13.23: The Evolution and Distribution of Galaxies (Exercises)

For Further Exploration

Articles

Andrews, B. “What Are Galaxies Trying to Tell Us?” *Astronomy* (February 2011): 24. Introduction to our understanding of the shapes and evolution of different types of galaxies.

Barger, A. “The Midlife Crisis of the Cosmos.” *Scientific American* (January 2005): 46. On how our time differs from the early universe in terms of what galaxies are doing, and what role supermassive black holes play.

Berman, B. “The Missing Universe.” *Astronomy* (April 2014): 24. Brief review of dark matter, what it could be, and modified theories of gravity that can also explain it.

Faber, S., et al. “Staring Back to Cosmic Dawn.” *Sky & Telescope* (June 2014): 18. Program to see the most distant and earliest galaxies with the Hubble.

Geller, M., & Huchra, J. “Mapping the Universe.” *Sky & Telescope* (August 1991): 134. On their project mapping the location of galaxies in three dimensions.

Hooper, D. “Dark Matter in the Discovery Age.” *Sky & Telescope* (January 2013): 26. On experiments looking for the nature of dark matter.

James, C. R. “The Hubble Deep Field: The Picture Worth a Trillion Stars.” *Astronomy* (November 2015): 44. Detailed history and results, plus the Hubble Ultra-Deep Field.

Kaufmann, G., & van den Bosch, F. “The Life Cycle of Galaxies.” *Scientific American* (June 2002): 46. On the evolution of galaxies and how the different shapes of galaxies develop.

Knapp, G. “Mining the Heavens: The Sloan Digital Sky Survey.” *Sky & Telescope* (August 1997): 40.

Kron, R., & Butler, S. “Stars and Strips Forever.” *Astronomy* (February 1999): 48. On the Sloan Digital Survey.

Kruesi, L. “What Do We Really Know about Dark Matter?” *Astronomy* (November 2009): 28. Focuses on what dark matter could be and experiments to find out.

Larson, R., & Bromm, V. “The First Stars in the Universe.” *Scientific American* (December 2001): 64. On the dark ages and the birth of the first stars.

Nadis, S. “Exploring the Galaxy-Black Hole Connection.” *Astronomy* (May 2010): 28. About the role of massive black holes in the evolution of galaxies.

Nadis, S. “Astronomers Reveal the Universe’s Hidden Structure.” *Astronomy* (September 2013): 44. How dark matter is the scaffolding on which the visible universe rests.

Schilling, G. “Hubble Goes the Distance.” *Sky & Telescope* (January 2015): 20. Using gravitational lensing with HST to see the most distant galaxies.

Strauss, M. “Reading the Blueprints of Creation.” *Scientific American* (February 2004): 54. On large-scale surveys of galaxies and what they tell us about the organization of the early universe.

Tytell, D. “A Wide Deep Field: Getting the Big Picture.” *Sky & Telescope* (September 2001): 42. On the NOAO survey of deep sky objects.

Villard, R. “How Gravity’s Grand Illusion Reveals the Universe.” *Astronomy* (January 2013): 44. On gravitational lensing and what it teaches us.

Websites

Assembly of Galaxies: http://jwst.nasa.gov/galaxies.html. Introductory background information about galaxies: what we know and what we want to learn.

Brief History of Gravitational Lensing: www.einstein-online.info/spot...ensing_history. From Einstein OnLine.

Cosmic Structures: skyserver.sdss.org/dr1/en/ast...structures.asp. Brief review page on how galaxies are organized, from the Sloan Survey.

Discovery of the First Gravitational Lens: astrosociety.org/wp-content/u.../ab2009-33.pdf. By Ray Weymann, 2009.

Local Group of Galaxies: http://www.atlasoftheuniverse.com/localgr.html. Clickable map from the Atlas of the Universe project. See also their Virgo Cluster page: http://www.atlasoftheuniverse.com/galgrps/vir.html.

RotCurve: burro.astr.cwru.edu/JavaLab/R...eWeb/main.html. Try your hand at using real galaxy rotation curve data to measure dark matter halos using this Java applet simulation.

Sloan Digital Sky Survey Website: http://classic.sdss.org/. Includes nontechnical and technical parts.

Spyglasses into the Universe: www.spacetelescope.org/scienc...ional_lensing/. Hubble page on gravitational lensing; includes links to videos.

Virgo Cluster of Galaxies: http://messier.seds.org/more/virgo.html. A page with brief information and links to maps, images, etc.

Videos

Cosmic Simulations: www.tapir.caltech.edu/~phopki...ies_cosmo.html. Beautiful videos with computer simulations of how galaxies form, from the FIRE group.

Cosmology of the Local Universe: http://irfu.cea.fr/cosmography. Narrated flythrough of maps of galaxies showing the closer regions of the universe (17:35).

Gravitational Lensing: https://www.youtube.com/watch?v=4Z71RtwoOas. Video from Fermilab, with Dr. Don Lincoln (7:14).

