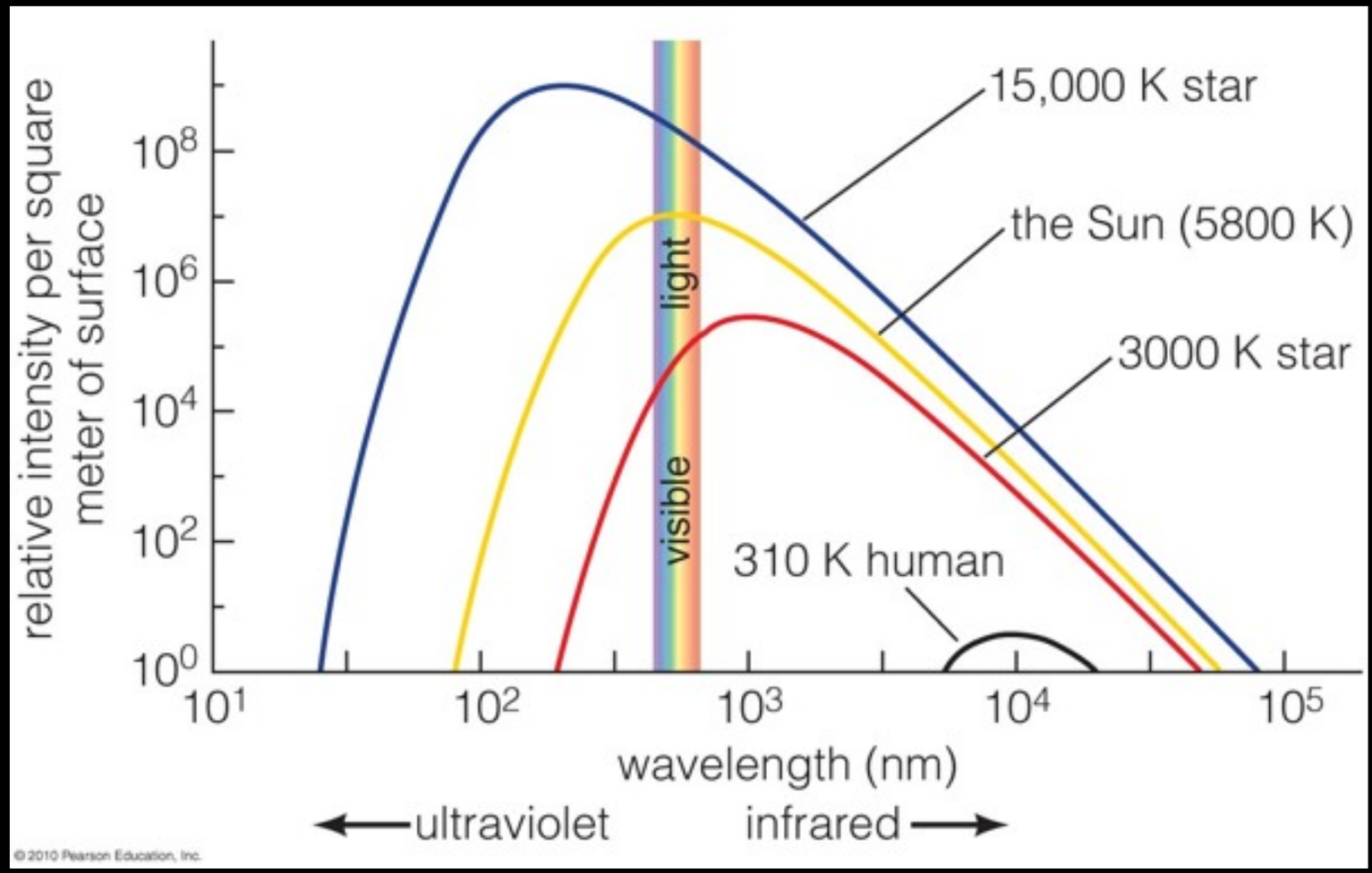
Thermal Radiation

- Also called "black-body radiation"
- Produces a continuous spectrum

Hotter objects peak at bluer wavelengths

Hotter objects emit more light at all wavelengths per square meter of surface area

Intensity goes as T^4



Luminosity

The star Betelgeuse has a temperature of about 3000 Kelvin.
The star Vega has a temperature of about 9000 Kelvin.

A) Each square meter of the surface of Betelgeuse is 3x1=3 times dimmer than that of Vega.
B) Each square meter of the surface of Betelgeuse is 3x2=6 times dimmer than that of Vega.
C) Each square meter of the surface of Betelgeuse is 3^2=9 times dimmer than that of Vega.
D) Each square meter of the surface of Betelgeuse is 3^4=81 times dimmer than that of Vega.
E) The surface of Betelgeuse is the same brightness as Vega, just peaking at different wavelengths.

Speed of Light

The speed at which radio waves travel is _____ the speed at which infrared rays travel.

A) faster than

B) the same as

C) slower than

Gravity

The force of gravity is an inverse square law. This means that, if you double the distance between two large masses, the gravitational force between them

A) also doubles.
B) weakens by a factor of 2.
C) weakens by a factor of 4.
D) is unaffected.
E) strengthens by a factor of 4.

Reminder:

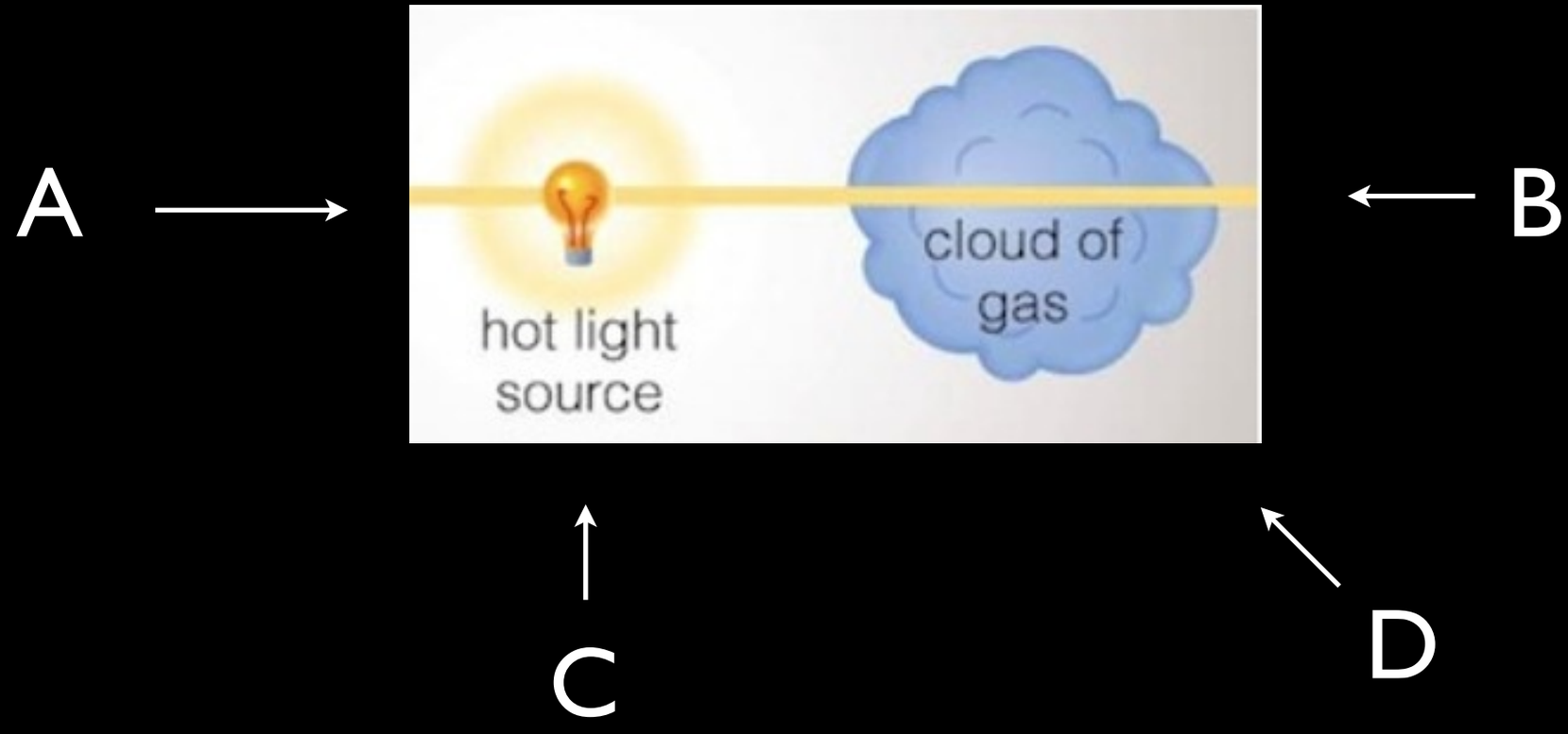
$F = G M m / d^2$

The Sun

Astronomers claim to know which elements are present in the Sun. However, no one has ever been to the Sun and we have never sent a spacecraft to directly sample the Sun. How can we know what the Sun is made out of ?

