

OpenStax Astronomy, Ch.6: WS Solutions (Apr-2021)

Solutions

1. 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.

Electromagnetic radiation from the visible/IR band and the radio band penetrates Earth's atmosphere. The Gran Telescopio Canarias, with its 10.4-m primary mirror, is the largest single visible light or infrared telescope, and the Arecibo telescope is the largest single-dish radio telescope.

2. When astronomers discuss the apertures of their telescopes, they say bigger is better. Explain why.

A larger aperture collects more light because there's a larger area onto which the light falls. Therefore, a larger aperture can detect fainter sources than a smaller one. Also, the diameter of the aperture is inversely proportional to the resolution; a larger aperture makes images with a higher resolution (finer detail) than a smaller one.

3. 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?

The amount of light a telescope can collect increases with the square of the aperture. Therefore, increasing the aperture diameter by a factor of two increases the area of light collection by a factor of four. The Keck telescope is four times more sensitive than the Hooker telescope.

4. What is meant by "reflecting" and "refracting" telescopes?

A reflecting telescope uses a mirror as the primary light collector, reflecting light into the spectrometer and detector. A refractor uses lenses to focus light.

5. Why are the largest visible-light telescopes in the world made with mirrors rather than lenses?

Because the light does not pass through the mirror so flaws inside the mirror do not affect the path of the light as they do with lenses. Only the front surface must be perfectly manufactured. It is also easier to support a mirror, because it can be held in place from the back. For these reasons, it's much easier and cheaper to manufacture a suitable large mirror than a suitable large lens.

6. Compare the eye, photographic film, and CCDs as detectors for light. What are the advantages and disadvantages of each?

The eye has the advantage of being readily available—no extra equipment is required. However, the eye is connected to an imperfect recording and retrieving device (the human brain), and it has a short integration time. Photograph plates can make a permanent record of an astronomical image and have much longer integration times than the eye, but they are extremely inefficient, retaining only 1% of the light that falls on them. CCDs, on the other hand, retain 60–70% or more of the incident light and provide more accurate measurements of brightness than photographic plates. Their output can be sent directly to computers for storage and analysis.

7. Why is it difficult to observe at infrared wavelengths? What do astronomers do to address this difficulty?



Both telescopes and Earth itself emit a lot of infrared radiation that is difficult to separate from the radiation coming from astronomical sources. To solve the problem, astronomers either shield the detector from its surroundings by cooling it or they make infrared observations from high in the atmosphere or from space.



8. Why do astronomers place telescopes in Earth's orbit? What are the advantages for the different regions of the spectrum?

Light from some bands of the electromagnetic spectrum does not penetrate Earth's atmosphere, so direct detection of those bands requires putting telescopes in space. For this reason, X-ray and gamma-ray space-based observatories are essential. Even in bands that do penetrate the atmosphere, like millimeter wavelengths, "pollution" from terrestrial sources can swamp faint astronomical signals, making it advantageous to place telescopes in space at these bands also. Infrared radiation is absorbed by water in Earth's atmosphere, so the higher up the telescope can be located, the less absorption by water it will have to deal with.

9. Describe the techniques radio astronomers use to obtain a resolution comparable to what astronomers working with visible light can achieve.

Radio astronomers use interferometry, in which the measurements of several telescopes are combined in order to produce a result that is comparable to that generated by a single telescope as large as the distance between the separate telescopes. In this way, the resolution of the observation is greatly increased, approaching the resolution of visible-light and infrared telescopes.

10. 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?

Astronomers are planning much bigger visible-light and infrared telescopes for the future, with primary mirrors around 30 m in diameter, to improve on the 10-m telescopes available today. Such large primary mirrors are too costly to try to put in space, so they are being built on the ground.

11. What would be the properties of an ideal astronomical detector? How closely do the actual properties of a CCD approach this ideal?

An ideal detector would be highly sensitive (100% efficiency), have a broad spectral response, be linear in its response (respond equally well at all wavelengths), have a large format (many pixels), have a wide dynamic range, and count individual photons. A modern CCD comes pretty close, with efficiency as high as 80%, a spectral response from 300–1100 nm, high linearity, a typical format size of 2048 × 4096 pixels, and good dynamic range.

12. 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 Mount McKinley (Denali) or Mount Everest?

In addition to high altitude, an observatory needs clear skies and reasonably mild weather conditions. No mountain is suitable for an observatory that is subject to frequent storms, has winds that often rise above 100 km/h, or that is normally shrouded in clouds. Also, we do not yet know how to operate effectively at altitudes above 5000 m; at such altitudes, oxygen would have to be supplied for breathing. These considerations rule out both Everest and Denali as practical observatory sites.

13. 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?



Again, the relative light-gathering power depends on the ratio of the diameters, and

therefore since $8 \text{ m} = 8000 \text{ mm}$, the telescope gathers $\left(\frac{8000}{7}\right)^2 = 1.3 \times 10^6$ times more light.

14. 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?

Over a 20-year period, the costs of the HST are \$2 billion for construction and launch plus \$5 billion for operations (including two revisits by shuttle astronauts), totaling \$7 billion. This is an average of \$350 million per year, or more than \$950,000 per day. The telescope may have a 30% duty cycle (i.e., it is actually able to observe 30% of the time, with the rest of the time spent either in sunlight when you can't observe or swinging the telescope to its next target). This means that there are 432 minutes each day available for observing, at a cost of about \$2220 per minute or \$133,000 per hour. With almost 319 million people in the United States, this is just over \$1 per person per year.