How Galaxies Were Cooked from the Primordial Soup: https://www.youtube.com/watch?v=wqNNCm7SNyw. A 2013 public talk by Dr. Sandra Faber of Lick Observatory about the evolution of galaxies; part of the Silicon Valley Astronomy Lecture Series (1:19:33).

Hubble Extreme Deep Field Pushes Back Frontiers of Time and Space: https://www.youtube.com/watch?v=gu_VhzhlqGw. Brief 2012 video (2:42).

Looking Deeply into the Universe in 3-D: https://www.eso.org/public/videos/eso1507a/. 2015 ESOCast video on how the Very Large Telescopes are used to explore the Hubble Ultra-Deep Field and learn more about the faintest and most distant galaxies (5:12).

Millennium Simulation: wwwmpa.mpa-garching.mpg.de/ga...rgo/millennium. A supercomputer in Germany follows the evolution of a representative large box as the universe evolves.

Movies of flying through the large-scale local structure: www.ifa.hawaii.edu/~tully/. By Brent Tully.

Shedding Light on Dark Matter: https://www.youtube.com/watch?v=bZW_B9CC-gI. 2008 TED talk on galaxies and dark matter by physicist Patricia Burchat (17:08).

Sloan Digital Sky Survey overview movies: astro.uchicago.edu/cosmus/projects/sloanmovie/.

Virtual Universe: https://www.youtube.com/watch?v=SY0bKE10ZDM. An MIT model of a section of universe evolving, with dark matter included (4:11).

When Two Galaxies Collide: www.openculture.com/2009/04/w...s_collide.html. Computer simulation, which stops at various points and shows a Hubble image of just such a system in nature (1:37).

Review Questions

1. How are distant (young) galaxies different from the galaxies that we see in the universe today?
2. What is the evidence that star formation began when the universe was only a few hundred million years old?
3. Describe the evolution of an elliptical galaxy. How does the evolution of a spiral galaxy differ from that of an elliptical?
4. Explain what we mean when we call the universe homogeneous and isotropic. Would you say that the distribution of elephants on Earth is homogeneous and isotropic? Why?
5. Describe the organization of galaxies into groupings, from the Local Group to superclusters.

6. What is the evidence that a large fraction of the matter in the universe is invisible?
7. When astronomers make maps of the structure of the universe on the largest scales, how do they find the superclusters of galaxies to be arranged?
8. How does the presence of an active galactic nucleus in a starburst galaxy affect the starburst process?

Thought Questions

1. Describe how you might use the color of a galaxy to determine something about what kinds of stars it contains.
2. Suppose a galaxy formed stars for a few million years and then stopped (and no other galaxy merged or collided with it). What would be the most massive stars on the main sequence after 500 million years? After 10 billion years? How would the color of the galaxy change over this time span? (Refer to Evolution from the Main Sequence to Red Giants.)
3. Given the ideas presented here about how galaxies form, would you expect to find a giant elliptical galaxy in the Local Group? Why or why not? Is there in fact a giant elliptical in the Local Group?
4. Can an elliptical galaxy evolve into a spiral? Explain your answer. Can a spiral turn into an elliptical? How?
5. If we see a double image of a quasar produced by a gravitational lens and can obtain a spectrum of the galaxy that is acting as the gravitational lens, we can then put limits on the distance to the quasar. Explain how.
6. The left panel of the thumbnail photo of Chapter 27 shows a cluster of yellow galaxies that produces several images of blue galaxies through gravitational lensing. Which are more distant—the blue galaxies or the yellow galaxies? The light in the galaxies comes from stars. How do the temperatures of the stars that dominate the light of the cluster galaxies differ from the temperatures of the stars that dominate the light of the blue-lensed galaxy? Which galaxy's light is dominated by young stars?
7. Suppose you are standing in the center of a large, densely populated city that is exactly circular, surrounded by a ring of suburbs with lower-density population, surrounded in turn by a ring of farmland. From this specific location, would you say the population distribution is isotropic? Homogeneous?
8. Astronomers have been making maps by observing a slice of the universe and seeing where the galaxies lie within that slice. If the universe is isotropic and homogeneous, why do they need more than one slice? Suppose they now want to make each slice extend farther into the universe. What do they need to do?
9. Human civilization is about 10,000 years old as measured by the development of agriculture. If your telescope collects starlight tonight that has been traveling for 10,000 years, is that star inside or outside our Milky Way Galaxy? Is it likely that the star has changed much during that time?
10. Given that only about 5% of the galaxies visible in the Hubble Deep Field are bright enough for astronomers to study spectroscopically, they need to make the most of the other 95%. One technique is to use their colors and apparent brightnesses to try to roughly estimate their redshift. How do you think the inaccuracy of this redshift estimation technique (compared to actually measuring the redshift from a spectrum) might affect our ability to make maps of large-scale structures such as the filaments and voids shown in Figure $28.3.8$ in Section 28.3?