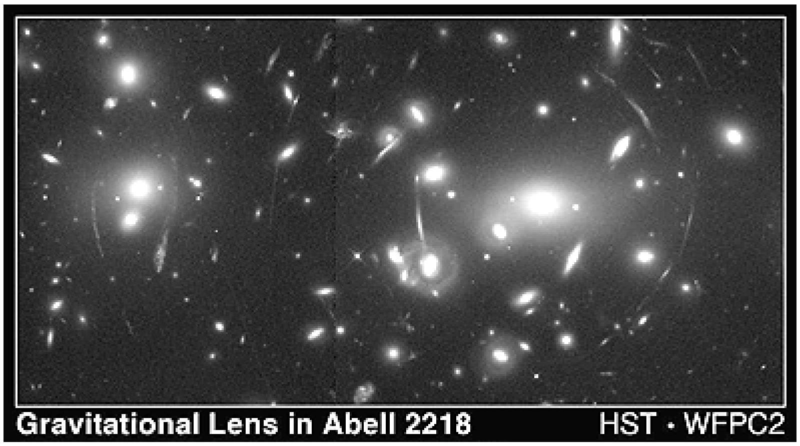

PHYSICS 300:

Beginning General Relativity

for Undergraduates

FALL 2007

Syllabus and Course Structure

Instructor

Paul M. Alsing
Class: Tues & Thur 4:00-5:15 p.m., Rm. 5
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Teaching Schedule: Office hours: After class 5:15-6:15, Tues-Thur, Rm. 15

Students often have the impression that you have to be (an) Einstein to understand his General Theory of Relativity (GR). And though GR does employ beautiful mathematical and geometrical concepts, it is an awe-inspiring physical theory whose concepts can be comprehended and learned, even in at an undergraduate level. The goal of this course is to expose students to the GR at an introductory level with a “physics-first” approach.

The realm of cosmos leaves one feeling both humbled and empowered. The universe is so large, and we are so small. Yet despite our small size in the universe, the study of GR and cosmology has given answers to questions once considered completely unanswerable: Did the universe have a beginning? How old is the universe? How will the universe end? How much “stuff” is there in the universe? What is gravity? Do black holes really never let anything escape? With the general theory of relativity and some experimental miracles, we have pretty good answers to many of these questions. However, there are a great many puzzles left to be solved. The matter with which we are familiar composes less than 5% of the total energy density of the universe. How did we learn about the existence of stuff that is there, but we can’t see or touch? How do we know that the universe is accelerating? And what are its consequences? Is there a quantum theory of gravity? In each lesson, we will discuss, and ponder these questions on the fundamental structure of our universe.

Textbook and Tools

- Textbook: **GRAVITY: An Introduction to Einstein’s General Relativity** by James B. Hartle
- Optional Textbook: **A Short Course in General Relativity**, by J. Foster and J.D. Nightingale
- Companion WebSite: http://wps.aw.com/aw_hartle_gravity_1/0,6533,512494-,00.html
- Computational tool: Mathematica:
- Additional Materials: Handouts and lecture notes from instructor

Prerequisites: This course is intended for undergraduates at the junior or senior level, but is open to all interested students. Students should have a knowledge of calculus (partial differentiation, simple integration, vectors, coordinate systems), and some level of classical mechanics (forces, preferably-least action principle).

Grading, Exams, Journals and Lesson Discussion Leaders (Overview)

There will be approximately 8 homework sets due every 2 weeks. There will be 2 in-class exams at roughly the 5 and 10 week point, and a final. A unique feature of this course is that students will be asked to keep a journal ("reading the book with a pencil"), which will be graded (every 2 weeks), to supply some intermediate derivations encountered in the readings, and to record insights, confusions and questions to be raised in the lectures. Students will also be asked to lead the beginnings of approximately 3-4 lectures, with a discussion of the material, relevant derivations, etc… from which the class discussion with then continue. Thus students will participate actively in this class, in an effort to learn from each other in team environment, and to convey one's thoughts, ideas, confusions etc… in a friendly "research group" atmosphere, mimicking how most real science is performed. This will be a new and fulfilling way to learn an exciting field of contemporary physics.

