Astronomy 1142: Review Guide For Final Exam

The final is Friday, December 10, noon-1:45 in the usual classroom.

Review Sessions

We will hold Q&A review sessions, *all in McPherson Lab room 1008*:

Wednesday, 12/8, 4:15-5:30 pm (walk over after class)

Thursday, 12/9, 11:30-12:45

Thursday, 12/9, 5:15-6:30 pm, led by TA John Bredall

Attending one of these review sessions will almost certainly improve your performance on the final. The more reviewing you have done in advance, the more helpful it will be. You are welcome to attend more than one review if you wish.

Mechanics

The exam will be mostly multiple choice, similar in style to the midterm, but longer in total number of questions, and with a few questions designed to take more time and thought to answer. There will also be an essay question, possibly two, longer than the one on the midterm, and worth 20-25% of the exam score.

You may bring your page of handwritten notes from the midterm *plus* one *new* page (both sides) of handwritten notes, and a calculator.

Please remember to complete your student evaluation (next sheet) and bring it with you to the final.

Topics and review advice

The exam will focus on material from the second half of the course, beginning with empirical evidence for General Relativity and running through black hole evaporation. This material does draw on our treatment of Newtonian gravity and special relativity from the first half of the course, so in that sense the exam is necessarily "cumulative." In terms of the online course notes, begin with the last two pages of section 6 (the relation between Newtonian gravity and GR and the empirical evidence for GR) and continue to the end.

The most useful way to review is (probably) to go carefully over the lecture notes and the solution sets to Homework 3 and 4, making up your handwritten notes as you go. You should also go over the solution to Part II of Homework 2, as the ideas from this part came back in the latter half of the course. Even if you have your own lecture notes, it is probably useful to look at my online notes alongside them as you review. I have put together a PDF file with all of the in-class questions, available from the web page (under Information Sheets), and it will be useful to review those, beginning with those from 10/18. You should ideally feel that you know the answers to all of these questions, and especially to those that are multiple choice (and thus similar in format to questions that will appear on the final).

Pay particular attention as you review to how physicists and astronomers have built up the evidence for the existence of black holes over the last 100 years, and the combination of theoretical arguments and astronomical observations that lead us to think that black holes exist and have the properties predicted by General Relativity. Pay attention to the roles that radio astronomy, X-ray astronomy, and "traditional" (visible light) astronomy have played in this story, and the role that gravity wave astronomy is playing now and may play in the future. Although we covered empirical evidence for

GR on the midterm, we are now in a position to understand more advanced empirical evidence for GR related to black holes and gravitational waves.

You should also pay attention to how gravitational wave detectors work, especially LIGO, and what we have learned and may learn in the future from their detection. You should know how the Event Horizon Telescope uses radio interferometry to image the scale of black hole event horizons and what it has discovered. You should understand the basic ideas of Hawking radiation and black hole evaporation.

Names you should know: Newton, Einstein, Schwarzschild, Chandrasekhar, Zwicky, Oppenheimer, Wheeler, Hawking

Equations

In addition to the equations reviewed for the midterms, you should be familiar with the following equations — what quantities are represented by the variables, what principles the equations express, and how they can be used:

$$
\begin{aligned}
M &= \frac{v^2 r}{G} \\
R_{\rm Sch} &= \frac{2GM}{c^2} = 3\,{\rm km}\left(\frac{M}{M_\odot}\right) \\
\theta &= \frac{l}{D} \\
\theta_{\rm min} &= \frac{\lambda}{D} \quad \text{or} \quad \frac{\lambda}{d} \\
E &\approx \frac{GM^2}{R} \quad \text{(Homework 3, Part III)} \\
L &= \frac{1}{12}\dot{M}c^2 = 1.2 \times 10^{12} L_\odot \left(\frac{\dot{M}}{1\,M_\odot\,{\rm yr}^{-1}}\right) \\
L_{\rm Edd} &= 3 \times 10^4 L_\odot \left(\frac{M}{M_\odot}\right) \\
h &\approx \frac{1}{5}\frac{R_{\rm Sch}}{D} \\
P &\approx \frac{2\pi R_{\rm Sch}}{c} \approx 10^{-3}\left(\frac{M}{10 M_\odot}\right)\ {\rm s.}
\end{aligned}
$$

Astronomy 1142: Student Evaluation

Mechanics

Your feedback on Astronomy 1142 will be valuable in helping to shape the way I teach this course and others like it. Thinking over the content of the course and evaluating its strong and weak points is also valuable as part of reviewing for the final exam. I therefore request that you set aside 20 minutes during your review for the final to complete this evaluation. Please bring it with you to the final, where I will have an envelope for collecting them. Your evaluation should be anonymous, and you may write it or type it as you prefer. I will not read any evaluations until after I have completed grading the course.

Please *ALSO* fill out the numerical portion of the online SEI evaluations for this class, prior to midnight on Dec. 9. The statistical information from SEI ratings is valuable both to me and to the Astronomy Department as a way of tracking improvement in the course or of flagging potential problems, and it provides our best gauge of overall student satisfaction. The SEI ratings thus complement the more specific feedback that you give me on this evaluation.

Content

For your evaluation, please tell me anything you wish about what aspects of the course you liked and what aspects could be improved. I list some questions below to prompt your thinking; you do not need to answer all of them or restrict yourself to them.

Please write or type your evaluation on a separate sheet. If you prefer to submit your evaluation via the free response box in the online SEI, that's fine — please just turn in a paper evaluation saying that you submitted your comments online.

1. What material did you find most valuable? What did we spend too much time on? What do you wish we had spent more time on?

2. What aspects of the lectures were most valuable? What aspects could be improved? Would a different balance between blackboard and Power Point be more effective?

3. Did you find the book a useful part of the course? Was the intersection between the book, the lectures, and the assignments adequate? Were the supplementary materials (course notes, other handouts) valuable/sufficient? Were the online resources (via the course web page and Carmen) valuable/sufficient?

4. Were the in-class questions useful for learning the course material and teaching you new things? What would make them better?

5. Were the homework assignments useful for learning the course material and teaching you new things? What would make them better?

For your reference, I have attached on the back side of this evaluation the learning objectives for GEC courses in the Natural Sciences and the specific learning objectives that I identified for this course when I first proposed it. Feel free to comment on the degree to which the course did or did not achieve these objectives.

If you enjoyed the course, please encourage other students to take it, or other Astronomy GE classes. Professor Chris Kochanek will teach A1142 this spring; I don't know who will be teaching it next year. Other Astronomy GE options include the special topics classes Life in the Universe (A1141) and Cosmology (A1143), the A1101 survey course with laboratory, and the programming and data oriented course Astronomical Data Analysis (A1221).

Learning Objectives for Natural Sciences GEC Courses

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.