[11] Telescopes (10/3/17)

Upcoming Items

1. Homework #6 not due until Tue Oct 17.
2. **Midterm #1 in one week! Exam formulae posted on website (Files -> exams)**
3. Read Ch. 7.1 and 7.2 by next class (skim the rest of Ch. 7) and do the self-study quizzes.

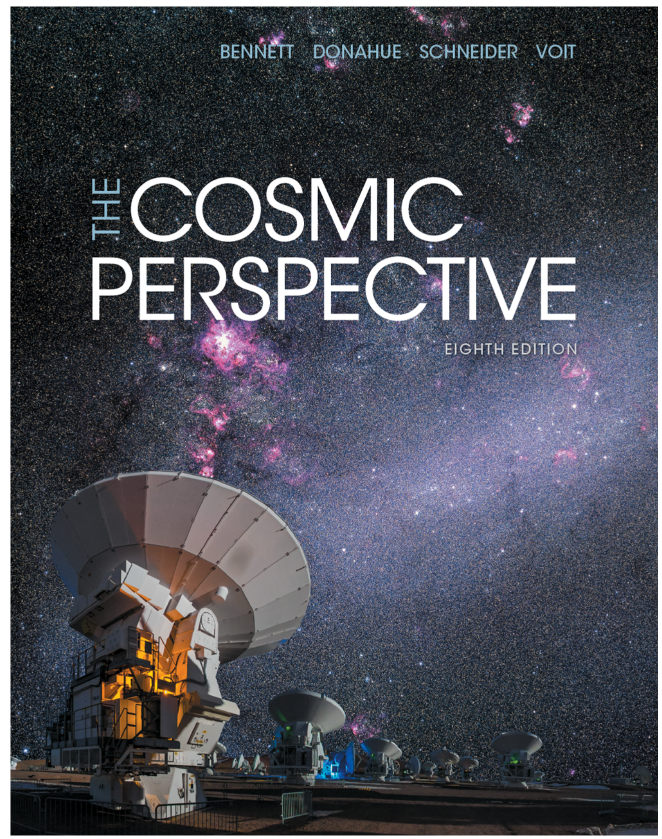
500 m Spherical Aperture Telescope (FAST), China

LEARNING GOALS

Chapter 6

For this class, you should be able to…

- *… compare the basic capabilities (light-gathering area, angular resolution) of telescopes with different diameters;*
- *… compare the advantages and disadvantages of space-borne telescopes versus ground-based telescopes.*



Nobel Prize in Physics, 2017: LIGO!

Any astro questions?

In-class Quiz!

Telescope 1 has a diameter of 10 meters and observes at a wavelength of 1 micron. Telescope 2 has a diameter of 5 meters and observes at a wavelength of 0.5 microns.

1. How does the light-collecting area of Telescope 1 compare with that of Telescope 2?

A. Telescope 1 has 1/2 the light-collecting area of Telescope 2
B. Telescope 1 has the same light-collecting area as Telescope 2
C. **Telescope 1 has 4 times the light-collecting area of Telescope 2**
D. There is not enough information to say.

2. How does the angular resolution of Telescope 1 compare with that of Telescope 2?

A. Telescope 1's minimum angle is ½ that of Telescope 2
B. **Telescope 1's minimum angle is the same as Telescope 2**
C. Telescope 1's minimum angle is 2x that of Telescope 2
D. There is not enough information to say

Debate on Thursday!

- Yes, with candy ☺
- Same rules as before, but different group will judge
- The debate topic:

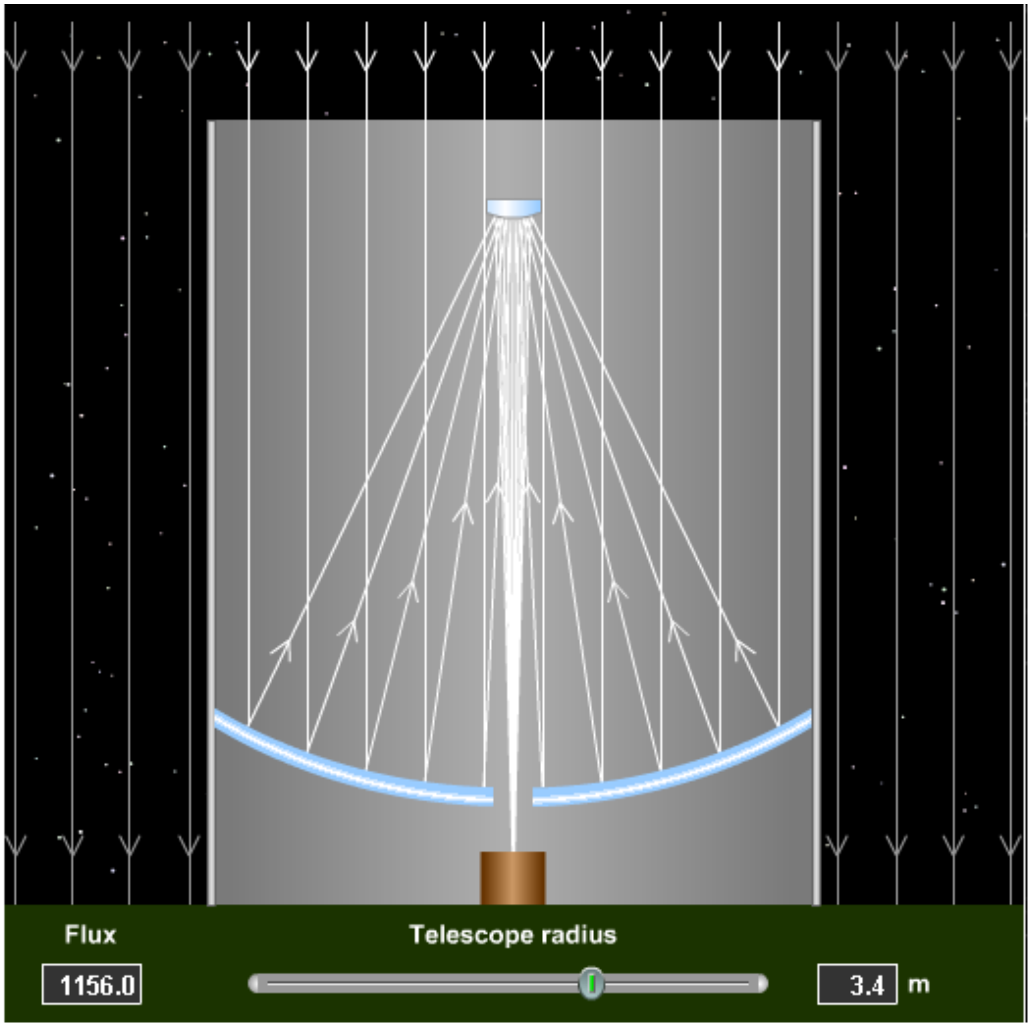
  Should Pluto be considered a planet?
- Suggestion: look up the official definition of a planet, per the International Astronomical Union (IAU)
- Good luck, and have fun!

