PHYS 561 General Relativity

Spring 2019 Syllabus

Instructor: Prof. Edison Liang, x3524
Office: Room 342, Herman Brown Hall

Class Time: Tuesday and Thursday – 10:50 AM – 12:05 PM

Classroom: Herman Brown Hall 453

Class Website: http://spacibm.rice.edu/~liang/phys561

Prerequisites: Special Relativity, Classical Mechanics, Classical Electrodynamics, Tensor Calculus, or Instructor consent

Main Textbook:
Hobson, Efstathiou and Lasenby (HEL): *General Relativity* (Cambridge 2006 or latest edition)

Supplemental References:
The following references, especially HS, are most useful for supplemental reading and home works. Copies of HS, LL, MTW, and LPPT are available in Fondren Library or HBH310 Dessler Reading Room. In the Course Schedule below we list the corresponding chapters of HEL and HS as reading material.

Hans Stephani (HS): *Relativity: An Introduction to Special and General Relativity* (Cambridge Paperback, 2004)
Landau & Lifshitz (LL): *Classical Theory of Fields* (Pergamon 1989)
Misner, Thorne & Wheeler (MTW): *Gravitation* (Freeman 1973)
Lightman, Press, Price & Teukolsky (LPPT): *Problem Book in Relativity & Gravitation* (Princeton 1975)

Other Useful References:

Hartle (H): *Gravity* (Addison-Wesley 2003)
Schutz (S): *First Course in General Relativity* (Cambridge 1985)
Rindler (R): *Essential Relativity* (Springer 1969)
Adler, Bazin & Schiffer (ABS): *General Relativity* (McGraw Hill 1965)
Einstein (E): The Meaning of Relativity (Princeton 2014)
Weinberg (W): *Gravitation & Cosmology* (Wiley 1972)

Grades: 50-60% Homeworks (Approx. one HW every two weeks)
10-15% Midterm Exam or Quiz
30-35% Final Project or Term Paper

Rice Honor Code:
Students are expected to uphold the Rice Honor Code. Students are allowed to work together on homework problems, but the final submitted homeworks and term paper must be his/her own work.

Course Objectives:
This is a graduate course on General Relativity (GR), Einstein's theory of gravitation. Most modern topics of GR will be covered with some mathematical rigor, including curved space-times, Einstein equations and solutions, black holes, gravitational waves, and experimental tests of GR. Cosmology will only be briefly discussed if time allows, since it is already covered in ASTR452. The goal of this course is to provide students with a solid working knowledge of GR, so that they will be well prepared for research in relativistic astrophysics, cosmology and particle physics, and other areas which may require some basic knowledge of GR.

Learning Outcomes:
Students are expected to turn in one homework assignment every two weeks, which will be graded, complete a midterm examination, and write a term paper or do a final project. The examination will consist of both conceptual questions and computational problems. Through homework and examination, student should become fluent in the basic concepts and problem solving in General Relativity. The term paper or final project will help students to develop skills in writing and literature search.

Disability:
Any student with a documented disability that requires accommodation should contact both the course instructor and Disability Support Services in the Allen Center.

Tentative Course Schedule

Lecture Module	Topic	Homeworks	HS/HEL Chapters
0	Introduction & Overview		
1	Review of Special Relativity	PS #1	1 – 9 / 1, 5, 6
2	Riemannian Geometry & Curved Space	PS #2	14 – 20 / 2, 3, 4
3	Physics in Curved Spacetimes	PS #3	12, 13, 21 / 7
4	Einstein Equations	PS #4	22, 33 / 8, 19
5	Black Holes, Neutron Stars & Gravitational Collapse	PS #5	23, 26, 35-39 / 9, 11-13
6	Gravitational Wave & Radiation	PS #6	27 – 29 / 17, 18
7	Experimental Tests of GR		24, 25 / 10, 18
8	Gravitational Lens & Cosmology (if time allows)		40 – 42 / 14 - 16

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Module No. **Tentative Topics**

1. Introduction & Review of Special Relativity: Inertial Frames; Galilean transformation & invariance; noninertial frames; Mach's Principle; Lorentz & Poincare Transformations; Newtonian mechanics in arbitrary coordinates; electrodynamics.

2. Reimannian geometry: space-time as curved manifold; coordinate transformations; Covariant derivatives & tensor calculus; tetrads & coordinate-free forms; parallel & Fermi-Walker transport; curvature tensor; Ricci & Weyl tensor; Bianchi Identities; Lie-derivatives; Killing vectors & symmetry; spatial slices & local inertial frames.

3. Physics in curved space times: particle trajectories; photon trajectories & geometric optics; null coordinates; covariant form of Maxwell & other field equations; hydrodynamics; thermodynamics & kinetic theory.

4. General Relativity: principles of equivalence; Einstein Field Equations; stress-energy tensor; variational principle; Lagrangian & Hamiltonian formulations; 3+1 decomposition; concepts of mass and energy; conservation laws; symmetries; asymptotic flatness.

5. Schwarzschild solution; Kruskal & Penrose diagrams; Resissner - Nordstrom solution; event horizon; black hole, white hole and wormhole; Hawking radiation; Kerr-Newman solutions; rotating hole & ergosphere; dragging of inertial frames; Lense-Thirring effect; no-hair theorems; singularities; photon & particle orbits; interior solutions; gravitational collapse.

6. Gravitational radiation: null frames & invariant characterization of asymptotic fields; linearzed waves; polarization; generation of GW: the quadruple formalism; test particle response to GW; GW detectors; sources of GW; GW as a new window on astronomy.

7. Experimental Tests of General Relativity: weak fields & PPN formalism; solar system tests; binary pulsar & other tests; GPB.

8. Gravitational lens, Robertson-Walker metric and Friedmann models, particle horizon; Λ – cosmologies, Kasner metric & Mixmaster cosmologies; standard hot big bang and inflation.