

PHYS 515: General Relativity I – Introduction to Gravity

Spring 2020

Class Time and Location: T-Th 1530-1650 pm, Loomis 158

Course website: <https://courses.physics.illinois.edu/phys515/sp2020/>

List of pre-requisite courses: PHYS 436.

Professor: Nico Yunes (Loomis 237B, soon to move to Loomis 247), nyunes[at]illinois.edu.

Teaching Assistant 1: Alejandro Cárdenas-Avendaño (Loomis 257), ac54[at]illinois.edu.

Teaching Assistant 2: Scott Perkins (Loomis 257), scottep3[at]illinois.edu.

Professor's Office Hours: Infinite by appointment. Nico's Office (Loomis 237B). If you can't find me, *email me*.

TA's Office Hours: By Appointment. Loomis 257. If you can't find them, *email them*.

What is this class about? General Relativity is an advanced graduate course that teaches the foundations of Einstein's theory of General Relativity. This class is a very mathematically intensive, laying the foundations for black hole theory, post-Newtonian theory and numerical relativity. In fact, General Relativity was initially taught in the mathematics department of universities! It is impossible to teach this subject without doing a deep-dive into the mathematics that are important in General Relativity, so the first half of this class is quite mathematically intensive. The second half of the course presents the physical consequences of Einstein's theory, with a (very brief) tour of its greatest hits: non-spinning (Schwarzschild) black holes and neutron stars, Solar System tests of gravitation, gravitational waves and an introduction to cosmology. Students interested in these physical applications are encouraged to take subsequent courses on General Relativity, physical cosmology and astrophysics.

Who should take this class? This course is intended for advanced graduate students. As such, it is assumed students have prior knowledge of Einstein's theory of *special* relativity, Newtonian gravitation and classical mechanics, Maxwell's theory of electrodynamics and advanced mathematics, including differential equations, advanced Calculus and advanced linear algebra. The purpose of the class is to prepare students who wish to specialize in General Relativity (analytical or numerical), relativistic astrophysics and cosmology for research. Other students with broader interests are welcomed to take this class, but they should be advised that there are other (perhaps less intensive) courses they can take to fulfill their elective requirements.

What is expected of students who take this class? Students are expected to attend class, complete all homework assignments and complete a midterm exam and a final exam (see breakdown of topics below). In addition, students are expected to be mature enough to independently do some amount of self-learning outside of class, including reading the assigned book (see below), reading papers mentioned in class, and watching video lectures recorded by Prof. Yunes. Since this is a graduate course, readings will not be assigned weekly, but rather, students are expected to find the topics in the course's textbook that are being covered in class and read about them in the textbook; in addition to the required class textbook, there are also other additional (recommended) textbooks that students can and should refer to if and when needed. Questions are always welcomed, either in class, or outside of class during office hours.

Textbooks:

- Required:
 - Spacetime and Geometry: An introduction to General Relativity (Pearson Press, 2004) by Carroll.
- Recommended:
 - Gravitational Waves (Oxford Press, 2008) by Maggiore
 - General Relativity, 1st Edition (University of Chicago Press, 1984) by Wald.
 - Gravitation, 1st Edition (W. H. Freeman, 1973) by Misner Thorne and Wheeler.
 - A First Course in General Relativity, 2nd Edition (Cambridge U., 2009) by Schutz.

Topics: (Approximately 29 Lectures of 80 minutes each)

- *Flat Spacetime and Manifolds [Chapters 1 and 2]*

- Special Relativity
- Tensor Calculus
- Classical Field Theory
- *Curvature [Chapters 3]*
 - Covariant Derivatives
 - Geodesics and Curvature Tensors
 - Killing Vectors
- *Gravity [Chapters 4]*
 - Einstein's Equations
 - Lagrangian Formulation
 - Equivalence Principle
- **Midterm [in-class, 2-hour block]**
- *Black Holes and Neutron Stars [Chapters 5]*
 - Properties
 - Geodesics
 - Experimental Tests
- *Gravitational Waves [Chapters 7]*
 - Linearized Theory and the Properties of Waves
 - Generation of Waves
 - Energy Loss and Detection
- *Cosmology [Chapters 8]*
 - Robertson–Walker Spacetimes
 - Friedman Equations
 - Redshift and Lensing
- **Final Exam [Take Home]**

No Class On: January 21 and 23 (Astro2020 Decadal meeting) March 16-March 20 (Spring Break) April 21 (April APS meeting)

Classes to Make up: 3 (80 min) classes = 240 minutes = 4 hours = 2 sessions

Video Classes: Set theory, maps and all that jazz.