Why are Telescopes Better than Eyes?

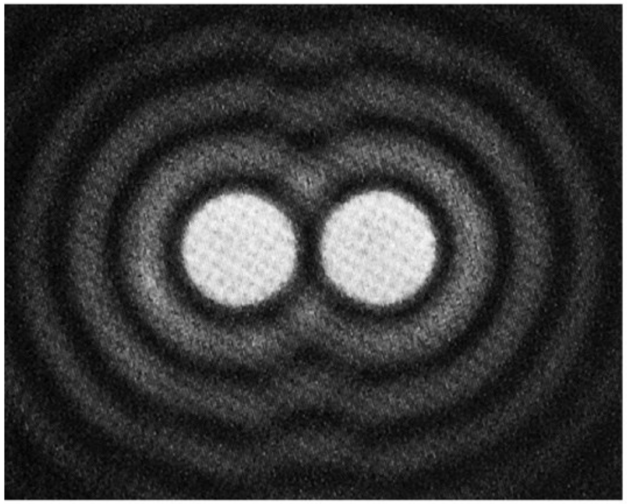
Why are Telescopes Better than Eyes?

- Telescopes have larger diameters
  Thus they gather more light per time from a source
- Telescopes are wider
  Improves angular resolution
  Can combine separate telescopes this way

Light-collecting Area

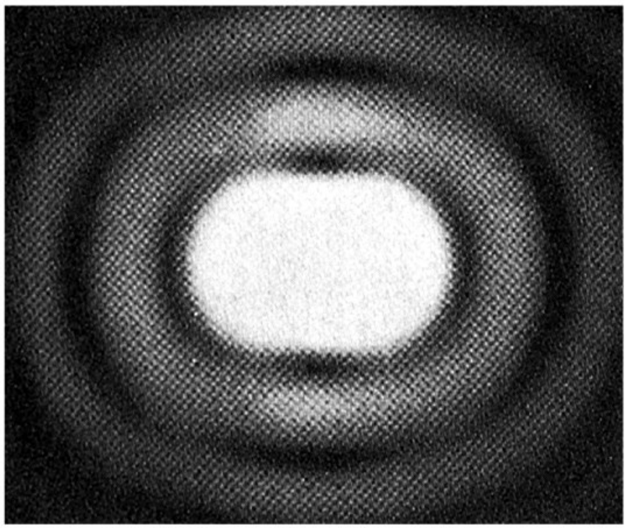


- Determined by the telescope's diameter: Area ∝ $(\text{diameter})^2$.
- The largest optical telescopes in use have a diameter of about 10 meters.



(a)

Two light sources with angular separation greater than angular resolution of telescope: Two sources easily distinguished



(b)

Light sources moved closer so that angular separation equals angular resolution of telescope: Just barely possible to tell that there are two sources

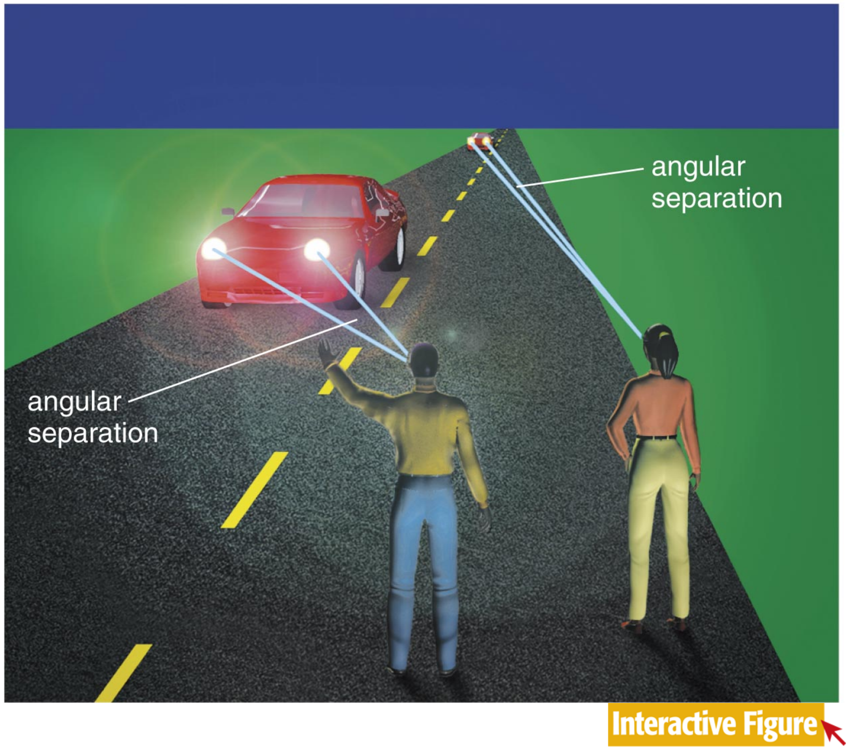
Angular Resolution

- The *minimum* angular separation that the telescope can distinguish.

- Resolution of telescope set by ***diffraction limit***

$$\theta_{\min} \cong 1.22 \frac{\lambda}{D},$$

where λ is wavelength of light observed and D is telescope diameter.



What Can Instruments Do?

- Note: an instrument is attached to a telescope to process the light that comes through

What Can Instruments Do?

