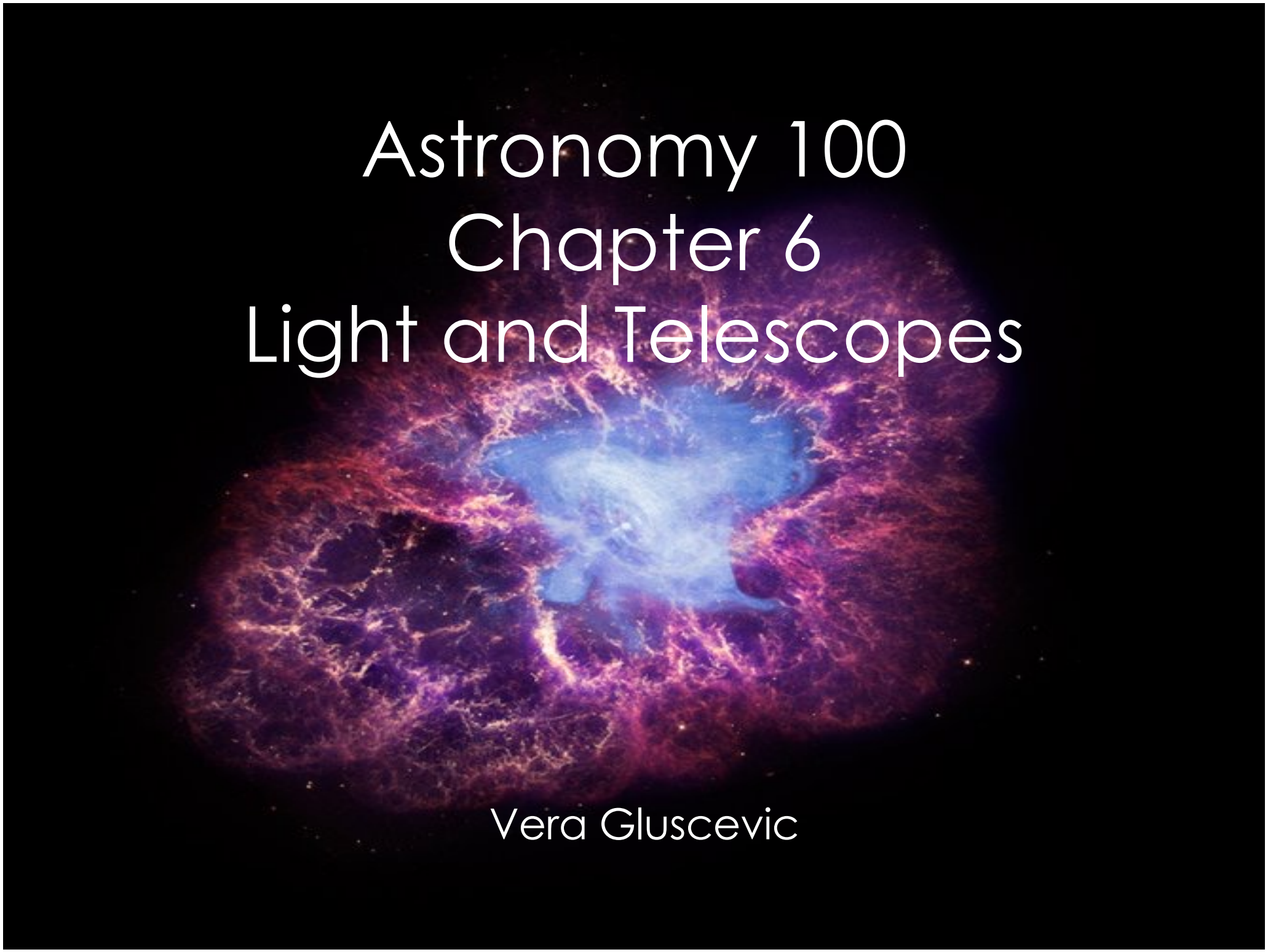
Midterm 1 is this week, Thursday February 10 @12pm.

- Material from textbook + lectures + homeworks, Chapters 1,2,3,4,5,6.
- 50 min for 50 multiple-choice questions, closed book/notes. Scantrons will be provided.
- Don't be late, exam starts promptly at noon. Bring #2 pencil and eraser.
- No class the day of midterm.
- No make-up exams (only 2 best midterm scores will count towards your final grade).
- USC code of ethics applies (no phones, no talking)

Astronomy 100
Chapter 6
Light and Telescopes



Vera Gluscevic

Plan for this lesson:

Light, waves, particles
Electromagnetic spectrum
Interactions of light with matter
Telescopes

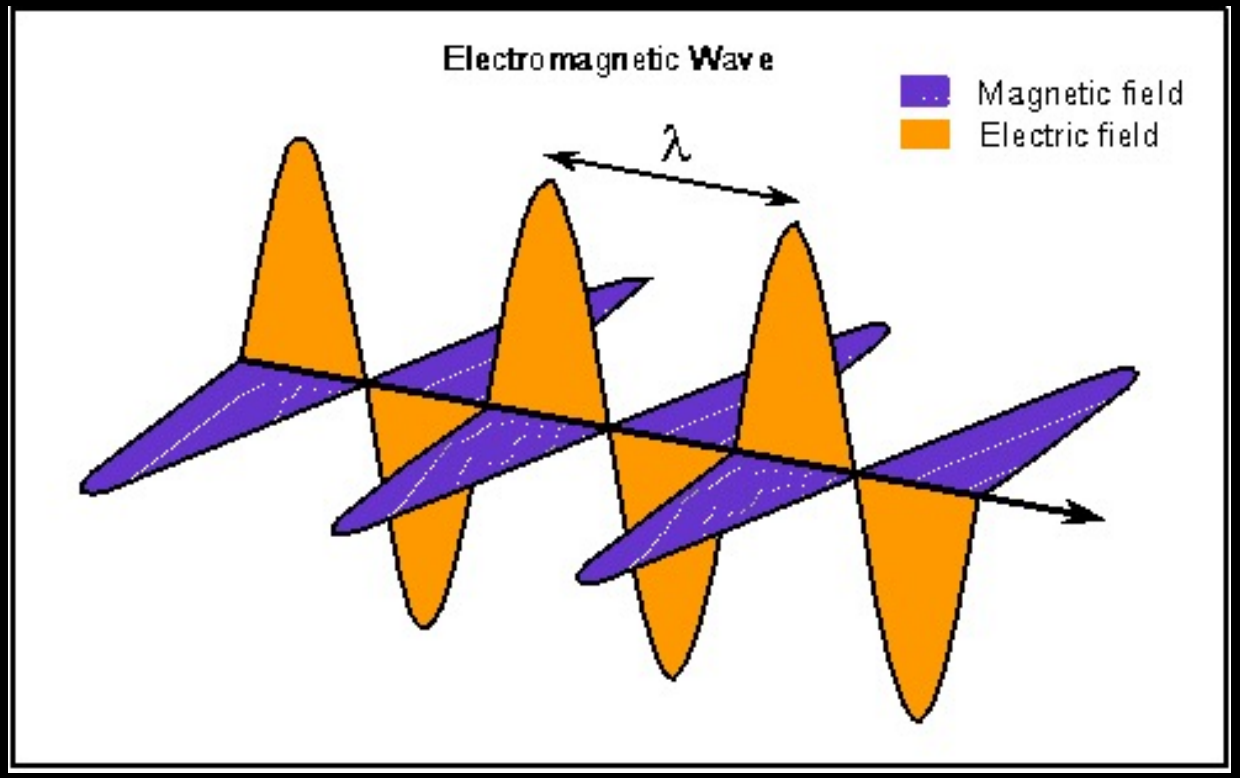
Light, waves, particles

Light

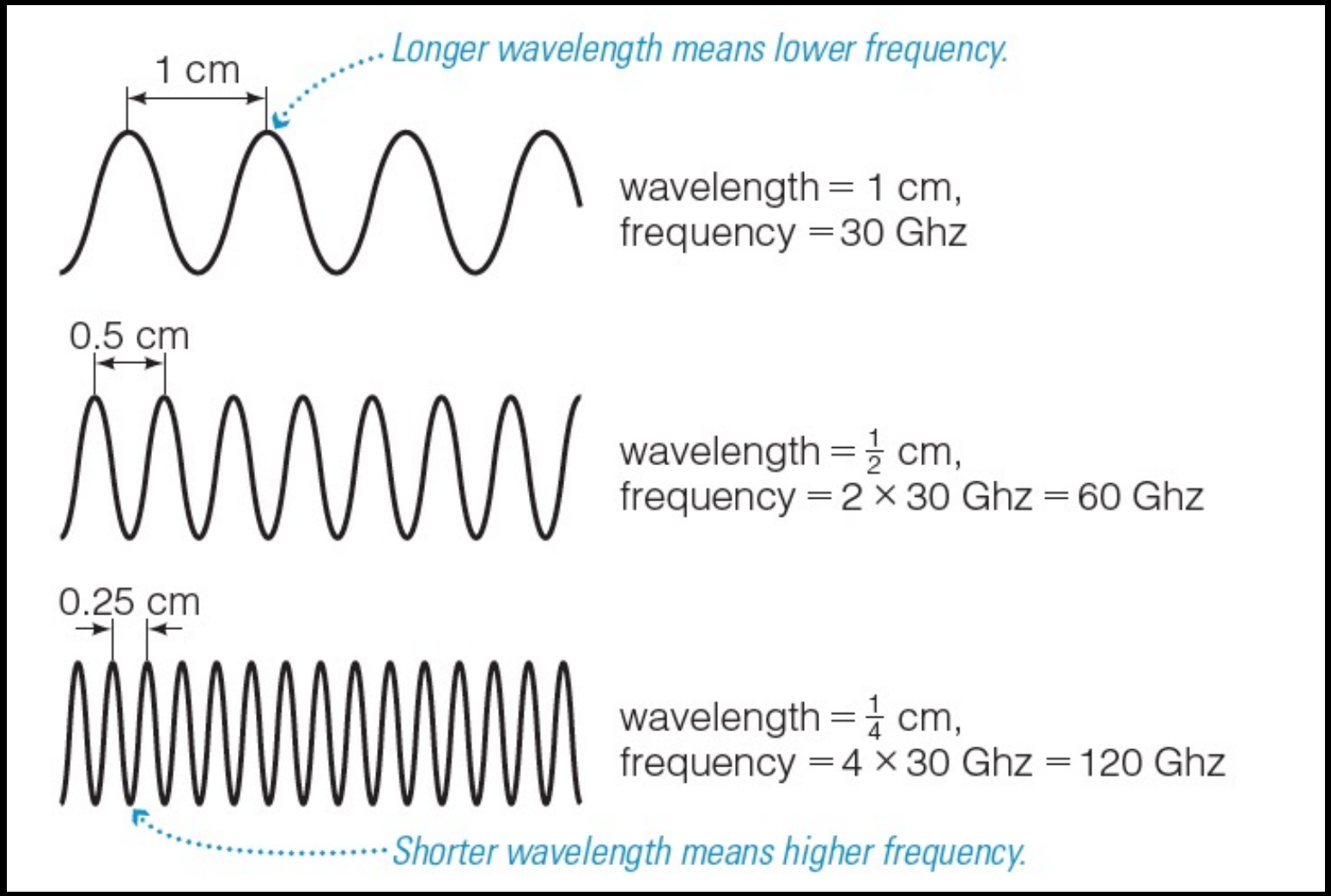
- Light comes from the acceleration of charged particles (such as electrons and protons)
- Light is an **electromagnetic wave**, made up of vibrating electric and magnetic fields.
- Unlike water waves or sound waves, light can travel through a vacuum.

