PHYS 2559: Gravity & Cosmology (January 2021)

Kent Yagi & Atsushi Yoshida

This is a TENTATIVE syllabus as of Dec. 24 2020.

1 Basics

Instructors:	Kent Yagi & Atsushi Yoshida
Lectures:	Jan. 4–15 10am – 3pm with one hour break in total (see Sec. 9 for more details)
Office hours:	5–6pm: Yagi; 6–7pm: Yoshida
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Grader:	Josef Zimmerman (jmz5fx@virginia.edu)

Class Web Page: UVA Collab *21J PHYS 2559-001*

2 Objectives

The goal of this course is to offer a basic, physical understanding of general relativity and cosmology. This course is distinct from the related courses (PHYS 5420 Introduction to Theory of General Relativity; PHYS 8420 Advanced General Relativity) in the sense that it is a more physics-oriented course. We aim to address fundamental questions regarding gravity and cosmology, such as

- What is general relativity?
- Why gravity is related to curved spacetime?
- What are black holes?
- What are gravitational waves?
- How did our Universe begin?
- How did our Universe evolve and where does it go?
- What are dark matter and dark energy?

(More advanced topics with mathematical rigor are left for the above more advanced courses.)

3 Textbooks

For the gravity part, we will use the original lecture notes/slides based on some of the reference books listed below.
For the cosmology part, we will be mainly following

- Barbara Ryden, *Introduction to Cosmology*

Other helpful books with the same level include

- Lambourne: *Relativity, Gravitation and Cosmology*
(easy to follow; excellent intro GR textbook; recommended by Prof. Zheng)
- Jim Hartle, *Gravity*
(wonderful undergraduate GR textbook with more weight on physics than math)
- Taylor, Wheeler and Bertschinger: *Exploring Black Holes*
(introducing GR with taking black holes as an exmaple, similar style to Hartle)
- Schutz, *A First Course in General Relativity*
(excellent intro GR textbook for undergrads; more math-oriented than Hartle; Prof. Yagi used this in PHYS 5240)
- Liddle: *An Introduction to Modern Cosmology*
(concise intro cosmology textbook for undergrads)

The following is the list of more advanced textbooks:

- Carroll, *Spacetime and Geometry*
(wonderful GR textbook for graduate students; Prof. Yagi used this in PHYS 5240)
- Misner, Thorne, and Wheeler, *Gravitation*
(useful and thorough 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*
(very advanced and mathematically rigorous),
- Dodelson and Schmidt, *Modern Cosmology*
(excellent cosmology textbook at graduate level)
- Mukhanov, *Physical Foundations of Cosmology*
(thorough explanation on early universe and thermal history)
- Weinberg, *Cosmology*
(detailed cosmology textbook, especially on cosmological perturbations)

4 Prerequisite

We assume students to know the introductory level of general physics (PHYS 1425, PHYS 2415) and special relativity (e.g. time dilation, length contraction: the depth that is covered in PHYS 2620). Calculus (including vector calculus and differential equations) and matrix algebra will be abundantly used.

5 Grade weighting

60%	Homework
40%	Final exam

Grade will be decided on curves.

6 Homework

Homework will be uploaded under "Assignments" section in the Collab website every day on Days 1–8 at 3pm. The student must submit his/her homework in Collab before 10:00:00am the next lecture day. As this course is extremely short and concentrated, assignments submitted late (with or without excuses) cannot be graded and hence will be automatically given 0 point. We encourage that you submit your homework before going to bed for your safety. The lowest-graded assignment will be dropped from the final grade.

Discussing the problems with each other is encouraged, but we 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. Also, do not just write down answers, **show derivations**!

In completing the homework, it is considered cheating to use online help (e.g. Chegg.com). We will frequently monitor these websites. If you have any doubts as to what is considered cheating, please ask us first before attempting the dubious method.