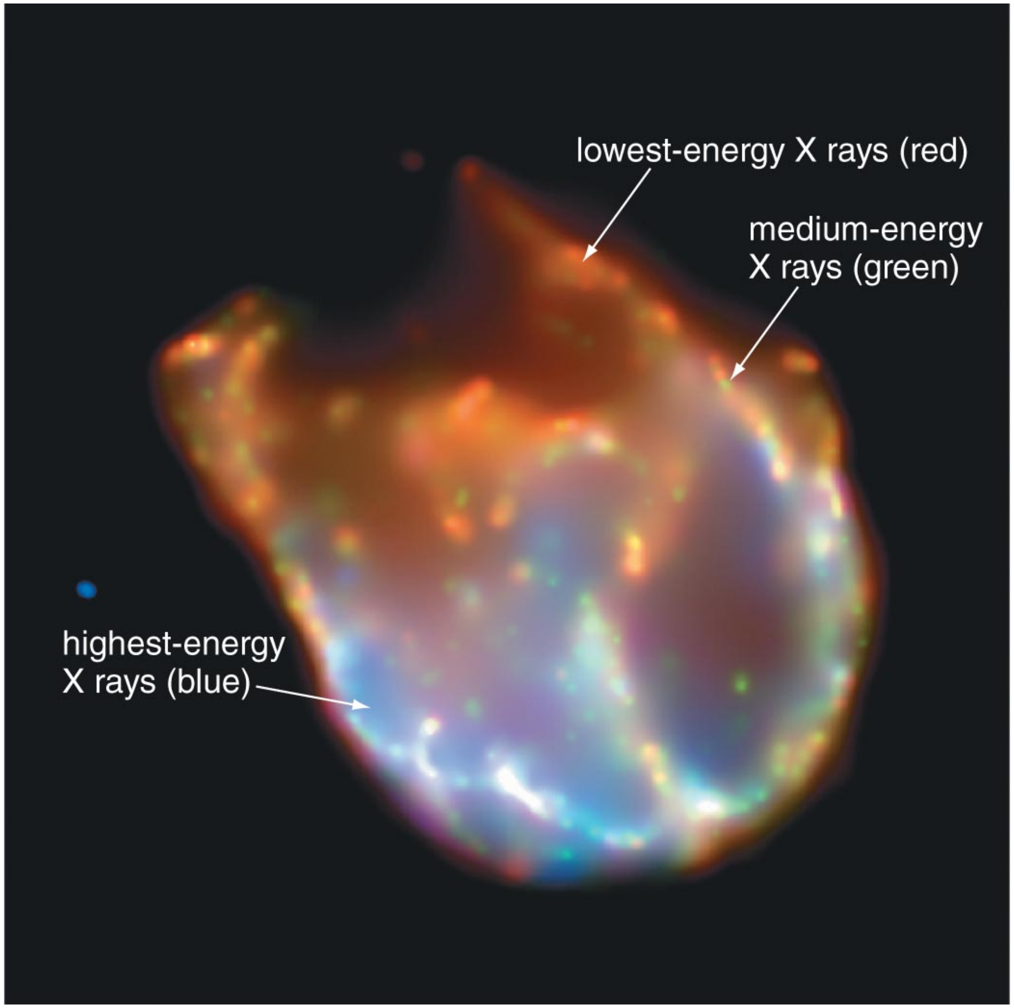
- Note: an instrument is attached to a telescope to process the light that comes through
- Instruments can add up light over a long time
  Our eyes have a limited “integration time”, ~0.1-0.2 sec
- Instruments can produce very precise spectra
- Instruments can produce very precise time resolution
  Note: “time domain astronomy” is a big thing now!
- Instruments can detect wavelengths of electromagnetic radiation far outside of human vision
  The type of telescope also depends on the wavelength
- For all these reasons, telescopes plus instruments continue to open up new insights in to the universe!

What do astronomers do with telescopes?

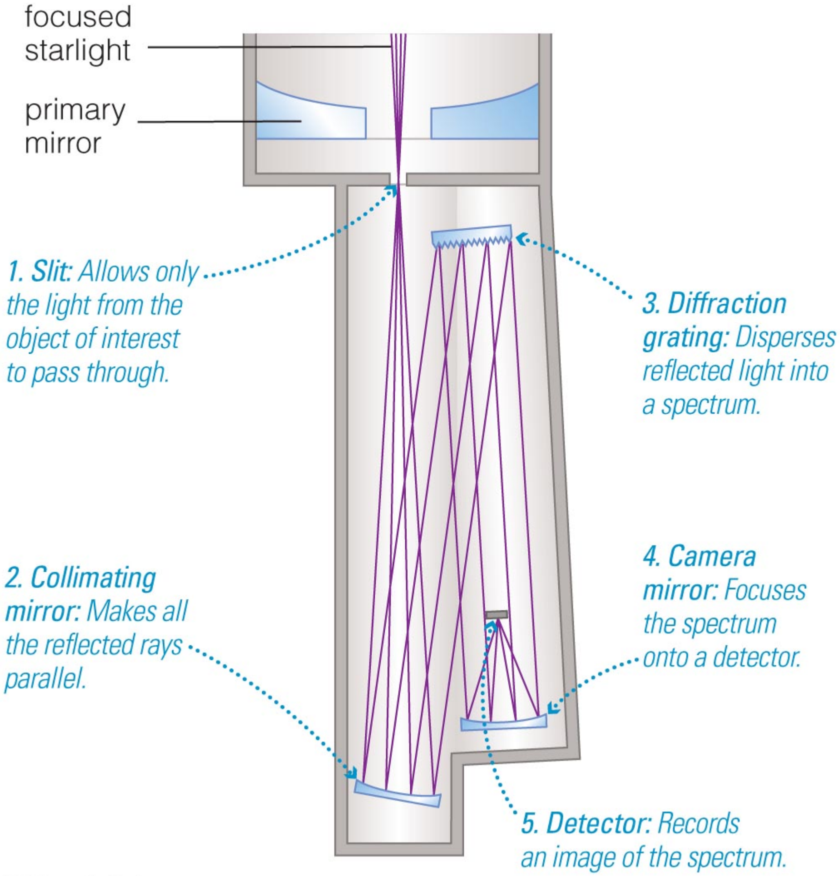
- **Imaging:** taking pictures of the sky.
- **Spectroscopy:** breaking light into spectra.
- **Time Monitoring:** measuring how light output varies with time.

Imaging

- Astronomical detectors can record forms of light our eyes can't see.
- Color is sometimes used to represent different energies of non-visible light.