Characterizing waves

- **Wavelength**: distance between adjacent peaks of the wave.
- **Frequency**: The number of peaks going by you every second.



Characterizing waves



Characterizing waves

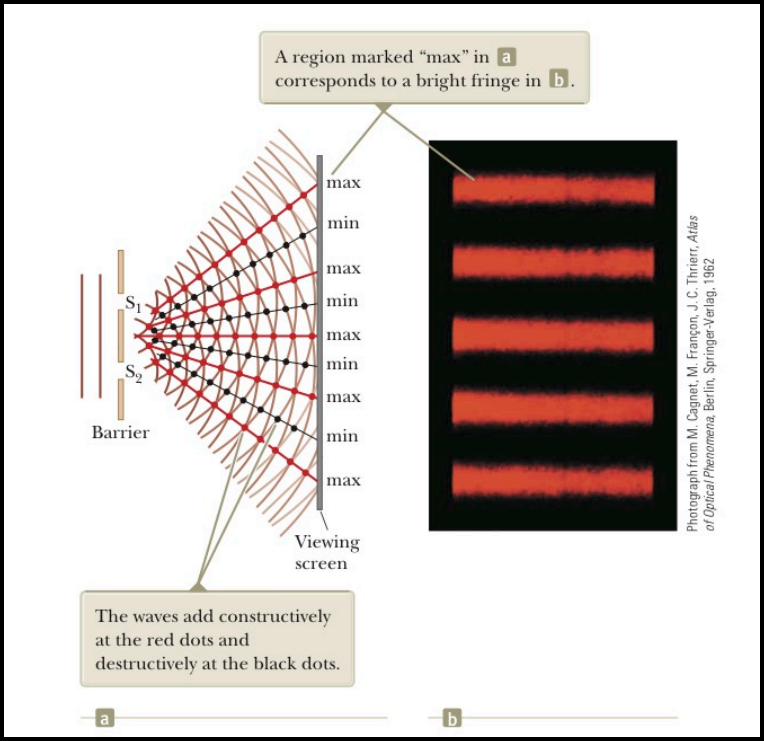
wavelength x frequency = speed

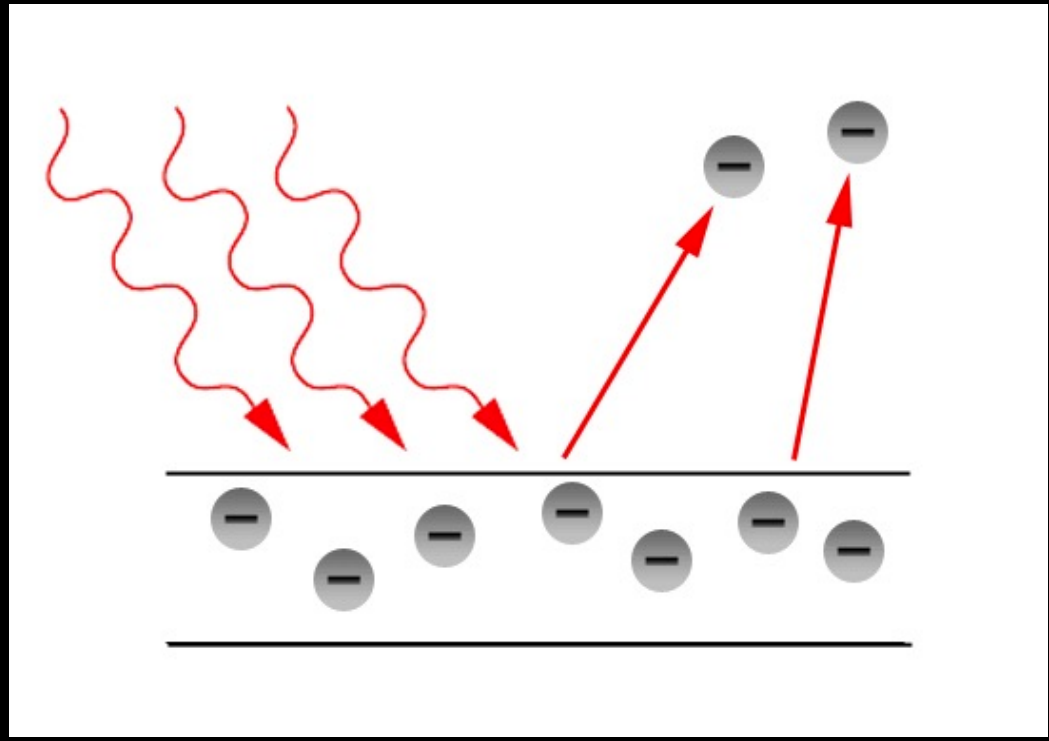
$\lambda \times f = c$

For light, the speed is $c = 3 \times 10^8$ m/s (in vacuum):
(shorter wavelength means higher frequency)

Light: wave or particle?

- Albert Einstein won the Nobel Prize in Physics for his 1905 work on the **photoelectric effect**, which demonstrated that light sometimes behaves like a particle.
- These packets (particles) of light are called **photons**.





Light: wave or particle?

https://www.youtube.com/watch?v=mlaVHxUSiNk

question for you

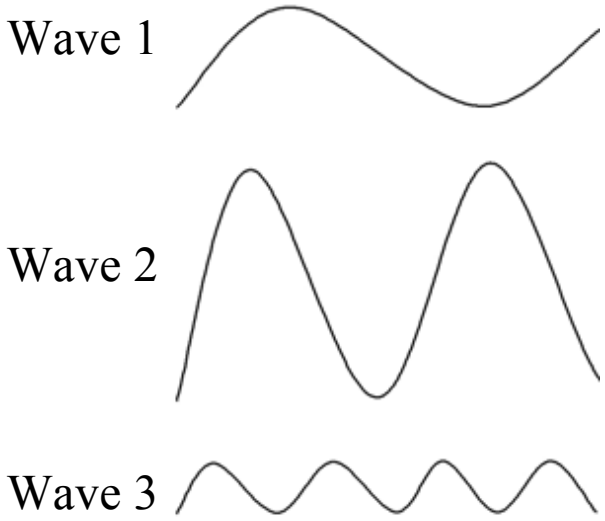
The wavelength of photon A is shorter than the wavelength of photon B. Which photon (A or B) has a higher frequency?

A. A
B. B
C. They have the same frequency
D. Cannot tell from information given

question for you

The diagram at right represents three different waves of light emitted at the same time by the Sun. Which wave will arrive first at a satellite orbiting just above Earth's atmosphere?

A. Wave 1
B. Wave 2
C. Wave 3
D. All three waves arrive at the same time.
E. I have no idea.



Electromagnetic spectrum

Light carries radiative energy

We can feel the "warmth" of the Sun even though the space in between the Earth and the Sun is very cold (and a vacuum)

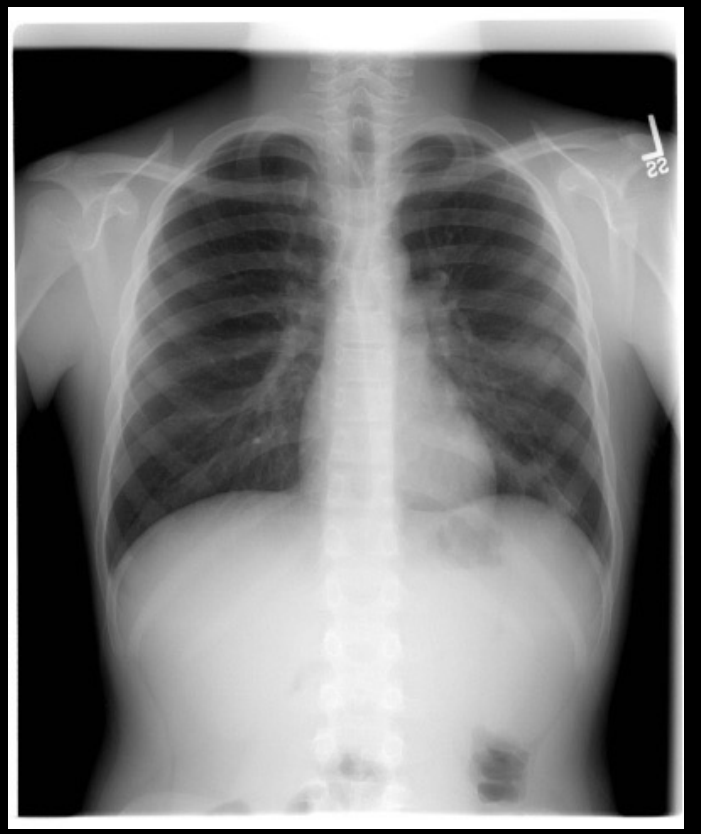
Light carries energy

- ✓ Each photon carries radiative energy determined by its frequency:

$$E = h \times f$$

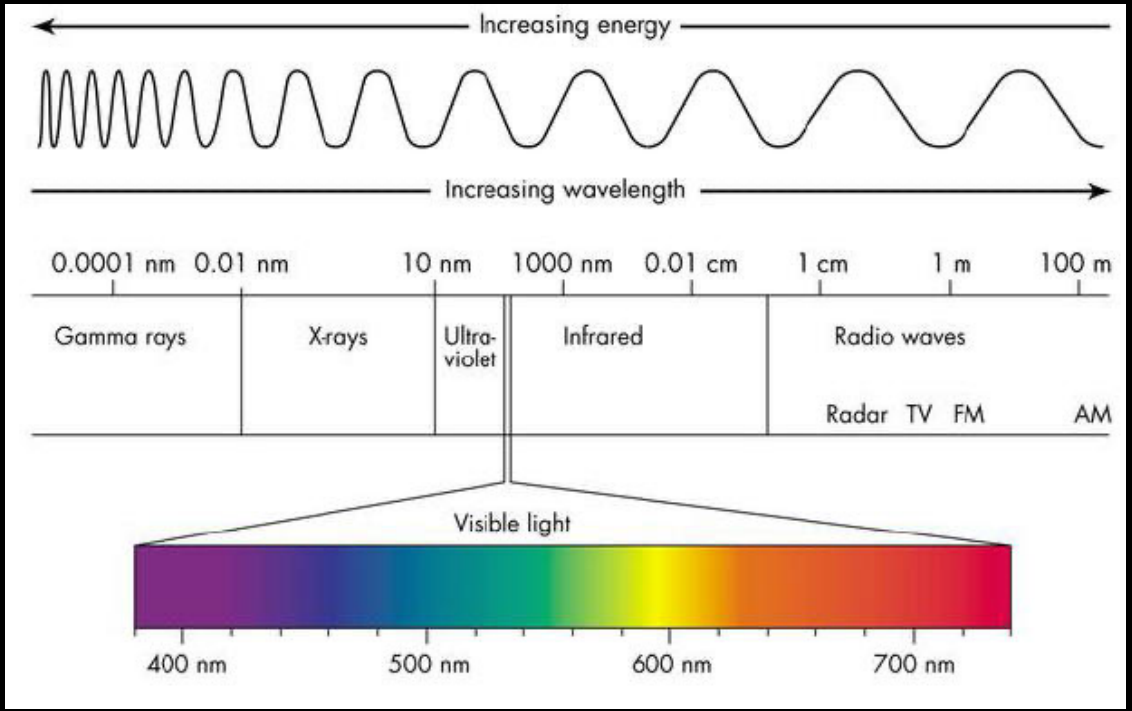
h = 6.626 x 10^{-34} J/s (Planck's Constant)

- ✓ **The higher the frequency, the more energy the photon carries**: X-rays and gmma rays are much more energetic than light waves or radio waves.

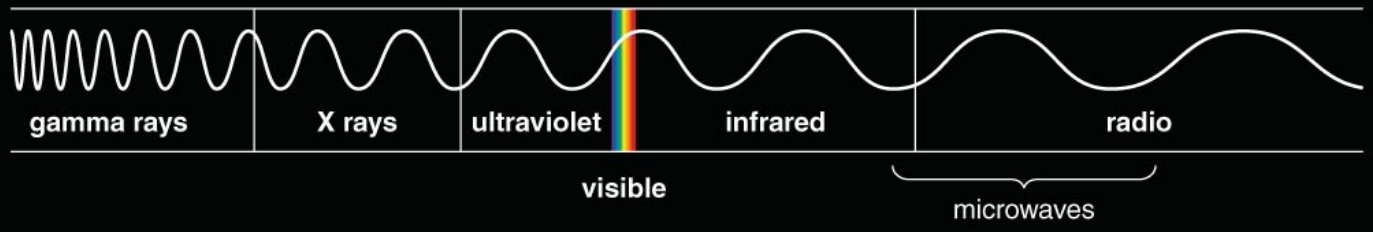


Electromagnetic spectrum

- **Visible** light is only a small part of what we call the **electromagnetic spectrum**.
- **Color** of the visible light is determined by its frequency.
- The EM spectrum includes: radio waves, infrared, visible, ultraviolet, x-rays, and gamma rays.



The Electromagnetic Spectrum



wavelength (meters)

← shorter longer →

10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 1 10^{2}

size of wavelength

frequency (hertz)

← higher lower →

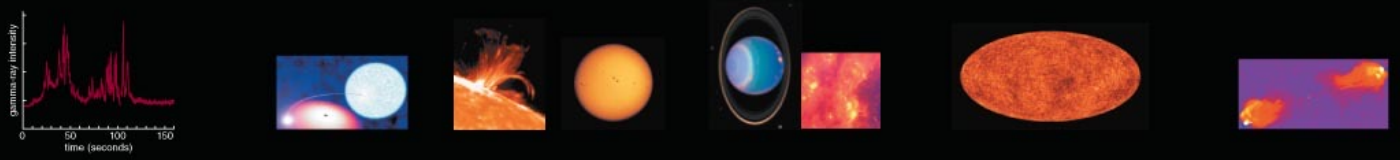
10^{20} 10^{18} 10^{16} 10^{14} 10^{12} 10^{10} 10^{8} 10^{6}

energy (electron-volts)

10^{6} 10^{4} 10^{2} 1 10^{-2} 10^{-4} 10^{-6} 10^{-8}

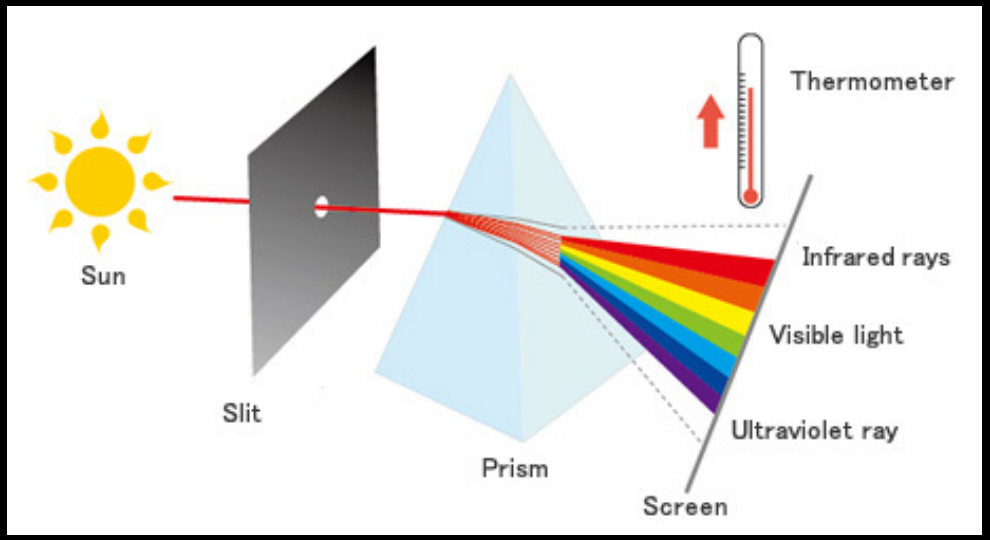
sources on Earth

cosmic sources



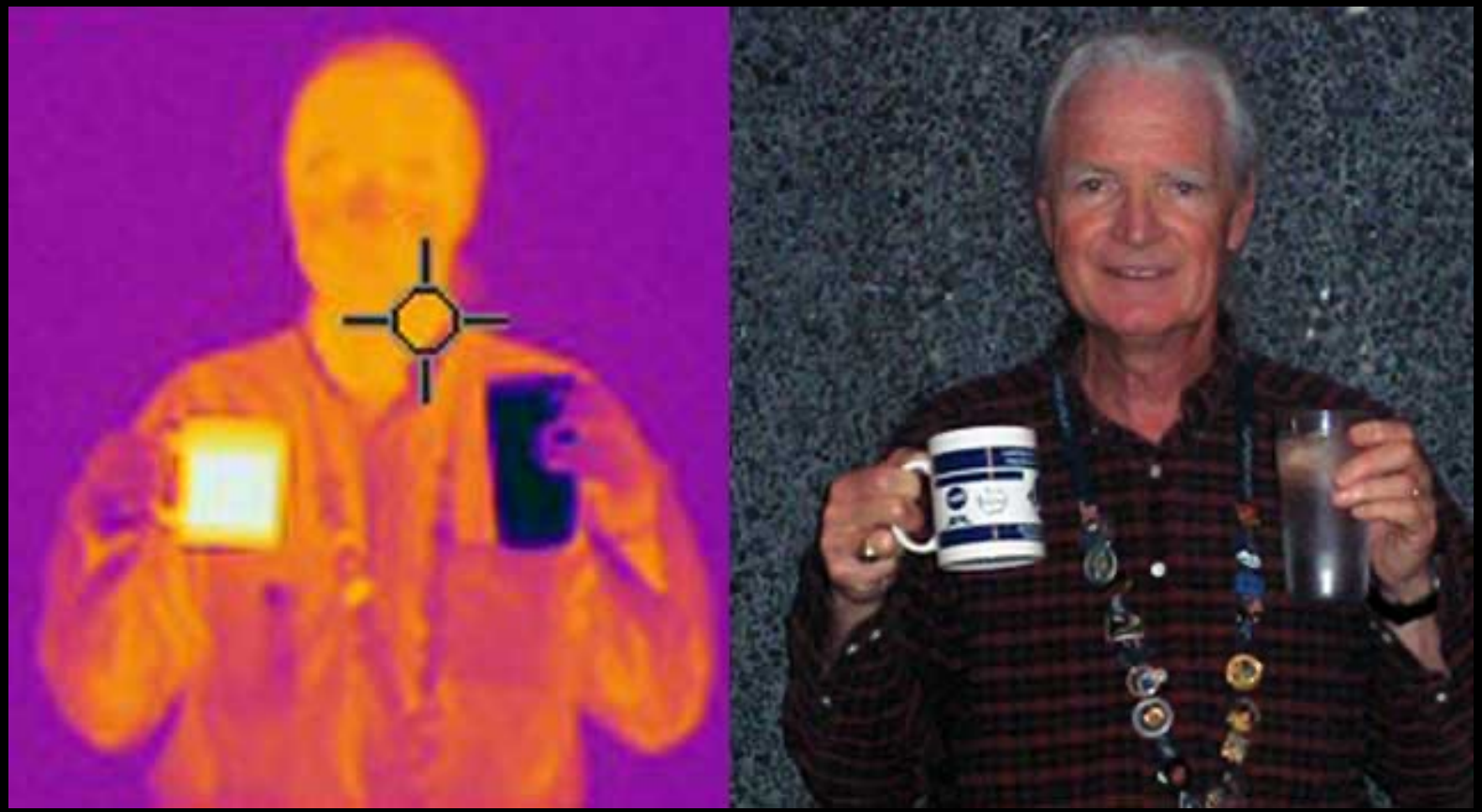
Infrared Light

Discovered by Sir Frederick William **Herschel** in 1800 (he also discovered the planet Uranus in 1781!)