A) The sun has an emission spectrum that we can compare to laboratory spectra to determine what makes the lines
B) The sun has an absorption spectrum that we can compare to laboratory spectra to determine what makes the lines
C) The peak of the sun's spectrum tells us what elements are in it
D) Analysis of moon rocks can tell us exactly what is in the sun

Where do you have to look to see an emission spectrum?



Telescopes

Astronomy 1120: Stars and Galaxies
Adam Ginsburg & Devin Silvia
July 12, 2010

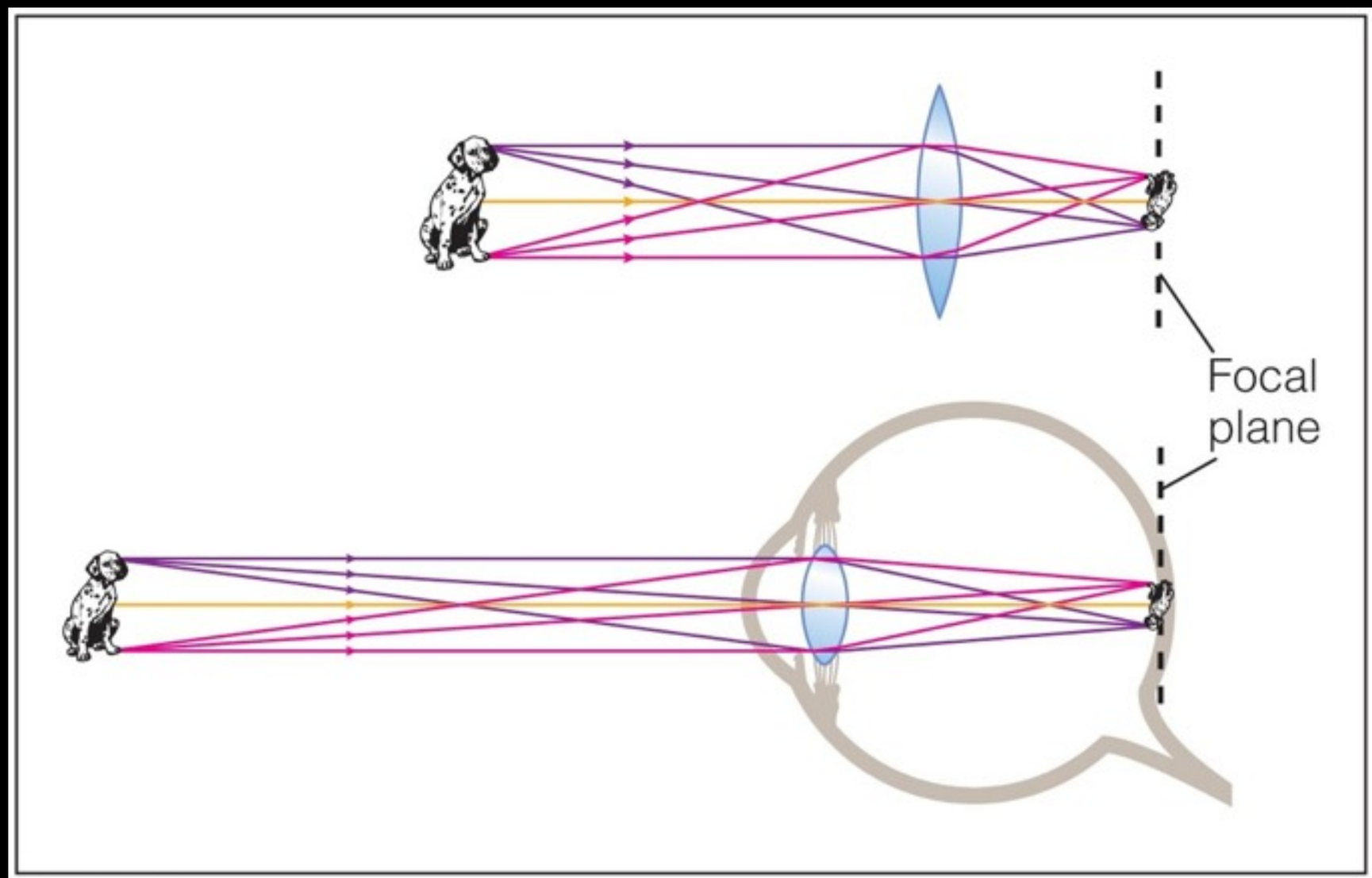
Learning Goals

- How does a telescope work?
- How does a digital camera work?
- What are the limits of telescopes (why do they need to be big)?
- What kinds of telescopes are there?

Optics

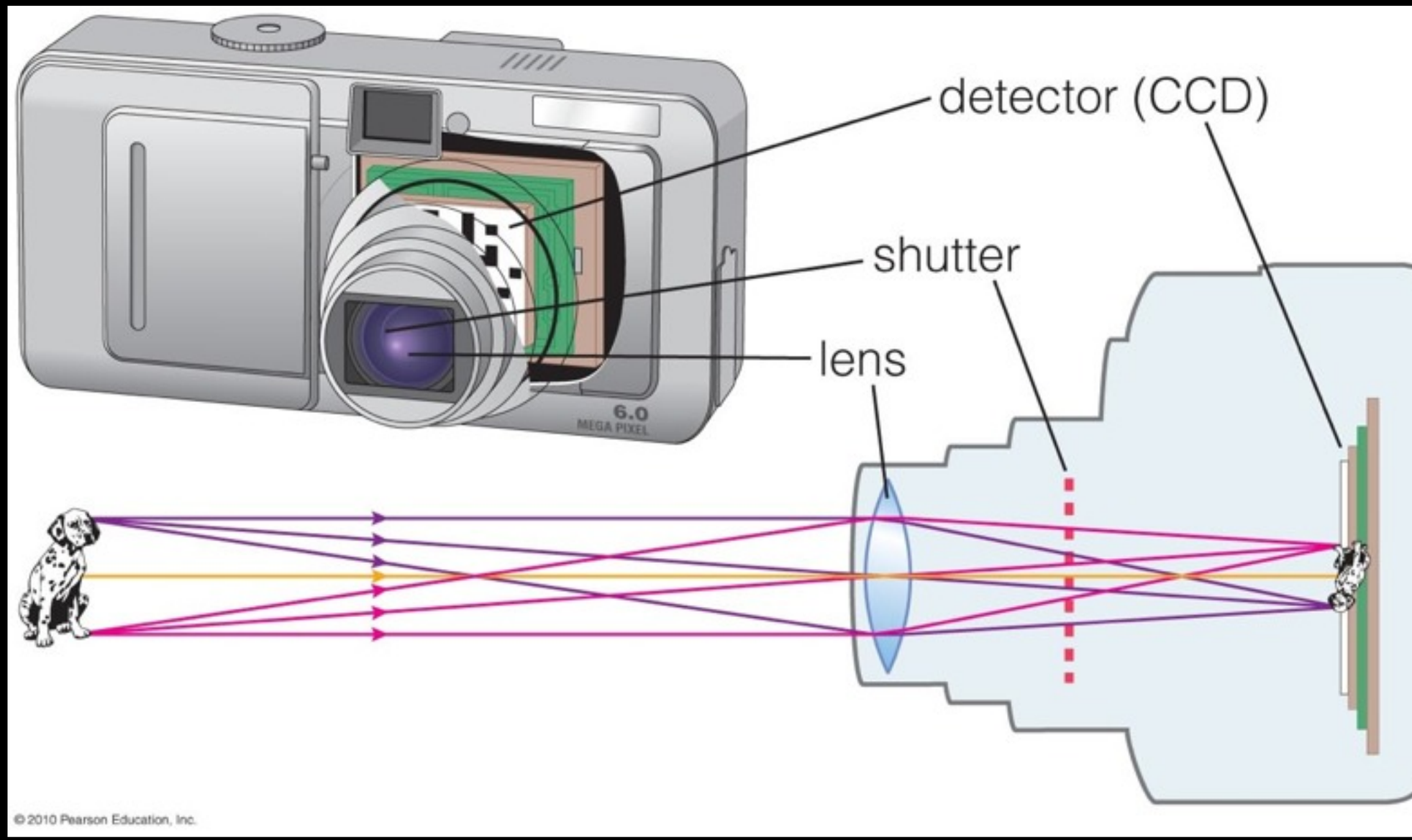
- A lens brings an image into focus by bending light

Focused light on a detector (such as the back of your eye or a CCD chip) makes an image