Credit Points: Everyone starts with 0 credit points (CPs). You gain CPs by doing homework, doing the final exam and participating in class (asking or answering questions). There will be 12 or 13 homework sets and in total they will be worth $\sim 70\%$ of your grade. There will be one midterm and one final exam, worth $\sim 12.5\%$ of your grade each. You can earn up to $\sim 5\%$ of your final grade by asking and answering questions *in class*.

Grade Scale: Your overall grade is correlated with your overall CP, as given by the following ranking table:

- Wizard
 - ★ > 970 CPs correlates with an A+.
 - ★ > 930 CPs and < 970 CPs correlates with an A.
 - ★ > 890 CPs and < 930 CPs correlates with an A-.
- Sorcerer
 - ★ > 850 CPs and < 890 CPs correlates with an B+.
 - ★ > 810 CPs and < 850 CPs correlates with an B.
 - ★ > 770 CPs and < 810 CPs correlates with an B-.

- Mage
 - ★ > 730 CPs and < 770 CPs correlates with an C+.
 - ★ > 690 CPs and < 730 CPs correlates with an C.
 - ★ > 650 CPs and < 690 CPs correlates with an C-.
- Enchanter
 - ★ > 600 CPs and < 690 CPs correlates with an D+.
 - ★ > 550 CPs and < 6000 CPs correlates with an D.
 - ★ > 500 CPs and < 550 CPs correlates with an D-.
- N/A
 - ★ < 500CPs correlates with an F.

Homework: handed-out on Thursdays and due one week later in class. Late homework will not be accepted. In general, you are allowed to use computer algebra software, like Maple or Mathematica, unless stated otherwise. If you do use computer algebra software, you must then hand in a well-formatted print out of your code. **Under no circumstances are you allowed to use a computer algebra *package*, such as grTensor or xTensor, to calculate tensorial quantities.**

Exams: The midterm and the final exams will be closed-book and in a 2 hour block. The only book your are allowed to use during exams are the ones listed above. You are allowed 1 sheet of paper (letter size) of hand-written notes.

Do's and Don'ts:

- Do sit as close as possible to the blackboard. My handwriting is not the best.
- Do come to class prepared to take notes. Lectures draw from material outside the class' textbook.
- Do put your cell phone on vibrate and, if it rings and you have to answer, do so outside.
- Do ask questions and feel free to interrupt or point out typos on the board or in the book.
- Do work in groups if you want to, but Do Not copy from a classmate; that's cheating.
- Do not bring a newspaper, magazine, iPod, iPad, or other pads or other sources of entertainment to class.
- If you need to use the bathroom, try to do so *before* or *after* class. Leaving the classroom while a lecture is going on disrupts the flow of the class' chi.

Academic Integrity

All activities in this course are subject to the Academic Integrity rules as described in Article 1, Part 4, Academic Integrity, of the Student Code. Infractions include, but are not limited to:

- cheating, plagiarism, fabrication,
- facilitating infractions of academic integrity,
- academic interference,
- computer-related infractions,
- unauthorized use of university resources,
- sale of class materials or notes.

Violations of any of these rules will be prosecuted and reported to the student's home college in compliance with the Student Code: Article 1, Part 4, Academic Integrity, of the Student Code.

All aspects of the course are covered by these rules.

Disability Access

<https://www.disability.illinois.edu/academic-support/instructor-information/examples-disability-statements-syllabus>

The Department of Physics is committed to being an open and welcoming environment for all of our students. We are committed to helping all of our students succeed in our courses.

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603, e-mail disability@illinois.edu or go to the DRES website. If you are concerned you have a disability-related condition that is impacting your academic progress, there are academic screening appointments available on campus that can help diagnosis a previously undiagnosed disability by visiting the DRES website and selecting "Sign-Up for an Academic Screening" at the bottom of the page.

If you are interested in obtaining information to improve writing, study skills, time management or organization, the following campus resources are available to all students:

- *Writer's Workshop*, Undergrad Library, 217-333-8796,

<http://www.cws.illinois.edu/workshop>

<https://www.disability.illinois.edu/strategies>,

<http://www.counselingcenter.illinois.edu/self-help-brochures/>

Also, most college offices and academic deans provide academic skills support and assistance for academically related and personal problems. Links to the appropriate college contact can be found by going to this website and selecting your college or school:

<http://illinois.edu/colleges/colleges.html>

If you are experiencing symptoms of anxiety or depression or are feeling overwhelmed, stressed, or in crisis, you can seek help through the following campus resources:

- *Counseling Center*, 206 Fred H. Turner Student Services Building, 7:50 a.m.-5:00 p.m., Monday through Friday
Phone: 333-3704,
- *McKinley Mental Health*, 313 McKinley Health Center, 8:00 a.m.-5:00 p.m., Monday through Friday
Phone: 333-2705, McKinley Health Education offers individual consultations for students interested in learning relaxation and other stress/time management skills, call 333-2714.