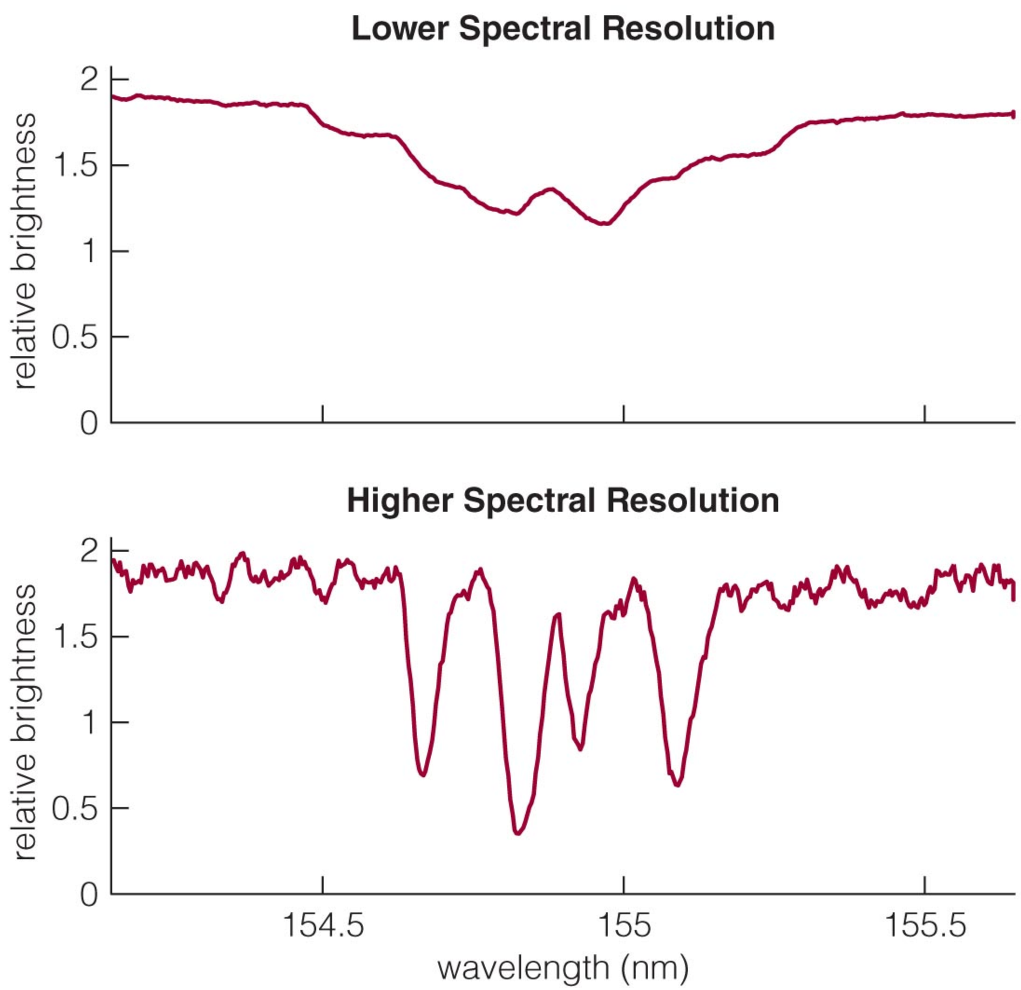


Spectroscopy



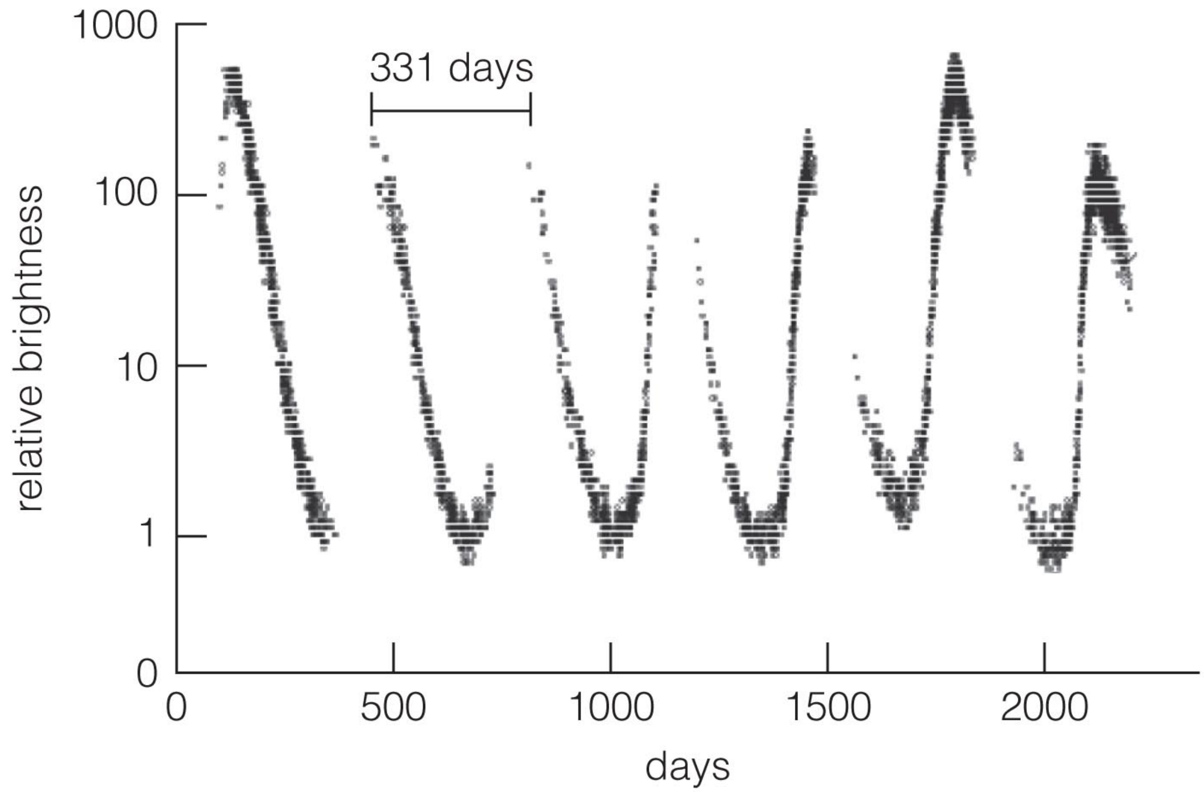
- A spectrograph separates the different wavelengths of light before they hit the detector.

Spectroscopy



- Graphing relative brightness of light at each wavelength shows the details in a spectrum.

