PHY-907 General Relativity

Credit Hours: 3+0

Prerequisite: **None**

Course Objectives: General Relativity (GR) is a physical theory of gravitation invented by Albert Einstein in the early twentieth century. The theory has strong mathematical setup, has immense predictive power, and has successfully qualified several experimental/observational experiments of astrophysics and cosmology. Black holes and relativistic cosmology are two main applications of GR. It is intended that GR and its major applications and achievements be discussed in the manner they deserve.

Core Contents: Special relativity revisited, Electromagnetism, The gravitational field equations, The Schwarzschild geometry, Schwarzschild black holes, Kerr metric, Further spherically symmetric geometries.

Detailed Course Contents: Special relativity revisited: Minkowski spacetime in Cartesian coordinates, Lorentz transformations, Cartesian basis vectors, Four-vectors and the lightcone, Four-vectors and Lorentz transformations, Four-velocity, Four-momentum of a massive particle, Four-momentum of a photon, The Doppler effect and relativistic aberration, Relativistic mechanics, Free particles, Relativistic collisions and Compton scattering, Accelerating observers, Minkowski spacetime in arbitrary coordinates.

Electromagnetism: The electromagnetic force on a moving charge, The 4-current density, The electromagnetic field equations, Electromagnetism in the Lorenz gauge, Electric and magnetic fields in inertial frames, Electromagnetism in arbitrary coordinates, Equation of motion for a charged particle, Electromagnetism in a curved spacetime.

The gravitational field equations: The energy–momentum tensor, The energy–momentum tensor of a perfect fluid, Conservation of energy and momentum for a perfect fluid, The Einstein equations, The Einstein equations in empty space, The weak-field limit of the Einstein equations, The cosmological-constant term.

The Schwarzschild geometry: General static isotropic metric, Schwarzschild solution, Birkhoff's theorm, Gravitational redshift, geodesics in Schwarzschild geometry, radial trajectories of massive particles, Circular motion of massive particles, stability of massive particle orbits, trajectories of photons, circular motion of photons, stability of photon orbits, Experimental tests of general relativity: Precession of planetary orbits, The bending of light, Accretion discs around compact objects.
Schwarzschild black holes: singularities in Schwarzschild metric, radial photon worldlines, radial particle worldliness in Schwarzschild coordinates, Eddington Finkelstein coordinates, black hole formation, Spherically symmetric collapse of dust, tidal forces near a black hole, Kruskal coordinates, wormholes and Einstein Rosen bridge, The Hawking effect of black hole evaporation.
Further spherically symmetric geometries: Spherically symmetric geometries: metric for stellar interior, relativistic equations of stellar structure, Schwarzschild interior solution, metric outside a spherically symmetric charged mass, Riessner-Nordstrom geometry and solution, Radial photon trajectories in RN geometry, radial massive particle trajectories.
Kerr metric: The Kerr metric, Limits of the Kerr metric, Ker Neumann Metric (handouts).
The Friedmann–Robertson–Walker geometry: The cosmological principle, synchronous commoving coordinates, homogeneity and isotropy of the universe, maximally symmetric 3-space, Friedmann-Robertson-Walker metric, geometrical properties of FRW metric, The cosmological redshift, The Hubble and deceleration parameters, Components of the cosmological fluid, Cosmological parameters, The cosmological field equations, General dynamical behaviour of the universe, Evolution of the scale factor, Analytical cosmological models.

Learning Outcomes: Students will understand of the theory and predictions of Einstein's general relativity. Students will be capable to read research papers and initiate research in general relativity. Students will be able to understand the dynamical evolution of the universe by studying cosmology.

Text Book: M.P. Hobson, G.P. Efstathiou, A.N. Lasenby, General Relativity, Cambridge University Press (2007). Refereed as: HEL

Weekly Breakdown		
Week	***Section***	***Topics***
1	HEL 5.1-5.7	Special relativity revisited: Minkowski spacetime in Cartesian coordinates, Lorentz transformations, Cartesian basis vectors, Four-vectors and the lightcone, Four-vectors and Lorentz transformations, Four-velocity, Four-momentum of a massive particle.
2	HEL 5.8-5.14	Four-momentum of a photon, The Doppler effect and relativistic aberration, Relativistic mechanics, Free particles, Relativistic collisions and Compton scattering, Accelerating observers, Minkowski spacetime in arbitrary coordinates.
3	HEL 6.1-6.4	Electromagnetism: The electromagnetic force on a moving charge, The 4-current density, The electromagnetic field equations, Electromagnetism in the Lorenz gauge.
4	HEL 6.5-6.7	Electric and magnetic fields in inertial frames, Electromagnetism in arbitrary coordinates, Equation of motion for a charged particle, Electromagnetism in a curved spacetime.
5	HEL 8.1-8.7	The gravitational field equations: The energy–momentum tensor, The energy–momentum tensor of a perfect fluid, Conservation of energy and momentum for a perfect fluid, The Einstein equations, The Einstein equations in empty space, The weak-field limit of the Einstein equations, The cosmological-constant term.
6	**First One Hour Test**	
7	HEL 9.1-9.7	The Schwarzschild geometry: General static isotropic metric, Schwarzschild solution, Birkhoff's theorm, Gravitational redshift, geodesics in Schwarzschild geometry, radial trajectories of massive particles.
8	HEL 9.8-9.13	Circular motion of massive particles, stability of massive particle orbits, trajectories of photons, circular motion of photons, stability of photon orbits.
9	HEL 10.1, 10.2, 10.4	Experimental tests of general relativity: Precession of planetary orbits, The bending of light, Accretion discs around compact objects.

10	HEL 11.1 - 11.6	Schwarzschild black holes: singularities in Schwarzschild metric, radial photon worldlines, radial particle worldliness in Schwarzschild coordinates, Eddington Finkelstein coordinates, black hole formation.
11	HEL 11.7 - 11.11	Spherically symmetric collapse of dust, tidal forces near a black hole, Kruskal coordinates, wormholes and Einstein Rosen bridge, The Hawking effect of black hole evaporation.
13	HEL 12.1-12.6	Further spherically symmetric geometries: Spherically symmetric geometries: metric for stellar interior, relativistic equations of stellar structure, Schwarzschild interior solution, metric outside a spherically symmetric charged mass, Riessner-Nordstrom geometry and solution
14	HEL 12.7-12.8 13.5, 13.6	Radial photon trajectories in RN geometry, radial massive particle trajectories, Kerr metric: The Kerr metric, Limits of the Kerr metric, Ker Neumann Metric (handouts).
15	HEL 14.1-14.7	The Friedmann–Robertson–Walker geometry: The cosmological principle, synchronous commoving coordinates, homogeneity and isotropy of the universe, maximally symmetric 3-space, Friedmann-Robertson-Walker metric, geometrical properties of FRW metric.
16	HEL 14.9, 14.10	The cosmological redshift, The Hubble and deceleration parameters.
17	HEL 15.1-15.6	Components of the cosmological fluid, Cosmological parameters, The cosmological field equations, General dynamical behaviour of the universe, Evolution of the scale factor, Analytical cosmological models.
18	**End Semester Exam**	