PHY-462 General Relativity

Credit Hours: 3-0

Pre-requisite: Special Relativity

Course Objectives:

The main objective of the course is to introduce the Einstein theory of General Relativity (GR), which gives the notion of gravity as a curvature of spacetime. Furthermore, we introduce the Einstein field equations, which are the fundamental equations in GR. After introducing the fundamentals of GR, we incorporate the three main applications of the Einstein's general theory of relativity: Gravitational Waves, Black holes and Accelerating Universe. In addition to this, we introduce the observational tests of GR and corresponding observational parameters to test the theory.

Core Contents:

Review of Special Relativity, Introduction to Reimann manifolds, Curvature tensor, Bianchi Identities, Einstein field equations, Linearized Einstein field equations, Gravitational waves, Black hole solutions, Singularities and horizons, Geodesics around black holes, Expanding universe, Friedman Robertson Walker metric, Friedman equations, Cosmological constant, Redshift in cosmology and observational parameters

Detailed Course Contents:

Review of Special Relativity, Tensors in Special Relativity, On the relation of gravitation to curvature, Tensor algebra in polar coordinates, Tensor calculus in polar coordinates, Christoffel symbols and the metric, Differential manifolds and tensors, Riemannian manifolds, Covariant differentiation, Parallel-transport, Geodesics and curvature, Curvature tensor, Bianchi identities, Ricci and Einstein tensors, The transition from differential geometry to gravity, Physics in slightly curved spacetimes, Conserved quantities, Einstein field equations, Einstein-Hilbert action, Perfect fluids in general relativity, Einstein's equations for weak gravitational fields: Nearly Lorentz Coordinate Systems, Gauge transformations, Linearized Riemann tensor, Weak-field Einstein equations, Newtonian Limit, The far field of stationary relativistic sources, The propagation of gravitational waves: The transverse-traceless gauge, the effect of waves on free particles, Tidal accelerations, Polarization of gravitational waves, An exact plane wave solution, Schwarzschild solution and Black holes, Classical tests of GR, Charged Black holes, Ker-Newman Black holes, Trajectories in the

Schwarzschild spacetime, Infalling particles, Kruskal-Szekeres coordinates, Penrose diagrams, Expanding universe, Homogeneity and isotropy of the universe, The cosmological principle, Cosmological metrics, Cosmological redshift, Measures of distances in cosmology, the accelerating universe, Cosmological dynamics: Dynamics of Robertson-Walker universe, Big gang and dark energy, Observational parameters, Introduction to inflation

Course Outcomes: Upon completion of the course, the students will be able to:

- understand the concept of curved spacetime and gravity as curvature of spacetime
- understand Einstein field equations and their applications
- understand black holes and gravity waves
- understand the accelerated expansion of the universe

Textbooks:

Bernard Schutz, A First Course in General Relativity, 2nd ed. Cambridge University Press, 2009. (referred as BC)

Steven Weinberg, Gravitation and Cosmology, John Wiley and Sons, 1972. (referred as SW)

James B. Hartle, Gravity: An introduction to Einstein's General Relativity, Pearson Education. (referred as JH)

Reference Books:

Charles W. Misner, Kip S. Thorne, John Archibald Wheeler, Gravitation, Princeton University Press.

James B. Hartle, Gravity: An introduction to Einstein's General Relativity, Pearson Education.

Sean Carrol, Spacetime and Geometry: An introduction to General Relativity, Addison Wesley.

Weekly Breakdown		
Week	Section	Topics
1	BS 3.1-3.8	Review of Special Relativity, Tensors in Special Relativity
2	BS 5.1-5.5	On the relation of gravitation to curvature, Tensor algebra in polar coordinates, Tensor calculus in polar coordinates, Christoffel symbols and the metric
3	BS 6.1-6.3	Differential manifolds and tensors, Riemannian manifolds, Covariant differentiation

4	BS 6.4-6.5	Parallel-transport, Geodesics and curvature, Curvature tensor
5	BS 6.6	Bianchi identities, Ricci and Einstein tensors
6	BS 7.1-7.4	The transition from differential geometry to gravity, Physics in slightly curved spacetimes, Conserved quantities
7	BS 8.1-8.2	Einstein field equations, Einstein-Hilbert action
8	Handouts	Perfect fluids in general relativity
		Midterm Exam
9	BS 8.3	Einstein's equations for weak gravitational fields: Nearly Lorentz Coordinate Systems, Gauge transformations, Linearized Riemann tensor
10	BS 8.4	Weak-field Einstein equations, Newtonian Limit, The far field of stationary relativistic sources
11	BS 9.1	The propagation of gravitational waves: The transverse-traceless gauge, the effect of waves on free particles, Tidal accelerations, Polarization of gravitational waves, An exact plane wave solution
12	BS 10.1-10.6	Schwarzschild solution and Black holes (Note: projects for students: Classical tests of GR, Black hole thermodynamics, Charged Black holes, Ker-Newman Black holes, etc.)
13	BS 11.1-11.2	Trajectories in the Schwarzschild spacetime, Infalling particles, Kruskal-Szekeres coordinates, Penrose diagrams
14	BS 12.1-12.2	Expanding universe, Homogeneity and isotropy of the universe, The cosmological principle, Cosmological metrics, Cosmological redshift, Measures of distances in cosmology, the accelerating universe
15	BS 12.3	Cosmological dynamics: Dynamics of Robertson-Walker universe, Big gang and dark energy, Observational parameters, Introduction to inflation