Universidad de los Andes

Departamento de Física

Introduction to General Relativity

Marek Nowakowski

Nombre del curso: Introduction to General Relativity
Código del curso: xxxx pregrado (4 cred.)
Unidad académica: Departamento de Física
Periodo académico: 202110
Horario:
Salón: Virtual (Blackboard Collaborate) ?
Requisito: Mechanics, Mathematical Methods Electromagnetism I and II

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Horario y lugar de atención: por correo electronico, en IP-402, en cualquier momento.

I Introduction

Special Theory of Relativity, General Theory of Relativity and Quantum Mechanics are the theories which emerged at the beginning of the 20th century and which mark the beginning of a new, modern era in physics. Whereas Quantum Mechanics governs the microscopic world, General Relativity is a theory of gravity, effective at large and cosmological scales. Indeed, unlike the other theories of fundamental interaction, gravity is "felt" by any object in the universe and in the framework of General Relativity it is also a basic description of the full dynamical spacetime. General Relativity, apart from giving corrections to observables in the solar system, explains also the existence of compact objects like neutron stars and black holes. It predicts gravitational waves which have been discovered only a few years ago and gained the Nobel Prize. It describes very well the cosmology as a dynamical expanding spacetime. A new discovery, also garlanded by the Nobel Committee, of an accelerated stage of the expansion has been found around the year 2000 and its theorectical basis is still being debated. In short, General Relativity is indispensable for the understanding of our universe at larger scales and is a very active field of research. Curiously, one of the missing links of fundamental physics is a quantum version of General Relativity which still awaits its discovery and acceptance. All this makes it an exciting part of physics having lots of potential for future discoveries.
"Until man will learn to form space like leather, there will be no sorrows apart from knowing God", Svetasvatara Upanishad.

II Objectives

The main objectives of the course are:

- To learn the very basics of the geometry of curved (Riemann) spaces and how they connect to General Relativity.
- To understand the physical principles of General Relativity as a theory of gravity and spacetime.
- To derive physical, observable consequences from the formal set-up of the theory

III Skills developed

On completion of the course, the student is expected:

- to be able to understand the connection between geometry and physics
- to be able to perform calculations related to geometrical structure of General Relativity

- to be able to apply the knowledge gained in this course to more advanced current topics of General Relativity and Cosmology

IV Weekly syllabus

The following topics will be covered during the semester (16 weeks).

- Week 1, 2:
  ELEMENTS OF SPECIAL THEORY OF RELATIVITY
  Lorentz tranformations/Relativistic Mechanics/Tensors in Minkowski spacetime/Relativistic Electrodynamics/Relativistic Hydrodynamics/Energy-Momentum tensor

- Week 4, 5:
  PHYSICAL BASIS OF GENERAL RELATIVITY
  Frames and the equivalence principle/The metric/Motion in gravitational fields and its Newtonian limit/The gravitational redshift

- Week 6, 7:
  GEOMETRICAL BASIS OF GENERAL RELATIVITY
  Tensors in curved spaces (Riemann spaces)/ Parallel transport and covariant derivatives/Riemann, Ricci tensors and Ricci scalar, Bianchi identities

- Week 8,9:
  BASIC LAWS OF GENERAL RELATIVITY
  The covariance principle/Physical laws in gravitational fields/Einstein's field equations and their Newtonian limit/The cosmological constant

- Week 10, 11:
  THE STATIC GRAVITATIONAL FIELD
  Schwarzschild metric/Motion in the Schwarzschild metric/ Light bending/Precession of perihelia/Radar echo delay/Lense-Thirring effect/Predictions and tests of General Relativity

- Week 12, 13:
  GRAVITATIONAL WAVES
  Weak limit of Einstein equations/Plane wave/Energy momentum tensor for gravitational waves/Quadrupole radiation/Sources of gravitational radiation

- Week 14, 15;
  MODELS OF STARS
  Hydrostatic equilibrium/The inner Schwarzschild metric/The Oppenheimer-Volkoff equation/Relativistic stars/Newtonian stars/The white dwarf

- Week 16:
  BASIC ELEMENTS OF COSMOLOGY
  The Robertson-Walker metric/The Friedmann equations/Expansion of the space and its acceleration

V Methodology

Since the present course is a theoretical course, the methodology involves teaching on the black board with a regular interaction with students. The students will choose topics to make a write up of projects. Apart from that a mild introduction into the mathematics of Riemannian geometry will help the student to master the topics. It will sometimes involve outside the classroom discussions with the students on topics related to the course.

VI Grades and evaluation criteria

100 %= 1 project 20 %
First exam 25 %
Second Exam 25 %
Final Exam 30 %
Homeworks will be given at regular intervals but will not be graded.

VII Bibliography

The topics given in the syllabus above can be found in the following books.

1. C. Bambi
"Introduction to General Relativity: A Course for Undergraduate Students of Physics"
Springer-Verlag 2018
2. N. Gray
"A Student's Guide to General Relativity"
Cambridge University Press 2019
3. N. M. J. Woodhouse
"General Relativity" (Springer Undergraduate Series)
Springer-Verlag 2007 4. J. B. Kogut
"Special Relativity, Electrodynamics and General Relativity: From Newton to Einstein"
Academic Press 2018
5. W.-G. Boskoff and S. Capoziello
"A Mathematical Journey to Relativity: Deriving Special and General Relativity with Basic Mathematics
Springer-Verlag 2020
6. D. Fleisch
"A Student's Guide to Vectors and Tensors"
Cambridge University Press 2012
7. C. Böhmer
"Introduction to General Relativity and Cosmology"
World Scientific 2016
8. J. D. Walecka
"Introduction to General Relativity"
World Scientific 2007
9. G. Ludyk
"Einstein in Matrix Form: Exact Derivation of Special and General Relativity without Tensors"
Springer-Verlag 2018
10. S. M. Carroll
"Spacetime and Geometry: An Introduction to General Relativity"
Pearson 2014
11. S. Weinberg
"Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity"
John Wiley and Sons 1972