12.16: Black Holes and Curved Spacetime (Exercises)

Articles

Black Holes

Charles, P. & Wagner, R. "Black Holes in Binary Stars: Weighing the Evidence." *Sky & Telescope* (May 1996): 38. Excellent review of how we find stellar-mass black holes.

Gezari, S. "Star-Shredding Black Holes." *Sky & Telescope* (June 2013): 16. When black holes and stars collide.

Jayawardhana, R. "Beyond Black." *Astronomy* (June 2002): 28. On finding evidence of the existence of event horizons and thus black holes.

Nadis, S. "Black Holes: Seeing the Unseeable." *Astronomy* (April 2007): 26. A brief history of the black hole idea and an introduction to potential new ways to observe them.

Psallis, D. & Sheperd, D. "The Black Hole Test." *Scientific American* (September 2015): 74–79. The Event Horizon Telescope (a network of radio telescopes) will test some of the stranger predictions of general relativity for the regions near black holes. The September 2015 issue of *Scientific American* was devoted to a celebration of the 100th anniversary of the general theory of relativity.

Rees, M. "To the Edge of Space and Time." *Astronomy* (July 1998): 48. Good, quick overview.

Talcott, R. "Black Holes in our Backyard." *Astronomy* (September 2012): 44. Discussion of different kinds of black holes in the Milky Way and the 19 objects known to be black holes.

Gravitational Waves

Bartusiak, M. "Catch a Gravity Wave." *Astronomy* (October 2000): 54.

Gibbs, W. "Ripples in Spacetime." *Scientific American* (April 2002): 62.

Haynes, K., & Betz, E. "A Wrinkle in Spacetime Confirms Einstein's Gravitation." *Astronomy* (May 2016): 22. On the direct detection of gravity waves.

Sanders, G., and Beckett, D. "LIGO: An Antenna Tuned to the Songs of Gravity." *Sky & Telescope* (October 2000): 41.

Websites

Black Holes

Black Hole Encyclopedia: http://blackholes.stardate.org. From StarDate at the University of Texas McDonald Observatory.

Black Holes: http://science.nasa.gov/astrophysics/focus-areas/black-holes. NASA overview of black holes, along with links to the most recent news and discoveries.

Black Holes FAQ: cfpa.berkeley.edu/Education/BHfaq.html. Frequently asked questions about black holes, answered by Ted Bunn of UC–Berkeley's Center for Particle Astrophysics.

Black Holes: Gravity's Relentless Pull: http://hubblesite.org/explore_astronomy/black_holes/home.html. The Hubble Space Telescope's Journey to a Black Hole and Black Hole Encyclopedia (a good introduction for beginners).

Introduction to Black Holes: www.damtp.cam.ac.uk/research/gr/public/bh_intro.html. The Cambridge University Relativity Group's pages on black holes and related calculations.

Movies from the Edge of Spacetime: archive.ncsa.illinois.edu/Cyberia/NumRel/MoviesEdge.html. Physicists simulate the behavior of various black holes.

Virtual Trips into Black Holes and Neutron Stars: http://antwrp.gsfc.nasa.gov/htmltest/rjn_bht.html. By Robert Nemiroff at Michigan Technological University.

Gravitational Waves

Advanced LIGO: www.advancedligo.mit.edu. The full story on this gravitational wave observatory.

eLISA: https://www.elisascience.org.

Gravitational Waves Detected, Confirming Einstein's Theory: http://www.nytimes.com/2016/02/12/science/ligo-gravitational-waves-black-holes-einstein.html. *New York Times* article and videos on the discovery of gravitational waves.

Gravitational Waves Discovered from Colliding Black Holes: http://www.scientificamerican.com/article/gravitational-waves-discovered-from-colliding-black-holes1. *Scientific American* coverage of the discovery of gravitational waves (note the additional materials available in the menu at the right).

LIGO Caltech: https://www.ligo.caltech.edu.

Videos

Black Holes

Black Holes: The End of Time or a New Beginning?: https://www.youtube.com/watch?v=mgtJRsdKe6Q. 2012 Silicon Valley Astronomy Lecture by Roger Blandford (1:29:52).

Death by Black Hole: www.openculture.com/2009/02/death_by_black_hole_and_its_kind_of_funny.htm. Neil deGrasse Tyson explains spaghettification with only his hands (5:34).

Hearts of Darkness: Black Holes in Space: https://www.youtube.com/watch?v=4tiAOldypLk. 2010 Silicon Valley Astronomy Lecture by Alex Filippenko (1:56:11).

Gravitational Waves

Journey of a Gravitational Wave: https://www.youtube.com/watch?v=FlDtXIBrAYE. Introduction from LIGO Caltech (2:55).

LIGO's First Detection of Gravitational Waves: https://www.youtube.com/watch?v=gw-i_VKd6Wo. Explanation and animations from PBS Digital Studio (9:31).

Two Black Holes Merge into One: https://www.youtube.com/watch?v=I_88S8DWbcU. Simulation from LIGO Caltech (0:35).

What the Discovery of Gravitational Waves Means: https://www.youtube.com/watch?v=jMVAgCPYYHY. TED Talk by Allan Adams (10:58).

Review Questions

1. If a black hole itself emits no radiation, what evidence do astronomers and physicists today have that the theory of black holes is correct?
2. What characteristics must a binary star have to be a good candidate for a black hole? Why is each of these characteristics important?
3. A student becomes so excited by the whole idea of black holes that he decides to jump into one. It has a mass 10 times the mass of our Sun. What is the trip like for him? What is it like for the rest of the class, watching from afar?
4. What is an event horizon? Does our Sun have an event horizon around it?
5. What is a gravitational wave and why was it so hard to detect?
6. What are some strong sources of gravitational waves that astronomers hope to detect in the future?
7. Suppose the amount of mass in a black hole doubles. Does the event horizon change? If so, how does it change?

Thought Questions

1. Imagine that you have built a large room around the people in Figure $24.1.3$ in Section 24.1 and that this room is falling at exactly the same rate as they are. Galileo showed that if there is no air friction, light and heavy objects that are dropping due to gravity will fall at the same rate. Suppose that this were not true and that instead heavy objects fall faster. Also suppose that the man in Figure $24.1.3$ in Section 24.1 is twice as massive as the woman. What would happen? Would this violate the equivalence principle?
2. A monkey hanging from a tree branch sees a hunter aiming a rifle directly at him. The monkey then sees a flash and knows that the rifle has been fired. Reacting quickly, the monkey lets go of the branch and drops so that the bullet can pass harmlessly over his head. Does this act save the monkey's life? Why or why not? (Hint: Consider the similarities between this situation and that in the previous exercise.)
3. Look elsewhere in this book for necessary data, and indicate what the final stage of evolution—white dwarf, neutron star, or black hole—will be for each of these kinds of stars.
    1. Spectral type-O main-sequence star

2. Spectral type-B main-sequence star
3. Spectral type-A main-sequence star
4. Spectral type-G main-sequence star
5. Spectral type-M main-sequence star
4. Which is likely to be more common in our Galaxy: white dwarfs or black holes? Why?
5. If the Sun could suddenly collapse to a black hole, how would the period of Earth's revolution about it differ from what it is now?