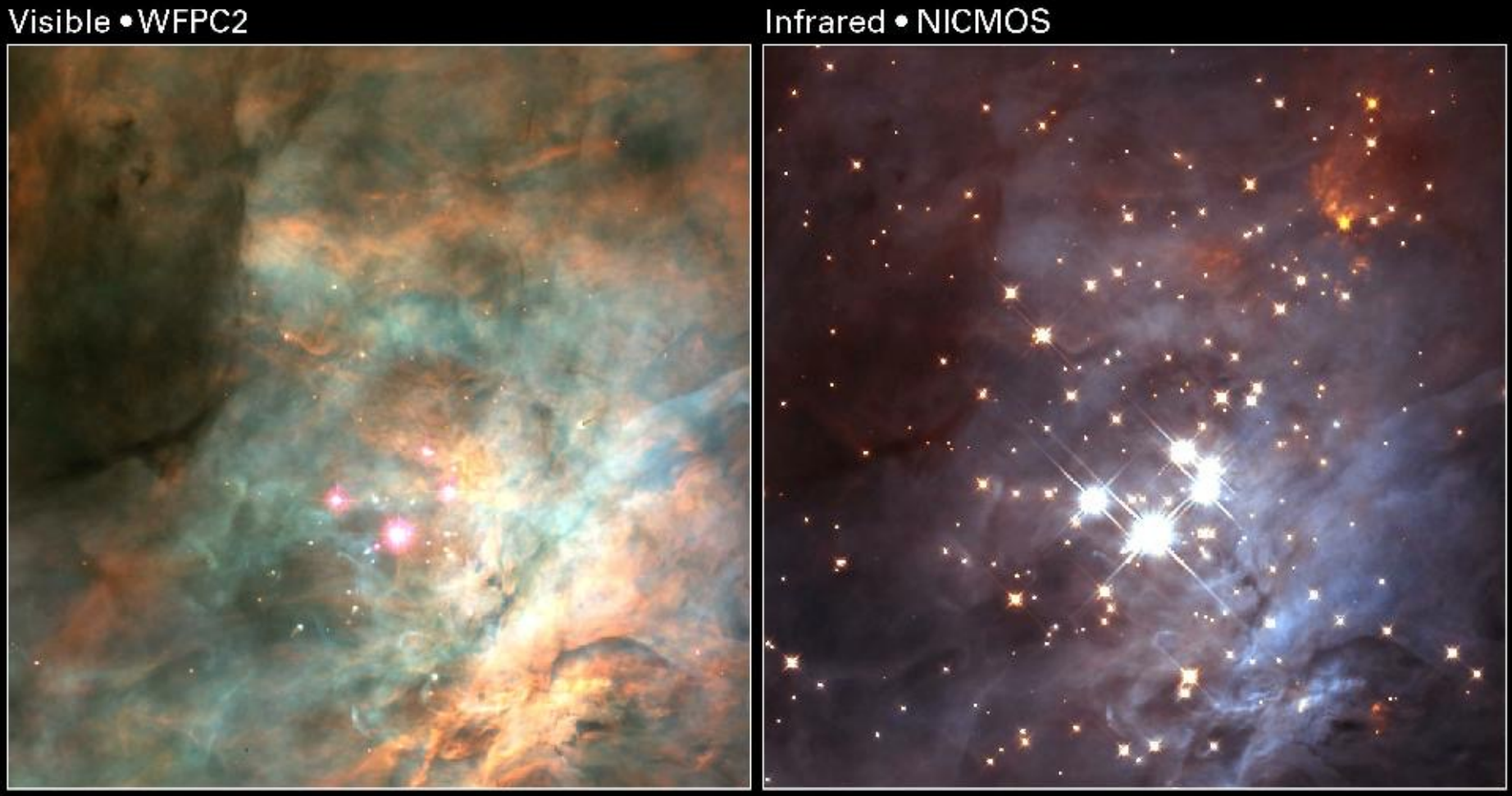


Consider a person in infrared light

Human body radiates in the infrared part of the EM spectrum.



Orion nebula in infrared light



question for you

Blue light has _____ compared to red light.

a) shorter wavelength
b) longer wavelength
c) higher energy photons
d) a and c
e) I have no idea.

question for you

Which of the following would be true about comparing gamma rays and radio waves?

A. The radio waves would have a lower energy and would travel slower than gamma rays.
B. The gamma rays would have a shorter wavelength and a lower energy than radio waves.
C. The radio waves would have a longer wavelength and travel the same speed as gamma rays.
D. The radio waves would have a shorter wavelength and higher energy than gamma rays.
E. I have no idea.

Interactions of light with matter

Light interacts with matter

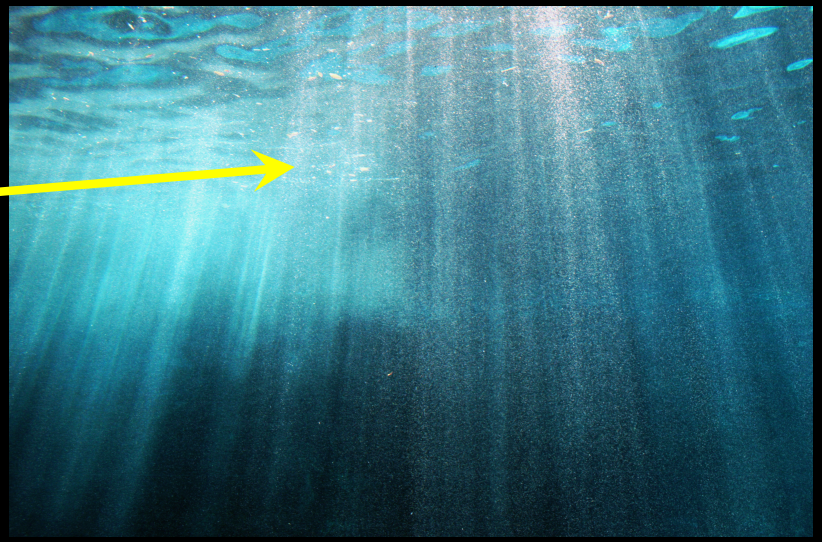
- **Emission**

- **Absorption**

Light interacts with matter

- **Reflection**

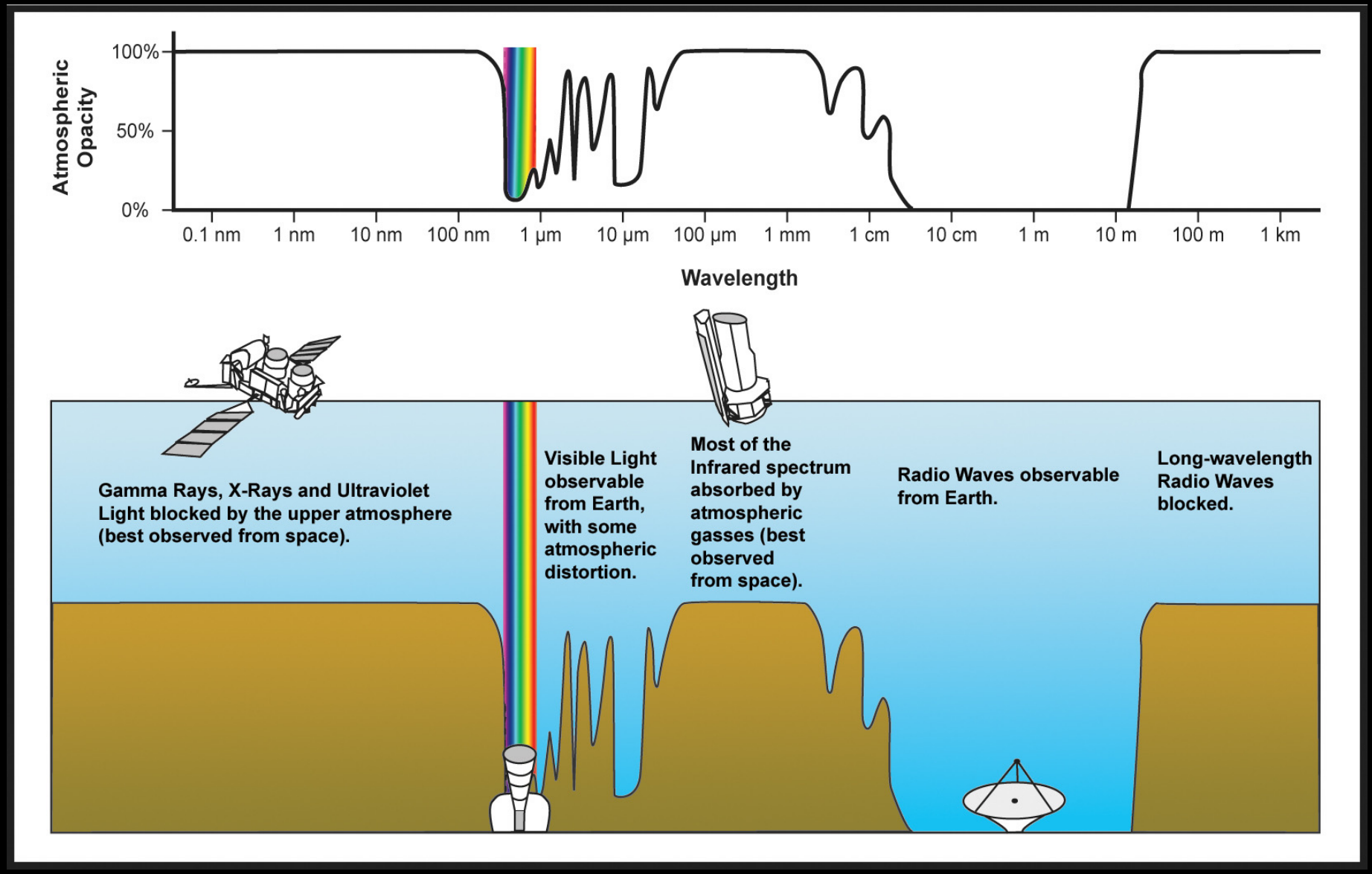
- **Transmission**



- Completely transparent - light goes through without being changed.
- Opaque - Does not transmit light (absorbs it).

