

## Astronomy 102: Black Holes, Time Warps, and the Large Scale Structure of the Universe

Fall 2011

In Astronomy 102 we present a physical and astronomical (but mostly non-mathematical) picture of the workings of Einstein's theory of relativity, and its application to black holes and the Big Bang. Black holes turn out really to occur in nature; the origin and expansion of the Universe turns out to have a lot in common with black holes; and all of this is connected with relativity in a manner that is a lot less mysterious than one might think. As we explore the connections we will find many good examples of the processes by which scientific theories are conceived and advanced in general.

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**Web Site:** <http://www.pas.rochester.edu/~laa/ast102/> . This is the main reference for this course; here you will find the lecture notes, the WebWork based homework, practice exams and real exams, as well as other useful resources, even a copy of this document.

**Lectures:** Tuesday and Thursday 2:00 - 3:15pm, in Hoyt Auditorium. All of material for each lecture will be available, for you to browse or to download in a form suitable for taking additional notes, on our Web site, about a week before the lecture is actually delivered. Note that about a third of the material we will introduce in lecture is not found in the textbooks. We will use the Interwrite **Personal Response System** (PRS) to provide real-time student feedback and encourage participation. Each student needs his/her own PRS transmitter.

**Required Text:** Kip Thorne, *Black Holes and Time Warps*, 5th edition (Pearson, 2003).

**Recommended texts:** Mike Seeds and Dana Blackman, *Foundations of Astronomy*, 11th edition (Brooks/Cole 2011), Stephen Hawking, *A Brief History of Time* (Bantam, 1988), and Joseph Silk, *The Big Bang*, third edition (Freeman, 2005). The book by Seeds is also used in three classes which belong to the same clusters as AST 102, so there are lots of copies of it around: mostly the 9<sup>th</sup> and 10<sup>th</sup> edition, but that would be fine. The book by Silk has recently gone out of print, but there are still many used copies around. You *do not need to buy these texts* and they are on reserve in the Physics, Optics and Astronomy library (Bausch and Lomb 374).

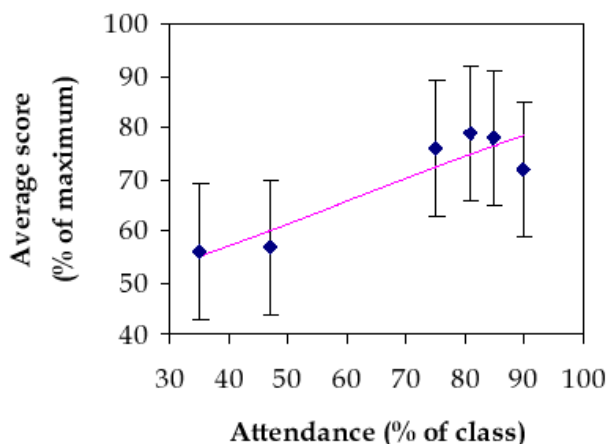
**Recitations:** Tuesdays 3:25-4:40 PM, in Bausch and Lomb 269; Wednesdays 3:25-4:40 PM in Bausch and Lomb 315 and 4:50-6:05 PM in Morey 502; Thursdays 4:50-6:05 in Hylan 101. They begin **the second week** of class. Will Bock and Theodore Lane will conduct the recitations. These sessions are opportunities for homework help and will be where and when we show the...

**Films and clips:** a few short movies elaborating on or illuminating crucial aspects of the material introduced in lectures or textbooks; and some TV clips, and most of one feature-length

Hollywood movie – Disney’s *The Black Hole* (1979) – as exhibits of Bad Astrophysics in Mass Media. The Bad Astrophysics exhibits will help you learn to detect the frequent, unintentionally humorous, mistakes made by filmmakers when they refer to astronomy or other sciences. Each film or clip will be followed by thorough discussions, led by the teaching assistants. They will be showing, in recitation, throughout the semester; screenings will be listed on the Recitations page of the AST 102 Web site. You should see each film and clip at least once; the Bad Astrophysics material will appear on Exams #2 and #3.

