in physics and finds application in a wide range of spatial scales:

• The engineering related to the GPS or Galileo global positioning systems needs to take into account relativistic corrections, just as these were needed to explain the anomalous advance of the perihelion of Mercury.

• The evolution of compact astronomical objects, stellar collapse, the formation of black holes and the energetic processes that those produce, are common topics of relativistic astrophysics in which GR is necessary.

• GR predicts the existence of gravitational waves. The first direct detection of a gravitational wave (GW150914), one hundred years after Einstein completed his theory, is one of the most important scientific achievements in recent times. Gravitational-Wave Astronomy is opening a new window to the Universe, complementary to the electromagnetic one, which will provide a new and fascinating vision of the Universe.

• Gravitational lenses are an inevitable consequence of GR that has found an important application in the search for dark matter in cosmology.

• The accelerated expansion of the Universe detected in the observation of distant supernovae has revealed a mysterious component of energy, presently unknown (dark energy), which is stimulating a large number of studies and speculation.

• In another direction, the study of gravitation at the quantum scale (quantum gravity) has become another important topic of research in theoretical physics.

PREVIOUS KNOWLEDGE

Relationship to other subjects of the same degree

There are no specified enrollment restrictions with other subjects of the curriculum.

Other requirements

It is recommended to course "RIC" after having completed the basic subjects of "Physics" and "Mathematics".

OUTCOMES

1105 - Degree in Physics

- Knowledge and understanding of the fundamentals of physics in theoretical and experimental aspects, and the mathematical background needed for its formulation.
- To know how to apply the knowledge acquired to professional activity, to know how to solve problems and develop and defend arguments, relying on this knowledge.
- Ability to collect and interpret relevant data in order to make judgements.
- Problem solving: be able to evaluate clearly the orders of magnitude in situations which are physically different, but show analogies, thus allowing the use of known solutions in new problems .
- Modelling & Problem solving skills: be able to identify the essentials of a process / situation and to set up a working model of the same; be able to perform the required approximations so as to reduce a problem to an approachable one. Critical thinking to construct physical models.
- Physics general culture: Be familiar with the most important areas of physics and with those approaches which span many areas in physics, or connections of physics with other sciences.

- Basic & applied Research: acquire an understanding of the nature and ways of physics research and of how physics research is applicable to many fields other than physics, e.g. engineering; be able to design experimental and/or theoretical procedures for: (i) solving current problems in academic or industrial research; (ii) improving the existing results.
- Foreign Language skills: Have improved command of English (or other foreign languages of interest) through: use of the basic literature, written and oral communication (scientific and technical English), participation in courses, study abroad via exchange programmes, and recognition of credits at foreign universities or research centres.
- Literature Search: be able to search for and use physical and other technical literature, as well as any other sources of information relevant to research work and technical project development.
- Learning ability: be able to enter new fields through independent study, in physics and science and technology in general.
- Communication Skills (written and oral): Being able to communicate information, ideas, problems and solutions through argumentation and reasoning which are characteristic of the scientific activity, using basic concepts and tools of physics.
- Students must have acquired knowledge and understanding in a specific field of study, on the basis of general secondary education and at a level that includes mainly knowledge drawn from advanced textbooks, but also some cutting-edge knowledge in their field of study.
- Students must be able to apply their knowledge to their work or vocation in a professional manner and have acquired the competences required for the preparation and defence of arguments and for problem solving in their field of study.
- Students must have the ability to gather and interpret relevant data (usually in their field of study) to make judgements that take relevant social, scientific or ethical issues into consideration.
- Students must be able to communicate information, ideas, problems and solutions to both expert and lay audiences.
- Students must have developed the learning skills needed to undertake further study with a high degree of autonomy.

LEARNING OUTCOMES

We expect to achieve a fundamental level in the use of Einstein's theory of gravitation. To this end, will acquire a basic level in the highlights of the geometry of curved spaces, and their relationship to the physics of gravitation:

Tensor-calculus: algebraic and differential.
-The geometrical properties and physical implications of three basic metric spaces: Schwarzschild, Friedmann-Lemaitre-Robertson-Walker, and linearized gravitational waves, which will lead to: the phenomenon of black hole, cosmological models and the generation and analysis of radiation gravitational respectively.
-The temporal and null geodesics and the problem of motion of test particles and light rays. Families of geodesic deviation equation and the corresponding physical meaning.
-At the end of the skill must provide a geometric vision, which will result in the use of diagrams temporary spaces in the discussion of physical problems.

Others characteristic of the degree:

-Develop critical thinking skills and application of scientific method.
-Be able to identify problems, including the similarities with other solution which is known, and devise strategies for their solution.
-Extend the ability to plan and organize own learning, based on individual work, from the literature and other sources.
-Evaluate the different causes of a phenomenon and its relative importance.
-Identify the essential elements of a complex situation, make the approximations needed to construct simplified models that describe and to understand their behavior and in other situations.
-Be able to perform an update of existing information on a specific problem, sort and analyze it.
-Building capacity to work together in addressing the complex problems that require collaboration with others.
-Promote the acquisition of resources for speaking and writing to complete a clear and coherent scientific argument.
-Encourage communication skills of the physical concepts involved in a problem by way of speaking and writing.
-Promote the understanding and use of new information technologies.