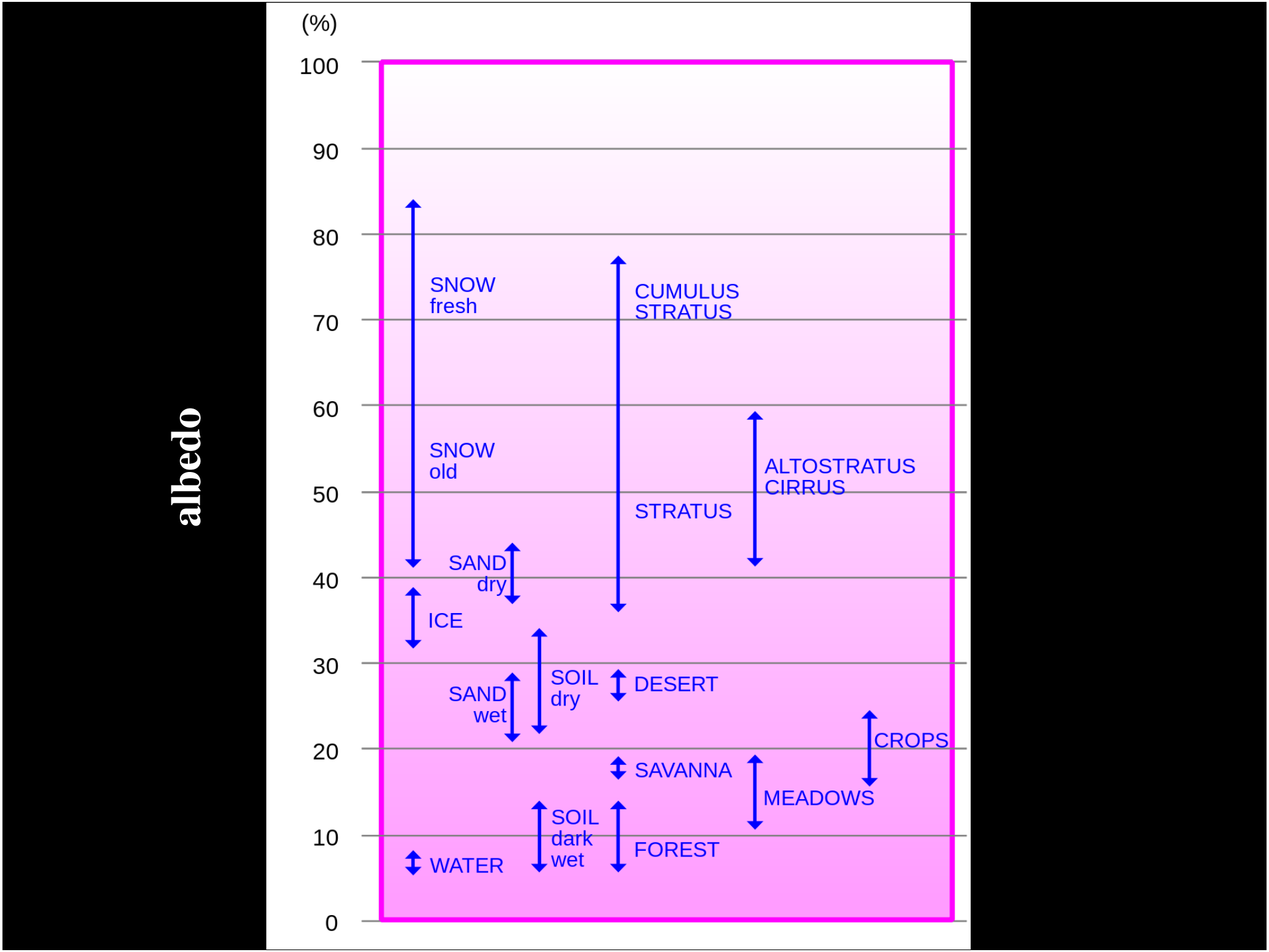
- **Opacity** - measure of what percentage of incident light is absorbed vs. transmitted.

How Transparent is Earth's Atmosphere?



How Reflective?

- The darker a surface, the more sunlight it absorbs. The lighter a surface, the less sunlight is absorbed. Whatever is not absorbed is reflected.
- Amount of reflection is called the **albedo**.
- Albedo = 0 means no reflection (all light absorbed).
- Albedo = 1 means total reflection (no absorption).
- Earth's albedo = 0.39
- Moon's albedo = 0.07


albedo
(%)
100
90
80
70
60
50
40
30
20
10
0
SNOW
fresh
SNOW
old
CUMULUS
STRATUS
STRATUS
ALTOSTRATUS
CIRRUS
SAND
dry
ICE
SAND
wet
SOIL
dry
DESERT
CROPS
SAVANNA
MEADOWS
SOIL
dark
wet
FOREST
WATER

Why is the grass green?

question for you

Why is the sky blue?

A. because it absorbs blue photons
B. because it reflects blue photons
C. because it transmits blue photons
D. both a and c
E. I have no idea.

Telescopes

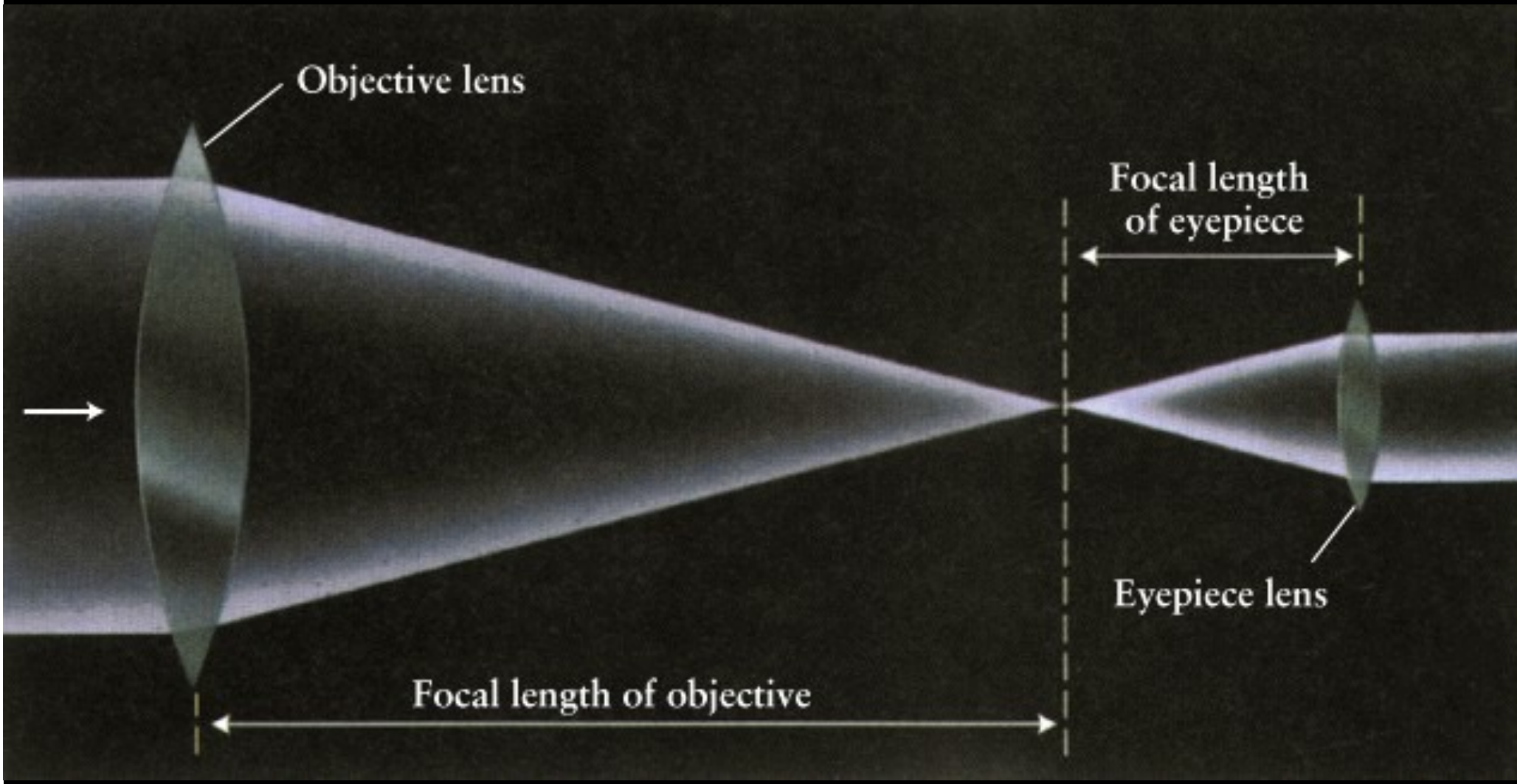
A Telescopes is a tool used to gather light from objects in the universe.

