

**General Relativity and Cosmology**

Code: 103946  
ECTS Credits: 6

| Degree          | Type | Year | Semester |
|-----------------|------|------|----------|
| 2500097 Physics | OT   | 4    | 0        |

**Contact**

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**Use of languages**

Principal working language: english (eng)  
Some groups entirely in English: Yes  
Some groups entirely in Catalan: No  
Some groups entirely in Spanish: No

**Prerequisites**

It is advisable to have taken Mecànica Teòrica i Sistemes no lineals, and Electrodinàmica i Radiació Sincrotró.

**Objectives and Contextualisation**

To learn the physical basis of General Relativity (GR) as well as the most important gravitational phenomena that are described with it. This goal requires mastering tensorial calculus. The classical tests of GR and the familiarization with the most important spacetimes are also included as part of the course.

**Skills**

- Apply fundamental principles to the qualitative and quantitative study of various specific areas in physics
- Be familiar with the bases of certain advanced topics, including current developments on the parameters of physics that one could subsequently develop more fully
- Carry out academic work independently using bibliography (especially in English), databases and through collaboration with other professionals
- Communicate complex information in an effective, clear and concise manner, either orally, in writing or through ICTs, and before both specialist and general publics
- Develop critical thinking and reasoning and know how to communicate effectively both in the first language(s) and others
- Develop independent learning strategies
- Formulate and address physical problems identifying the most relevant principles and using approximations, if necessary, to reach a solution that must be presented, specifying assumptions and approximations
- Generate innovative and competitive proposals for research and professional activities.
- Respect the diversity and plurality of ideas, people and situations
- Use critical reasoning, show analytical skills, correctly use technical language and develop logical arguments
- Use mathematics to describe the physical world, selecting appropriate tools, building appropriate models, interpreting and comparing results critically with experimentation and observation
- Using appropriate methods, plan and carry out a study or theoretical research and interpret and present the results

- Work independently, have personal initiative and self-organisational skills in achieving results, in planning and in executing a project
- Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

## Learning outcomes

1. Calculate curvature tensor.
2. Calculate particle trajectories in gravitational fields solving the geodesic equation.
3. Calculate the effect of red shift and the deflection of light produced by a gravitational field.
4. Calculate the geodesics in a curved space.
5. Calculate the simple-distribution energy-momentum tensor for matter.
6. Communicate complex information in an effective, clear and concise manner, either orally, in writing or through ICTs, in front of both specialist and general publics.
7. Describe experimental evidence for the existence of gravitational waves.
8. Describe experimental evidence in favor of general relativity and the principle of equivalence in terrestrial and astrophysical observations.
9. Describe gravitational waves and their characteristic properties.
10. Describe observational evidence in favour of big bang cosmology.
11. Describe the basic concepts of current knowledge regarding the structure and evolution of the universe.
12. Describe the characteristics of the gravitational field generated by stars and black holes in addition to the effects they produce.
13. Develop critical thinking and reasoning and communicate ideas effectively, both in the mother tongue and in other languages.
14. Develop independent learning strategies.
15. Establish the bases for describing the evaporation and thermodynamics of black holes.
16. Generate innovative and competitive proposals for research and professional activities.
17. Obtain physical magnitudes measured by different observers from pseudo-Riemannian metrics.
18. Obtain the Newtonian limit of Einsteins equations with weak non-relativistic sources.
19. Obtain tidal forces from the curvature tensor.
20. Relate general relativity and electromagnetism establishing their similarities and differences.
21. Respect diversity in ideas, people and situations.
22. Use Einsteins equations in a linearized manner so as to describe weak gravitational fields, including the generation, propagation and detection of gravitational waves.
23. Use covariant equations and tensor calculus.
24. Use critical reasoning, show analytical skills, correctly use technical language and develop logical arguments
25. Use differential geometry to implement the principle of equivalence.
26. Use space-time symmetries for solving problems of dynamics and relativistic kinematics.
27. Use the approach of homogeneity and isotropy to describe the structure and evolution of the universe on a large scale.
28. Use the approximation of spherical symmetry in the study of stars and black holes.
29. Work independently, take initiative itself, be able to organize to achieve results and to plan and execute a project.
30. Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.
31. Carry out academic work independently using bibliography (especially in English), databases and through collaboration with other professionals

## Content

Special Relativity

The Equivalence Principle

Tensors in curved space

Einstein's equations

Spherical symmetry. Black holes

Weak fields. Gravitational radiation

Cosmology

## Methodology

This course will be given entirely in English. All the course material (problems, homework and exams) will be distributed in English and students will be encouraged to do all the exercises/exams in English, although in Catalan or Spanish will also be accepted and assessed with the same criteria.