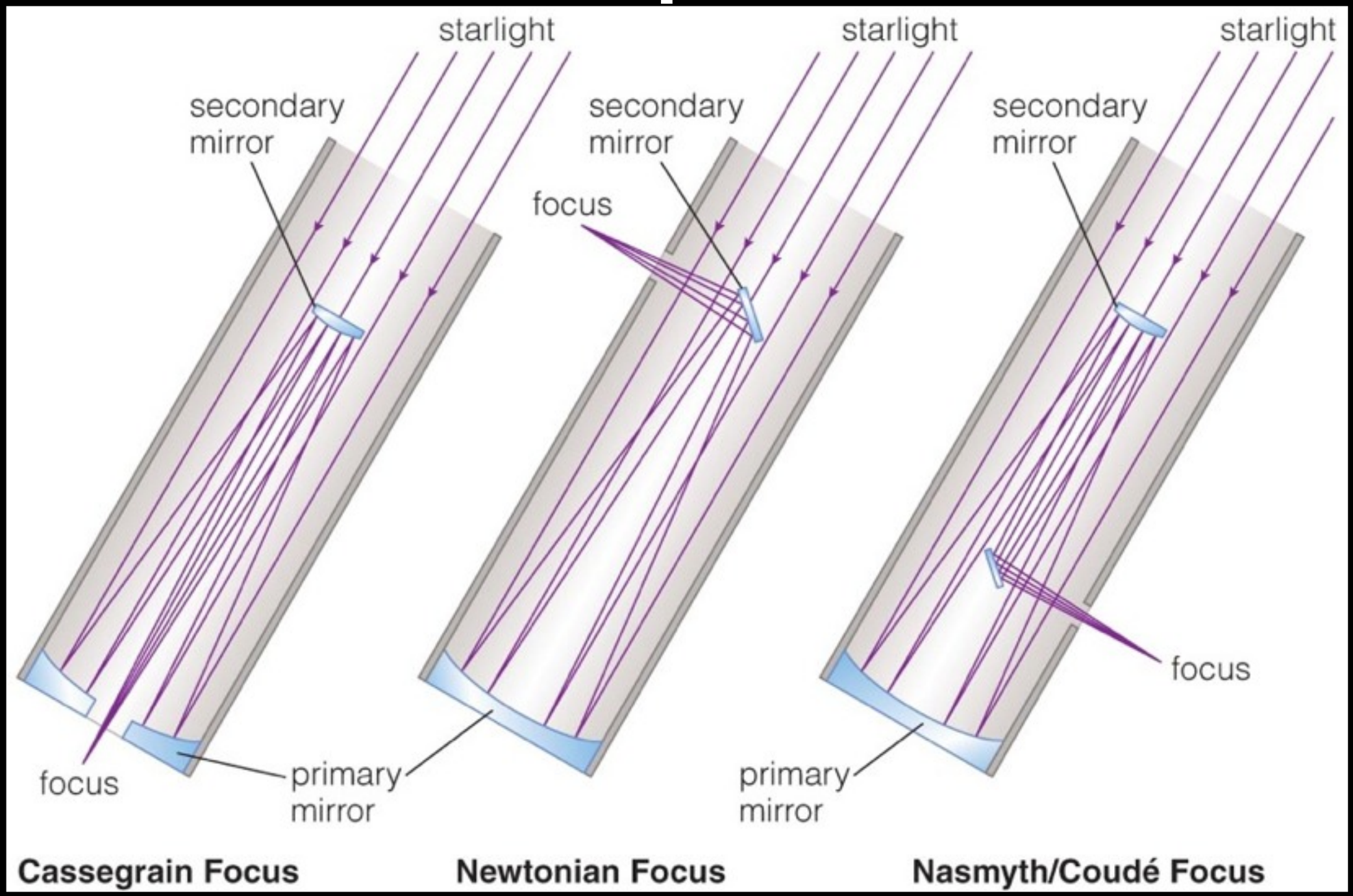
Digital Cameras vs. Telescopes

Digital cameras work like your eye: a glass lens brings light into focus on a CCD



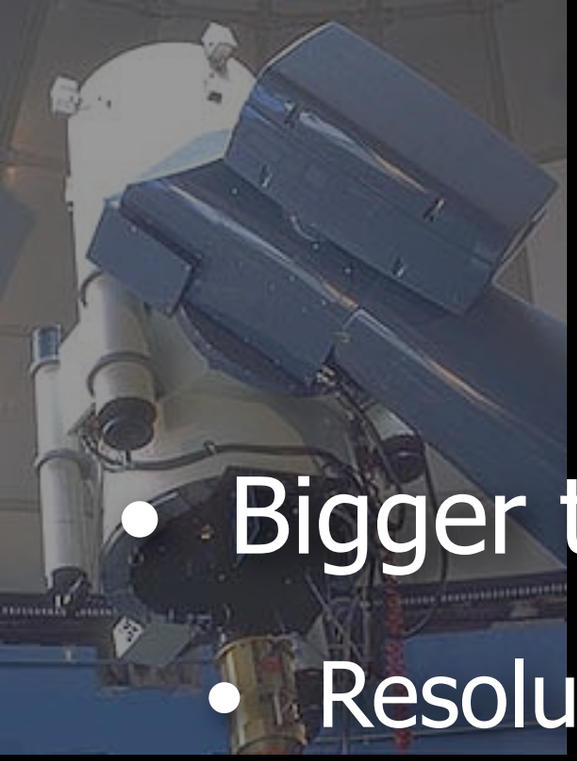
Digital Cameras vs. Telescopes

Modern telescopes are reflectors



Why mirrors?

- Mirrors are cheaper to build because only one curved surface needs to be made
- It is easier to support a mirror - it only needs to be held up from the back
- For infrared, radio, ultraviolet, and X-ray telescopes, there are no materials like glass that can focus light.



0.6m

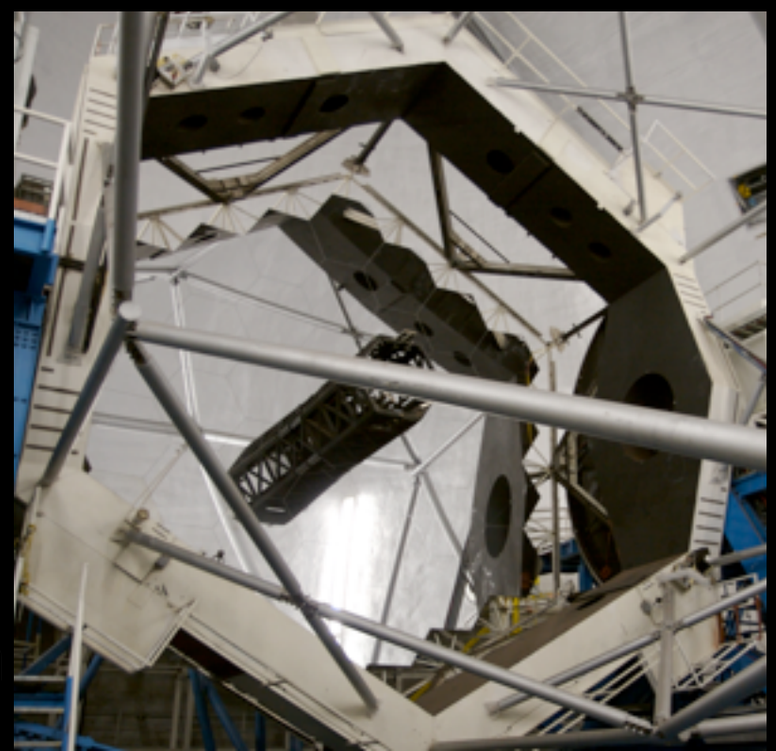
Size

30m

- Bigger telescopes are better
  - Resolution: the smallest object you can distinguish depends on the diameter of the telescope
  - Collecting Area: You can bring more photons onto your detector with a bigger telescope

3.5m

10.2m



0.6m

Size

30m

Resolution ∝ Diameter

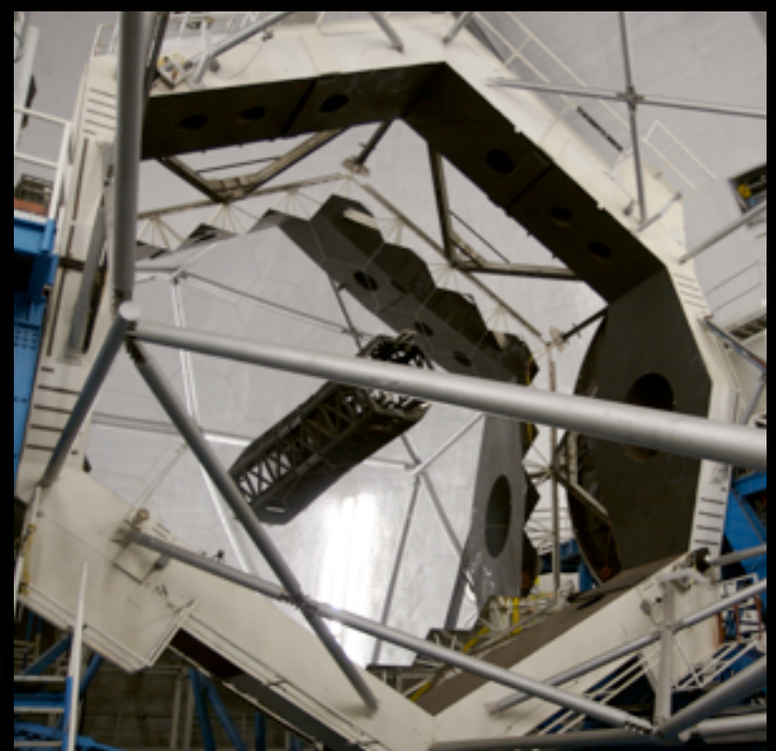
"Diffraction Limit" ∝ Wavelength / Diameter

($\theta = \lambda / D$)

Collecting Area ∝ Diameter^2

3.5m

10.2m



Comparing Resolution

- How much better is the resolution of a 30m telescope than a 3m telescope?

