Astronomy 142: Recovery Homework Set

If you failed to turn in one of the homework assignments, or if you scored below 70% on one of the assignments, then you can complete this *optional* assignment to replace the lowest one of your four homework scores. The highest replacement score you can get is 70% (i.e., if you score anything higher than 70% on this assignment, it will replace your lowest homework score with a 70%).

You should not do this assignment if you got at least 70% on all four of the homework assignments, since it will not help your grade at all. However, you may find it useful to think about these questions as you review for the final exam.

If you decide to do this assignment, bring it with you to the final exam and turn it in before the start of the exam; I will not accept assignments after that. You may consult with others in the class when you are working on it. If you need clarification on a question, I will provide it. However, I won't provide detailed guidance, since I have already done that for the four homework assignments, and since you can refer to the written solution sets that I have provided for those assignments. These will almost certainly be useful to you, so if you are missing one, you can get it from me after class or ask me to email it to you.

Roughly speaking, there are three questions related to each of the four homework assignments. All questions have equal weight.

1. The radius of the earth is (approximately) 6000 km. At the earth's surface, the acceleration due to earth's gravity is 9.8 m/s^2, towards the center of the earth. The distance to the moon is (approximately) 360,000 km. What is the acceleration of the moon due to earth's gravity, in m/s^2? What is the direction of this acceleration?

2. The escape velocity from the surface of the earth is $11\,\mathrm{km\,s^{-1}}$. Consider a white dwarf whose mass ($0.6M_\odot$) is 200,000 times the mass of the earth and whose radius is equal to the radius of the earth. What is the escape velocity from the surface of the white dwarf?

3. You discover a new planet in the outer solar system. It has a moon, whose distance from the planet is the same as that of earth's moon (360,000 km). However, the moon goes around the planet once every two months, instead of once every month. Is your new planet more massive than the earth or less massive than the earth, and by what factor? (In other words, what is the ratio of the planet's mass to the earth's mass?)

4. You have a lump of glowing hot iron. Over time, it cools off, by radiating heat and light to its surroundings. What happens to the mass of the lump of iron as it cools off? (Assume that you can measure the mass of the iron lump with perfect precision.)

5. What is the connection between the long lifetime of the sun (many billions of years) and Einstein's famous formula $E = mc^2$?

6. A muon lives for 10^{-6} sec. Suppose a muon is produced in the atmosphere at a height of 10^4 meters, moving at 50% of the speed of light. Can it reach the ground? Explain your answer.

7. Suppose that Chandrasekhar had found that a white dwarf could be supported against gravitational collapse by electron degeneracy pressure for any mass up to $200M_\odot$. How would that have changed astronomer's expectations about the existence of stellar mass black holes?

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8. In Homework 3, Part III, we showed that the collapse of a stellar core to form a neutron star releases gravitational energy equal to 300 times the energy that the sun would generate by nuclear fusion over 10 billion years, $E_{\rm grav} \approx GM^2/R \approx 300 E_\odot$. The gravitational energy released in growing a supermassive black hole is approximately $GM^2/(10 R_{\rm Sch})$, where $R_{\rm Sch}$ is the black holes Schwarzschild radius. Drawing on the result from Homework 3 (which you may assume to be true without rederiving), what is the ratio of the gravitational energy released in growing a $10^9 M_\odot$ black hole to the energy $10^{11} E_\odot$ released by a galaxy's worth (10^{11}) of sun-like stars over 10 billion years?

9. By observing the X-ray spectrum of a stellar mass black hole, you can infer the temperature of the gas that is producing the most intense X-ray emission. How can this help you determine whether the black hole is non-spinning or spinning rapidly?

10. If I observe an accretion disk around a black hole from far away, there is just as much gas moving towards me as away from me. Doppler shifts from the gas motions increase the energy of some photons and decrease the energy of others. However, if I measure the spectrum and detect the 6.4 keV line from highly ionized iron, I find more photons redshifted to energies below 6.4 keV than blueshifted to energies above 6.4 keV. Why?

11. I observe an X-ray binary whose X-ray luminosity is $6 \times 10^4 L_\odot$. What is the minimum possible mass of the compact object whose accretion is powering the X-ray emission? Could this object be a neutron star, or must it be a black hole?

12. As part of estimating the mass of an active black hole by reverberation mapping, you measure the time delay between variations in the continuum emission produced by the accretion disk near the black hole and variations in the line emission produced by more distant gas. What is the important information that you get from this time delay? You may want to reference the equation $M = v^2 r/G$ in your answer.