# Syllabus — Cosmology and Black Holes — Not Finalized

Spring 2023, Deep Springs College, Prof. **Brian Hill**

## Overview

In two momentous leaps, Einstein discovered that space and time are not what we thought them to be. They are intertwined. I cannot explain how they are intertwined in this overview. If I could, there would be no need for a course. You have never experienced this intertwining, because it only becomes apparent when either (a) you are moving at near the speed of light, or (b) you are in the vicinity of an object even heavier and denser than our Sun. The intertwining is highly counterintuitive. We call the intertwined fabric of space and time, "spacetime."

More than anyone else since Einstein, John Archibald Wheeler has influenced our understanding of spacetime. He is an author or co-author on the best-known textbooks in the field and his students have gone on to advance the subject dramatically. Most notable of his students, perhaps, is Kip Thorne.

We will work through Wheeler's, Thorne's and others' descriptions of three things: (1) special relativity, which is how space and time are related in the absence of gravity, (2) the behavior of spacetime around a black hole, and (3) the behavior of the spacetime of the entire universe, which is the subject of cosmology.

## Unit Outline

*The following is provisional!*

### Term 4 — Galilean Relativity, Special Relativity, Black Holes

I. Euclidean Space: Euclidean Metric, Euclidean Rotations, Galilean Relativity

II. Minkowski Space: Lorentz Metric, Lorentz Transformations, Special Relativity

III. Polar Coordinates in Flat and Curved Spacetime in 2+1 and 3+1 Dimensions

IV. The Lifecycle of Stars, The Schwarzschild Metric, Stellar-Mass Black Holes, Supermassive Black Holes

### Term 5 — The Big Bang, The Metric for the Universe, Gravitational Waves

V. Homogeneity, Isotropy, and the Historical Evidence for the Big Bang

VI. Friedmann–Robertson–Walker Metric

VII. Evidence for Dark Matter and Dark Energy

VIII. Gravitational Waves, Black Hole Mergers (time permitting)

## Texts

I plan to draw from:

- ***A Journey into Gravity and Spacetime***, by John Archibald Wheeler ← could be great for our class, except the presentation is almost at a for-children level — I will be reading this for insights
- ***Black Holes and Time Warps***, by Kip Thorne ← another great survey, but again at a mathematical level a little below where we want to be
- ***Spacetime Physics, 2nd Edition***, by Edwin F. Taylor and John Archibald Wheeler ← great for many purposes, but for what I want to cover, it is too focused on special relativity with very little general relativity
- ***Exploring Black Holes: Introduction to General Relativity***, by Edwin F. Taylor and John Archibald

Wheeler ← whether it was consciously or subliminally I don't recall, this book is probably the inspiration for the course proposal — it is closest in level to the level we will be working at, and is lacking only insofar as it needs additional chapters on cosmology to get to all of our major topics
- Selected historical papers that established Big Bang cosmology
- Selected modern papers containing the evidence for dark matter and dark energy
- Selected modern papers on gravitational wave detection and black hole mergers

However, on the first day, we will discuss whether you would prefer to just follow Einstein. See below.

## Other Resources

There may be a desire to read Einstein directly, despite Wheeler and his colleagues being the more modern and masterful pedagogues. Einstein has written a monograph that is both precise and accessible and has been reprinted many times. Therefore, for about 2/3 of our course we could draw from:

- ***Relativity: The Special and General Theory***, by Albert Einstein

However, to get into modern topics such as supermassive black holes, dark matter, dark energy, and gravitational waves, we need something that is much more recent.br

## Grading

- 45% homework, 20% for midterm (near the end of term 4), 25% for final (near the end of term 5), 10% active preparation and participation in discussions

## Miscellaneous Policies

There will be a lot of handouts. Get a three-ring binder to keep all the handouts and problem sets organized. Assignments should be on 8 1/2 x 11 paper (and not torn out from a bound notebook). Multi-page assignments should be stapled. Corrections should be erased (if done in pencil) or recopied (if done in pen).

The College's general policies on absences and late work are applicable. There was an email from the Dean on this September 8, 2022. The policies below are consistent with that email:

Whereas missed coursework affects both your classmates and professors by lowering the thinking and understanding you bring to a given class, and interrupts the course schedule that has been set up and is adjusted on an ongoing basis with substantial care. The same is true for absences — whereas a handful of absences might be “normal” at colleges with large lectures or less serious academics, at Deep Springs we expect students to miss *no classes* save for legitimate health issues or emergencies requiring also missing labor and governance obligations.

For a student wishing to submit a course assignment past its required deadline, the student may request an extension on the assignment directly from the professor 48 hours in advance. Within 48 hours of the due date, the student must request an extension directly from the Dean. Exceptions will be granted by the Dean only if the student faces unforeseen and unforeseeable circumstances. A student who misses the deadline will be penalized a number of points that is roughly equivalent to a whole letter grade for each 24-hour period the assignment is late. Assignments cannot be turned in after solutions and graded assignments have been passed back, which generally happens 1-2 classes after they were turned in.