PHYS 4380
Introduction to the General Relativity Theory of Gravitation
Fall 2020
Tentative Syllabus

This is an undergraduate course that introduces the neophyte to Einstein's theory of general relativity and other topics in the field of gravitation. Einstein’s theory of gravity is a geometrical theory of gravitation and it is also a classical physics theory. Its beauty resides in the relatively simple fundamental concepts upon which it is built. But the price paid for this simplicity is the 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 its role and the capacity to delve deeper in these areas of current research. Please note that this course is as demanding as a graduate class. The main difference with the graduate class will reside in the amount of HW and exercises required in the tests (less than what it is required for the graduate students).

Instructor

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***Prerequisites**:* Knowledge of Classical Mechanics, Electromagnetic Theory, Mathematical Methods of Physics, Modern Physics.

Course outline

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.
3. Perfect fluids in special relativity. Dust. Perfect fluids and general fluids.
4. Introduction to curvature and non-Euclidean geometries. Christoffel symbols and non-coordinate basis.
5. Curved manifolds. Riemannian manifolds. Covariant differentiation. Parallel transport and geodesics. Curvature tensor. Bianchi identities, Ricci and Einstein tensors.
6. Physics in curved spacetimes. Einstein field equations.
7. Gravitational radiation. Propagation of gravitational waves. Generation of gravitational waves. Detection of gravitational waves. Energy carried away by gravitational waves.
8. The Schwarzschild solution. Properties. Experimental tests of relativity. Advance of the perihelion of Mercury. Bending of light. Black Holes.
9. Spherical solutions for stars. Static perfect fluid Einstein equations.
10. Cosmology (tentative). Newtonian Cosmology. The cosmological principle. Friedman's equation. Hubble's law in relativistic cosmology. Cosmological models. Inflation. Quantum Gravity.

Evaluation

Evaluation will consist on the following: homework assigned 50%. Three exams, first one 15%, second one 15%, final 20%.

Bibliography

Course book:
A first course in General Relativity   2nd edition
Bernard Schutz
Cambridge

ISBN 978-0-521-88705-2

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
Spacetime and Geometry: An Introduction to General Relativity by Sean Carroll
Gravity: An Introduction to Einstein's General Relativity by James B. Hartle
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.