There are 2 different types of telescopes

- A **refracting** telescope uses a *glass* ***lens*** to concentrate incoming light

- A **reflecting** telescope uses ***mirrors*** to concentrate incoming light

A **refracting** telescope uses a *glass* ***lens*** to concentrate incoming light

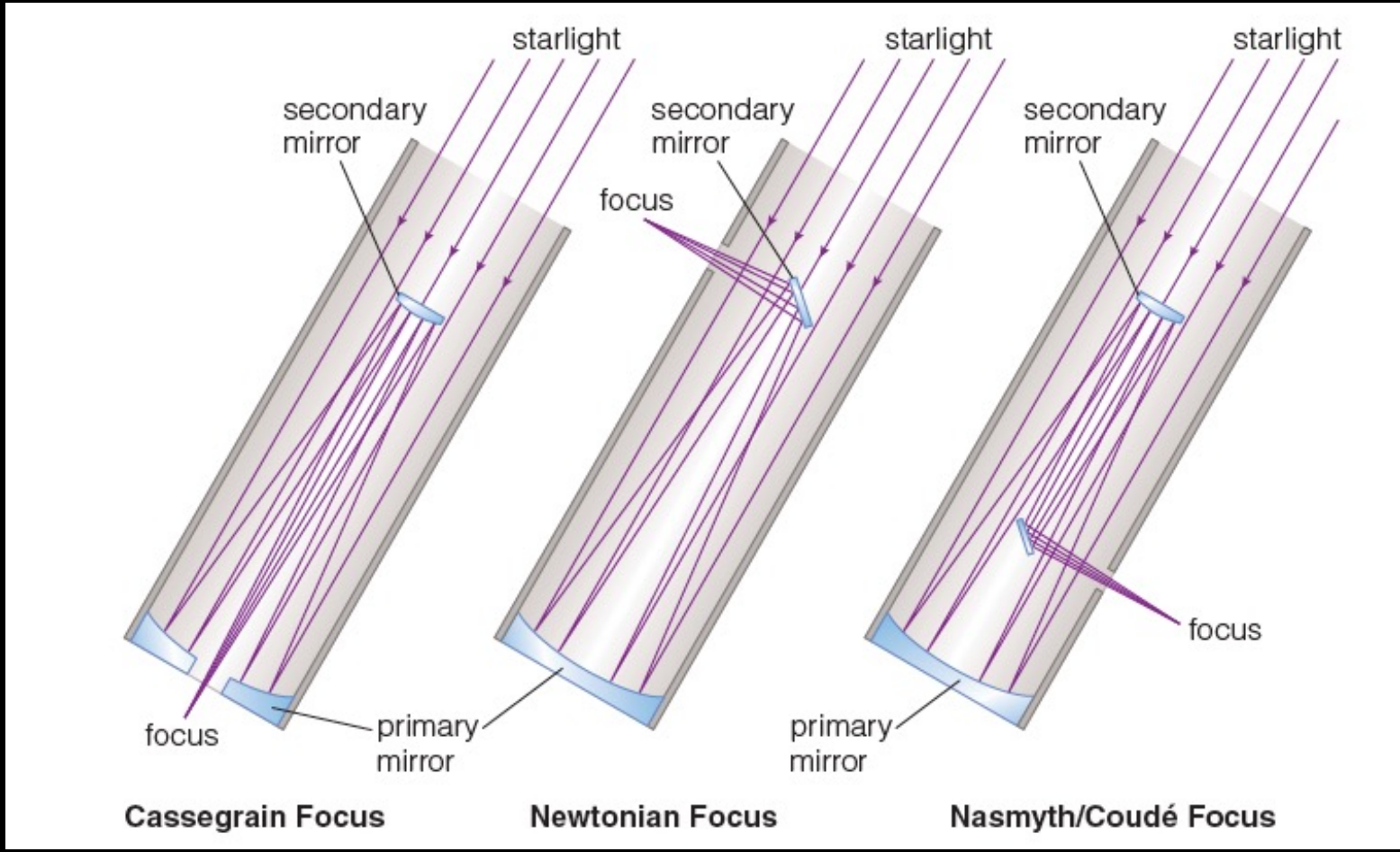


Refractors

- Largest refracting telescope ever built is 40" (100 cm) in diameter.
- They suffer from "chromatic aberration" and are no longer used for astronomy.

Photo:
Yerkes Observatory, Wisconsin, 1m diameter.

A **reflecting** telescope uses ***mirrors*** to concentrate incoming light



There are many variations to this basic reflector, the Newtonian, the Cassegrain, and the Schmidt-Cassegrain.

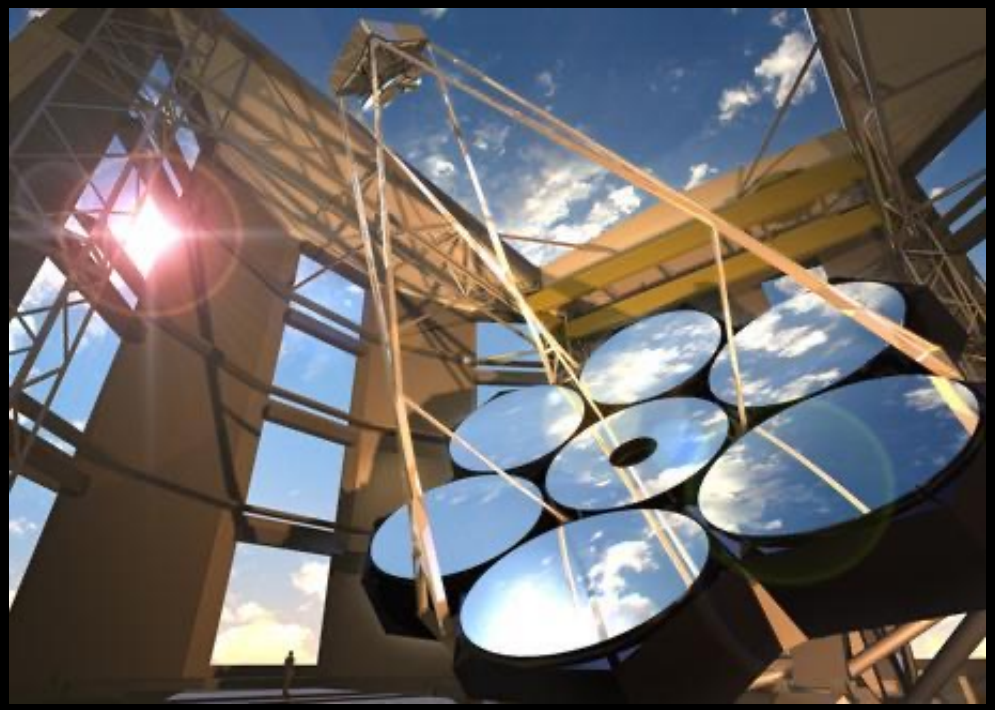
Main functions of a telescope

1. **Gather as much light as possible**: make objects appear brighter.
2. **Resolve objects:** see fine detail.
3. **Magnify images**: magnification = (objective focal length / eyepiece focal length)

A larger objective lens provides a **brighter** (not bigger) image

Properties of telescopes

Light gathering power is proportional to **area** of mirror or lens, proportional to R^2



Properties of telescopes

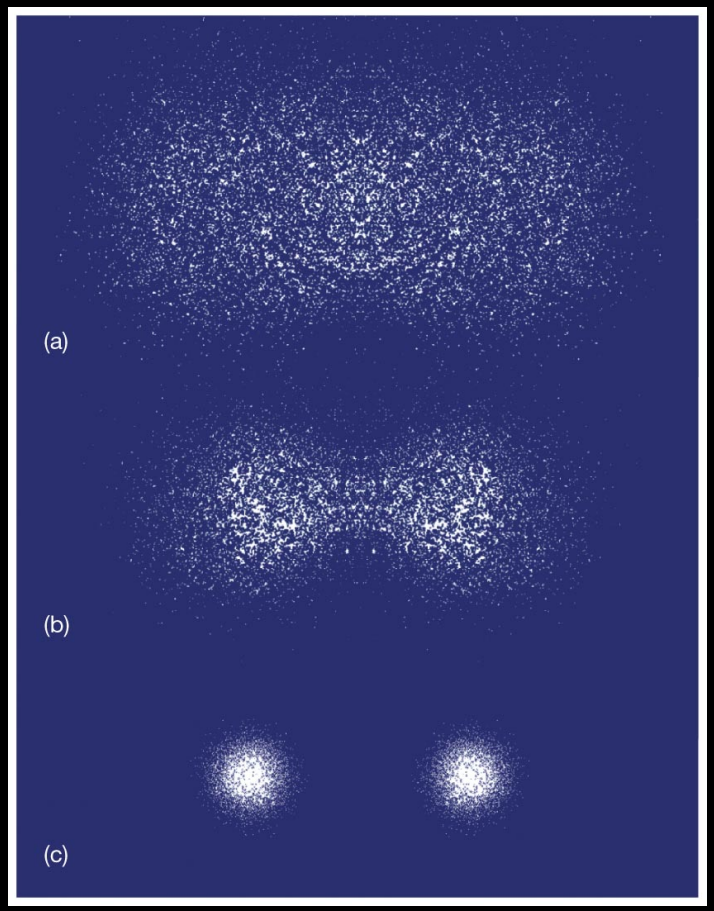
Resolving power is the ability to see detail, or to resolve two objects near one another.

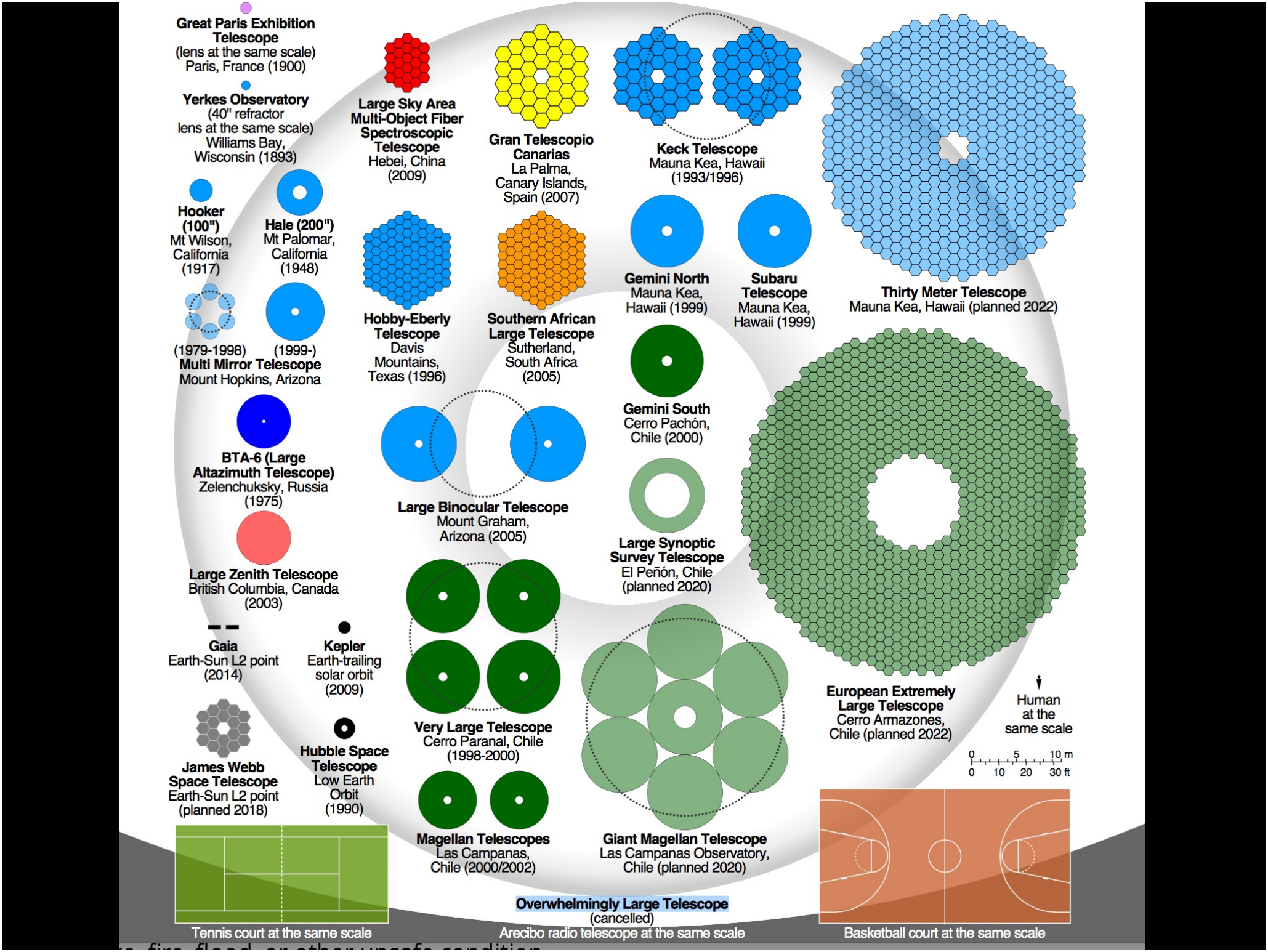
The angular resolution of a telescope is determined by the **diameter** of the mirror or lens (smaller number for resolution=better resolution):