My Education Philosophy

Reading with a Journal + Homework + Reworks + Teaching Each Other =
Understanding the Magic of our Universe & Becoming a Powerful Thinker

I think that physics is both about learning the wonder of the universe, and training your mind to think on its own. Your ability to learn on your own is a key product of a physics education. The homework, the journal, the reworks, and the class discussions are all included to help each of us build a solid toolbox of logic, self-checks, mathematics, physics principles that will help you in any career field.

Reading with a Journal

Some of you (like me) often delude themselves by thinking that they can get away with doing few of the readings. *This subject is hard. You will need to read the book.* I will design my lectures around the concepts covered in the book, not the book itself. I will complement the readings, not repeat them. General relativity is hard both conceptually and mathematically. You will need many repetitions of this material as possible from many different perspectives. I would like you to do the readings for each lesson *before* each lesson and record your questions, reactions, and ideas in a journal. The only way to learn physics is to do physics. I think the best way to learn this subject is to read the text with pencil and paper handy to fill-in steps in derivations; this is also part of the journal. If you think this is a busywork exercise, you are mistaken. It is too easy to convince yourself while scanning material (books, journal articles, etc…) that you think you understand what you are reading. But if you can't get from one line to the next in a set of equations, then there is something fundamental that you are missing. Filling in the blanks confirms to oneself that you are truly following and comprehending the material.

As you read, you may have the urge to do a web search on an interesting topic or unanswered question. Use the knowledge you gain from the text and web searches to explore your own ideas. Jot down ideas and questions to ask in class. This is the idea for journaling assignments. As you read and maintain your journal, remember you are reading this out of passion and curiosity – you could have taken other classes, but you chose to study the structure of the universe ☺. The journals will be graded on effort, meeting some minimum content, and maintaining the spirit of the assignment.

Problem Sets

You may have heard mathematics is the language of physics. Of all physics disciplines, I believe this is the truest for general relativity. Thus, it is very important to practice the mathematics (language) in order to learn the concepts. There will be approximately one required problem set due every other week. On problem sets, I will happily accept print-outs from Mathematica; Matlab; Maple; or results from another calculating aid for any problem that I do not explicitly require done by pencil and paper. In fact, many of the homework assignments will require some type of computer aid to complete the problem in a reasonable amount of time. Using Mathematica, many calculations that would ordinarily take hours, we will be able to do in seconds. I will use several Mathematica files during class (available as links on the relevant lessons), and these files should be the starting point for many problem set assignments. Collaboration: Anyone and anything as long as you document. I will post solutions to assignments after they are due.

Problem Set and Test Reworks

I will reserve about 20% of the points on every homework assignment and tests for possible extra 'rework' points. For example, tests are worth 600 points. This will be divided up into 480+120 pts, with your base score being based on the 480 points. The other 20% or 120 points, will be set aside for possible additional credit, if you rework what you got wrong the homework/test to one hundred percent correct. As an example, suppose you get a 75% on the test. Your base score will be 0.75*480 = 360 points. If you rework the test (your mistakes), and get all of it correct, your score will be changed to 0.75*480 + 1.0*120 = 480 pts. Since the test is still worth 600 points, your new score will be 480/600 or 80%. If you do not do the rework, your score will be 0.75*480 + 0*120 = 360 pts, which equates to a 360/600 or 60%. Basically, I think it is very important to correct your mistakes. Also, the better you do on the test originally, the less there is for you to rework.

