Astronomy 2142: Review Guide For Final Exam

The final is Friday, April 25, noon-1:45 in the usual classroom.

Review Sessions

We will hold two Q&A review sessions, both in McPherson Lab 4054.

Tuesday, 4/22, 4:00-5:15 pm

Wednesday, 4/23, 5:30-6:45 pm, led by TA Wynne Turner

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 both reviews 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 three 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 (energy source of the sun), as the ideas from this part came back in the latter half of the course. Re-read your essays. Even if you have your own lecture notes, it is probably useful to look at my online notes alongside them as you review.

I will put together a PDF file with all of the in-class questions, and it will be useful to review those. 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. Also pay attention to the empirical evidence for GR, from the early tests of planetary orbits, light-bending, and gravitational redshift to the more recent 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 detections. 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:

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

Although you don't need to know the equations themselves, you should know that the Einstein Field Equation specifies how the curvature of spacetime is determined by the distribution of matter and energy and that the geodesic equation specifies the spacetime paths followed by freely falling particles. They are analogous, respectively, to the Newtonian equations $F_{\mathrm{grav}} = GMm/r^2$ and $a_{\mathrm{grav}} = F_{\mathrm{grav}}/m$.

You should know that the Schwarzschild metric is an exact solution to Einstein's Field Equation that describes the curved spacetime around a mass M, which could be a star or a black hole.

Astronomy 2142: Student Evaluation

Mechanics

Your feedback on Astronomy 2142 will be valuable in helping to shape the way I teach this course and others like it. Although I have taught Black Holes before, this was the first time teaching at as a 2000-level GE themes course.

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.

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. If it would be useful, you could refer to the learning objectives for the Number, Nature, Mind GE theme that are listed on the course syllabus.

Please write or type your evaluation on a separate sheet.

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?

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 pushing you to think about it more deeply? 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?

6. Did the essay assignments, and the course in general, prompt you to think more deeply about the relation between mathematics, physical theories, and the natural world? Did you find this a valuable component of the course?