DESCRIPTION OF CONTENTS

1. Special relativity

Introduction. Geometric structure of space-time (Space-time as affine space; The light cone. Temporal, spatial and isotropic wordlines; Synchronization and temporal interval; Inertial observer. Simultaneity. Temporal coordinate interval; Spatial interval; Inertial reference system; Interval between two events; Minkowski's vector space; 4-velocity and 4-acceleration; Lorentz transformations). Particle mechanics in special relativity. Tensors in special relativity. Movement of charges in an electromagnetic field. Maxwell's equations in the 4-dimensional formalism. Fluids in special relativity (Number flux; Continuity equation; 4-momentum flux; Energy-momentum tensor; Energy-momentum conservation equation; Perfect fluid).

2. Curved spacetime. Differential geometry

The gravitational field in special relativity. The equivalence principle. Euclidean space as a differentiable manifold. Tensor calculus in curvilinear coordinates. Differentiable manifolds. Space-time as a differentiable manifold (Metric in general relativity; Covariant derivative; Divergence and Gauss theorem; Parallel transport; Curvature tensor; Geodesic deviation equation; Bianchi identities, Ricci tensor and Einstein tensor). Physics in a curved space-time (Particle mechanics; Fluid mechanics; Electrodynamics).

3. Einstein's equations

Einstein's equations. Mathematical structure of Einstein's equations. Weak-field approximation. Linearized Einstein's equations. Newtonian limit of the equations. Lovelock's theorem. Derivation of Einstein's equations from a variational principle.

4. Gravitational radiation.

Properties of gravitational waves (Plane waves solution; Polarization). Effect of a gravitational wave on a particle. Generation of gravitational waves. Quadrupole formula. Examples (Gravitational waves emitted by a harmonic oscillator; Gravitational waves emitted by a binary system in circular orbit). Gravitational-wave detection.

5. Spherically symmetric solutions

Metric in spherical symmetry (Coordinates of a spherically symmetric spacetime; Spacetime with spherical symmetry and static; Einstein's equations for a static perfect fluid; The exterior geometry: Schwarzschild metric; The interior structure of a static star). Geodesics in Schwarzschild geometry (Circular orbits. Advance of perihelion; Deflection of light). The causal structure of Schwarzschild spacetime (Light cones; Free-falling observer; Incoming Eddington-Finkelstein coordinates; Outgoing Eddington-Finkelstein coordinates; Kruskal-Szekeres coordinates and the maximal extension of Schwarzschild spacetime).

6. Cosmology

Homogeneity and isotropy. Friedmann's equations (Ricci tensor and Christoffel symbols; cosmological matter terms; Einstein's equations in cosmology). The cosmological redshift. Cosmological models (General considerations; Important solutions of Friedmann's equations: (1) Flat and matter-dominated models; (2) Matter-dominated models without cosmological constant; (3) Einstein's static universe; (4) The de Sitter universe; (5) Radiation-dominated models without cosmological constant).

WORKLOAD

ACTIVITY	Hours	% To be attended
Theory classes	45,00	100
	0,00	100
Readings supplementary material	22,50	0
Preparing lectures	22,50	0
Preparation of practical classes and problem	22,50	0
TOTAL	**112,50**	

TEACHING METHODOLOGY

The teaching methodology of the course will be based on theoretical-practical classes on the blackboard in which the basic theoretical contents of the subject will be provided, along with practical examples of problems and exercises that better illustrate the theoretical concepts. In combination with discussions and deductions on the blackboard, graphic tools that include images, videos or presentations could also be used to illustrate some of the concepts explained. The notes of the subject, prepared by the teacher, will be made available to the students in the Virtual Classroom from the beginning of the course. Although most of the topics of the program will be addressed directly during the classes, some specific aspects of the syllabus could be left indicated for further study without being directly addressed. The student will be encouraged and guided in expanding the contents of the course using material from the recommended bibliography and review research articles.

EVALUATION

The assesment system is as follows:

1) **Written examinations** (80%): One part will assess the understanding of the theoretical-conceptual and formal nature of the subject, both through theoretical questions, conceptual questions and numerical or simple particular cases. Another part will assess the applicability of the formalism, by solving problems and critical capacity regarding the results. Proper argumentations and adequate justifications will be important in both cases.

2) **Continuous assessment** (20%): assessment of exercices and problems presented by students, questions proposed and discussed in class, oral presentation of problems solved or any other method that involves an interaction with students.

REFERENCES

Basic

- «A first course in general relativity», Bernard Schutz, Cambridge University Press, 2009.
- «Spacetime and Geometry», Sean M. Carroll, Addison Wesley, 2003.
- «A student's manual for a first course in general relativity», Robert B. Scott, Cambridge University Press, 2016.

Additional

- «Gravity. An introduction to Einstein's general relativity», J.B. Hartle, Addison Wesley, 2003.
- «General relativity an introduction to physicists», Hobson, M.P., Efstathiou G.P., Lasenby, A.N., Cambridge University Press, 2006.
- «Gravitation», C.W. Misner, K.S. Thorne, J.A. Wheeler, Princeton University Press, 2017.
- «Relativity and Cosmology», Wolfgang Rindler, Oxford University Press, 2005.