Sometimes the concepts you missed on one assignment become clearer after a few lessons. To encourage these revelations, I will accept these corrections anytime before lesson 16 (for the assignments due before Fall Break) or anytime before lesson 32 (for the assignments due after Spring Break). If you lose points on any assignment, I will delineate the section of the assignment that requires rework in order to earn the 20%. When you resubmit an assignment, please include the original assignment with the original. My goal is to have you understand the beauty of general-relativity physics and the amazing connection to geometry. I intend this rework policy to give you a 2^{nd} chance on every homework assignment to ensure that you learned the intended lessons. Rework collaboration: anyone and anything so long as it is documented (see below).

Lesson Discussion Leaders

Once your education through formal schooling is complete, there is something new that you will learn - you won't always have a teacher to guide you. As a result, you will need to find ways to educate yourself. Part of the aim of this course is to help you learn to do this. If you look around at many of the graduate students you will find that they take specialized ‘graduate seminar’ classes, that often they organize around a particular topic which they desire to learn and teach themselves. Classes are usually constructed as a few introductory lectures after which students would collectively read papers, and then an individual would volunteer to summarize them - giving a presentation, and leading a classroom discussion for the relevant paper for that class period. Though these classes are usually led by a faculty member (so that the students can get credit), they are student driven, since there is a deep desire for the those involved to learn something new of current interest, or a topic that may not usually be offered in the department. It is also a great way to learn to ‘give talks’ in front of a friendly crowd.

I’d like our classroom to operate similarly. Each student will pick two lessons before Fall Break, and two lessons after Fall Break on which they will be the discussion leader. Students will be expected to lead a 15 minute discussion on the relevant topic for that class period. Students will concur with the instructor before hand on which material he/she will or would like to discuss. The instructor will be there for ‘backup’, but the student should try to do their best to field questions and ‘get the discussion’ on the day’s topic rolling. Collaboration: anyone and anything needed to help in preparation.

Documentation / Collaboration

You must document all sources of help (people and documents) by adding a hand written or typed cover sheet to your assignment or rework indicating whom you have worked with (if any), or the additional documents/sources used. Any work that is merely copied from some source will receive no credit. If you have questions concerning documentation, please ask me.

The intent of joint effort assignments is to help you learn the course material. Working with other students is a rewarding way to begin to learn how to collaborate with others, and can be one of the most satisfying experiences of your formal education. However, please don't use "joint effort" as a crutch, simply counting on classmates to give you the answers. It's fine to compare answers to help locate and correct errors. It's also acceptable to get help on a problem you find difficult. If you find yourself putting minimal time into homework by leaning on classmates who have already done the work, then you are not learning “how to think”.

Extra Instruction (EI) / Office Hours

This is an ambitious class designed to introduce you to one of the most beautiful but difficult subject in physics. If you have the desire to learn this subject, I will work as hard as I need to so that you can discover as much as you can in this fascinating field. For this reason, I am available for EI at any time you can find me. I will hold office hours right after class in my Physics office, Rm 15. If you need additional help, we can arrange to meet from 5 p.m. onwards in my office at the High Performance Computing Center on the corner of University and Central (the building just west of Parking Services). I am also available at home during the evening until 10 p.m. at 271-8792. During the day you can get a hold of me at my work phone number 853-6940 or my cell 681-4509.

Because this class is also about learning to think, solving problems, and learning independently, I do ask that you come to EI with a little preparation. When you come to EI, please bring at least one or two pages of your handwritten math indicating some of your own attempts at solving the problem at hand. If you don't know where to start, try writing down any possibly relevant equations and massaging them into some quantity relevant to the question. If you didn't understand some phrase in the book, bring some supplementary sources that you looked through to provide you with alternative explanations. I suspect that about 30 minutes of calculating and following blind alleys on any problem is beneficial to your learning; however, more than 60 minutes of work is just frustrating and does not generally help you learn. At the 30-60 minute point, I suggest you ask a classmate, come in for EI, or call me.