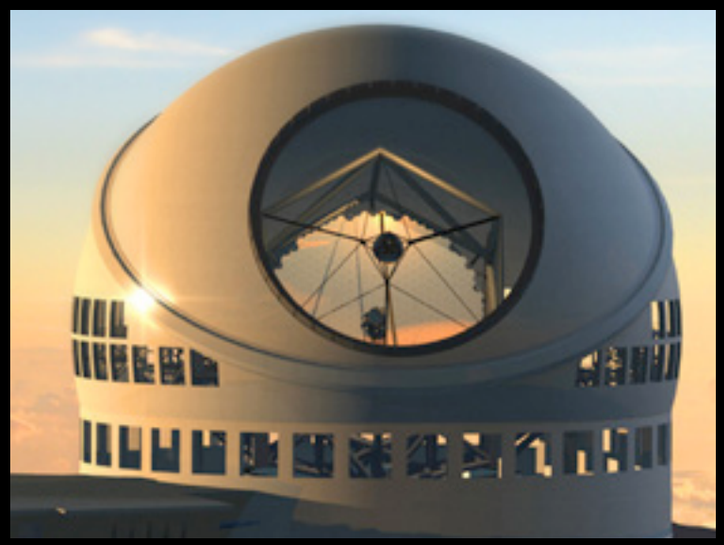
A) 2x

B) 5x

C) 10x

D) 30x

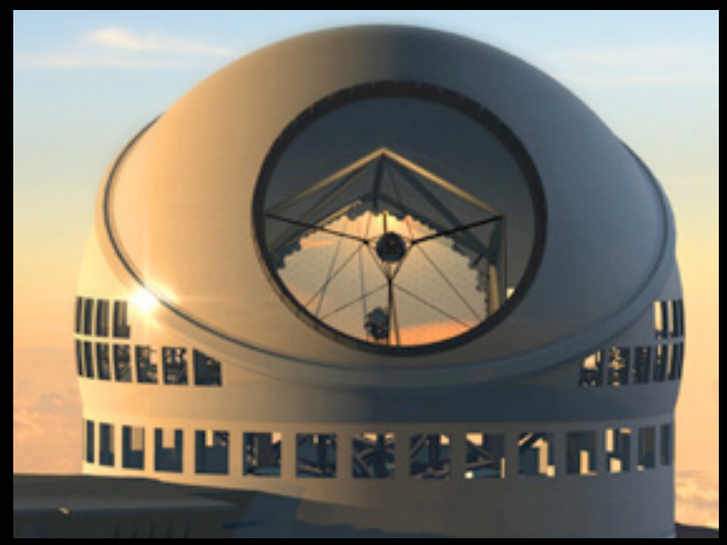
E) 100x



Comparing Resolution

- How much better is the resolution of a 30m telescope than a 3m telescope?

C) 10x



Comparing Area

- How much more collecting area does a 30m telescope have compared to a 3m telescope?

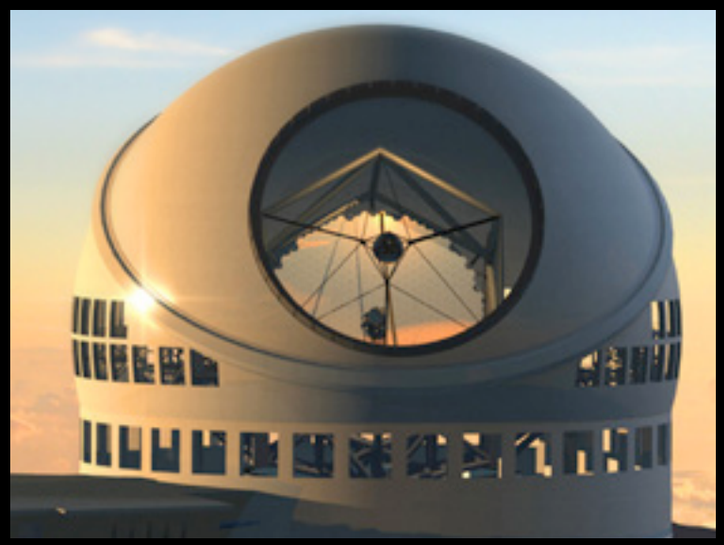
A) 2x

B) 5x

C) 10x

D) 30x

E) 100x



Comparing Area

- How much more collecting area does a 30m telescope have compared to a 3m telescope?

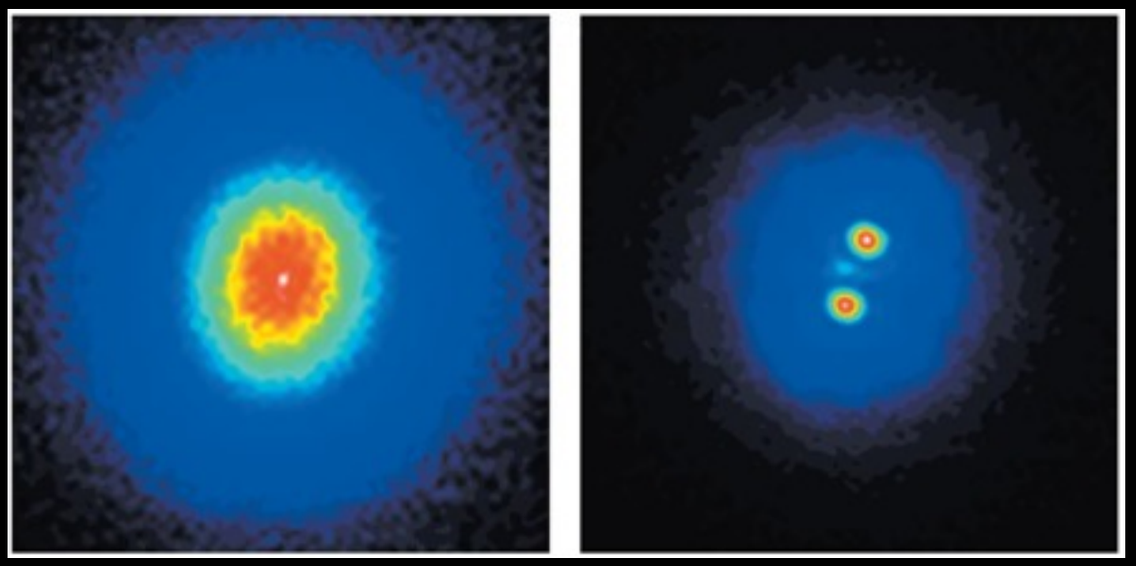
E) 100x

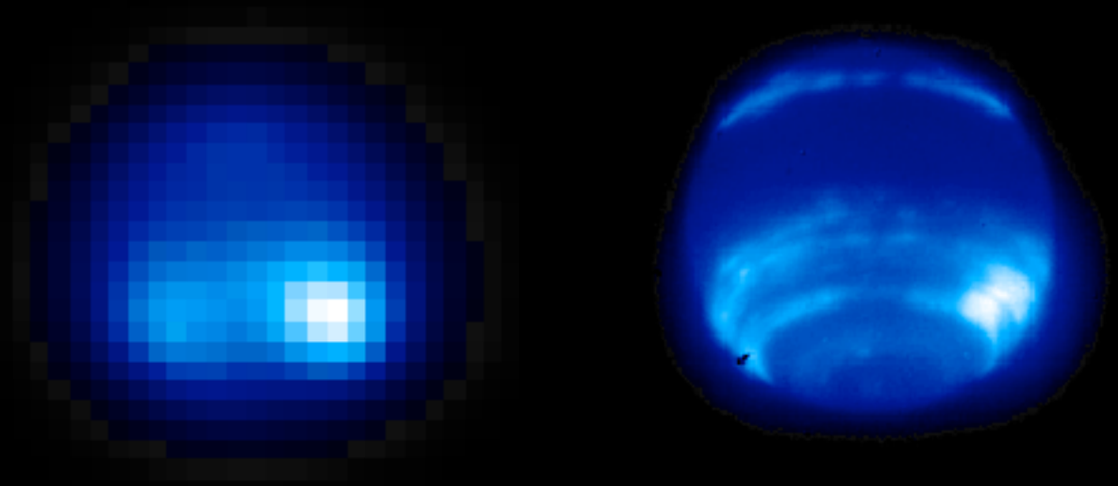
Twinkling and the Atmosphere

- The resolution of the Keck 10m and the SBO 24” from the ground are nearly the same: the atmosphere blurs images

