**Astronomy 142: Black Holes**
**Winter 2012**

Meetings: MWF, 11:30-12:48, Ramseyer Hall 100
Final exam: Monday, March 12, 11:30-1:18, in regular classroom
Web page: `http://www.astronomy.ohio-state.edu/~dhw/A142`

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### 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.

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, 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.

### Prerequisites

The only prerequisite is math at the level of Math 075 or 076 (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

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.

**Assignments, exams, and grading:**

Grades will be based on four take-home assignments (40% total), a midterm exam (25%), and a final exam (35%). 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 5-8 hours. The grading scale for the take-home assignments is "standard" – i.e., 95=A, 85=B, etc., and the scores for the four assignments will be averaged together to determine your letter grade for the homework portion. The midterm and final will be assigned letter grades.

## 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. I will provide my lecture notes on the course web page, and they should be helpful for following the lectures and for review, but I do *not* expect that you can learn the course material from these notes (or from the book) unless you are attending lecture. As a rule of thumb, you should expect that your course grade will drop one level (e.g., B+ to B) for each two lectures that you miss.

If you do miss a class, check with me for any handouts you might have missed, and check the course web page for anything that has been posted there.

The take-home assignments are intended to be challenging. However, you are *welcome* to come to my office hours or Ying Zu' office hours to get help on them. 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 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 first advice is to spend some time each week going over the lecture notes, 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.

As you know, the expectation for OSU courses is two hours of out-of-the-classroom work for each class hour, so for a five-hour course like this one you should expect to spend ten hours per week outside of class. In practice, I think most of you will find that you don't need quite this much time, at least in the weeks when we don't have assignments. However, to do well in the course you must put in the time you need to do well on the assignments, keep up with the reading, and review what we are covering in lecture.

## Students with Disabilities

Any student who feels that he or she may need an accommodation based on the impact of a disability should contact me to discuss specific needs. I will work with the Office for Disability Services to verify the need for accommodation and develop appropriate strategies. Students with disabilities who have not previously contacted ODS are encouraged to do so in advance by visiting the ODS website and requesting an appointment.

## Academic Misconduct

All OSU instructors are required to report suspected cases of academic misconduct to the Committee on Academic Misconduct. See the University's Code of Student Conduct for details.

**Learning objectives**

The general learning objectives for GEC courses in the Natural Sciences are:

1. To understand the basic principles and central facts of the physical and biological sciences, and their interrelationships.

2. To understand when, where, and how the most important principles and facts were discovered, thus understanding the key events in the history of science both as events in human history and as case studies in the methods of science.

3. To understand the interaction between science and technology.

4. To understand the social and philosopical implications of major scientific discoveries.

The specific learning objectives of *Astronomy 142: Black Holes* are:

• Qualitative physical understanding of Newton's and Einstein's theories of gravity, space, and time, the similarities and differences between them, and the senses in which Einstein's theory has superseded Newton's.

• Understanding of how Einstein's theory leads to the prediction of black holes and of the properties it predicts black holes to have.

• Understanding of the interplay between gravity, pressure, and nuclear energy generation in governing the life cycle of stars, and of how and why the deaths of massive stars are expected to lead to the formation of black holes.

• Understanding of how astronomers discovered the first empirical evidence for black holes and of how they have set out to demonstrate the existence of black holes as conclusively as possible.

• Understanding of why supermassive black holes are thought to be the central engines of quasars, the most luminous objects in the cosmos, and of the observational methods that are used to study quasars and the dormant black holes they have left behind in the centers of galaxies.

• Understanding of the ways that advanced space missions currently under development might lead to deeper understanding of black holes, by measuring X-rays from gas falling towards the event horizon and by measuring gravity waves — propagating ripples in spacetime — produced by colliding black holes at the far edge of the universe.

## Course Schedule

While the dates of exams and assignments will remain fixed, the schedule of topics is approximate and subject to some adjustment. All readings are from Thorne's book.

**Week 1: Overview: Black Holes In Theory and Reality**
Reading: Prologue

**Week 2: Gravity according to Newton**
Wednesday 1/11: Homework 1 handed out.
Friday 1/13: No class.

**Week 3: Relativity and spacetime**
Reading: Chapter 1.
Monday 1/16: Martin Luther King Holiday, no class
Friday 1/20: *Homework 1 due.*

**Week 4: Einstein's theory of gravity**
Reading: Chapters 2 and 3.
Friday 1/27: Homework 2 handed out

**Week 5: The life and death of stars**
Reading: Chapters 4 and 5.
Friday 2/3: *Homework 2 due.*

**Week 6: The discovery of black holes**
Reading: Chapters 6 and 8. (Chapter 7 optional.)
Wednesday, 2/8: *Midterm Exam, in class*
Friday, 2/10: Homework 3 handed out.

**Week 7: Quasars**
Reading: Chapter 9
Friday, 2/17: *Homework 3 due.*

**Week 8: Supermassive black holes**
Friday 2/24: Homework 4 handed out.

**Week 9: Rippling spacetime**
Reading: Chapter 10 (Chapter 11 optional)
Friday 3/2: *Homework 4 due.*

**Week 10: Black hole exotica**
Reading: Chapters 12 and 14 (Chapter 13 optional)

**Monday 3/12:** *Final exam, 11:30 - 1:18*, Ramseyer Hall 100