Time Monitoring



- A light curve represents a series of brightness measurements made over a period of time.

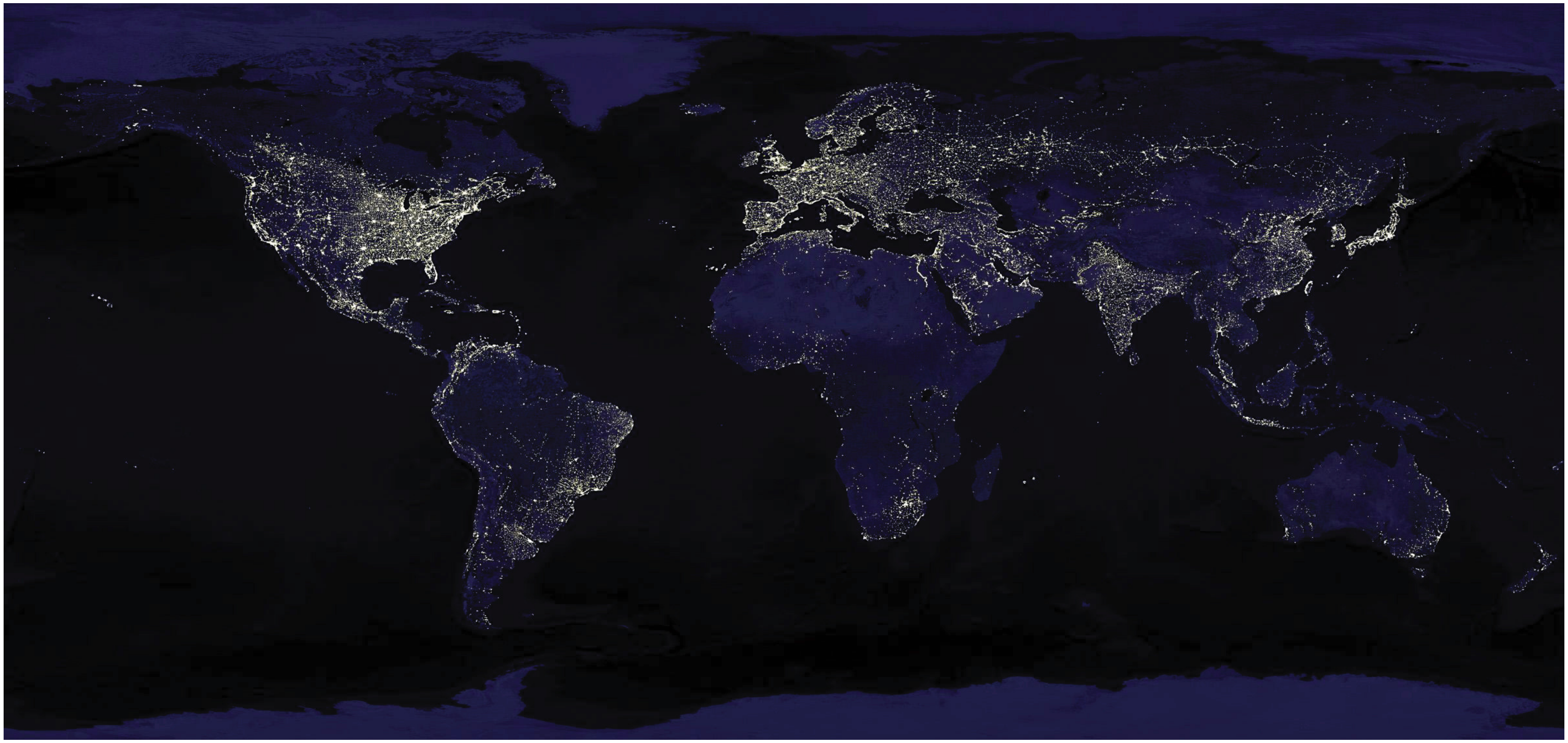
How does Earth's atmosphere affect ground-based observations?

- Group question: what are the different effects?

How does Earth's atmosphere affect ground-based observations?

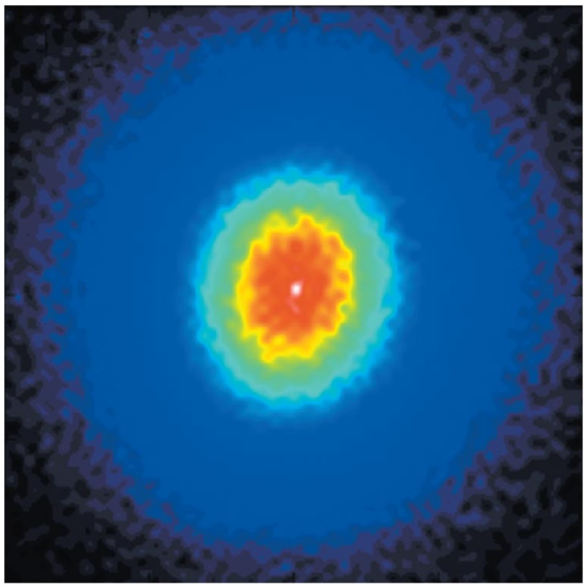
- The atmosphere moves, which causes blurring
  The blurring is worse at shorter wavelengths
- The atmosphere also scatters light, which makes it tougher to see dim sources
  “Sky glow”; it’s the reason you can’t see stars in the day
- The best ground-based sites for astronomical observing are therefore:
  - calm (not too windy)
  - high (less atmosphere to see through)
  - dark (far from city lights)
  - dry (few cloudy nights)

Light Pollution

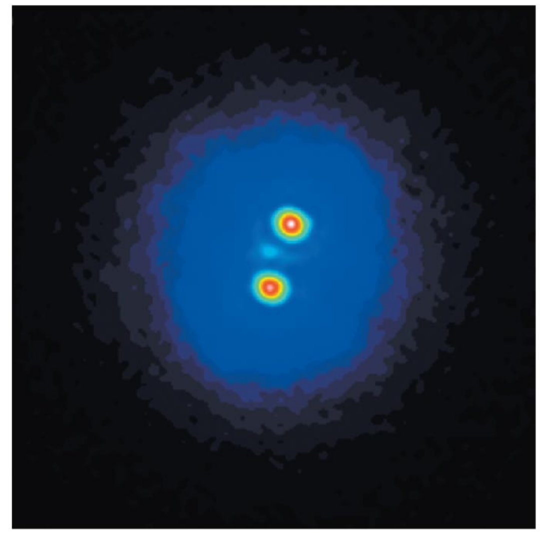


- Scattering of human-made light in the atmosphere is a growing problem for astronomy.