$$\text{angular resolution (arcsec)} = 0.25\,\frac{\text{wavelength } (\mu\text{m})}{\text{diameter (m)}}$$

(μm = 10^{-6} m)

Earth's atmosphere limits resolving power to **1" (arcsecond)** for visible wavelengths.




Great Paris Exhibition Telescope
(lens at the same scale)
Paris, France (1900)
Yerkes Observatory
(40" refractor
lens at the same scale)
Williams Bay,
Wisconsin (1893)
Large Sky Area Multi-Object Fiber Spectroscopic Telescope
Hebei, China
(2009)
Gran Telescopio Canarias
La Palma,
Canary Islands,
Spain (2007)
Keck Telescope
Mauna Kea, Hawaii
(1993/1996)
Thirty Meter Telescope
Mauna Kea, Hawaii (planned 2022)
Hooker (100")
Mt Wilson,
California
(1917)
Hale (200")
Mt Palomar,
California
(1948)
Hobby-Eberly Telescope
Davis
Mountains,
Texas (1996)
Southern African Large Telescope
Sutherland,
South Africa
(2005)
Gemini North
Mauna Kea,
Hawaii (1999)
Subaru Telescope
Mauna Kea,
Hawaii (1999)
(1979-1998)
(1999-)
Multi Mirror Telescope
Mount Hopkins, Arizona
Gemini South
Cerro Pachón,
Chile (2000)
BTA-6 (Large Altazimuth Telescope)
Zelenchuksky, Russia
(1975)
Large Binocular Telescope
Mount Graham,
Arizona (2005)
Large Synoptic Survey Telescope
El Peñón, Chile
(planned 2020)
Large Zenith Telescope
British Columbia, Canada
(2003)
Gaia
Earth-Sun L2 point
(2014)
Kepler
Earth-trailing
solar orbit
(2009)
European Extremely Large Telescope
Cerro Armazones,
Chile (planned 2022)
Human at the same scale
0 5 10 m
0 10 20 30 ft
Very Large Telescope
Cerro Paranal, Chile
(1998-2000)
James Webb Space Telescope
Earth-Sun L2 point
(planned 2018)
Hubble Space Telescope
Low Earth
Orbit
(1990)
Magellan Telescopes
Las Campanas,
Chile (2000/2002)
Giant Magellan Telescope
Las Campanas Observatory,
Chile (planned 2020)
Overwhelmingly Large Telescope
(cancelled)
Tennis court at the same scale
Arecibo radio telescope at the same scale
Basketball court at the same scale

Differences in the temperature and density of small portions of Earth's atmosphere cause passing starlight to quickly change direction, making stars appear to **twinkle**.

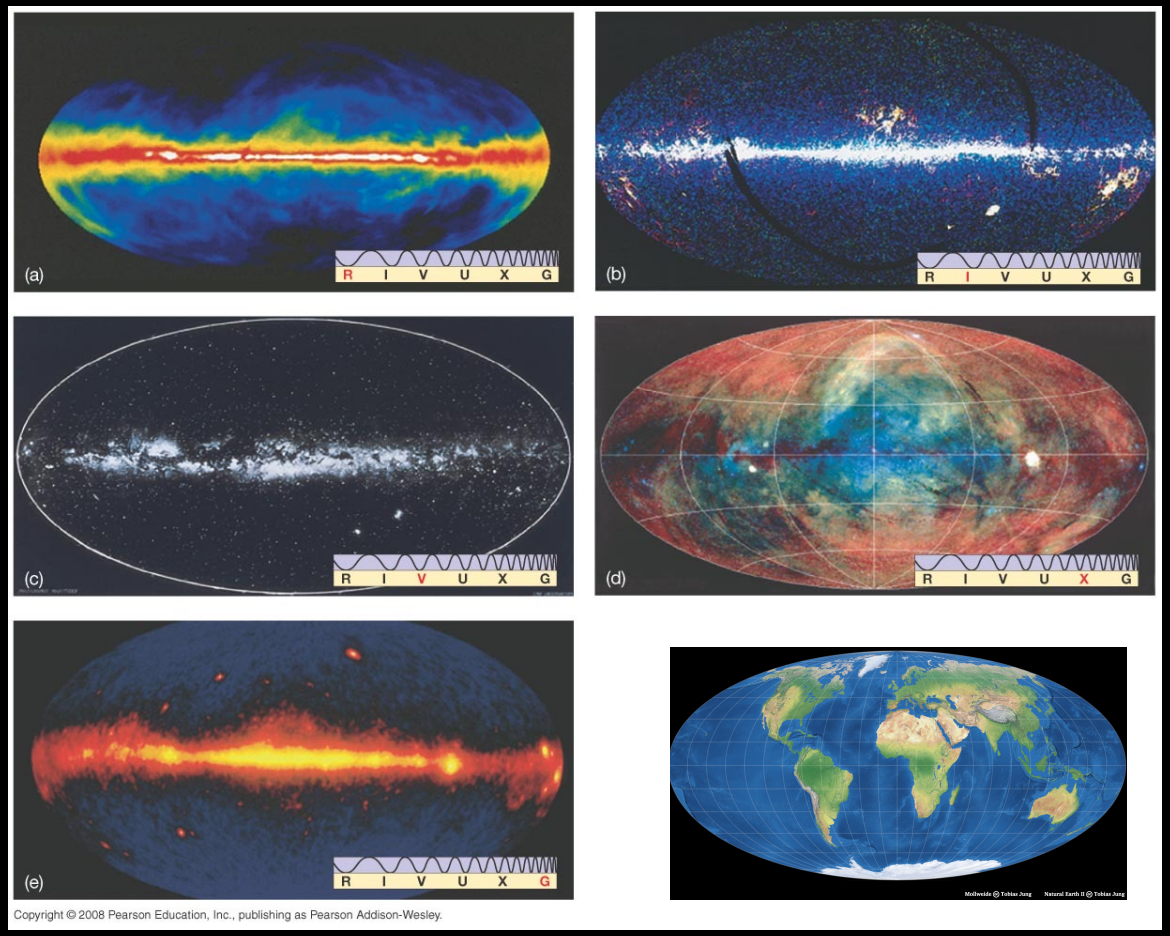
Adaptive optics

Radio telescopes

- **A radio telescope** "sees" radio waves, and can locate sources of radio waves from space.

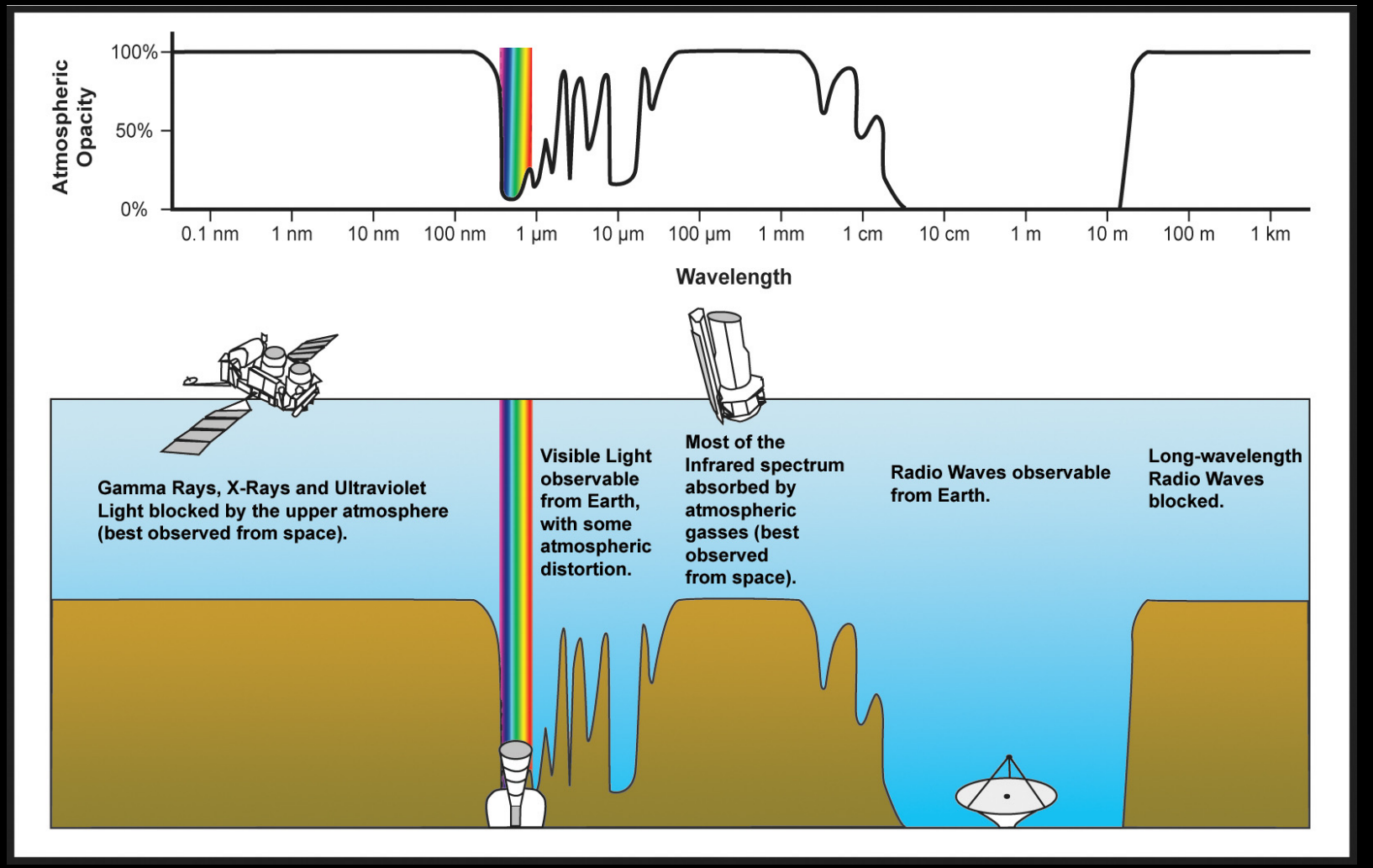
Radio astronomy

- Radio waves are not blocked by clouds of gas and dust and allow us to peer inside the center of the Milky Way.