Late Policy

It is bad form to just turn something in late, to anyone. You always face the individual to whom something is going to be late, and let them know what is going on. You coordinate your joint priorities, and you tell them when you will be ready. This is a key part of working as a team. Unless you receive an extension from me, homework will incur a 25% reduction for each calendar day that it is late. I expect you to coordinate extensions with me in advance every time something will be late. Example: If you turn in an assignment one day late and score 60 out of 100, then you will receive a 45 (60 times 75%). If you complete an assignment over the weekend, please e-mail me when you have completed the assignment.

Bonus Point Opportunities

In order to motivate critical reading, listening, and thinking, I have a few standing options for bonus points. To claim these points, please turn-in a piece of paper with your name, the date and time of your discovery, and the source of the points. Overall, there is no limit to the number of bonus points you can earn except where noted.

2 Points: Be the first to identify an error in physics or math on the board during class. Please point it out during class, and turn-in a piece of paper to remind me to give you the points.

10 Points: Be the first to identify an error in physics or math in the textbook not already on the errata web page. We'll submit the correction to Prof Hartle so that he can add it to the errata.

1 Point: Be the first to identify a spelling or grammar mistake in the textbook, or in any document written by me. After pointing out the errors to me, please turn-in a piece of paper to remind me to give you the points. Max 10 points per document.

20 Points: Turn in two pages of your solutions to a problem set in LaTeX (with source code). Limit 3 per student.

Grades

Grades will be determined from the following point assignments.

	Before Fall Break	After Fall Break	Total	Percentage
Reading, Thinking, Curiosity Journal (50 Pts each)	200	200	400	10 %
Problem Sets (100/150 Pts Ea)	400	600	1000	25 %
Lesson Leaders (100 Pts Ea)	200	200	400	10 %
Tests (600 Pts Ea)	600	600	1200	30 %
Final Exam	N/A	N/A	1000	25 %
Total Points	1400	1600	4000	100.0 %

Final Comment

There are ample opportunities to ‘score points’ in this class, from classroom participation, lesson leaders, journals, homeworks, tests and reworks. It is my hope that you will be able to focus more on the learning and understanding in the class, and ‘let the grades come naturally.’ I would like the goal of this course to be your first steps towards a much deeper understanding the physics that describes our universe. I am really looking forward to the opportunity to introduce you to this truly beautiful and richly rewarding subject.

Course Schedule

We have a wonderful textbook that teaches general relativity with a different approach than most textbooks. Hartle's pedagogical approach is to explore the math and topics in general relativity before we prove and derive the topics. In an effort to maintain a coherent storyline to the class, I have chosen to progress through the book in order. We will work with, play with, and understand the role of metrics for the first third of the class. During the second third, we will explore black holes, and cosmology. During the last third, we will learn how the metrics are connected to the matter density through Einstein's equation, and then we will derive the metrics we used during the first half of the class.

This schedule below is our target, but not a requirement. Prof. Victor Weisskopf, one of the great quantum physicists of the 1940s-1960s, used to say, "it is better to cover a little and uncover a lot." As the class develops, I will post the latest course schedule on the class website.

Lecture	Main topics of lesson	Readings
1 **(Tu)**	OVERVIEW. Introduction to gravitational physics	WEEK 1: This syllabus Hartle: pg xv, pg xxii, Chapter 1
2 **(Th)**	GEOMETRY I: Curvature, coordinates and line elements	Hartle: Chapter 2, pg 13 – 28
3 **(Tu)**	PHYSICS REVIEW. Gravitational & Inertial mass, least action principle	WEEK 2: Hartle: Chapter 3, pg 31 – 45
4 **(Th)**	SPECIAL RELATIVITY I: Review the subject, add line element, units, 4-vectors, basis vectors, coordinate independent quantities	Hartle: Chapter 4: Sections 4.1 – 4.6 Chapter 5: Sections 5.1 – 5.2 **Journal Wk 1-2 DUE, Lectures 1-4** **Problem Set 1 DUE**
5 **(Tu)**	SPECIAL RELATIVITY II: acceleration, forces, special coordinates, least action principle	WEEK 3: Hartle: Chapter 5: Sections 5.3 – 5.6

