Fall 2017 UNIVERSITY OF MARYLAND, College Park

Physics 675/475 **Introduction to Relativity Gravitation and Cosmology** Prof. B. L. Hu

Description: This is an introductory course on the basic principles of the theory of general relativity for the understanding of the structure and dynamics of spacetime and matter. We shall develop ideas and techniques toward the establishment of the Einstein equation, then explore its simple applications to gravitational waves, black holes and cosmology.
Topics covered are described in the Contents (below) and a Schedule will be provided as we move along.
Advanced topics in gravitational physics are covered in Physics 776 and 879
Prerequisites: A good grade in classical mechanics and mathematical physics courses, some knowledge of differential geometry would be helpful but not required.

Lectures: M W 1:00pm - 2:15pm, in PSC 3150
Lecturer: Prof. B. L. Hu, Office: PSC3153, Phone: (301) 405-6029 -- you will get faster response via email blhu@umd.edu. Any material you wish to give to me *except homework* please leave it with our faculty assistant Heather Markle hmarkle@umd.edu in PSC 3140 Phone (301) 405-6016
Office hours: MW 2:15 -3:15 pm. On some Wednesdays when there will be Gravitation seminars which I want to attend we will end at 3pm and resume at 4:15pm (plse let me know if/when you are coming).
TA: Batoul Banihashemi Office: 3103B Toll Physics Bldg Phone: 301.405.6189 Email: baniha@umd.edu
Office hour: Thursdays 3-4pm

Textbooks: "Required"
James B. **Hartle**, *Gravity, An Introduction to Einstein's General Relativity* (Addison-Wesley, Pearson, San Francisco 2003). QC173.6H38 2003 ISBN 0-8053-8662-9
Bernard F. **Schutz**, *A First Course in General Relativity*, 2nd edition (Cambridge, 2009) - QC173.55 ISBN 0 521 27703 5 **ISBN-13:** 978-0521887052 – quite easy to read http://202.38.64.11/~jmy/documents/ebooks/Schutz%20A%20First%20Course%20in%20General%20Relativity%28Second%20Edition%29.pdf
Both books' materials are based on undergraduate courses the authors had taught for years. These books are labeled as `required' largely because their contents parallel what will be taught in the course, and many homework problems will be assigned from there. *Try to read the text before coming to the lecture*. This will enable you to ask questions about ideas you may not be able to grasp in a first reading. It could also stimulate other students' offering different thoughts and perspectives in the discussions.

Additional textbooks and monographs -- We divide them into Track 1 and 2:

Track 1 is at an elementary (Senior-1st year graduate) level and **Track 2** is at an intermediate (2nd – 3rd year graduate) level. Traditionally 675 is taught at a level in-between to fulfill the dual needs of students seeking some general knowledge of general relativity and prepare those who wish to specialize in gravity research. The latter will find Phys 776 covering important topics useful for that purpose. For special themes, those wanting to do *gravitational wave* or *quantum gravity* research may find Phys 879 useful.

TRACK 1: (suitable for undergraduate physics major students)

I highly recommend the following two books to UG students to read, for fun. They reflect on Wheeler's special interest and ability in making sophisticated topics accessible to an uninitiated yet inquisitive mind:
E. F. **Taylor** and J. A. **Wheeler**, *Spacetime Physics: Introduction to Special Relativity*
(Freeman, New York, 1992) QC17.65T37 ISBN 0 7167 2327 1 Fun to read (for freshman/sophomore)
E. F. **Taylor** and J. A. **Wheeler**, *Exploring Black Holes: Introduction to General Relativity*
(Freeman, New York, 2002) Fun to read (for junior/senior)

TRACK 2:
C. W. **Misner.** K. S. **Thorne** and John A. **Wheeler**, (MTW) *Gravitation* (Freeman, San Francisco. 1973) QC178.M57 ISBN 0 7167 0344 0
- Often regarded as THE encyclopedia of gravitation theory. It has both Track 1 and Track 2 materials.
S. **Weinberg**, *Gravitation and Cosmology* (Wiley, New York, 1972) QC6.W47 ISBN 0 471 92567 5

- An authoritative monograph, taking a field theorist/ particle physicist's approach. Special is its Chapter 13. Of historical importance is Chapter 15 which brought up generations of theoretical cosmologists.

Sean **Carroll**, *Spacetime and Geometry: An Introduction to General Relativity* (Pearson 2003)
ASIN**:** B01NH01PDS - A lucid, more tightly knit rendition of MTW.

Robert M. **Wald**, *General Relativity* (Chicago, 1984) QC173.6.W35 ISBN 0 226 87033 2
- Advanced monograph. Elegant treatment, more suitable for the mathematically minded.

Other useful books: (will expand this list as we cover more advanced topics):

Alan P. **Lightman** et al, *Problem Book in Relativity and Gravitation* (Princeton University Press, 1973) QC173.55P76 ISBN 0 681 08162-X
-This book is useful for assisting you to work out problems (but don't copy from it for your homework!).

A **Liddle**, *An Introduction To Modern Cosmology*, Second Edition (Wiley 2003)

M. **Roos**, *Introduction To Cosmology*, Third Edition (Wiley 2003)
- The above two introductory books are suitable for UG students.

M **Maggiore**, *Gravitational Waves*: Volume 1: Theory and Experiments (Oxford University Press 2008)

P. J. E. **Peebles,** *Principles of Physical Cosmology* (Princeton, 1993)
QB981.P424 ISBN 0 691 01933 9 Intermediate
- I will recommend books on black holes and the early universe as we move closer to these subjects.

