Physics 5240: Introduction to the Theory of General Relativity Spring 2018

Basics:

Instructor:	Kent Yagi
Office:	Physics 318
Lectures:	9:00–9:50am MWF, Physics room 210
Office hours:	Monday and Tuesday 14:00–15:00 (For quick questions, you are welcome to come to my office at other times or ask after class.)
Phone:	982-2329
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Grader:	Robin Smith (rts3cb@virginia.edu)

Class Web Page: UVA Collab *18Sp PHYS 5240*

Textbooks:

- Bernard F. Schutz, *A First Course in General Relativity*,
- Sean M. Carroll, *Spacetime and Geometry*.

Other Books and References: (doesn't mean that I've read all of them...)

1. General Relativity
    - Hartle, *Gravity*
      (similar level to Schutz, more on physics than maths),
    - Misner, Thorne, and Wheeler, *Gravitation*
      (useful as a reference book),
    - Landau and Lifshitz, *The Classical Theory of Fields*
      (nice and concise),
    - Weinberg, *Gravitation and Cosmology*
      (non-geometric, field-theory approach),
    - Wald, *General Relativity*
      (advanced and mathematical),
    - Carroll, *Lecture Notes on General Relativity*
      ⟨⟨https://www.preposterousuniverse.com/grnotes/⟩⟩,
2. Compact Stars and Black Holes
    - Shapiro and Teukolsky, *Black Holes, White Dwarfs and Neutron Stars*
      (standard textbook),

- Chandrasekhar, *The Mathematical Theory of Black Holes*
  (good reference book on black holes),
- Poisson, *A Relativist's Toolkit: The Mathematics of Black-Hole Mechanics*
  (not only black holes but includes advanced topics in GR that are not covered in standard textbooks like Schutz),
- Townsend, *Black holes: Lecture notes*
  ⟨⟨https://arxiv.org/pdf/gr-qc/9707012.pdf⟩⟩,
  (nice lecture notes on black holes),

3. Gravitational Waves

   - Maggiore, *Gravitational Waves*
     (very good textbook covering various topics on gravitational waves),
   - Poisson and Will, *Gravity*
     (includes details of post-Newtonian calculations for gravitational waves),

4. Cosmology

   - Mukhanov, *Physical Foundations of Cosmology*
   - Weinberg, *Cosmology*

5. Differential Geometry for Physicists

   - Schutz, *Geometrical Methods of Mathematical Physics*

Grade weighting:

30%	Homework
30%	Midterm exam
40%	Final exam

Homework: Will always be due at the **start** of the class in which it is due. Late homework will be assessed a penalty, which will grow as time increases. Discussing the problems with each other is encouraged, but I expect each individual to write up their own solutions without direct copying. Copying another person's solution that you did not substantially participate in is unacceptable. In a limited number of occasions, you may ask for an extension of due dates in advance provided you have good reasons to do so.

Each problem worths 10 points unless otherwise stated. You may be able to find some of the solutions online, but **try solving problems by yourself first**. The primary purpose of assigning these problems is for you to **struggle and learn**. Also, don't just write down answers, **show derivations**!

I will make at least one problem of each mid-term and final exams to be the same as (or at the very least very similar to) one of the homework problems, so take them seriously and make sure that you can solve them on your own.

Attendance: You are responsible for the material presented in class, turning in your homework on time, knowing problem assignments, and knowing any administrative announcements made, such as changes to the syllabus or changes to the scheduling of homework or exams.

Exam Dates: Exams to be held in the normal classroom.

MID-TERM EXAM, Wednesday, March 14, 9:00 a.m. – 9:50 a.m.

FINAL EXAM, Thursday, May 10, 2:00 p.m. – 5:00 p.m.

Topics to be covered

Here is a tentative plan on what topics to be covered, though it is likely that we will not have time to go through all of them. The structure is subject to change based on how much progress we make during each lecture. For the references below, "S.XX" means Chapter XX in Schutz while "C.XX" means Chapter XX in Carroll.

1. Overview [S.5; C.1,2]
2. Special Relativity (SR) [S.1; C.1]
   - Fundamental principles of SR
   - Inertial frame
   - Spacetime diagram
   - Timelike, spacelike, null
   - Invariance of intervals
   - Lorentz transformation
3. Vector Analysis in SR [S.2; C.1]
   - Definition of vectors
   - Basis
   - Scalar product
   - Four-velocity and four-momentum
4. Tensor Analysis in SR [S.3; C.1]
   - One forms
   - (0,2) tensors
   - (M, N) tensors
   - Metrics
5. Tensor Analysis in non-Cartesian Coordinates [S.5]

- Tensor algebra
- Christoffel symbols
- Covariant derivative

6. Curved Spacetime and Manifolds [S.6,7 ; C.2]
   - Equivalence Principle
   - Manifolds
   - Vectors, one-forms, tensors
   - Metrics
   - Local flatness
7. Geodesics and Curvature [S.6; C.3]
   - Covariant derivative
   - Stoke's theorem
   - Parallel transport
   - Geodesics
   - Curvature
   - Geodesic deviation
   - Bianchi identities
   - Symmetries and Killing tensors
8. Gravitation [S.4,7,8; C.1,4]
   - Weak gravity
   - Stress-energy tensor
   - Einstein Equations
   - Lagrangian formulation
9. Non-rotating Black Holes [S.11; C.5]
   - Schwarzschild metric
   - Birkhoff's theorem
   - Geodesics
   - Singularities & Event horizon
   - Maximally extended solution
   - Penrose diagram
10. Charged/Rotating Black Holes [S.11; C.6]

- Charged black holes
- Rotating black holes
- Penrose process and black hole thermodynamics

11. Compact Stars [S.10]
    - Relativistic hydrostatic equilibrium (TOV) equation
    - White dwarfs
    - Constant density stars
    - Neutron stars

12. Gravitational Waves [S.8,9; C.7]
    - Linearized gravity & gauge transformation
    - Propagation & polarization
    - Gravitational wave production
    - Energy loss
    - Compact binary

13. Experimental Tests of Relativity [S.11; C.5,7]
    - Solar System: perihelion precession & deflection of light
    - Binary pulsars: orbital period decay
    - Gravitational waves

14. Cosmology [S.12; C.8]
    - Maximally symmetric spacetime
    - Robertson-Walker metric
    - Friedmann equation
    - Evolution of our universe
    - Redshift & distance
    - Inflation

Finally... YOUR COMMENTS AND FEEDBACK ARE WELCOME!