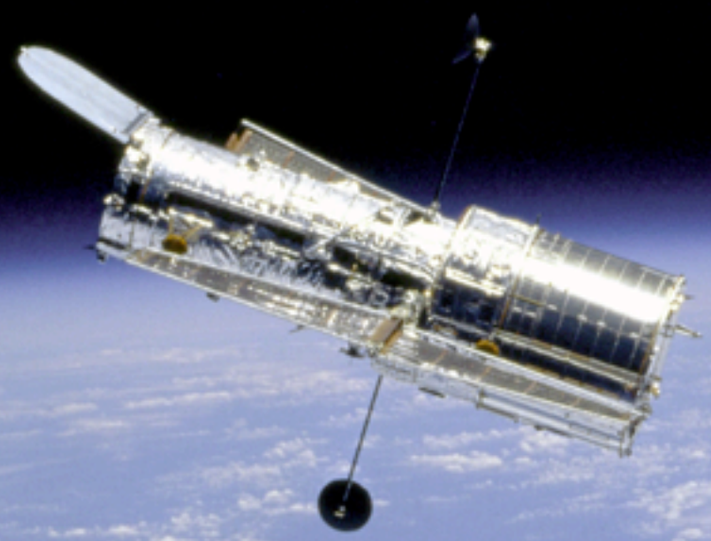
Correcting for Atmosphere

- Telescopes in space
- Adaptive Optics on the ground



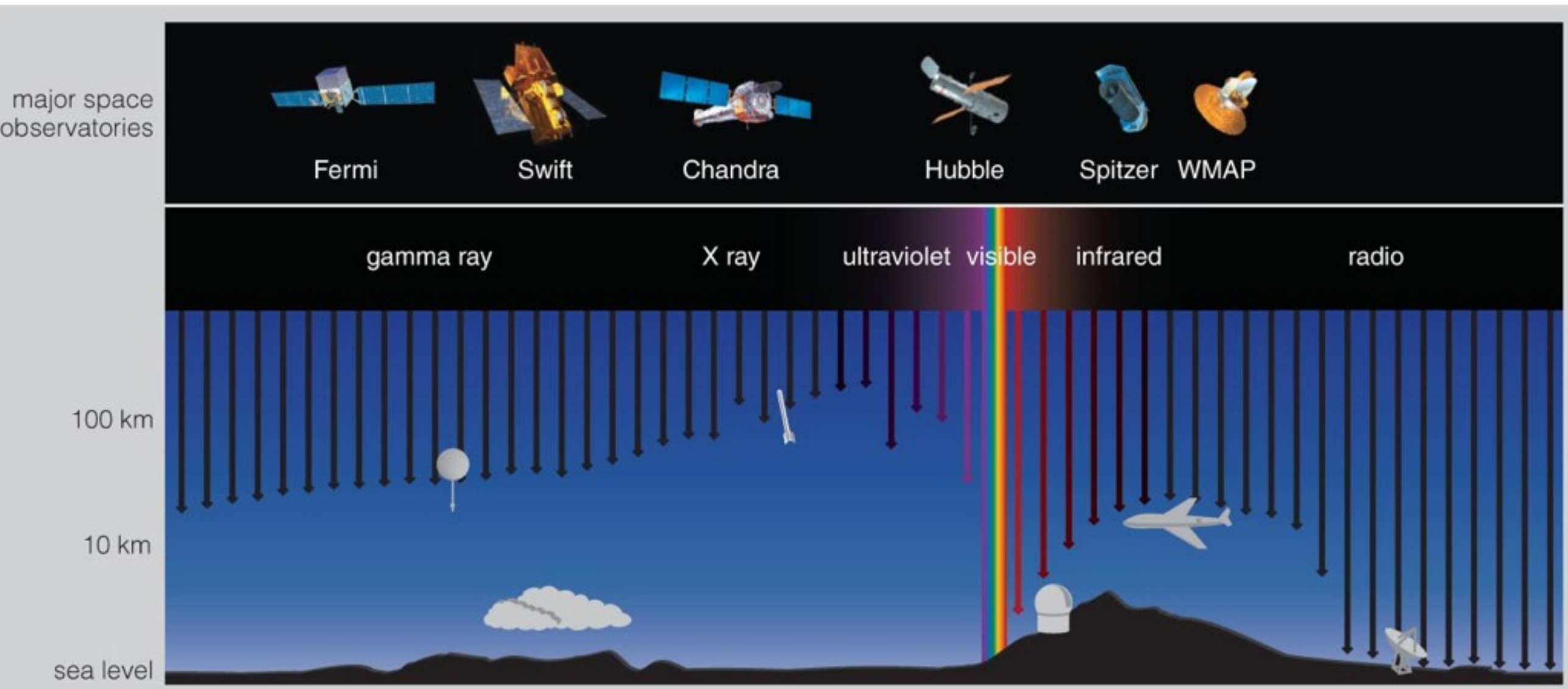


The Hubble Space Telescope

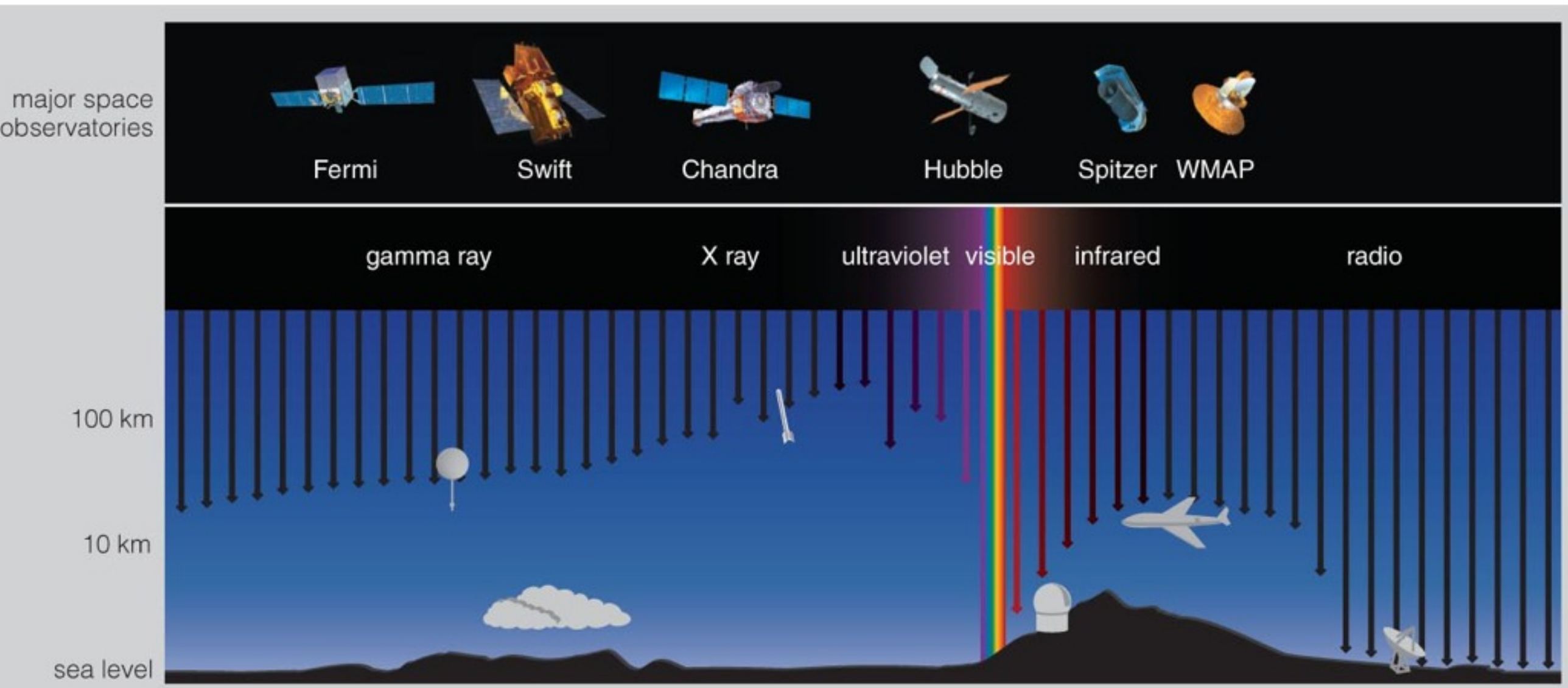


- It’s above the atmosphere!
- It can see ultraviolet and has the best resolution of any optical telescope

Other wavelengths in space



The Atmosphere: The astronomer's greatest nemesis

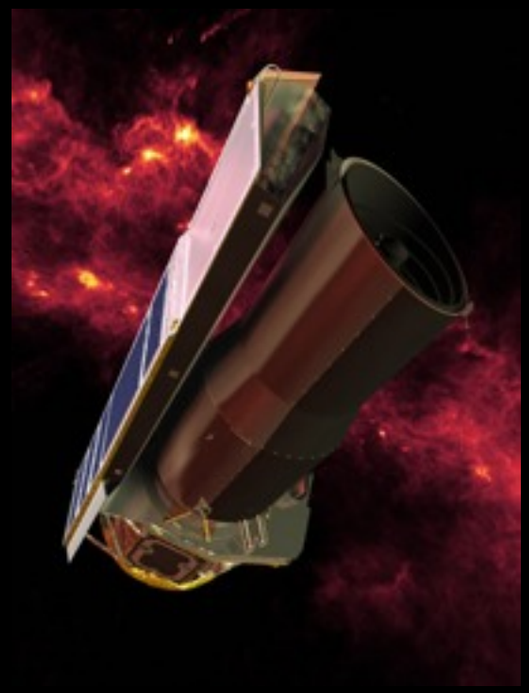


Why not put everything in space?