Adaptive Optics



a Atmospheric blurring makes this ground-based image of a double star look like that of a single star.



b When the same telescope is used with adaptive optics, the two stars can be clearly distinguished. The angular separation between the two stars is 0.28 arcsecond.

- Rapidly changing the shape of a telescope's mirror compensates for some of the effects of turbulence.

Calm, High, Dark, Dry

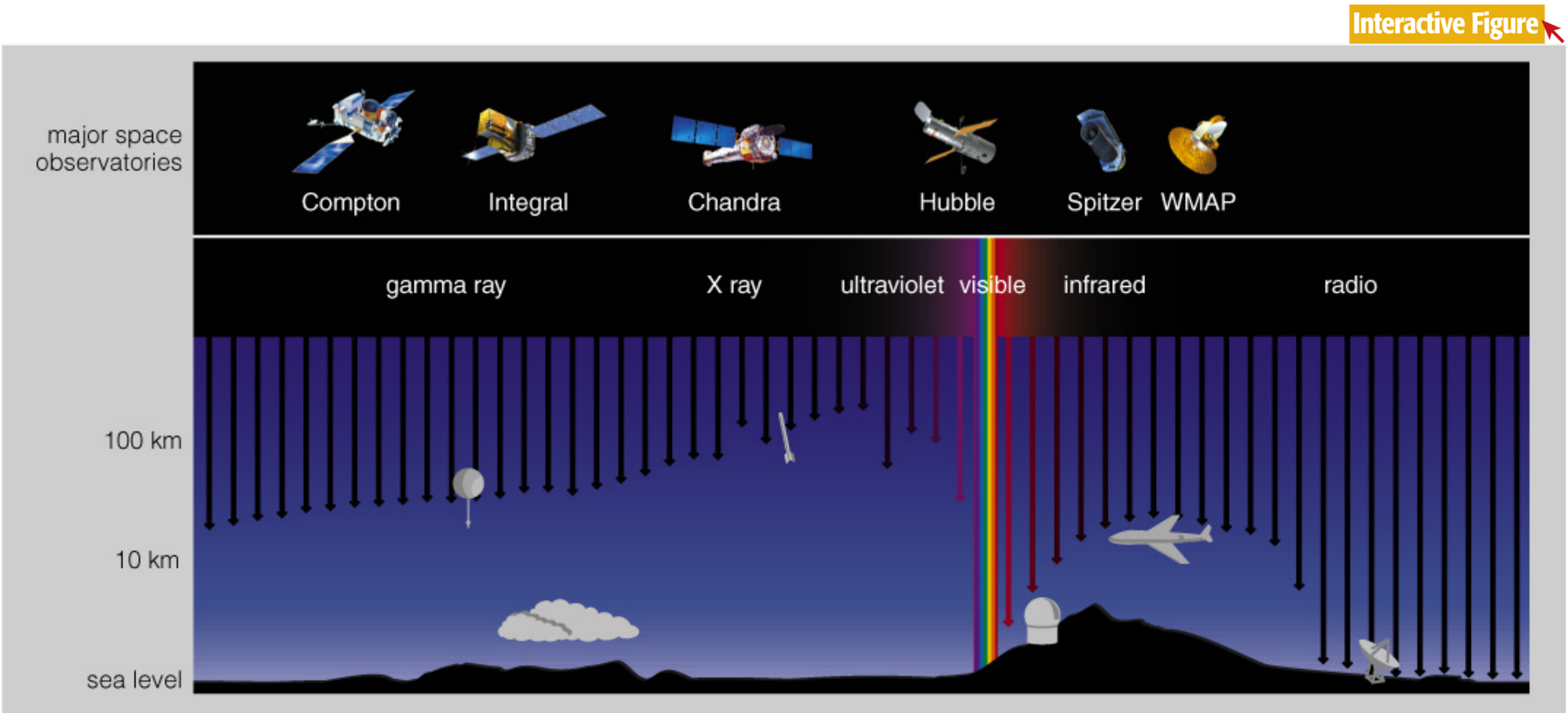
- The best observing sites are atop remote mountains.

Summit of Mauna Kea, Hawaii

Why do we put telescopes into space?

- *It is NOT because they are closer to the stars!…*

- Only radio and visible light pass easily through Earth's atmosphere.
- We need telescopes in space to observe other forms.



Atomic absorption

Molecular absorption

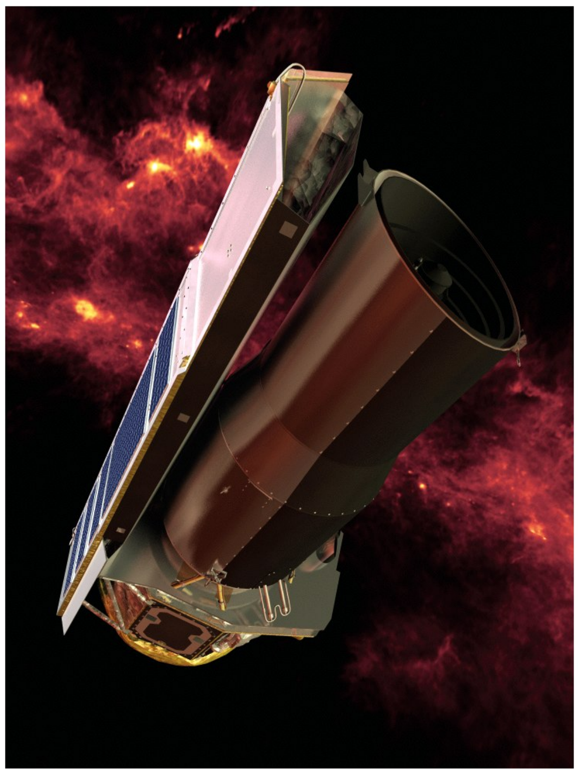
Ionospheric reflection > 10 m

Telescopes in space solve all three problems

- Location/technology can help overcome light pollution and turbulence.
- But nothing short of going to space can solve the problem of atmospheric absorption of light.

Are there any drawbacks to putting telescopes in space?