7 Exam

Final exam to be held on **the last day at 1–3pm** (after the last day's lecture). Final exam will be held online via Zoom. Please make sure to have your webcams ready so that we can monitor you during the exams. Final exam session may be recorded.

8 Resources

Homework solutions will be uploaded under "Resources" in the Collab website. Lecture slides and notes will also be uploaded there after each lecture.

9 Schedule

Each day consists of a 90-minute lecture and a 30-minute discussion session on gravity by Prof. Yoshida, and a similar lecture/discussion session on cosmology by Prof. Yagi. During the discussion session, we will go over solving exercise problems.
Lectures and discussion sessions are all performed online. They will be live-streamed on Zoom through "Online Meetings" in the Collab website. The recorded videos will also be available there after each lecture, however, students are expected to attend each lecture and discussion session in order for us to have your feedback more easily and that each lecture becomes more lively. For the same reasons, if possible, we would like to ask you to have your webcam on.
Daily schedule as below:

Day 1–9
[Day 10 (final day) is the exam day and has shorter lectures. The special schedule on this day will be announced later.]

10:00am – 10:30am: Lecture (Gravity)
10:30am – 10:35am: break
10:35am – 11:05am: Lecture (Gravity)
11:05am – 11:10am: break
11:10am – 11:40am: Lecture (Gravity)
11:40am – 11:45am: break

11:45am – 12:15pm: Discussion (Gravity)
12:15pm – 12:45pm: lunch break

12:45pm – 1:15pm: Lecture (Cosmology)
1:15pm – 1:20pm: break
1:20pm – 1:50pm: Lecture (Cosmology)
1:50pm – 1:55pm: break
1:55pm – 2:25pm: Lecture (Cosmology)
2:25pm – 2:30pm: break

2:30pm – 3:00pm: Discussion (Cosmology)

Here is a tentative plan on what topics to be covered each day. The structure is subject to change based on how much progress we make during each lecture.

Day	Gravity	Cosmology
Day 1	**§0 Overview** **§1 Special Relativity (I)** -Time Dilation & Length Contraction; -Lorentz Transformation;	**§0 Overview** -Cosmic History -Cosmological Principle **§1 Spatially-flat Universe** -Friedmann/Accelerating Equations -Equation of State
Day 2	**§2 Special Relativity (II)** -Doppler Shift; -Four-Vectors;	**§2 Cosmic Evolution** -Energy Density Evolution -Scale Factor Evolution -Redshift -Proper/Horizon Distance -Benchmark Models
Day 3	**§3 Differential Geometry (I)** -Metric; -Intrinsic and Extrinsic Curvature; -Vectors on Curved Surface; -Geodesics	-Matter + Λ or Radiation Universe **§3 Spatially-curved Universe** -Friedmann Equation -Empty Universe -Matter + Λ + Curvature
Day 4	**§4 Differential Geometry (II)** -Tensors; -Covariant Derivatives; -Parallel Transport	**§4 Measuring Cosm. Parameters** -Deceleration Parameters -Luminosity Distance -Standard Candles/Sirens
Day 5	**§5 Equivalence Principle** -Gravity as Fictitious Force; -Gravity as Geometry;	**§5 Cosmic Microwave Background** -Recombination -Photon Decoupling/Last Scattering
Day 6	**§6 Curved Spacetime** -Metrics, Connection, Curvature; -Robertson-Walker Spacetime	-Temperature Fluctuation -Acoustic Oscillations
Day 7	**§7 Geometry outside a Star** -Deflection of Light; -Gravitational Redshift	**§6 Inflation** -Flatness/Horizon Problem
Day 8	**§8 Black Holes**	-Slow-roll Inflation
Day 9	**§9 Einstein Equation**	**§7 Large Scale Structure** -Gravitational Instability
Day 10	**§10 Gravitational Waves**	-Baryon Acoustic Oscillations **§8 Dark Matter** -Galaxy Rotation Curves -MACHO

Final Exam on Day 10