**The AST 102 Film Festival:** We will also watch two feature-length Hollywood movies, *Star Trek* (2009) and *Contact* (1997). They are both good movies, rich in references to and discussion of black holes and related objects, but one of them is scientifically correct much more frequently than the other. Due to low attendance in previous years, we will poll the class to determine the best way to ensure all have an opportunity to view these films. You should see each of them at least once, as the material introduced thereby will appear on Exam #3.

**Class Participation:** All members of the class are expected to attend all of the lectures and are encouraged to attend the recitation. This is for your own good! One might gain the impression, from the comprehensive on-line course resources we offer, that this might as well be a distance-learning class, but that would be a mistake. Students who attended AST 102 lectures during 1996-2006 did better on the exams than those who did not, as is illustrated in the graph at right. To emphasize this importance, class participation will comprise 5% of your grade. Your class-participation score will be based upon response to PRS questions.



**E-mail list server:** [ast102@mail.rochester.edu](mailto:ast102@mail.rochester.edu). Messages sent to this address will be resent to everybody in the class. Obviously this provides a good way to make general announcements. We also encourage use of the list server to ask questions about readings, lectures, homework problems and the like; the rest of the class will probably also be interested in your questions and the answers you’ll receive. (We will answer e-mail questions privately, too.)

**Homework assignments:** Six problem sets, to be assigned at regular intervals during the semester. Each problem set will involve the use of the **WebWork** system, a computer program that enables students to answer homework questions interactively with immediate feedback and automatic grading. Your problems sets will in general be different from those of your classmates. Your percentage score on each problem set will count as 2.5% of your grade in the course – that is, all six comprise 15% of your final grade.

Students are *strongly* encouraged to discuss the homework problems, and work together toward the solution. Only the solutions you submit must be the result of your own thought and expressed in your own words.

**Examinations:** Three tests, given online with WebWork during the hours of 12– 6 PM on 29 September, 8 November and 13 December. You are allowed one hour and fifteen minutes to

complete the exam once you begin, though you can begin at anytime within the six-hour window. Each exam will emphasize the material not covered on a previous exam and there is no *comprehensive* final exam. You must take all tests in order to pass the course. No “senior option” will be allowed. If you miss an exam due to illness or emergency, a makeup exam may be scheduled by appointment. *All makeups will be oral examinations*, an hour and fifteen minutes in length, administered and graded by the instructor. Your percentage score on each exam will count as 26.67% of your grade in the course – that is the three exams together comprise 80% for your final grade.

The best way to study for the examination is to do the homework and work out the sample exams that will appear on WebWork about a week before each exam.

**Academic Honesty:** In this class, *cheating* is defined as submission of homework or exam solutions that are not your own work, or submission of solutions under someone else’s name. According to University rules, any detected act of cheating that is not the result of a simple misunderstanding must be handed over to the Board on Academic Honesty for investigation.

**Grades:** As discussed above, grades are based 5% on class participation, 15% on the six homework assignments, and 80% on the three examinations. Final grades will be set by percentage score on an absolute scale, as follows:

Percentage Score	≥ 85	≥ 80	≥ 75	≥ 70	≥ 65	≥ 60	≥ 55	≥ 50	≥ 40	< 40
Final Grade	A	A-	B+	B	B-	C+	C	C-	D	E

The last time it was taught by Dan Watson in Fall 2009 the class average grade was a B+.