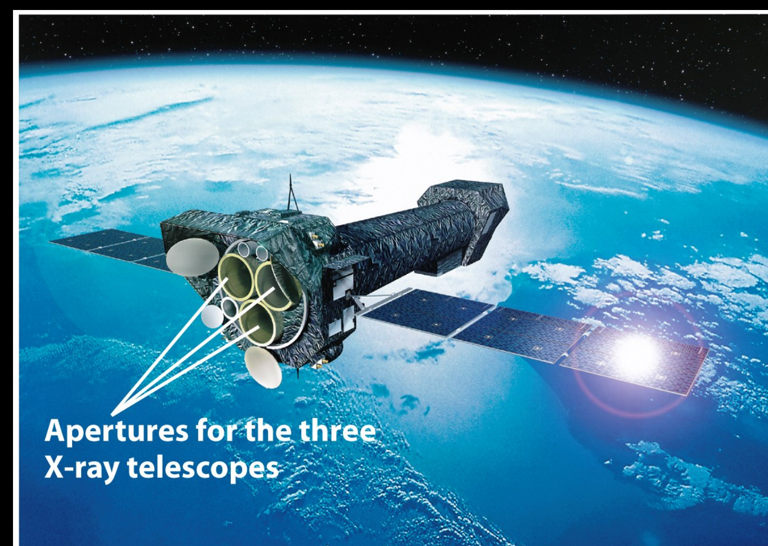
Chandra X-ray Observatory



Spitzer: IR

Hubble Space Telescope: near-IR, visible, near-UV

Compton Gamma Ray Observatory



XMM-Newton

Full-scale model of the James Webb Space Telescope (IR).

Telescopes and observatories outside of the visible band…

- Current astronomical observatories operate from long-wavelength radio waves ($\lambda \sim 4$ m) to very high-energy gamma rays ($\lambda \sim 10^{-18}$ m).
- The challenges…
  1. Focusing (some wavelengths cannot yet be focused!).
  2. Detectors (different strategies for different wavelengths).
  3. Earth's atmosphere gets in the way.

How do we observe invisible light?

- A standard satellite dish is essentially a telescope for observing radio waves.

Radio Telescopes

- A radio telescope is like a giant mirror that reflects radio waves to a focus.

Arecibo radio telescope, Puerto Rico; 300m diam.

Very minor issue compared with human tragedy, but Arecibo was damaged by Hurricane Maria.

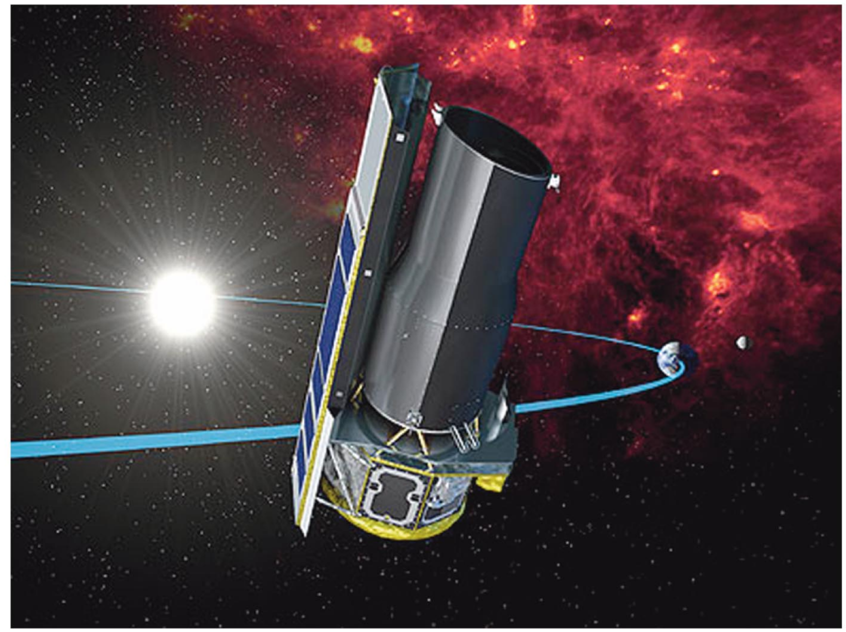
The National Science Foundation is considering divesting from, or demolishing, Arecibo

Arecibo From the Top

Photo I took at a conf. there in 2012. Incredibly gigantic; like 3 football fields across!

Infrared and Ultraviolet Telescopes

SOFIA



Spitzer

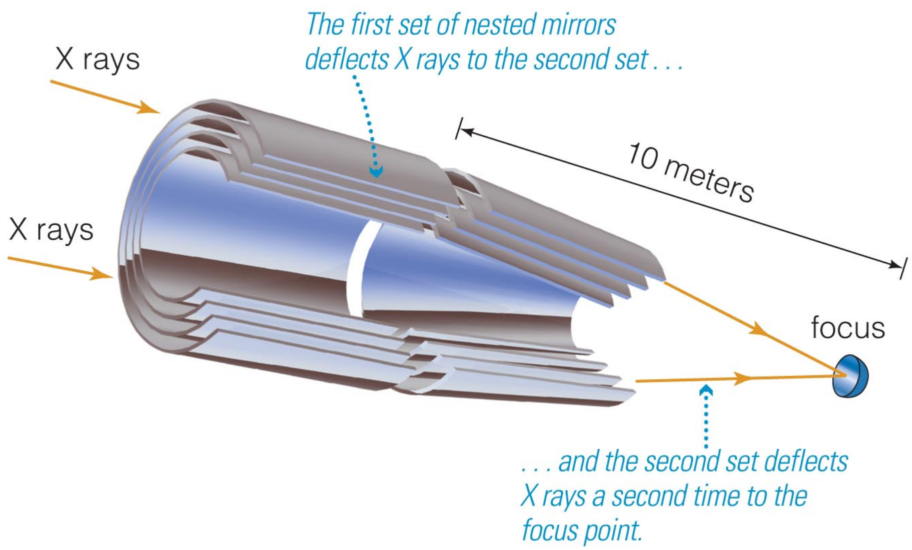
- Infrared and ultraviolet light telescopes operate like visible-light telescopes but need to be above atmosphere to see all wavelengths.

X-Ray Telescopes

- X-ray telescopes also need to be above the atmosphere. Why? Atmosphere blocks X-rays (fortunately!)

a Artist's illustration of the Chandra X-Ray Observatory, which orbits Earth.

