COURSE DATA

Data Subject	
Code	43298
Name	General Relativity
Cycle	Master's degree
ECTS Credits	6.0
Academic year	2021 - 2022

Study (s)

Degree	Center	Acad. year	Period
2150 - M.D. in Advanced Physics	Faculty of Physics	1	First term

Subject-matter

Degree	Subject-matter	Character
2150 - M.D. in Advanced Physics	3 - Advanced astrophysics	Optional

Coordination

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

SUMMARY

Fundamentals of Relativity. Observers in a gravitational field. Formulation of physical laws in curved space. Energy tensor. Relativistic hydrodynamics. Maxwell's equations. Einstein's equations. Linearization. I isometries Killing fields. Spherical symmetry. Exact solutions. Schwarzschild geometry: extensions and generalizations. Spherical gravitational collapse. Formation of black holes: characteristic properties. Evolutionary formalism of relativity. 3 +1 formulation of the fundamental equations. Numerical Relativity: Relativistic Astrophysics applications. Gravitational radiation.

PREVIOUS KNOWLEDGE

Relationship to other subjects of the same degree

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

Other requirements

The student should have completed a degree course on "Relativity and Cosmology".

OUTCOMES

2150 - M.D. in Advanced Physics

- Students should communicate conclusions and underlying knowledge clearly and unambiguously to both specialized and non-specialized audiences.
- Students should demonstrate self-directed learning skills for continued academic growth.
- Students should possess and understand foundational knowledge that enables original thinking and research in the field.
- Ser capaces de obtener y de seleccionar la información y las fuentes relevantes para la resolución de problemas, elaboración de estrategias y asesoramiento a clientes.
- Comprender de una forma sistemática el campo de estudio de la Física y el dominio de las habilidades y métodos de investigación relacionados con dicho campo.
- Concebir, diseñar, poner en práctica y adoptar un proceso sustancial de investigación con seriedad académica.
- Realizar un análisis crítico, evaluación y síntesis de ideas nuevas y complejas en el área de la Física.
- Analizar una situación compleja extrayendo cuales son las cantidades físicas relevantes y ser capaz de reducirla a un modelo parametrizado.
- Evaluar la validez de un modelo o teoría propuesto por otros miembros de la comunidad científica.
- Saber modelizar matemáticamente los problemas físicos sencillos nuevos, conectados con problemas conocidos. Ser capaz de expresar en términos matemáticos nuevas ideas.
- Elaborar una memoria clara y concisa de los resultados de su trabajo y de las conclusiones obtenidas en el área de la Física.
- Exponer y defender públicamente el desarrollo, resultados y conclusiones de su trabajo en el área de la Física.
- Comprender los aspectos formales y el aparato matemático de la relatividad general, y desarrollar la capacidad de intuición espaciotemporal en cuatro dimensiones.

LEARNING OUTCOMES

At the end of the teaching-learning process the student of "Astrophisics" will have learned to:

1. Select and correctly use various sources of information in both traditional and electronic format.

2. Know the basics of databases and bibliographic resources typica of the field: inspire, spires, arXiv.

3. Properly handle and interpret qualitative and quantitative physical data, which validate the known theories in the field.

4. Analyze information from physical systems.

5. Prepare written documents and reports in an understandable and organized way. Document and illustrate such documents.

6. Articulate structured, consistent, oral speech, with a good diction and use of technical vocabulary.

7. Understand the arguments used in the field of Astronomy and Astrophysics.

8. Understanding the mathematical description of physical processes governing the formation and evolution of celestial objects at both stellar and cosmological scales, being able to develop and manage the mathematical techniques and skills for their application in simple cases of the Einstein equations of gravitation.

9. Understand the methodology to perform and interpret celestial catalogs.

10. Develop the appropriated tools to manage and mastering the Einstein equations.

DESCRIPTION OF CONTENTS

1. Lorentzian geometry

(a) The Minkowski space-time.
(b) Causal character of subspaces.
(c) Space-time coordinates and reference systems.

2. Observers congruences.

(a) Local observer. Relative quantities.
(b) Gravitational redshift.
(c) Fermi-Walker transport.
(d) Time-like congruences: acceleration, vorticity, shear and expansion.

3. Relativistic positioning systems.

(a) Location systems.
(b) Relativistic positioning systems. Emission coordinates.
(c) Autolocating positioning systems.

4. Cartan formalism.

(a) Curvature and torsion of a linear connexion.
(b) Curvature and torsion valued forms.
(c) Cartan equations.

