

27.E: Active Galaxies, Quasars, and Supermassive Black Holes (Exercises)

For Further Exploration

Articles

Bartusiak, M. "A Beast in the Core." *Astronomy* (July 1998): 42. On supermassive black holes at the centers of galaxies.

Disney, M. "A New Look at Quasars." *Scientific American* (June 1998): 52.

Djorgovski, S. "Fires at Cosmic Dawn." *Astronomy* (September 1995): 36. On quasars and what we can learn from them.

Ford, H., & Tsvetanov, Z. "Massive Black Holes at the Hearts of Galaxies." *Sky & Telescope* (June 1996): 28. Nice overview.

Irion, R. "A Quasar in Every Galaxy?" *Sky & Telescope* (July 2006): 40. Discusses how supermassive black holes powering the centers of galaxies may be more common than thought.

Kormendy, J. "Why Are There so Many Black Holes?" *Astronomy* (August 2016): 26. Discussion of why supermassive black holes are so common in the universe.

Kruesi, L. "Secrets of the Brightest Objects in the Universe." *Astronomy* (July 2013): 24. Review of our current understanding of quasars and how they help us learn about black holes.

Miller, M., et al. "Supermassive Black Holes: Shaping their Surroundings." *Sky & Telescope* (April 2005): 42. Jets from black hole disks.

Nadis, S. "Exploring the Galaxy-Black Hole Connection." *Astronomy* (May 2010): 28. Overview.

Nadis, S. "Here, There, and Everywhere." *Astronomy* (February 2001): 34. On Hubble observations showing how common supermassive black holes are in galaxies.

Nadis, S. "Peering inside a Monster Galaxy." *Astronomy* (May 2014): 24. What X-ray observations tell us about the mechanism that powers the active galaxy M87.

Olson, S. "Black Hole Hunters." *Astronomy* (May 1999): 48. Profiles four astronomers who search for "hungry" black holes at the centers of active galaxies.

Peterson, B. "Solving the Quasar Puzzle." *Sky & Telescope* (September 2013): 24. A review article on how we figured out that black holes were the power source for quasars, and how we view them today.

Tucker, W., et al. "Black Hole Blowback." *Scientific American* (March 2007): 42. How supermassive black holes create giant bubbles in the intergalactic medium.

Voit, G. "The Rise and Fall of Quasars." *Sky & Telescope* (May 1999): 40. Good overview of how quasars fit into cosmic history.

Wanek, C. "How Black Holes Helped Build the Universe." *Sky & Telescope* (January 2007): 42. On the energy and outflow from disks around supermassive black holes; nice introduction.

Websites

Monsters in Galactic Nuclei: <http://chandra.as.utexas.edu/stardate.html>. An article on supermassive black holes by John Kormendy, from *StarDate* magazine.

Quasar Astronomy Forty Years On: <http://www.astr.ua.edu/keel/agn/quasar40.html>. A 2003 popular article by William Keel.

Quasars and Active Galactic Nuclei: www.astr.ua.edu/keel/agn/. An annotated gallery of images showing the wide range of activity in galaxies. There is also an introduction, a glossary, and background information. Also by William Keel.

Quasars: "The Light Fantastic": <http://hubblesite.org/newscenter/arc...35/background/>. This brief "backgrounder" from the public information office at the HubbleSite gives a bit of the history of the discovery and understanding of quasars.

Videos

Active Galaxies: https://www.youtube.com/watch?v=Y_HgsFmwCeg. Part of the *Astronomy: Observations and Theories* series; half-hour introduction to quasars and related objects (27:28).

Black Hole Chaos: The Environments of the Most Supermassive Black Holes in the Universe: <https://www.youtube.com/watch?v=hzSgU-3d8QY>. May 2013 lecture by Dr. Belinda Wilkes and Dr. Francesca Civano of the Center for Astrophysics in the CfA Observatory Nights Lecture Series (50:14).

Hubble and Black Holes: <http://www.spacetelescope.org/videos/hubblecast43a/>. Hubblecast on black holes and active galactic nuclei (9:10).

Monster Black Holes: <https://www.youtube.com/watch?v=LN9oYjNKBm8>. May 2013 lecture by Professor Chung-Pei Ma of the University of California, Berkeley; part of the Silicon Valley Astronomy Lecture Series (1:18:03).

Collaborative Group Activities

1. When quasars were first discovered and the source of their great energy was unknown, some astronomers searched for evidence that quasars are much nearer to us than their redshifts imply. (That way, they would not have to produce so much energy to look as bright as they do.) One way was to find a “mismatched pair”—a quasar and a galaxy with different redshifts that lie in very nearly the same direction in the sky. Suppose you do find one and only one galaxy with a quasar very close by, and the redshift of the quasar is six times larger than that of the galaxy. Have your group discuss whether you could then conclude that the two objects are at the same distance and that redshift is *not* a reliable indicator of distance. Why? Suppose you found three such pairs, each with different mismatched redshifts? Suppose *every* galaxy has a nearby quasar with a different redshift. How would your answer change and why?
2. Large ground-based telescopes typically can grant time to only one out of every four astronomers who apply for observing time. One prominent astronomer tried for several years to establish that the redshifts of quasars do not indicate their distances. At first, he was given time on the world’s largest telescope, but eventually it became clearer that quasars were just the centers of active galaxies and that their redshifts really did indicate distance. At that point, he was denied observing time by the committee of astronomers who reviewed such proposals. Suppose your group had been the committee. What decision would you have made? Why? (In general, what criteria should astronomers have for allowing astronomers whose views completely disagree with the prevailing opinion to be able to pursue their research?)
3. Based on the information in this chapter and in Black Holes and Curved Spacetime, have your group discuss what it would be like near the event horizon of a supermassive black hole in a quasar or active galaxy. Make a list of all the reasons a trip to that region would not be good for your health. Be specific.
4. Before we understood that the energy of quasars comes from supermassive black holes, astronomers were baffled by how such small regions could give off so much energy. A variety of models were suggested, some involving new physics or pretty “far out” ideas from current physics. Can your group come up with some areas of astronomy that you have studied in this course where we don’t yet have an explanation for something happening in the cosmos?