- It's very expensive to launch spacecraft
- Most space observatories use 10-20 year old technology because it's tried and tested
  - Ground based observatories can use the most modern technology because you can test it on-site
- It is also slower to transfer data from space

NASA's Great Observatories

Compton Gamma Ray Observatory



Spitzer Space Telescope
Infrared

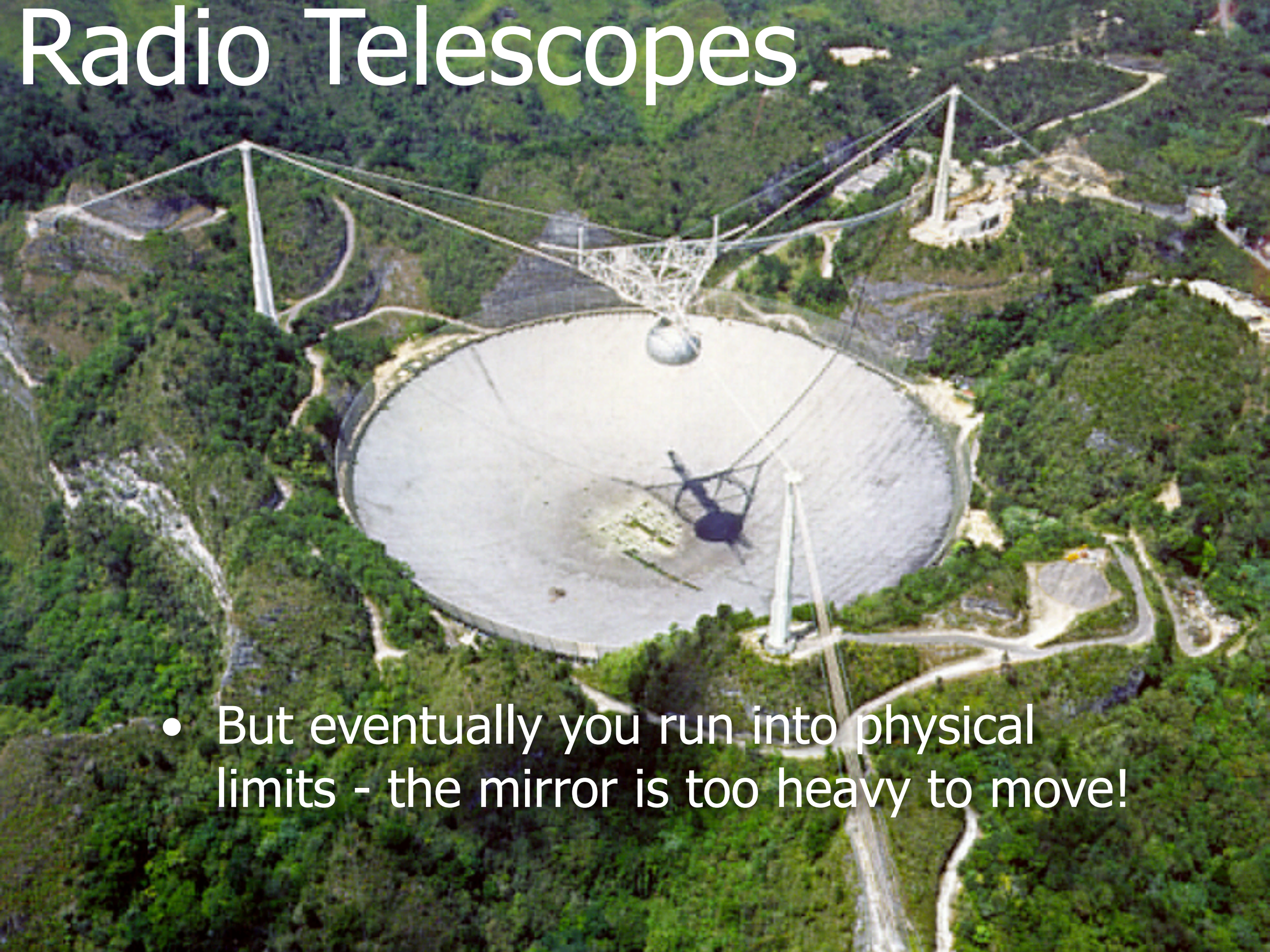
Hubble Space Telescope
UV/Visible

Chandra X-Ray Observatory

Radio Telescopes

- Can be built *very* big

Radio Telescopes

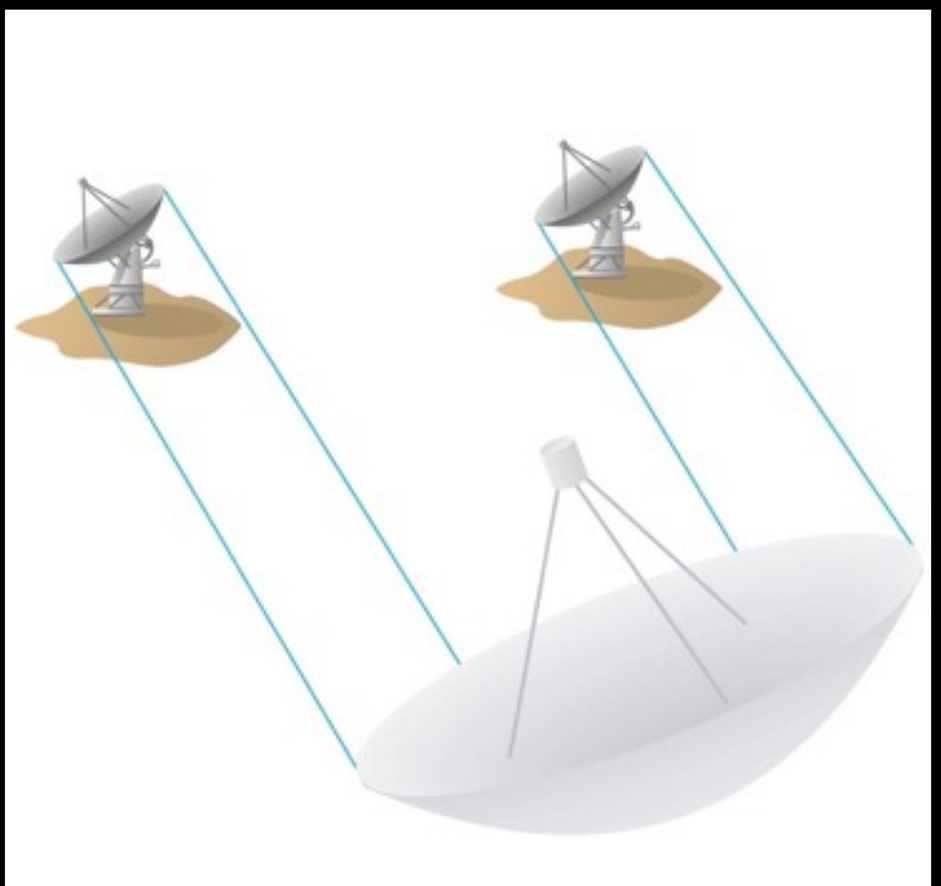


- But eventually you run into physical limits - the mirror is too heavy to move!

Interferometry

Interferometers

- Interferometers combine the signals from multiple telescopes
- The resolution is proportional to the spacing between telescopes, while the collecting area is the sum of the individual areas



Interferometers

Thanks to interferometry, a properly spaced set of 10-meter radio telescopes can achieve the angular resolution of a single, 100-kilometer radio telescope.

A) Yes, but with much lower sensitivity than a single, 100-kilometer telescope.
B) Yes, and the resulting interferometer will have exactly the same properties as a single, 100-kilometer telescope.
C) Yes in principle, but such an interferometer has never been constructed.
D) No, interferometry only works over much smaller distances.
E) No, the blurring effects of Earth's atmosphere limit the achievable angular resolution.

Why do we need so many types of telescope?

