Introduction to General Relativity I: Fall 2021

M- W-F 10:00 --10:50, 105 Allen Hall

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Program for first semester: Special Relativity, time dilation, length contraction and simultaneity. Lorentz transformations, intervals, world lines and geometry of SR, variational principle: Minkowski space-time, metric, space-time diagrams. Covariance of SR. Scalars, vectors and tensors. Applications of SR to astrophysics and particle physics: Doppler shifts (transverse and longitudinal), stellar aberration, beaming and gamma ray bursts, kinematical thresholds: an astrophysical puzzle: Ultrahigh energy cosmic rays and GZK. Energy in SR. Accelerated observers: an event horizon: Some quantum aspects: Unruh temperature and accelerated observers. General coordinate systems, geodesics and the variational method: Christoffel symbols.

Gravity at last: the equivalence of inertial and gravitational mass, the equivalence principle: gravitational redshift and light bending, tidal forces, gravity as geometry. GPS: SR + GR in action. Weak field limit. The geometry of space-time outside a non-rotating spherical star: the Schwarschild metric: consequences, Killing vectors and conservation laws, the gravitational redshift. Particle orbits: advance in the perihelion of Mercury, light bending, radar echo. PPN and solar system tests of GR. Gravitational lensing: thin lenses, microlensing and Machos, macrolensing and Dark Matter. Tidal forces and geodesic deviation, the geodetic effect, Lense-Thirring (frame dragging) and Gravity Probe B-experiment.

The march towards Einstein's field equations: geometry first, a taste of Riemannian geometry, absolute and covariant derivatives, curvature and the curvature tensor. Local observers and vierbeins.

The second semester will include: energy momentum tensors, fluids: sound waves and eqn. of state. Einstein equations. A gravitating fluid and the Jeans instability: the origin of structure and galaxy formation. A *tour de force* on stellar evolution, relativistic stars and TOV: white dwarfs, neutron stars, supernovaes (I and II) and Black Holes. Schwarschild and Kerr black holes. Gravitational collapse, event horizons and ergospheres. Some quantum aspects of BH: Hawking radiation, evaporation, BH thermodynamics and the information paradox. Gravitational Waves: Taylor Hulse pulsar, LIGO, perturbations: ringing and quasinormal modes of Black Holes. Cosmology: homogeneous and isotropic Universe, FRW, standard Big Bang the CMB. The cosmological constant and Lambda CDM. Elements of Inflation, quantum fluctuations as seeds of CMB anisotropies and Galaxy formation. Basics of Gravitational collapse in expanding cosmology: structure formation. Some elements of field quantization in curved-space times (time permitting!!).

Books: I recommend the following outstanding books:, I) General Relativity, an Introduction for Physicists by M. P. Hobson, G. Efstathiou, A. N. Lasenby, II) Modern General Relativity, Mike Guidry, III) Gravity an introduction to Einstein's General Relativity by J. Hartle. Other excellent books are: An introduction to GR: spacetime and geometry by S. Carroll, although this book is more geometric-oriented. S. Weinberg's Cosmology and Gravitation is a classic and highly recommended. I will borrow material from many different books. Books I+II) are more up to date in cosmology and

astrophysical applications, III) is more pedagogical and a true jewel, the ideal book is a combo of I+II+III +Weinberg, but it does not exist (yet!).

Format of the course:

After each class I will send a pdf with scanned classnotes for the day.

One homework problem set (4-5 problems) per week, one take home midterm and a take home final. The final grade is the average of HM+mid+final.
All homework and exams should be clearly written and explained, no work shown = no grade!, please label equations. No need for fancy typesetting, just handwritten clearly will do!.

PROTOCOL: Homework and exams MUST be submitted via e-mail as **PDF files** which will be returned with grades and corrections. Please send small (compressed) pdf files!!. Work should be individual, I can be consulted (see below).

OFFICE HOURS AND CONSULTATIONS: In accordance with health guidelines and social distancing protocols, in person office hours will be restricted by appointment only. For appointments: send me an e-mail with possible (prioritized) meeting times, I will try to accommodate your requests.

I will be available via e-mail every day and commit myself to answering all questions within 24 hours. If needed we can schedule a ZOOM meeting if there is no suitable in-person arrangement with prior appointment.