Lecture	Main topics of lesson	Readings
6 **(Th)**	GEOMETRY II: Subsurface, basis vectors, transforming vectors and coordinates GENERAL RELATIVITY I: Clocks in a gravitational field	Review Handouts Hartle: Chapter 6: Sections 6.1 – 6.4
7 **(Tu)**	GENERAL RELATIVITY II: Weak field metric	WEEK 4: Hartle: Chapter 6: Sections 6.5 – 6.6 Chapter 7: Sections 7.1 – 7.3
8 **(Th)**	GENERAL RELATIVITY III: Spacetime with general coordinates, light cones GEOMETRY III: length and volume, basis vectors, embedding diagrams	Hartle: Chapter 7: Sections 7.4 – 7.5 Chapter 7: Sections 7.6 – 7.9 **Journal Wk 3-4 DUE, Lectures 5-8** **Problem Set 2 DUE**
9 **(Tu)**	GENERAL RELATIVITY IV: Geodesics	WEEK 5: Hartle: Chapter 8: Section 8.1-8.3 Hartle: Supplement to Chapter 8
10 **(Th)**	GENERAL RELATIVITY V: Using geodesics, wormholes	Hartle: Chapter 8: Section 8.4 Other Curiosities: Morris and Thorne. Wormholes in Spacetime and Their Use for Interstellar Travel. American Journal of Physics v56, p395 (1988) (read sections F – end) (only 3.5 pages)
11 **(Tu)**	TEST 1	WEEK 6:

Lecture	Main topics of lesson	Readings
12 **(Th)**	SPHERICAL STATIC MASS I: Time dilation again, geometrical meaning	Hartle: Chapter 9: Sections 9.1 – 9.2 **Journal Wk 5-6 DUE, Lectures 9-12** **Problem Set 3 DUE**
13 **(Tu)**	SPHERICAL STATIC MASS II: Particle orbits, Photon orbits	WEEK 7: Hartle: Chapter 9: Sections 9.3-9.2
14 **(Th)**	GRAVITATIONAL LENSING	Hartle: Chapter 11
15 **(Tu)**	BLACK HOLES I: A hole is born	WEEK 8: Hartle: Chapter 12: Section 12.1-12.2 **Journal Wk 7-8 DUE, Lectures 13-15** **Problem Set 4 DUE**
16 **(Th)**	FALL BREAK	NO CLASS
17 **(Tu)**	BLACK HOLES II: Into the abyss	WEEK 9: Chapter 12: Section 12.3 – 12.4
18 **(Th)**	BLACK HOLES III: Galaxy centers, evaporation, X-ray binaries	Hartle: Chapter 13
19 **(Tu)**	BLACK HOLES IV: A slightly rotating "thing"	WEEK 10: Hartle: Chapter 14 **Journal Wk 9-10 DUE, Lectures 17-20** **Problem Set 5 DUE**
20 **(Th)**	BLACK HOLES V: Rotating Black Holes	Hartle: Chapter 15

Lecture	Main topics of lesson	Readings
21 **(Tu)**	TEST 2	WEEK 11:
22 **(Th)**	GRAVITY WAVES:	Hartle: Chapter 16
23 **(Tu)**	COSMOLOGY I: The observed Universe COSMOLOGY II: The evolution and composition of the universe, the "Big Bang", flat universes	WEEK 12: Hartle: Chapter 17 Hartle: Chapter 18: 18.1 – 18.3 Supplement to Chapter 18
24 **(Th)**	COSMOLOGY III: The age and size of the universe, curved universes. (Mathematica)	Hartle: Chapter 18: 18.6 – 18.7 **Journal Wk 11-12 DUE, Lectures 17-20** **Problem Set 6 DUE**
25 **(Tu)**	COSMOLOGY IV: Which Universe is ours?	WEEK 13: Hartle: Chapter 19
26 **(Th)**	GEOMETRY VI: basis vectors, dual basis vectors	Hartle: Chapter 20: Sections 20.1-20.3
27 **(Tu)**	GEOMETRY VII: The Covariant Derivative and Div, Grad, Curl	WEEK 14: Hartle: Chapter 20: Sections 20.4 – 20.5 **Journal Wk 13-14 DUE, Lectures 25-27** **Problem Set 7 DUE**