Lectures will be given at a level like Hartle, Schutz or Track 1 of MTW. My lectures do not adhere to any one book in its ordering of topics or emphasis, but are self-contained and have their own logical consistency. The best way is to follow closely the lectures and consult the corresponding topics discussed in any one of these books which suit your understanding best, work out the assigned problems, then try out extras from these books plus those in Lightman et al's *Problem Book*.

Course webpage: Please check for new announcements, adjustment of topics or due dates in the course website at ELMS/CANVAS system: www.elms.umd.edu/page/student-support where you will also be able to access your exam grades. For questions call the Help Desk at 301.405.1500 or email elms@umd.edu.

Homework / Discussion Session / Tests : Developing problem solving skills, both conceptual and technical, is the goal of many academic endeavors. Before you reach the PhD stage, you are usually given a problem and asked to find a solution. You may find out that one particular approach in reaching a solution may be better than others. Regardless, when you get the right answer, the task is considered well done. For PhD research you are usually given a chain of problems or one bigger problem to solve, or you may not be given a problem at all. You have to formulate a meaningful problem, then solve it. When you become a professor the challenge shifts more to asking good questions which can address the important key issues in your field and seeking solutions to help make advances. Why am I saying this, you may wonder? This is just to impress upon you that your wrestling with a problem and trying to find a solution on your own, elegantly and thoroughly, is necessary to gain some **knowledge of,** and imperative to **mastering, a subject**.

The search for **information**, specifically finding the solutions to a problem, has become so much easier in the internet age. Comes with it is the temptation to consult, if not simply copying, the solutions, and hand in as your own work. There are two concerns with this: One, without your thinking things through, it will remain as external information, not internalized knowledge. Doing so will result in poor performances in your examinations. Two, it is not fair to other students who do an honest job. To avoid this situation, we will try a new format different from the conventional homework handed-in, graded and passed back, all quietly done, alone, but serving the purpose of doing homework all the same, hopefully with some additional benefits, namely, group discussions.

I propose that you a) **work on the assigned homework**, by yourself, one problem after another in a continuous manner, in parallel to the lectures. b) **consult me** for conceptual & technical issues, and **the TA** for problem solving specifics, if you find the class materials hard to understand or the problems difficult to solve, **after** you have made some serious attempts. c) Attend the weekly **problem discussion sessions** conducted by the TA, scheduled in the afternoon of **Fridays** (time and place to be announced) devoted to problem solving, when you can raise questions of how to, why so, what for, and benefit from discussions with your fellow students, guided by your TA. Note 5 tests will be given in these sessions also.

Instead of a homework grade, there will be 5 tests given in the **Discussion Sessions**, on a problem related to the assigned homework or from the lectures. They are **open book tests** – you can bring one book of your choice. Each test will last 25min**. Four best of the 5 tests will be counted as your Test score which counts 100 points** (out of the total of 300 points) **toward your course score.** The dates of the 5 tests are tentatively set on: **Sept 15, Sept 29, Oct 13, Nov 10, Dec 1.** Make sure you can come to all of these tests, since there will not be make-up tests or make-up exams given.

<u>Exams:</u> Exams are meant to test your understanding of the materials taught and learned, to help you gauge your progress in the course. Two 75-minute exams are planned, to be held in class. Please mark down on your calendar: Exam 1 will be on **Wed October 25**, covering materials up to the end of the lecture a week before (Oct 18). Exam 2 will be on **Monday December 11**, covering the material since Oct 18. (There will be no exam given on the official final exam date of this course -- You can view Exam 1 as the midterm and Exam 2 as the final.) Please make all necessary preparations and arrangements to ensure you can take these exams because **no make-up exam will be given**. **Each exam counts 100 points (**out of a total of 300 points) **in your course score**. These are closed book exams, but you are allowed to bring an 8x11 formula sheet (but not sketches of solutions to problems) to each exam and turn it in with your exam paper. **Academic dishonesty is a serious violation** and will be dealt with strictly according to University policy**.**

Your course grade will be determined (`curved') according to your total course score: Test score (see above) plus 2 Exams, each counting 100 points = total max 300 points.

<u>A Request</u>**:** Because this course serves both graduate and undergraduates I ask that graduate students be a bit tolerant, especially at the beginning, for the extra time it may take for Q&A in class. Toward the end of the course, I ask the UGs in this course to be more understanding if the material may seem a bit hard. I would be happy to explain to you in more details after class. You all are encouraged to seek help from the TA for the homework problems and course materials. Since some of you may be taking this course for enrichment or cultural purposes, I'd be happy to discuss with you any topic you find exciting or interesting.
Course Contents:

A logbook of *Topics covered in the Lectures* will appear on the course website every 3-4 weeks.

1. <u>Special Relativity</u> Review: Spacetime approach, 4 vectors, Relativistic dynamics: use of invariants. Introduction to <u>General Relativity</u>: Gravitational redshift; Principle of Equivalence; Matter and spacetime curvature.
2. <u>Curved Spacetime</u>: Principle of Covariance, coordinate transformations; Tensor Analysis, geometry of curved space. How matter moves in curved spacetimes: connection and geodesic equations. How to measure the curvature of spacetime, curvature and geodesic deviations.
3. <u>Einstein's Equation</u>: Vacuum solutions; Relativistic matter; Dynamics of spacetime and matter
4. <u>Linearized Theory</u>: Gravitational radiation; Einstein's equation for weak fields; Generation, propagation and detection of gravitational waves; Conservation of energy momentum and angular momentum
5. <u>Relativistic Astrophysics</u>: Spherically symmetric spacetimes; Schwarzschild metric; Stellar models and gravitational collapse; Black holes. Trajectories around a compact object. How does a black hole look like?
6. <u>Relativistic Cosmology</u>: Cosmological principles; Standard Model: Robertson-Walker metric and Friedmann solution; De Sitter spacetime and inflationary cosmology; The early universe. Quantum effects.