ADVANCED GENERAL RELATIVITY

Sunil Mukhi

Outline for an online course organised by ICTS, Bengaluru,

March 20 – April 30, 2023.

The goal of this course is to provide a brief, but hopefully precise, overview of topics relevant to current research on General Relativity. The course will focus exclusively on classical aspects of gravity and, towards the end, on the quantum behaviour of particles/fields in gravitational backgrounds.

List of topics:

1. Brief review of basic General Relativity and relevant mathematics. [1]
2. Geometry and topology of spacetimes: causality, globally hyperbolic space-times, Cauchy surfaces. [2]
3. Geodesics, focusing and Raychaudhuri equations, Penrose and Hawking singularity theorems. [3]
4. Review of Schwarzschild black holes, asymptotically deSitter and anti-deSitter space-times. [1]
5. Black holes: causality properties, cosmic censorship. [2]
6. Thermal properties of Rindler space and black holes, Hawking radiation, black hole entropy and thermodynamics. [3]

Total: 10-12 lectures of 90 minutes each. [ ] = tentative number of lectures assigned to each topic. The topics may evolve slightly as the course progresses.

Pre-requisites: The course should be accessible to anyone who has had a one-semester course on basic General Relativity as well as some exposure to basic Topology and Differential Geometry. In GR, familiarity will be assumed with space-time metrics, general coordinate invariance, Riemann curvature, Einstein equations, Einstein-Hilbert action, isometries, geodesics and some classical solutions. In TDG, familiarity will be assumed with topological spaces, separability, connectedness, compactness, homotopy, differentiable manifolds.

References for the course:

Edward Witten, “Light Rays, Singularities and All That”, arXiv:1901.03928.

Robert Wald, “General Relativity” (textbook).

Tom Hartman “Lectures on Quantum Gravity and Black Holes” (Chapters 2 and 3 only!), downloadable at http://www.hartmanhep.net/topics2015.

Aron Wall, “Survey of Black Hole Thermodynamics’’, arXiv: and references therein, arXiv: 1804.10610.

References for the pre-requisites:

(i) Basic General Relativity:

- James Hartle, “Gravity – An Introduction to Einstein’s General Relativity”

- Sean Carroll, “Spacetime and Geometry: An Introduction to General Relativity”, Chapters 1—4.
- Steven Weinberg, “Gravitation and Cosmology”. Chapters 1—7, 12, 13.
- Sunil Mukhi, “Classical General Relativity” (22 video lectures), https://youtu.be/f7LdeEKzIwY

(ii) Topology and Differential Geometry:

- Sunil Mukhi and N. Mukunda, “Lectures On Advanced Mathematical Methods For Physicists”, Chapters 1—4.
- Sunil Mukhi, “Topology and Differential Geometry for Physicists”, (11 video lectures) https://youtu.be/F_Ug6y54wJ4
- I.M. Singer and J.A. Thorpe, “Lecture Notes on Elementary Topology and Geometry”.