5. Space-time curvature.

(a) Curvature tensor. Weyl conformal tensor. Cotton tensor. The Bianchi identities.
(b) The Ricci identities. Evolution equations for the expansion and the shear.
(c) Conformal geometries. Intrinsic characterization of conformally flat geometries.

6. Isometries

(a) Killing fields. Stationary gravitational fields.
(b) The Lie algebra of Killing fields. Maximal symmetry.
(c) Spherically symmetric space-times. Robertson-Walker metrics.

7. Evolution Formalism for Relativity.

(a) Geometry of space-like foliations. Induced metric and extrinsic curvature.
(b) Lapse function and shift vector.
(c) Expression of the metric in adapted coordinates to the foliation.
(d) Einstein's equations in 3 + 1 form. Dynamical quantities.

8. Numerical Relativity

(a) Brief historical introduction to Numerical Relativity.
(b) Formulations of the Einstein's equations adapted to numerical work. 3 + 1 formulation.
(c) Numerical hydrodynamics and MHD (magnetohydrodynamics) in General Relativity.
(d) High-resolution shock-capturing schemes.

9. Application of Numerical Relativity: Relativistic Astrophysics.

(a) Relativistic rotating stars.
(b) Gravitational collapse.
(c) Accretion on compact objects.
(d) Mergers of compact binaries.

10. Gravitational radiation.

(a) Weak gravitational fields. Gravitational waves.
(b) Astrophysical sources of gravitational radiation.
(c) Detection of gravitational waves.

WORKLOAD

ACTIVITY	Hours	% To be attended
Theory classes	39,50	100
Other activities	4,00	100
Seminars	2,50	100
Preparing lectures	52,00	0
Preparation of practical classes and problem	52,00	0
TOTAL	**150,00**	

TEACHING METHODOLOGY

MD1 – Standard theory lecture.
MD3 – Problem solving.
MD4 – Problems.
MD5 – Seminars.
MD8 – Conferences of experts.

EVALUATION

1) Written exam on the contents (theory and practical exercices) of the course (50%).

2) Assistance to the classroom and evaluation of the proposed practical homework (50%).

In order to obtain an overall positive evaluation, it is required that each of the above score result greater than or equal to 3 out of 10.

REFERENCES

Basic

- E. Gourgoulhon, Relativité Reinstreinte des particules à l'Astrophysique (EDP Sciences, CNRS Éditions, 2010). Versión en inglés: Special Relativity in General frames (Springer-Verlag, 2013), accesible en Éric Gourgoulhon homepage: \url{http://luth.obspm.fr/~luthier/gourgoulhon/}
- N. Straumann, General Relativity and Relativistic Astrophysics (Springer-Verlag, Berlin, 1984).
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- R. d'Inverno, Introducing Einstein's Relativity, (Clarendon Press, Oxford, 1998).
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- E. Gourgoulhon, 3+1 Formalism and bases of Numerical Relativity, Lecture Notes in Physics 846, (Springer, 2012); arXiv: gr-qc/0703035.
- T. W. Baumgarte and S. L. Shapiro, Numerical Relativity. Solving Einstein's Equations on the Computer (Cambridge Univ. Press, 2010).
- L. Rezzolla and O. Zanotti, Relativistic Hydrodynamics (Oxford University Press, 2013).

Additional

- S. Weinberg, Gravitation and Cosmology (Wiley, New York, 1972).
- L. Landau and E. M. Lifshitz, The Classical Theory of Fields, (Elsevier, Amsterdam, Fourth ed., 1975. Reprinted, 2007).
- F. de Felice, C. J. S. Clarke, Relativity on Curved Manifolds (Cambridge U.P., Cambridge, 1990).
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- L. Smarr and J.W. York, Jr., Kinematical conditions in the construction of spacetime., Phys. Rev. D. 17, 2529-2551 (1978).

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- C. Heinicke and F. Hehl, Schwarzschild and Kerr solutions of Einstein's field equation: An Introduction, International Journal of Modern Physics D, Vol. 24, No 2 (2015) 1530006 (78 pages).
- J. D. Norton, General covariance and the foundations of general relativity: eigth decades of dispute, Rep. Prog. Phys. {\bf 56} (1993) 791-858. \url{http://iopscience.iop.org/article/10.1088/0034-4885/56/7/001/meta}

ADDENDUM COVID-19

This addendum will only be activated if the health situation requires so and with the prior agreement of the Governing Council

English version is not available