PHYS 5393 - PHYS 4380 Spring 2025 Introduction to the General Relativity Theory of Gravitation

Mario C. Díaz

Phone: (956) 8826690, mobile (956)-5722614. E-Mail: mario.diaz@utrgv.edu, Office location: BINAB 2.126, Office hours: by appointment, Course webpage: http://www.mariodiaz.org/general-relativity.html

Course Information

Meeting Days: Tuesday & Thursday
Time: 2:00 PM - 3:15 PM.
Location: BLHSB 1.418, EHABW W1.274.
Course Modality: Hybrid. But I strongly encourage all students to be present at the Brownsville campus (BLHSB 1.418).

Course Description: This is a beginning graduate/advanced undergraduate level course that introduces the student to Einstein's theory of general relativity and other topics in the field of gravitation. Each item in each chapter of the layout presented below can be considered a topic knowledge that constitutes a major course requirement.

1 Learning Objectives for this course

The beauty of General Relativity resides in the relatively simple fundamental concepts upon which it is built. But the price paid for this simplicity is the rather complex and elaborate mathematical formalism that it is needed to describe it. This Math resides in the realm of differential geometry. This course will assume no previous knowledge of differential geometry but I will introduce all the required elements (Riemannian geometry and tensor analysis) needed to understand and describe the physical nature of gravitation. The Topics and areas to be covered will include the Principle of Equivalence, physics on curved manifolds and Einstein's equations of General Relativity. I will also present exact solutions of Einstein's equations, and introduce and discuss, as the most significant among them, the Schwarzschild and Kerr solutions. I will also cover briefly topics in black hole physics and cosmology. The course will end with a discussion of gravitational radiation and its detection. Ours are quite interesting times: gravitational waves, one of the most elusive physical phenomenon speculated about in the history of physics, were discovered in 2015 starting a completely new era in astronomy. Our current status on the understanding of the evolution of the universe and its structure at large scale are depending on a mysterious so called dark matter as well as an equally perplexing dark energy. With gravitational waves all three of them are deeply related to Einstein's theory of gravitation. This course will give the student an appreciation of the theory and the capacity to delve deeper in these areas of current research.

WARNING: the topics in the layout below are tentative. There is no guarantee that we will be able to cover all of them. I will prioritize in depth understanding by the majority of the students over amount of topics covered. Prerequisites: Knowledge of Classical Mechanics, Electromagnetic Theory, Mathematical Methods of Physics, Modern Physics.

2 Course layout

1. Special relativity.
Lorentz transformations. Mathematical properties of Minkowski spacetime. Relativistic mechanics. The twin paradox. The Doppler effect. Vector algebra in 4-dimensions. Four-velocity and four-momentum.

2. Tensor algebra.
Manifolds and coordinates. Tensor fields. Tensor calculus. Differential forms and index lowering and raising. Perfect fluids in special relativity. Dust. Perfect fluids and general fluids.

3. Differential Geometry.
Introduction to curvature and non-Euclidean geometries. Christoffel symbols and non-coordinate basis. Curved manifolds. Riemannian manifolds. Covariant differentiation. Parallel transport and geodesics. Curvature tensor. Bianchi identities, Ricci and Einstein tensors.

4. Physics in curved spacetimes.
Einstein field equations. Weak field limit. Advance of the perihelion of Mercury. Bending of light.

5. Gravitational radiation.
Propagation of gravitational waves. Generation of gravitational waves. Detection of gravitational waves. Energy carried away by gravitational waves.

6. The Schwarzschild solution.
Properties. Experimental tests of relativity. Black Holes. Spherical solutions for stars. Static perfect fluid Einstein equations.

7. Cosmology.
Newtonian Cosmology. The cosmological principle. Friedman's equation. Hubble's law in relativistic cosmology. Cosmological models. Inflation. Quantum Gravity.

3 Evaluation

Evaluation will consist on the following: Attendance: it is not required. But absences will be considered a lack of engagement and a cavalier attitude indicative of disdain for the course.
Assigned Homework, although will not be graded will count 40% towards the final grade. There will be four exams, each one counting counting 15% of the final grade.

4 Bibliography, a.k.a. Required reading

Course book: no "official" course book. No "required reading", save the notes, but if you don't read you will not learn, and if you want to understand at a competitive level it will be good to read and consult references often. I will be providing pdfs of lecture notes regularly throughout the semester.

Reference Books

A quite useful one is A first course in General Relativity 2nd edition, there is a 3rd edition now. Bernard Schutz Cambridge

A recently published book who particularly excels at describing the philosophical and conceptual aspects of GR is:
General Relativity, the essentials
Carlo Rovelli, Cambridge, 2021.

Also quite recent is:
General Relativity, The theoretical minimum by Leonard Susskind and André Cabannes. Basic books, 2023.

An excellent book:
Spacetime and Geometry: An Introduction to General Relativity
Sean Carroll

Excellent to discuss and focus on the physics more than the math:
Gravity: An Introduction to Einstein's General Relativity
James B. Hartle

Additional

Introducing Einstein's Relativity, Ray D'Inverno, Oxford, 1996.
The Classical Theory of fields, Landau, L.D. and Lifshitz, 1971, Oxford.
Problem Book in relativity and gravitation, Lightman, A.P. Press, W.H., Price, R.H. and Teukolsky, S.A., 1975, Princeton U.P.
An Introduction to general Relativity and Cosmology, Jerzy Plebanski & Andrzej Krasinski, CUP.
Einstein's Space-Time, Rafael Ferraro, Springer.
Introduction to General Relativity, JD Walecka
Gravitation, Misner C.W. Thorne, K.S. and Wheeler,J.A., 1973, Freeman.
Gravitation and Space-Time, Ohanian YH. and Ruffini,R., 1994, Norton.
General relativity, and introduction to the gravitational field, Stephani, H., 1982 Cambridge U.P.
Schutz, Geometrical Methods of mathematical Physics,

1980, Cambridge U.P.
General relativity, Wald, R.M. , 1984, University of Chicago Press.
Gravitation and Cosmology, Weinberg, S. 1972, Wiley, New York.