X-Ray Telescopes

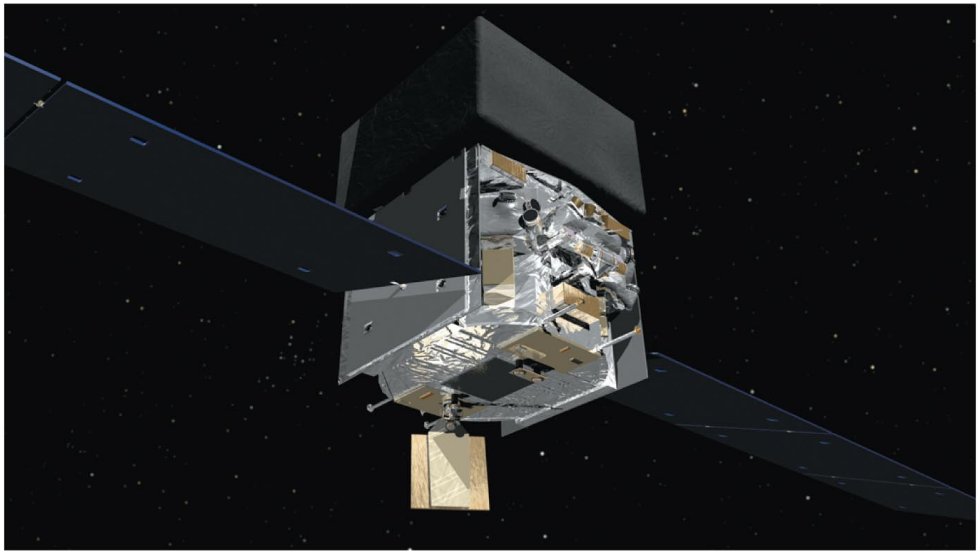


b This diagram shows the arrangement of Chandra's nested, cylindrical X-ray mirrors. Each mirror is 0.8 meter long and between 0.6 and 1.2 meters in diameter.

- Focusing of X-rays requires special mirrors.
- Mirrors are arranged to focus X-ray photons through grazing bounces off the surface.

Gamma-Ray Telescopes

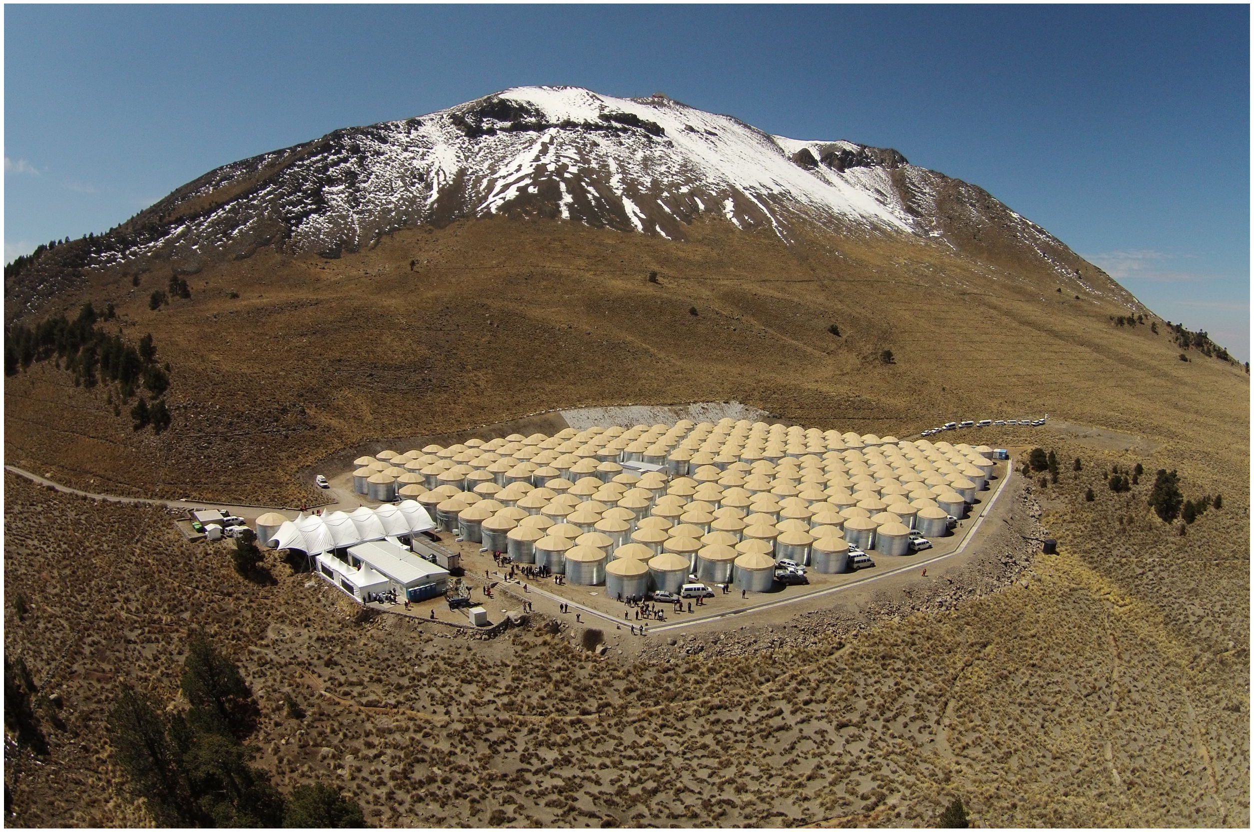
- Low-energy gamma-ray telescopes also need to be in space.
- Focusing gamma rays is extremely difficult.



Fermi Gamma-Ray Observatory

High-energy gamma-rays... from ground?

Very high energy gamma rays split nuclei in atmosphere, which then hit others, causing a cascade. That cascade can reach the ground and they make trails in water tanks (e.g.)



High Altitude Water Cerenkov detector near Pueblo, Mexico.

UMd physics prof Jordan Goodman is the principal investigator

Photons with $E=10^{11}$-10^{14} x visible light!!!

https://www.hawc-observatory.org/img/hawc_site_201503_hires.jpg

Looking Beyond Light

- We can also gain knowledge by collecting other signals using different sorts of "telescopes"
  - neutrinos
  - cosmic rays
  - gravitational waves

Arial view of part of LIGO