Astronomy 1142: Black Holes
Autumn 2021

Meetings: MWF, 3:00 - 3:55, Evans Lab 1008
Web page: `http://www.astronomy.ohio-state.edu/∼dhw/A1142`

Midterm exam: Wednesday, October 13, in class
Final exam: Friday December 10, noon-1:45 pm, in regular classroom

Instructor: Professor David Weinberg, Dept. of Astronomy, weinberg.21@osu.edu, 292-1773
4055A McPherson Lab (4th floor, enter through main office), mailbox by office

In-person office hours: Thursday, 11:30-12:30, McPherson 4055
Virtual office hours: Friday, 9:15-10:30, Zoom ID 827 776 2849, Passscode 1420
I will usually be available after class 3:55 - 4:20 on Monday and Wednesday

Teaching Assistant: John Bredall, PhD Student, Dept. of Astronomy, bredall.1@osu.edu

Course Material

Black holes are among the strangest objects ever conceived by science, with gravity so strong that it traps light and warps space and time almost beyond recognition. But black holes are more than theoretical oddities — astronomical observations provide strong evidence that they exist, in at least two varieties. Stellar mass black holes are created in the explosive deaths of massive stars, and they can "light up" and become detectable by ingesting the outer layers of orbiting companions. Supermassive black holes, millions or even billions of times more massive than the sun, reside at the centers of galaxies and power quasars, the most luminous objects in the universe. Pairs of black holes can spiral together by emitting gravitational waves, ripples of spacetime that propagate through the cosmos at the speed of light.

This course will tell the story of black holes: how they were conceived as theoretical ideas, how they might form from dying stars, how they were discovered, what roles they play in cosmic history, how they distort space and time, how they produce tiny but detectable gravitational wave signals, and some of the remaining mysteries they present to contemporary physics. Along the way we will learn about Newton's theory of gravity, Einstein's theory of space and time, the life cycle of stars, and the nature of quasars. We will also see how astronomers use observations from telescopes and satellites together with basic physical principles to demonstrate the reality of black holes. The Nobel Prize in Physics from 2017 and the Nobel Prize in Physics from 2020 were both tightly connected to topics of this course, as were earlier Nobel Prizes from 1983, 1993, and 2002.

Course Topics

More specifically, the topics I aim to cover are:

- Newton's theory of gravity
- Special Relativity and spacetime
- General Relativity: Einstein's theory of gravity
- Stellar death and black hole birth
- Stellar mass black holes
- Galaxies, quasars, and supermassive black holes
- The Milky Way's central black hole and the Event Horizon Telescope
- Gravitational waves and black hole mergers
- Black hole evaporation and other exotica

Prerequisites

The only prerequisite is math at the level of Math 1050 (actually, well below this level would be sufficient). The math in this course will not go beyond simple algebra, but there will be equations and geometrical or mathematical reasoning in the lectures and in the assignments. The math itself will not be difficult, but the concepts will be challenging, and *translating concepts into equations and back is one of the major things you will learn during the course.*

Textbook and Lecture Notes

The textbook is *Black Holes and Time Warps: Einstein's Outrageous Legacy*, by Kip Thorne.

This is not your typical science textbook. It was written as a popular book for a broad audience, and it covers both the science of black holes and the history of black hole discoveries. It does not perfectly match to our course material, covering some topics in less detail than we will treat them and other topics in more detail. On the whole, it is a great book, written by one of the world's most creative black hole researchers.

I will specify required and optional reading assignments with each new section of the course.

I will provide lecture notes through the course web page as we get to each new section of the course. You can decide for yourself how best to use them, but you will probably find some hybrid between taking your own class notes and referring to my notes is the most effective.

Assignments, exams, and grading

Grades will be based on four take-home assignments (30% total), in-class questions (20% total), a midterm exam (20%), and a final exam (30%). The take-home assignments will consist of questions from the lectures and reading and problems for you to work out, and they should typically take 4-8 hours apiece. I will accept assignments up to 3 days late but with a substantial penalty (see individual assignments for specifics). There will be in-class questions on most class days. I will drop the three lowest scores from the in-class questions and average the rest. While there is no direct attendance grade, if your attendance is poor you will inevitably do poorly on the in-class question grade, and probably on everything else as well.

