PHYS 561 General Relativity

Spring 2021 Syllabus

Instructor: Prof. Edison Liang, x3524, email: liang@rice.edu
Office: Room 342, Herman Brown Hall

Class Time: Tu Th – 11:20 AM – 12:40 PM Fully Online. Zoom Link will be provided on Canvas.

Office Hours: TuTh 1 pm – 3 pm Online Only.

Classroom: None

Class Website: see canvas.rice.edu; see also http://spacibm.rice.edu/~liang/phys561 (Zoom link and most class material are only available on canvas).

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

Textbooks:
Hans Stephani (HS): *Relativity: An Introduction to Special and General Relativity* (Cambridge Paperback, 2004 or latest edition)
Hobson, Efstathiou and Lasenby (HEL): *General Relativity* (Cambridge 2006 or latest edition)

In the Course Schedule below, we list the corresponding chapters of HEL and HS as reading material.

Supplemental References:
The following references are most useful for supplemental reading and some home works. Copies of LL, MTW, and LPPT are available in Fondren Library or HBH Rm.310 (Dessler Reading Room).
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% Homeworks (approx. one Problem Set every two weeks)
20% Midterm Exam
30% 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 submitted homeworks and term paper must be his/her own work. Whenever a solution is available in reference books or on the internet, students should spend at least 2 hours on the problem on his/her own, before consulting the reference or internet.

Course Objectives:
This is a graduate level 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 and singularities, relativistic stars, gravitational waves, experimental tests and gravitational lensing. Cosmological applications will only be briefly mentioned if time allows, since cosmology is covered separately in ASTR452. The goal of this course is to provide students with a solid foundation in the concepts and mathematical techniques of GR, so that they will be well prepared for research in relativistic astrophysics, cosmology, particle physics, and other areas which may require some working knowledge of GR.

Learning Outcomes:
Students are expected to turn in one homework assignment every two weeks, 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 home works and examination, students should become fluent in the basic concepts and problem solving skills in General Relativity. The term paper or final project will help students to develop skills in writing and literature search.

Remote Delivery

The lectures of this course will be delivered online via Zoom, with cloud recordings. Instructor may hold additional online tutorials or problem sessions upon public demand. Office hours for this instructor are tentatively scheduled for TuTh 1 pm to 3 pm. Students can arrange Zoom meetings or phone conversations with the instructor during these hours via email. Students who want to request Zoom or phone meetings outside the office hours should contact instructor via email. Home works, examination and term paper/project should be submitted online in pdf format via canvas or email.

Disability:

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

Title IX Responsible Employee Notification

Rice University cares about your wellbeing and safety. Rice encourages any student who has experienced an incident of harassment, pregnancy discrimination or gender discrimination or relationship, sexual, or other forms of interpersonal violence to seek support through The SAFE Office. Students should be aware when seeking support on campus that most employees, including myself, as the instructor/TA, are required by Title IX to disclose all incidents of non-consensual interpersonal behaviors to Title IX professionals on campus who can act to support that student and meet their needs. For more information, please visit safe.rice.edu or email titleixsupport@rice.edu.

Tentative Course Schedule

Lecture Module	Topics	Homeworks	Chapters in HS/HEL
	Introduction & Overview		
1	Review of Special Relativity	PS #1	1 – 9 / 1, 5, 6
2	Review of Riemannian Geometry	PS #2	14 – 20 / 2, 3, 4
3	Physics in Curved Spacetimes	PS #3	12, 13, 21 / 7
4	Einstein Equations & General Relativity	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 (if time allows)	PS #7	40 – 42 / 14 - 16

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Module No. Content of Each Module (approx. 3 - 4 lectures)

1. Introduction & Review of Special Relativity (SR): Inertial Frames; Galilean transformation & invariance; noninertial frames; Mach's Principle; Lorentz & Poincare Transformations; index notation and 4-tensors; electrodynamics, thermodynamics and hydrodynamics in SR.

2. Reimannian geometry: space-time as curved manifold; coordinate transformations; Covariant derivatives & tensor calculus; Newtonian and Lagrangian mechanics in arbitrary coordinates; tetrads & coordinate-free forms; parallel transport and 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 in curved space-time.

4. General Relativity (GR): principles of equivalence; Einstein Field Equations; stress-energy tensor; variational principle; Lagrangian & Hamiltonian formulations

of GR; 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; singularity theorems; photon & particle orbits; global structure; relativistic stars; gravitational collapse.

6. Gravitational wave (GW): 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 GR: weak fields & PPN formalism; solar system tests; binary pulsar & other tests; GPB; EHT.

8. Gravitational lens, Robertson-Walker metric and Friedmann models, particle horizon; Λ – cosmologies and deSitter space, Kasner metric.