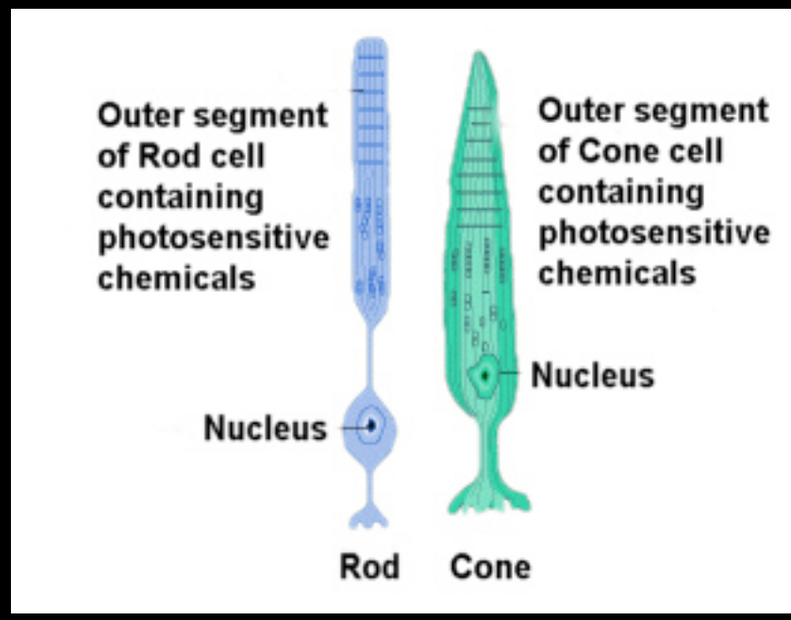
- Each wavelength reveals something different
  - X-rays are great for looking at neutron stars, supernova remnants, and other very hot objects
  - UV is good for looking at hot stars and very thin gas
  - Optical is good for stars and hot nebulae
  - Infrared and Radio are good for dust-obscured stars and cold nebulae
  - Radio can see the Cosmic Microwave Background and weird objects like pulsars

Recording Light

- Telescopes bring the light to a focus, but what do you put at the focus?
  - Your eye is very inefficient
    - So is photographic film (though film is more efficient than your eye)
  - Since the 1980's, "Charge-Coupled Devices" (CCDs) have been the best way to record optical light

Your Eye

- Your eye contains two kinds of photo-sensitive cells. Photons break apart chemicals in these cells, which your brain interprets.
  - Rods see only black-and-white (like CCDs) but are more sensitive
  - Cones detect color
- To get dark adapted, you let the chemicals reach equilibrium in the dark

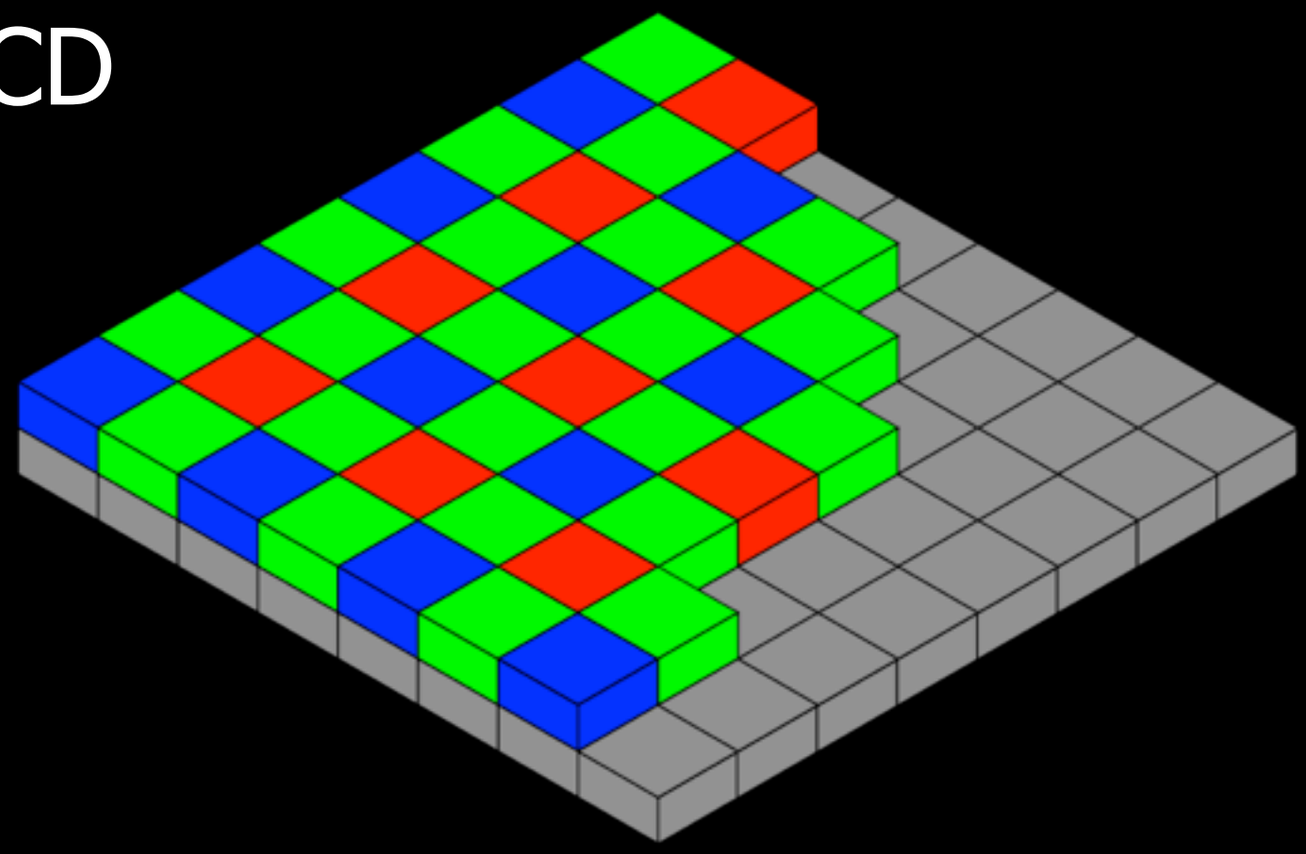


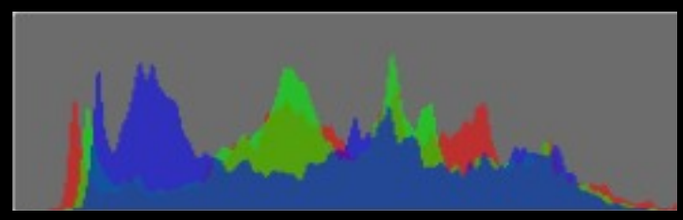
CCDs

- Made of a grid of individual "light buckets" (pixels)
- Similar technology is used in digital cameras
- Up to 90% efficient at catching photons
- But they only tell you how many photons, not what color they are

Filters

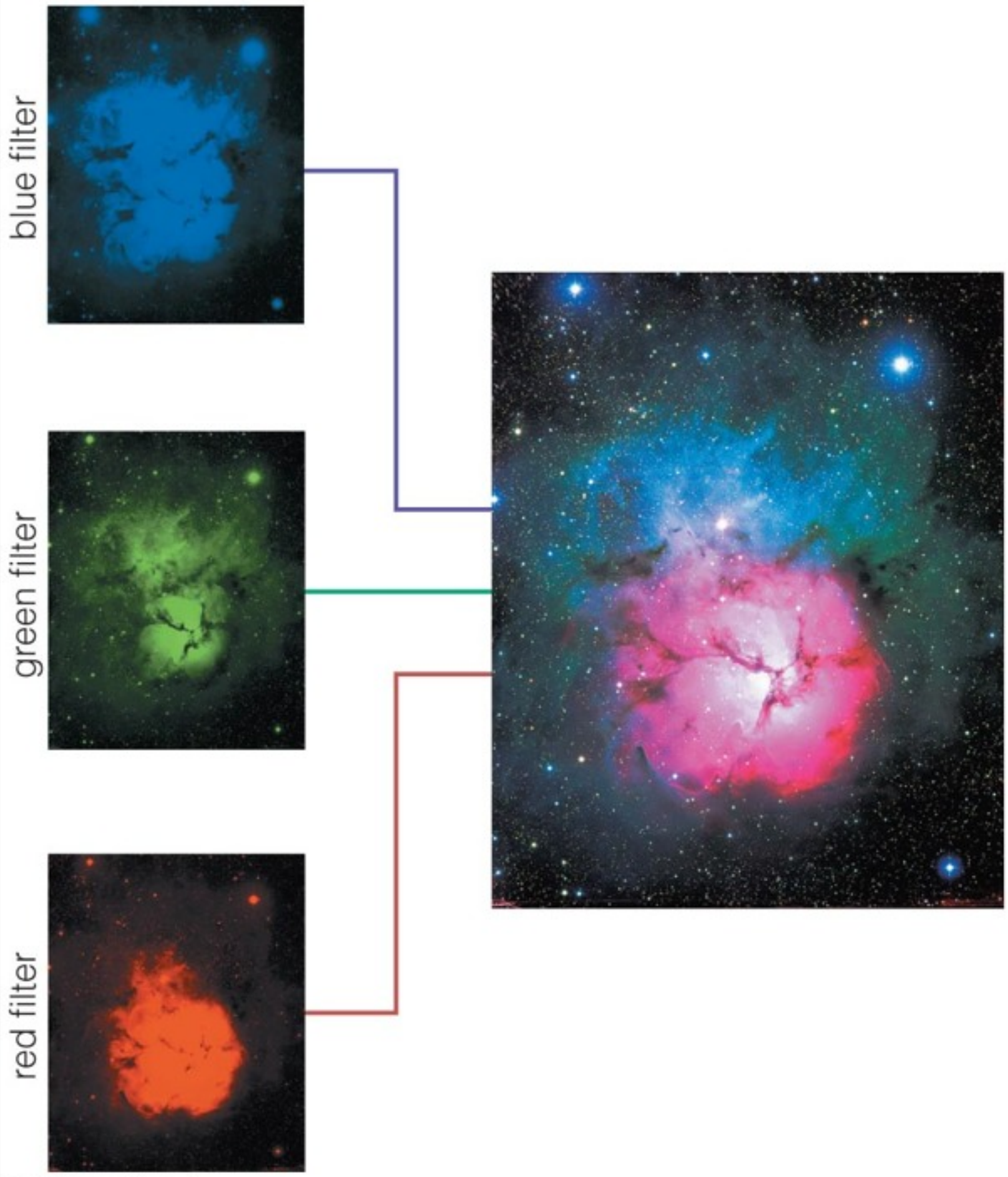
- To get color information, you put a filter in front of the CCD
- Digital cameras have mixed color filters across the detector, so they take 4 images at once and combine them