This course will consist of theory and problem classes. There will be an equilibrium among work at class and at home.

Problem lists will be given to be solved individually or in groups. The solutions to the problems will be discussed in the problem classes.

The students will solve individually and hand in after a limited time a selection of 'homework' problems that will count for the final course mark.

The students will have to prepare 2 written exams: a mid-term exam and a final exam, the latter of which can be re-taken once.

## Activities

| Title                            | Hours | ECTS | Learning outcomes   |
|----------------------------------|-------|------|---|
| <b>Type: Directed</b>            |       |      |   |
| Problem lectures and discussion  | 15    | 0.6  | 5, 1, 3, 4, 2, 6, 11, 12, 9, 14, 13, 15, 31, 16, 18, 19, 17, 24, 20, 29, 30, 23, 27, 28, 25, 22, 26       |
| Theory lectures                  | 30    | 1.2  | 5, 1, 3, 4, 2, 6, 11, 7, 8, 10, 12, 9, 13, 15, 18, 19, 17, 24, 20, 23, 27, 28, 25, 22, 26                 |
| <b>Type: Autonomous</b>          |       |      |   |
| Discussion and work in group     | 48    | 1.92 | 5, 1, 3, 4, 2, 6, 11, 7, 8, 10, 12, 9, 14, 13, 16, 18, 19, 17, 24, 20, 21, 30, 23, 27, 28, 25, 22, 26     |
| Study of theoretical foundations | 50    | 2    | 5, 1, 3, 4, 2, 6, 11, 7, 8, 10, 12, 9, 14, 13, 15, 31, 16, 18, 19, 17, 24, 20, 29, 23, 27, 28, 25, 22, 26 |

## Evaluation

There will be a resit exam for students that: a) have done Exam 1 and Exam 2 and b) have failed the course with a mark of at least 3.5 (over 10).

Details on this exam will be announced in due course.

Students not attending Exam 2 will have the mark "Not presented - no available"

## Evaluation activities

| Title      | Weighting | Hours | ECTS | Learning outcomes   |
|------------|-----------|-------|------|---|
| Exam 1     | 35%       | 2     | 0.08 | 5, 1, 3, 4, 2, 6, 11, 7, 8, 10, 12, 9, 14, 13, 15, 16, 18, 19, 17, 24, 20, 29, 23, 27, 28, 25, 22, 26 |
| Exam 2     | 50%       | 2     | 0.08 | 5, 1, 3, 4, 2, 6, 11, 7, 8, 10, 12, 9, 14, 13, 15, 16, 18, 19, 17, 24, 20, 29, 23, 27, 28, 25, 22, 26 |
| Homework   | 15%       | 1     | 0.04 | 5, 1, 3, 4, 2, 6, 14, 13, 15, 31, 16, 18, 19, 17, 24, 20, 21, 29, 30, 23, 27, 28, 25, 22, 26          |
| Resit Exam | 85%       | 2     | 0.08 | 5, 1, 3, 4, 2, 6, 11, 7, 8, 10, 12, 9, 14, 13, 15, 16, 18, 19, 17, 24, 20, 29, 23, 27, 28, 25, 22, 26 |

## Bibliography

- E. Massó, "Notes on GR" (Available in Campus Virtual)
- B.F. Schutz, A First Course in General Relativity, Cambridge Univ Press, 2009.
- J.B. Hartle, Gravity: an introduction to Einstein's General Relativity, Addison-Wesley, 2003.
- R.J.A. Lambourne, Relativity, gravitation and cosmology, Cambridge Univ Press, 2010.
- S. Weinberg, Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity, J. Wiley & Sons, 1972.