6.E: Astronomical Instruments (Exercises)

For Further Exploration

Articles

- Blades, J. C. "Fixing the Hubble One Last Time." *Sky & Telescope*(October 2008): 26. On the last Shuttle service mission and what the Hubble was then capable of doing.
- Brown, A. "How Gaia will Map a Billion Stars." *Astronomy* (December 2014): 32. Nice review of the mission to do photometry and spectroscopy of all stars above a certain brightness.
- Irion, R. "Prime Time." *Astronomy* (February 2001): 46. On how time is allotted on the major research telescopes.
- Jedicke, Peter & Robert. "The Coming Giant Sky Patrols." *Sky & Telescope* (September 2008): 30. About giant telescopes to survey the sky continuously.
- Lazio, Joseph, et al. "Tuning in to the Universe: 21st Century Radio Astronomy." *Sky & Telescope* (July 2008): 21. About ALMA and the Square Kilometer Array.
- Lowe, Jonathan. "Mirror, Mirror." *Sky & Telescope* (December 2007): 22. On the Large Binocular Telescope in Arizona.
- Lowe, Jonathan. "Next Light: Tomorrow's Monster Telescopes." *Sky & Telescope* (April 2008): 20. About plans for extremely large telescopes on the ground.
- Mason, Todd & Robin. "Palomar's Big Eye." *Sky & Telescope*(December 2008): 36. On the Hale 200-inch telescope.
- Subinsky, Raymond. "Who Really Invented the Telescope." *Astronomy*(August 2008): 84. Brief historical introduction, focusing on Hans Lippershey.

Websites

- Websites for major telescopes are given in [link], [link], [link], and [link].

Videos

- Astronomy from the Stratosphere: SOFIA: https://www.youtube.com/watch?v=NV98BcBBA9c. A talk by Dr. Dana Backman (1:15:32)
- Galaxies Viewed in Full Spectrum of Light: https://www.youtube.com/watch?v=368K0iQv8nE. Scientists with the Spitzer Observatory show how a galaxy looks different at different wavelengths (6:22)
- Lifting the Cosmic Veil: Highlights from a Decade of the Spitzer Space Telescope: https://www.youtube.com/watch?v=nkrNQcwkY78. A talk by Dr. Michael Bicay (1:42:44)

Collaborative Group Activities

1. Most large telescopes get many more proposals for observing projects than there is night observing time available in a year. Suppose your group is the telescope time allocation committee reporting to an observatory director. What criteria would you use in deciding how to give out time on the telescope? What steps could you take to make sure all your colleagues thought the process was fair and people would still talk to you at future astronomy meetings?
2. Your group is a committee of nervous astronomers about to make a proposal to the government ministers of your small European country to chip in with other countries to build the world's largest telescope in the high, dry desert of the Chilean Andes Mountains. You expect the government ministers to be very skeptical about supporting this project. What arguments would you make to convince them to participate?
3. The same government ministers we met in the previous activity ask you to draw up a list of the pros and cons of having the world's largest telescope in the mountains of Chile (instead of a mountain in Europe). What would your group list in each column?
4. Your group should discuss and make a list of all the ways in which an observing session at a large visible-light telescope and a large radio telescope might differ. (Hint: Bear in mind that because the Sun is not especially bright at many radio wavelengths, observations with radio telescopes can often be done during the day.)
5. Another "environmental threat" to astronomy (besides light pollution) comes from the spilling of terrestrial communications into the "channels"—wavelengths and frequencies—previously reserved for radio astronomy. For example, the demand for cellular phones means that more and more radio channels will be used for this purpose. The faint signals from cosmic radio sources could be drowned in a sea of earthly conversation (translated and sent as radio waves). Assume your group is a congressional committee being lobbied by both radio astronomers, who want to save some clear channels for doing astronomy,

and the companies that stand to make a lot of money from expanding cellular phone use. What arguments would sway you to each side?

6. When the site for the new Thirty-Meter Telescope on Hawaii's Mauna Kea was dedicated, a group of native Hawaiians announced opposition to the project because astronomers were building too many telescopes on a mountain that native Hawaiians consider a sacred site. You can read more about this controversy at http://www.nytimes.com/2015/12/04/sc...cope.html?_r=0 and at http://www.nature.com/news/the-mount...escope-1.18446. Once your group has the facts, discuss the claims of each side in the controversy. How do you think it should be resolved?
7. If you could propose to use a large modern telescope, what would you want to find out? What telescope would you use and why?
8. Light pollution (spilled light in the night sky making it difficult to see the planets and stars) used to be an issue that concerned mostly astronomers. Now spilled light at night is also of concern to environmentalists and those worrying about global warming. Can your group come up with some non-astronomical reasons to be opposed to light pollution?