Homework assignments must be submitted on paper, not electronically. If you are unable to attend class on the day an assignment is due, turn the assignment in to my mailbox in 4055 McPherson Lab prior to class.

You will be allowed one page (both sides) of handwritten notes for the midterm and two pages (both sides) of handwritten notes for the final.

Makeup exams will be allowed only under exceptional circumstances and by prior arrangement. Makeup exams will be oral and/or essay exams that cover the same general topics as the original exam but in different form.

How To Do Well In This Course

The most important advice is: come to class, start early on the take-home assignments, and get help on those assignments if you need it.

The take-home assignments are intended to be challenging. However, you are welcome to come to my in-person or virtual office hours to get help on them. You may also want to form study groups with others in the class to work on the assignments. You are welcome to do so, though the assignment you turn in at the end must be your own work. If you devote enough time to the assignments and get help on them as needed, you should be able to do well on this portion of the course grade. The work you put into the assignments will also improve your performance on the exams, but that is not the primary purpose of the assignments. They are an integral part of the course in their own right.

For doing well on the exams, my advice is to spend some time each week going over the lecture notes and the in-class questions, identify any things you don't understand, and ask me about them. There will also be question & answer review sessions before the midterm and the final, and attending these will likely improve your performance. I will give other advice in advance of the exams themselves.

Electronics

Calculators are allowed in class and exams. For exams, you may *not* use a cell phone, so you'll need a physical calculator if you want one. For the take-home assignments and some in-class questions, *you will need a calculator with scientific notation, and you will need to know how to use it.*

Except for in-class questions, I ask that you not use cell phones, iPads, or laptops in class. If you regularly use an iPad for taking notes that is OK, but please let me know and please use it in a way that doesn't distract others.

Academic Misconduct

It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term academic misconduct includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-487). For additional information, see the Code of Student Conduct (studentconduct.osu.edu).

Students with Disabilities

Students with disabilities (including mental health, chronic or temporary medical conditions) that have been certified by the Office of Student Life Disability Services will be appropriately accommodated and should inform me as soon as possible of their needs. The Office of Student Life Disability Services is located in 098 Baker Hall, 113 W. 12th Avenue; telephone 614-292-3307, slds@osu.edu.

Learning objectives

The Curriculum Committee of the College of Arts & Sciences requests that syllabi of all GE courses list the goals and learning objectives for the relevant category of the GEC.

As a Natural Science GE course, the goals are: "Students understand the principles, theories, and methods of modern science, the relationship between science and technology, the implications of scientific discoveries and the potential of science and technology to address problems of the contemporary world."

More specifically, the "Expected Learning Outcomes" for GE Physical Science courses are:

1. Students understand the basic facts, principles, theories and methods of modern science.

2. Students understand key events in the development of science and recognize that science is an evolving body of knowledge.

3. Students describe the inter-dependence of scientific and technological developments.

4. Students recognize social and philosophical implications of scientific discoveries and understand the potential of science and technology to address problems of the contemporary world.

Black holes are an ideal subject for addressing these objectives. In this course we will examine one of the most remarkable scientific stories of the past two centuries, one in which theory, observation, and technology all play crucial and interlocking roles. This story illuminates many facets of the way that scientific inquiry and scientific discovery work to advance human knowledge. Relativity and black holes challenge many of our everyday notions about the nature of reality, sometimes raising questions at the border of science and philosophy.

Some notable dates

Mon Sep 6: Labor Day, no class

Fri Sep 10: Homework assignment 1 handed out

Fri Sep 17: Homework assignment 1 due (at beginning of class)

Fri Sep 24: Homework assignment 2 handed out

Fri Oct 1: Homework assignment 2 due (at beginning of class)

Wed Oct 13: Midterm exam, in class (full period)

Fri Oct 15: Fall break, no class

Fri Oct 29: Homework assignment 3 handed out

Fri Nov 5: Homework 3 due

Mon Nov 22: Homework 4 handed out

Wed Nov 24 and Fri Nov 26: Thanksgiving break, no class

Fri Dec 3: Homework 4 due (at beginning of class)

Fri Dec 10: Final exam, noon - 1:45 pm, in usual classroom

I may adjust the handout/due dates of the homework assignments depending on progress of the class. I won't change the date of the midterm unless we get thrown seriously off schedule by the pandemic.