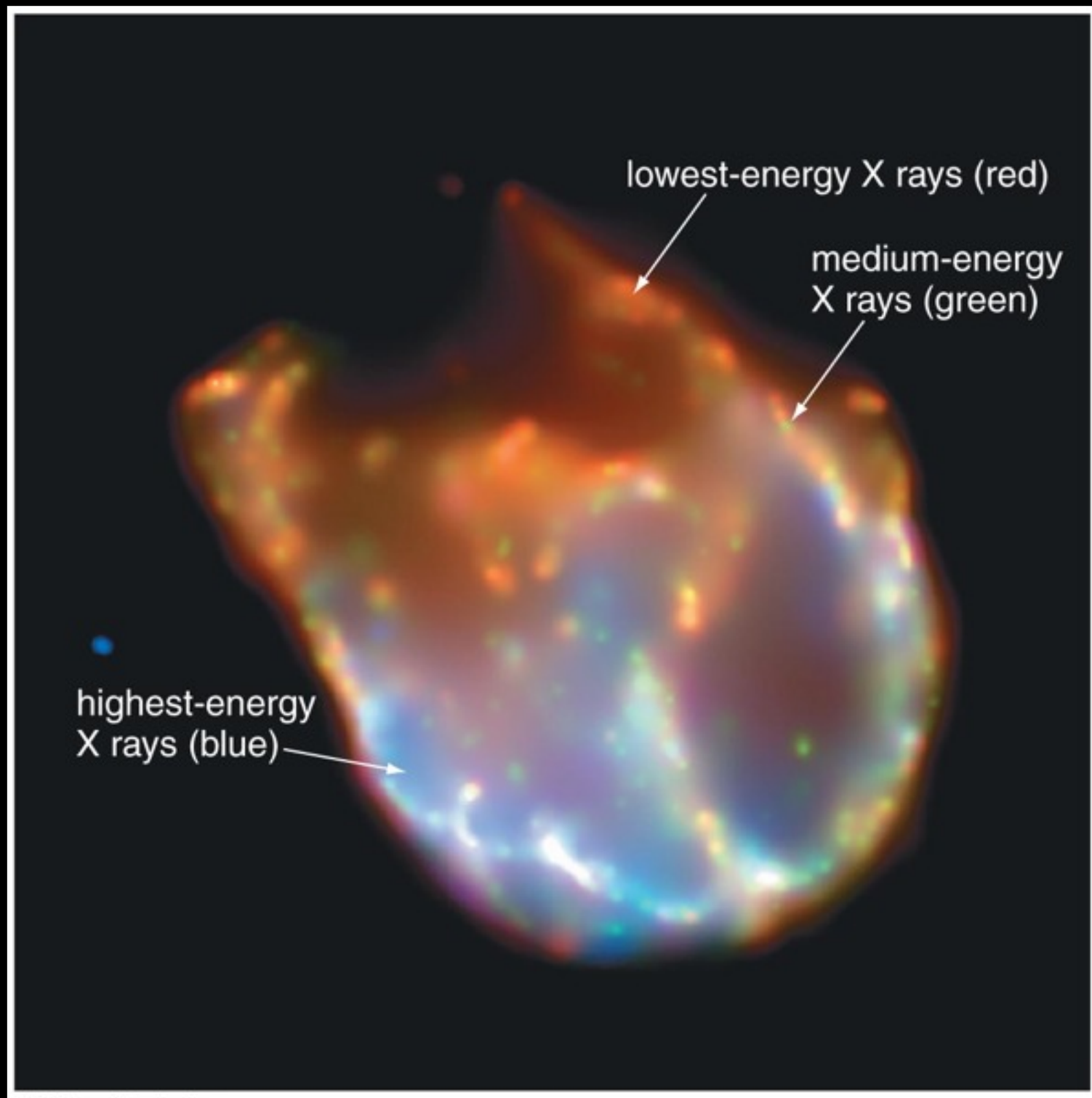
Filters

- Astronomical imagers will take separate images in each filter and combine them later
- All color photos of the sky are composites



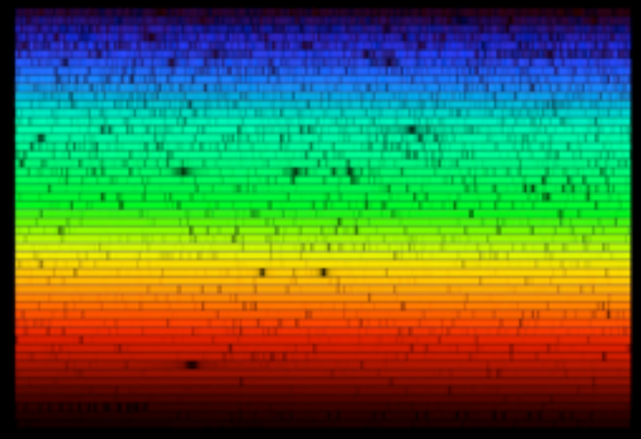
False Color

- Our eyes can't see X-rays or infrared or radio photons
- Astronomers color-code images with false colors to convey more information

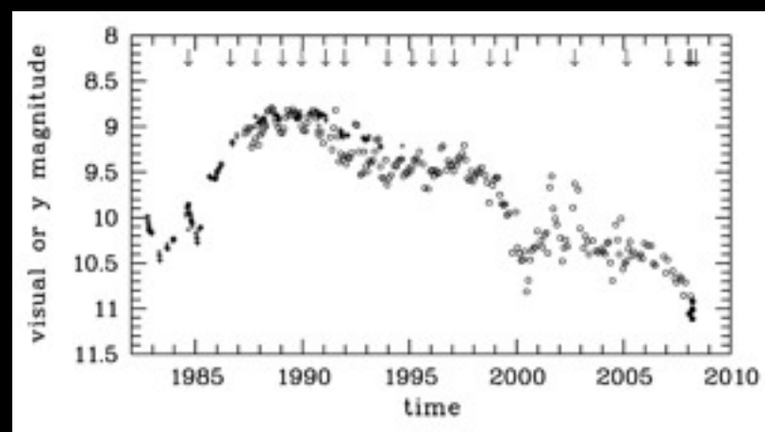


What else do telescopes do?

- Imaging: Collect photons and make an image of the sky
- Spectroscopy: Divide up photons by wavelength
  - Composition
  - Motion



- Timing: How do objects change?
  - Variable stars, pulsars, explosions



Telescope Review

- **The largest optical telescopes are designed to have**

A. high magnification, large collecting area, and high angular resolution.
B. high magnification, large collecting area, and low angular resolution.
C. low magnification, large collecting area, and low angular resolution.
D. large collecting area and high angular resolution - the magnification is of secondary importance.
E. large collecting area and low angular resolution - the magnification is of secondary importance.

Learning Goals Revisited

- How does a telescope work?
  - Telescopes focus light on to detectors
- What are the limits of telescopes (why do they need to be big)?
  - Resolution, collecting area
- What kinds of telescopes are there?
  - Different ones for each wavelength, some in space, some on the ground

Lecture Tutorial

- Page 49: Telescopes and Earth's Atmosphere