Review Questions

1. What are the three basic components of a modern astronomical instrument? Describe each in one to two sentences.
2. Name the two spectral windows through which electromagnetic radiation easily reaches the surface of Earth and describe the largest-aperture telescope currently in use for each window.
3. List the largest-aperture single telescope currently in use in each of the following bands of the electromagnetic spectrum: radio, X-ray, gamma ray.
4. When astronomers discuss the apertures of their telescopes, they say bigger is better. Explain why.
5. The Hooker telescope at Palomar Observatory has a diameter of 5 m, and the Keck I telescope has a diameter of 10 m. How much more light can the Keck telescope collect than the Hooker telescope in the same amount of time?
6. What is meant by “reflecting” and “refracting” telescopes?
7. Why are the largest visible-light telescopes in the world made with mirrors rather than lenses?
8. Compare the eye, photographic film, and CCDs as detectors for light. What are the advantages and disadvantages of each?
9. What is a charge-coupled device (CCD), and how is it used in astronomy?
10. Why is it difficult to observe at infrared wavelengths? What do astronomers do to address this difficulty?
11. Radio and radar observations are often made with the same antenna, but otherwise they are very different techniques. Compare and contrast radio and radar astronomy in terms of the equipment needed, the methods used, and the kind of results obtained.
12. Look back at Figure $6.4.2$ of Cygnus A and read its caption again. The material in the giant lobes at the edges of the image had to have been ejected from the center *at least* how many years ago?
13. Why do astronomers place telescopes in Earth's orbit? What are the advantages for the different regions of the spectrum?
14. What was the problem with the Hubble Space Telescope and how was it solved?
15. Describe the techniques radio astronomers use to obtain a resolution comparable to what astronomers working with visible light can achieve.
16. What kind of visible-light and infrared telescopes on the ground are astronomers planning for the future? Why are they building them on the ground and not in space?
17. Describe one visible-light or infrared telescope that astronomers are planning to launch into space in the future.

Thought Questions

1. What happens to the image produced by a lens if the lens is “stopped down” (the aperture reduced, thereby reducing the amount of light passing through the lens) with an iris diaphragm—a device that covers its periphery?
2. What would be the properties of an ideal astronomical detector? How closely do the actual properties of a CCD approach this ideal?
3. Many decades ago, the astronomers on the staff of Mount Wilson and Palomar Observatories each received about 60 nights per year for their observing programs. Today, an astronomer feels fortunate to get 10 nights per year on a large telescope. Can you suggest some reasons for this change?
4. The largest observatory complex in the world is on Mauna Kea, the tallest mountain on Earth. What are some factors astronomers consider when selecting an observatory site? Don't forget practical ones. Should astronomers, for example, consider building an observatory on Denali (Mount McKinley) or Mount Everest?
5. Suppose you are looking for sites for a visible-light observatory, an infrared observatory, and a radio observatory. What are the main criteria of excellence for each? What sites are actually considered the best today?

6. Radio astronomy involves wavelengths much longer than those of visible light, and many orbiting observatories have probed the universe for radiation of very short wavelengths. What sorts of objects and physical conditions would you expect to be associated with emission of radiation at very long and very short wavelengths?
7. The dean of a university located near the ocean (who was not a science major in college) proposes building an infrared telescope right on campus and operating it in a nice heated dome so that astronomers will be comfortable on cold winter nights. Criticize this proposal, giving your reasoning.

Figuring for Yourself

1. What is the area, in square meters, of a 10-m telescope?
2. Approximately 9000 stars are visible to the naked eye in the whole sky (imagine that you could see around the entire globe and both the northern and southern hemispheres), and there are about 41,200 square degrees on the sky. How many stars are visible per square degree? Per square arcsecond?
3. Theoretically (that is, if seeing were not an issue), the resolution of a telescope is inversely proportional to its diameter. How much better is the resolution of the ALMA when operating at its longest baseline than the resolution of the Arecibo telescope?
4. In broad daylight, the size of your pupil is typically 3 mm. In dark situations, it expands to about 7 mm. How much more light can it gather?
5. How much more light can be gathered by a telescope that is 8 m in diameter than by your fully dark-adapted eye at 7 mm?
6. How much more light can the Keck telescope (with its 10-m diameter mirror) gather than an amateur telescope whose mirror is 25 cm (0.25 m) across?
7. People are often bothered when they discover that reflecting telescopes have a second mirror in the middle to bring the light out to an accessible focus where big instruments can be mounted. “Don’t you lose light?” people ask. Well, yes, you do, but there is no better alternative. You can estimate how much light is lost by such an arrangement. The primary mirror (the one at the bottom in Figure $6.1.5$) of the Gemini North telescope is 8 m in diameter. The secondary mirror at the top is about 1 m in diameter. Use the formula for the area of a circle to estimate what fraction of the light is blocked by the secondary mirror.
8. Telescopes can now be operated remotely from a warm room, but until about 25 years ago, astronomers worked at the telescope to guide it so that it remained pointed in exactly the right place. In a large telescope, like the Palomar 200-inch telescope, astronomers sat in a cage at the top of the telescope, where the secondary mirror is located, as shown in Figure $6.1.5$. Assume for the purpose of your calculation that the diameter of this cage was 40 inches. What fraction of the light is blocked?
9. The HST cost about $1.7 billion for construction and $300 million for its shuttle launch, and it costs $250 million per year to operate. If the telescope lasts for 20 years, what is the total cost per year? Per day? If the telescope can be used just 30% of the time for actual observations, what is the cost per hour and per minute for the astronomer’s observing time on this instrument? What is the cost per person in the United States? Was your investment in the Hubble Space telescope worth it?
10. How much more light can the James Webb Space Telescope (with its 6-m diameter mirror) gather than the Hubble Space Telescope (with a diameter of 2.4 m)?
11. The Palomar telescope’s 5-m mirror weighs 14.5 tons. If a 10-m mirror were constructed of the same thickness as Palomar’s (only bigger), how much would it weigh?