COURSE DATA

DATA SUBJECT

Code: 43298
Name: General Relativity
Cycle: Master's Degree
ECTS Credits: 6
Academic year: 2025-26

STUDY (S)

Degree	Center	Acad. year	Period
2150 - Master's degree in Advanced Physics	Facultat de Física	1	First quarter

SUBJECT-MATTER

Degree	Subject-matter	Character
2150 - Master's degree in Advanced Physics	Advanced astrophysics	ELECTIVES

COORDINATION

SANCHIS GUAL NICOLAS

CERDA DURAN PABLO

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. Black holes beyond general relativity and modified theories of gravity. 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>>.

COMPETENCES / LEARNING OUTCOMES

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Analizar una situación compleja extrayendo cuales son las cantidades físicas relevantes y ser capaz de reducirla a un modelo parametrizado.

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.

Comprender los aspectos formales y el aparato matemático de la relatividad general, y
desarrollar la capacidad de intuición espaciotemporal en cuatro dimensiones.

Concebir, diseñar, poner en práctica y adoptar un proceso sustancial de investigación con seriedad académica.

Elaborar una memoria clara y concisa de los resultados de su trabajo y de las conclusiones obtenidas en el área de la Física.

Evaluar la validez de un modelo o teoría propuesto por otros miembros de la comunidad científica.

Exponer y defender públicamente el desarrollo, resultados y conclusiones de su trabajo en el área de la Física.

Realizar un análisis crítico, evaluación y síntesis de ideas nuevas y complejas en el área de la Física.

Saber modelizar matemáticamente los problemas físicos sencillos nuevos, conectados con problemas conocidos. Ser capaz de expresar en términos matemáticos nuevas ideas.

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.

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.

DESCRIPTION OF CONTENTS

1. Introduction to General Relativity

Introduction. Special relativity. Equivalence principle. Curved manifolds. Observers in curved spacetime. Energy-momentum tensor. Einstein's equations. Cartan's tetrad formalism.

2. Black Holes

Isometries and Killing fields. Schwarzschild and Kerr metrics. Other metrics.

3. Evolutionary formalism of Einstein's equations.

Evolutionary formalism. 3+1 formulation. Formulations of Einstein's equations: ADM, BSSN, and FCF. Mass, energy, and angular momentum. Other formulations: characteristic formulation and harmonic formulation. Examples of numerical relativity: punctures and excision. Choptuik critical collapse.

4. Black holes beyond general relativity and modified theories of gravity

Simplicity of black hole solutions in general relativity and no-hair theorems. Modified theories of gravity. Astrophysical implications of physics beyond the standard model. Observational constraints on fundamental physics, gravitational wave and electromagnetic observations. Extension of the 3+1 formulation in theories beyond GR.

5. Gravitational radiation

Linearized Einstein equations. Vacuum solutions. Generation of gravitational waves. Sources of gravitational radiation. Detection of gravitational waves.

WORKLOAD

PRESENCIAL ACTIVITIES

Activity	Hours
Theory	39,50
Seminar	2,50
Other activities	4,00
Total hours	**46,00**

NON PRESENCIAL ACTIVITIES

Activity	Hours
Attendance at other activities	4,00
Individual or group project	15,00
Independent study and work	0,00
Preparation of lessons	35,00
Preparation for assessment activities	15,00
Resolution of case studies	35,00
Total hours	**104,00**

TEACHING METHODOLOGY

MD1 - Theoretical classes with participatory lectures.
MD5 - Seminars.
MD6 - Visits to external scientific facilities and companies.
MD8 - Expert lectures.

EVALUATION

1) Grade of the written exam on the course content and practical work (50%).
2) Attendance to in-person classes and completion of practical work during non-class hours (50%).

To obtain a positive overall evaluation (equal to or greater than 5 out of 10), each of the above components must have a grade equal to or greater than 3 out of 10.

This evaluation system will be used for both the first and second call.

REFERENCES

Basic References:

N. Straumann, General Relativity and Relativistic Astrophysics, Springer-Verlag, Berlin (1984)

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R. M. Wald, General Relativity, The University of Chicago Press, Chicago (1984)

M. Alcubierre, Introduction to 3+1 Numerical Relativity, Oxford University Press (2008).

T. W. Baumgarte and S. L. Shapiro, Numerical Relativity. Solving Einstein's Equations on the Computer, Cambridge Univ. Press (2010)

Complementary References:

W. Rindler, Relativity, Special, General, and Cosmological, Oxford University Press, 2a ed. (2006)

E. Gourgoulhon, 3+1 Formalism in General Relativity, Springer-Verlag, Berlin (2012)

S. Weinberg, Gravitation and Cosmology, Wiley, New York (1972)

H. Stephani, General Relativity, Cambridge University Press, Cambridge (1982)

F. de Felice, C. J. S. Clarke, Relativity on Curved Manifolds, Cambridge U.P., Cambridge (1990)

L. P. Hughston, K. P. Tod, An Introduction to General Relativity, Cambridge U. P. (1990)

J. Plebanski, A. Krasinski, An Introduction to General Relativity and Cosmology, Cambridge U. P. (2006)

H. Stephani, D. Kramer, M. Maccallum, C. Hoenselaers and E. Herlt, Exact Solutions to Einstein's Field Equations, Second edition, Cambridge Univ. Press (2003)

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J. A. Font, Numerical hydrodynamics and magneto-hydrodynamics in general relativity, Living Reviews in Relativity, 7 (2008) [http://www.livingreviews.org/lrr-2008-7]

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J.W. York, Jr. The initial value problem and dynamics, en Sources of Gravitational Radiation" edited by L. Smarr, Cambridge Univ. Press: Cambridge (1979) pp. 175-201.

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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 1530006 (2015)

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