	Date	Subject	Required/recommended reading
<b>Preliminaries</b> , including our first meetings with the odd properties of black holes, which we will spend the rest of the semester explaining.			
	1 September 2011	<i>How big is that?</i> An introduction to the sizes, masses, distances, ages and speeds commonly encountered in astronomy.	<i>Seeds, chapter 1</i>
	6 September 2011	<i>Prologue in outer space:</i> what it's like to be in the neighborhood of some typical black holes.	Thorne, pp. 23-59.
	8 September 2011		
	10 September 2011	<i>Homework 1 Due by 6:30 PM</i>	
<b>Relativity:</b> a non-mathematical introduction to the special and general theories of relativity.			
	13 September 2011	<i>Einstein's theories:</i> special relativity; the warping of space and time; the Lorentz transformation and velocity-addition formulas; general relativity; experimental verifications of relativity.	Thorne, pp. 59-120. <i>Seeds, chapter 5.</i>
	15 September 2011		
	20 September 2011		
	22 September 2011	Gravitational radiation, general relativity's analogue of light.	Thorne, pp. 357-396..
	23 September 2011	<i>Homework 2 Due by 5:30 PM</i>	
	27 September 2011	General relativity predicts the existence of black holes	Thorne, pp. 121-139. <i>Hawking, chapter 6</i>
	28 September 2011	Review session for Exam #1: 7-11 PM, location TDB	
	29 September 2011	<b>Exam #1</b> , covering all subjects discussed to date.	
<b>Quantum mechanics:</b> important microscopic properties of the very dense progenitors of black holes and their relatives, the degenerate stars.			
	4 October 2011	<i>Material strength and the uncertainty principle:</i> can quantum mechanics keep black holes from forming?	Thorne, pp. 140-163. <i>Hawking, pp. 57-85.</i>
	6 October 2011	<i>Degenerate stars.</i> White dwarf stars and the Chandrasekhar maximum mass; neutron stars and the Oppenheimer maximum mass; supernovae; the inevitable formation of black holes.	Thorne, pp. 164-257. <i>Seeds, pp. 265-268, 285-295.</i>
	13 October 2011		
<b>Observations of black holes.</b> They really do exist in nature, and here's how we know.			
	18 October 2011	Properties of real black holes.	Thorne, pp. 258-299.
	20 October 2011	Energetics of black holes, and the discovery of quasars.	Thorne, pp. 300-321.
	21 October 2011	<i>Homework 3 Due by 5:30 PM</i>	
	25 October 2011	<i>Black holes unveiled.</i> Astronomical objects thought, or known, to involve black holes: X-ray binary stars, active galaxy nuclei, the center of the Milky Way, and gamma-ray bursters.	Thorne, pp. 322-356. <i>Seeds, pp. 295-303, 356-376; Silk, pp. 259-284.</i>
	27 October 2011		
	1 November 2011		
	3 November 2011		
	4 November 2011	<i>Homework 4 Due by 5:30 PM</i>	

	Date	Subject	Required/recommended reading
	7 November 2011	Review session for Exam #2: 7-11 PM, location TBD	
	8 November 2011	<b>Exam #2</b> , emphasizing subjects introduced since Exam #1.	
<b>The outsides and insides of horizons:</b> black holes and their relation to thermodynamics, Hawking radiation, and odd relativistic objects that can be considered to be combinations of black holes.			
	10 November 2011	<i>Black holes aren't quite black:</i> quantum fluctuations near the horizon, and black-hole evaporation.	Thorne, pp. 412-448. <i>Hawking</i> , pp. 105-120.
	15 November 2011	<i>Inside black holes:</i> physics beyond the black-hole horizon; or is it metaphysics?	Thorne, pp. 397-411, 449-482.
	17 November 2011	<i>Wormholes and space travel:</i> How (potentially) to use black holes to travel very long distances in a short time.	Thorne, pp. 483-522.
	22 November 2011	<i>Wormhole time machines:</i> Time travel may indeed be possible, if only in a limited sense, using wormholes.	Thorne, pp. 483-522.
<b>Cosmology:</b> the Big Bang and the large-scale structure of the Universe, which turns out to be very black-hole-like.			
	29 November 2011	<i>The homogeneous, isotropic, expanding Universe:</i> According to GR it begins and/or ends in a singularity. <i>Homework 5 Due by 5:30 PM</i>	<i>Hawking</i> , pp. 1-36; <i>Silk</i> , pp. 105-158.
	1 December 2011	<i>The Big Bang, its observation, and Big Bang cosmology:</i> The present expansion and large-scale structure of the universe, dark matter, and the history and fate of matter-dominated universes.	<i>Seeds</i> , pp. 378-400; <i>Hawking</i> , pp. 37-84 and 121-150; <i>Silk</i> , pp. 29-104 and 149-186.
	6 December 2011		
	8 December 2011		
	<a href="#">9 December 2011</a>	<i>Homework 6 Due by 5:30 PM</i>	
	12 December 2011	Review session for Exam #3: 7-11 PM, location TBD	
	13 December 2011	<b>Exam #3</b> , emphasizing subjects introduced since Exam #2.	