Review Questions

1. Describe some differences between quasars and normal galaxies.
2. Describe the arguments supporting the idea that quasars are at the distances indicated by their redshifts.
3. In what ways are active galaxies like quasars but different from normal galaxies?
4. Why could the concentration of matter at the center of an active galaxy like M87 not be made of stars?
5. Describe the process by which the action of a black hole can explain the energy radiated by quasars.
6. Describe the observations that convinced astronomers that M87 is an active galaxy.
7. Why do astronomers believe that quasars represent an early stage in the evolution of galaxies?
8. Why were quasars and active galaxies not initially recognized as being “special” in some way?
9. What do we now understand to be the primary difference between normal galaxies and active galaxies?
10. What is the typical structure we observe in a quasar at radio frequencies?
11. What evidence do we have that the luminous central region of a quasar is small and compact?

Thought Questions

1. Suppose you observe a star-like object in the sky. How can you determine whether it is actually a star or a quasar?
2. Why don’t any of the methods for establishing distances to galaxies, described in Galaxies (other than Hubble’s law itself), work for quasars?
3. One of the early hypotheses to explain the high redshifts of quasars was that these objects had been ejected at very high speeds from other galaxies. This idea was rejected, because no quasars with large blueshifts have been found. Explain why we would expect to see quasars with both blueshifted and redshifted lines if they were ejected from nearby galaxies.

4. A friend of yours who has watched many *Star Trek* episodes and movies says, “I thought that black holes pulled everything into them. Why then do astronomers think that black holes can explain the great *outpouring* of energy from quasars?” How would you respond?
5. Could the Milky Way ever become an active galaxy? Is it likely to ever be as luminous as a quasar?
6. Why are quasars generally so much more luminous (why do they put out so much more energy) than active galaxies?
7. Suppose we detect a powerful radio source with a radio telescope. How could we determine whether or not this was a newly discovered quasar and not some nearby radio transmission?
8. A friend tries to convince you that she can easily see a quasar in her backyard telescope. Would you believe her claim?

Figuring for Yourself

1. Show that no matter how big a redshift (z) we measure, v/c will never be greater than 1. (In other words, no galaxy we observe can be moving away faster than the speed of light.)
2. If a quasar has a redshift of 3.3, at what fraction of the speed of light is it moving away from us?
3. If a quasar is moving away from us at $v/c = 0.8$, what is the measured redshift?
4. In the chapter, we discussed that the largest redshifts found so far are greater than 6. Suppose we find a quasar with a redshift of 6.1. With what fraction of the speed of light is it moving away from us?
5. Rapid variability in quasars indicates that the region in which the energy is generated must be small. You can show why this is true. Suppose, for example, that the region in which the energy is generated is a transparent sphere 1 light-year in diameter. Suppose that in 1 s this region brightens by a factor of 10 and remains bright for two years, after which it returns to its original luminosity. Draw its light curve (a graph of its brightness over time) as viewed from Earth.
6. Large redshifts move the positions of spectral lines to longer wavelengths and change what can be observed from the ground. For example, suppose a quasar has a redshift of $\frac{\Delta\lambda}{\lambda} = 4.1$. At what wavelength would you make observations in order to detect its Lyman line of hydrogen, which has a laboratory or rest wavelength of 121.6 nm? Would this line be observable with a ground-based telescope in a quasar with zero redshift? Would it be observable from the ground in a quasar with a redshift of $\frac{\Delta\lambda}{\lambda} = 4.1$?
7. Once again in this chapter, we see the use of Kepler’s third law to estimate the mass of supermassive black holes. In the case of NGC 4261, this chapter supplied the result of the calculation of the mass of the black hole in NGC 4261. In order to get this answer, astronomers had to measure the velocity of particles in the ring of dust and gas that surrounds the black hole. How high were these velocities? Turn Kepler’s third law around and use the information given in this chapter about the galaxy NGC 4261—the mass of the black hole at its center and the diameter of the surrounding ring of dust and gas—to calculate how long it would take a dust particle in the ring to complete a single orbit around the black hole. Assume that the only force acting on the dust particle is the gravitational force exerted by the black hole. Calculate the velocity of the dust particle in km/s.
8. In the Check Your Learning section of Example 27.1.1 in Section 27.1, you were told that several lines of hydrogen absorption in the visible spectrum have rest wavelengths of 410 nm, 434 nm, 486 nm, and 656 nm. In a spectrum of a distant galaxy, these same lines are observed to have wavelengths of 492 nm, 521 nm, 583 nm, and 787 nm, respectively. The example demonstrated that $z = 0.20$ for the 410 nm line. Show that you will obtain the same redshift regardless of which absorption line you measure.
9. In the Check Your Learning section of Example 27.1.1 in Section 27.1, the author commented that even at $z = 0.2$, there is already an 11% deviation between the relativistic and the classical solution. What is the percentage difference between the classical and relativistic results at $z = 0.1$? What is it for $z = 0.5$? What is it for $z = 1$?
10. The quasar that appears the brightest in our sky, 3C 273, is located at a distance of 2.4 billion light-years. The Sun would have to be viewed from a distance of 1300 light-years to have the same apparent magnitude as 3C 273. Using the inverse square law for light, estimate the luminosity of 3C 273 in solar units.

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