Lecture	Main topics of lesson	Readings
28 **(Th)**	THANKSGIVING	NO CLASS
29 **(Tu)**	EINSTEIN EQUATION I: Tidal forces, curvature tensor	WEEK 15: Hartle: Chapter 21: Sections 21.1 – 21.3
30 **(Th)**	EINSTEIN EQUATION II: Left hand side: curvature	Hartle: Chapter 21: Sections 21.4 – 21.5 Supplement to Chapter 21
31 **(Tu)**	EINSTEIN EQUATION III: Right hand side; stress-energy tensor	WEEK 16: Hartle: Chapter 22: Sections 22.1-22.2
32 **(Th)**	EINSTEIN EQUATION IV: Checking the metrics of black holes, cosmology, gravity waves for their stress energy	Hartle: Chapter 22: Sections 22.3-22.4 **Journal Wk 15-16 DUE, Lectures 28-32** **Problem Set 8 DUE**

PHYSICS 300 — 2007 FALL SEMESTER CALENDAR

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
AUGUST						
19	20	21 LECTURE 1	22	23 LECTURE 2	24	25
26	27	28 LECTURE 3	29	30 LECTURE 4 Journal Wk 1-2 DUE Lectures 1-4 Problem Set 1 DUE	31	
SEPTEMBER						
						1
2	3 ------LABOR DAY------	4 LECTURE 5	5	6 LECTURE 6	7	8
9	10	11 LECTURE 7	12	13 LECTURE 8 Journal Wk 3-4 DUE Lectures 5-8 Problem Set 2 DUE	14	15
16	17	18 LECTURE 9	19	20 LECTURE 10	21	22
23	T6 24	25 LECTURE 11 TEST 1	26	27 LECTURE 12 Journal Wk 5-6 DUE Lectures 9-12 Problem Set 3 DUE	28	29
30						
OCTOBER						
	1	2 LECTURE 13	3	4 LECTURE 14	5	6
7	8	9 LECTURE 15 Journal Wk 7-8 DUE Lectures 13-15 Problem Set 4 DUE	10	11 ------------FALL--------- --- NO CLASS ---	12 ----------BREAK--------------	13
14	15	16 LECTURE 17	17	18 LECTURE 18	19	20
21	22	23 LECTURE 19	24	25 LECTURE 20 Journal Wk 9-10 DUE Lectures 17-20 Problem Set 5 DUE	26	27
28	T18 29	30 LECTURE 21	31			
NOVEMBER						
				1 LECTURE 22	2	3
4	5	6 LECTURE 23 TEST 2	7	8 LECTURE 24 Journal Wk 11-12 DUE Lectures 17-20 Problem Set 6 DUE	9	10
11	12	13 LECTURE 25	14	15 LECTURE 26	16	17 -
18	19	20 LECTURE 27 Journal Wk 13-14 DUE Lectures 25-27 Problem Set 7 DUE	21	22 ---THANKSGIVING--- ---NO CLASS- --	23 ---------------------------------	24
25	26	27 LECTURE 29	28	29 LECTURE 30	30	
DECEMBER						
						1

2	3	4 LECTURE 31	5	6 LECTURE 32 Journal Wk 15-16 DUE Lectures 28-32 Problem Set 8 DUE	7	8
9	10	11 ------ FINAL ----- TEST 1	12 EXAM DURING FINALS	13 WEEK ----- WEEK -----	14	15