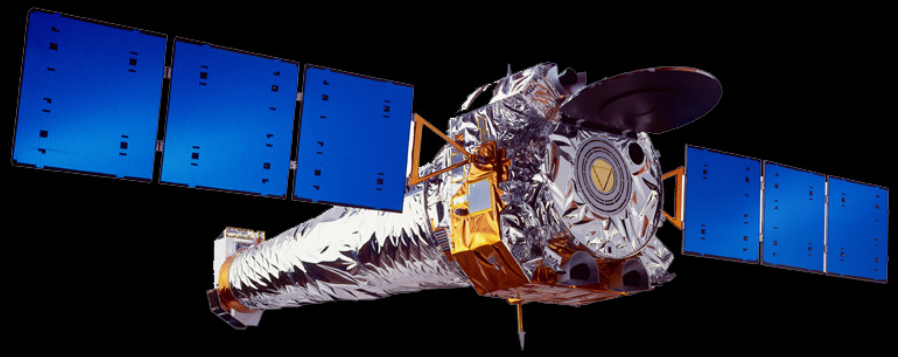
We are interested in the whole spectrum!

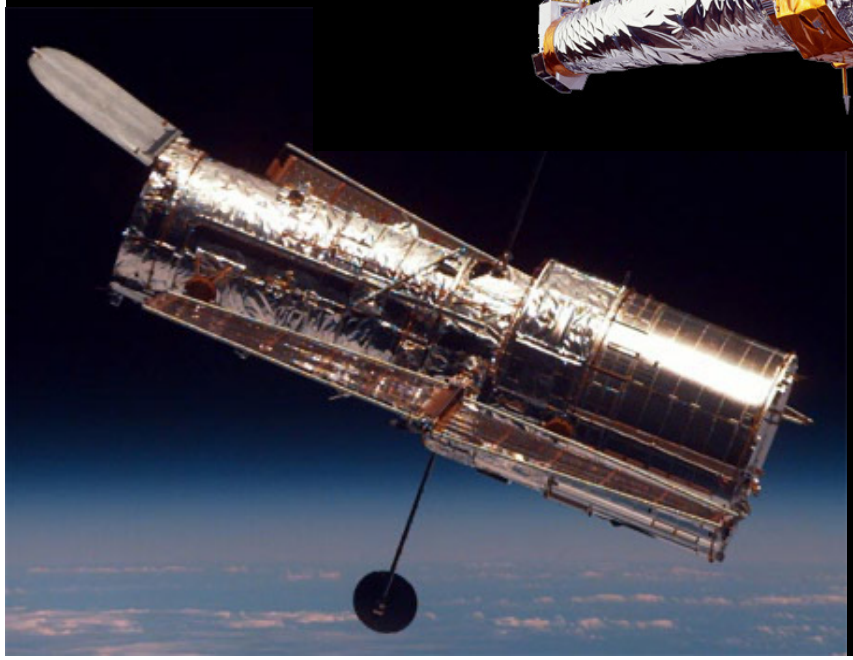
Bigger wavelengths-> need bigger telescopes.

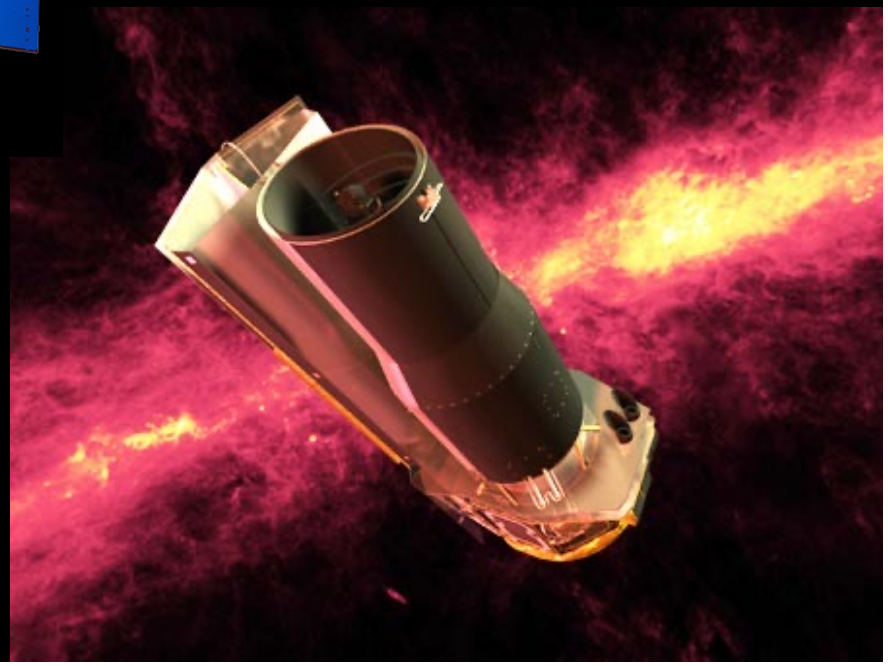


Telescopes in space

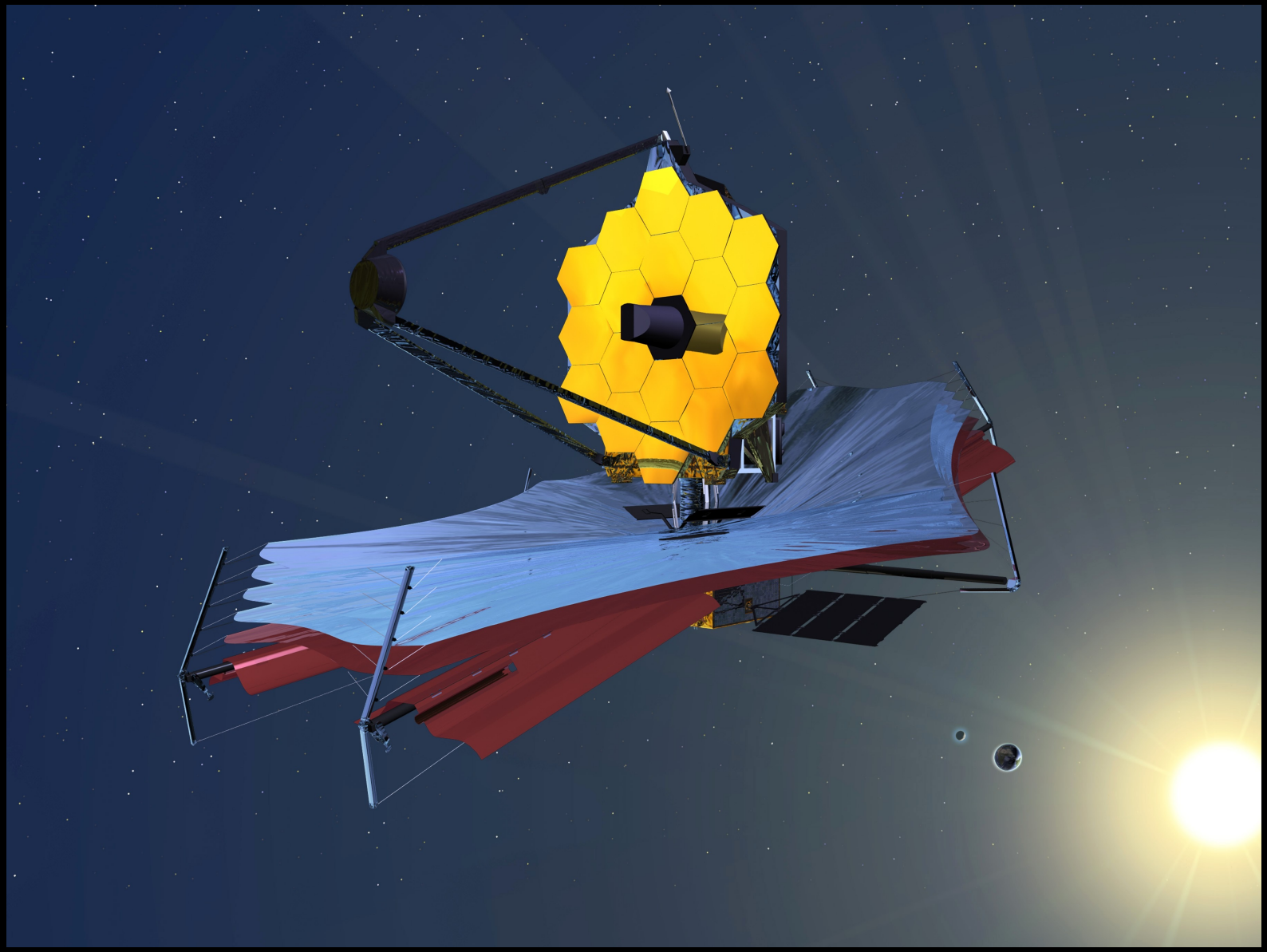
- Can view wavelengths blocked by Earth's atmosphere.
- Don't have to deal with atmospheric disturbances and thus can achieve higher resolving power.



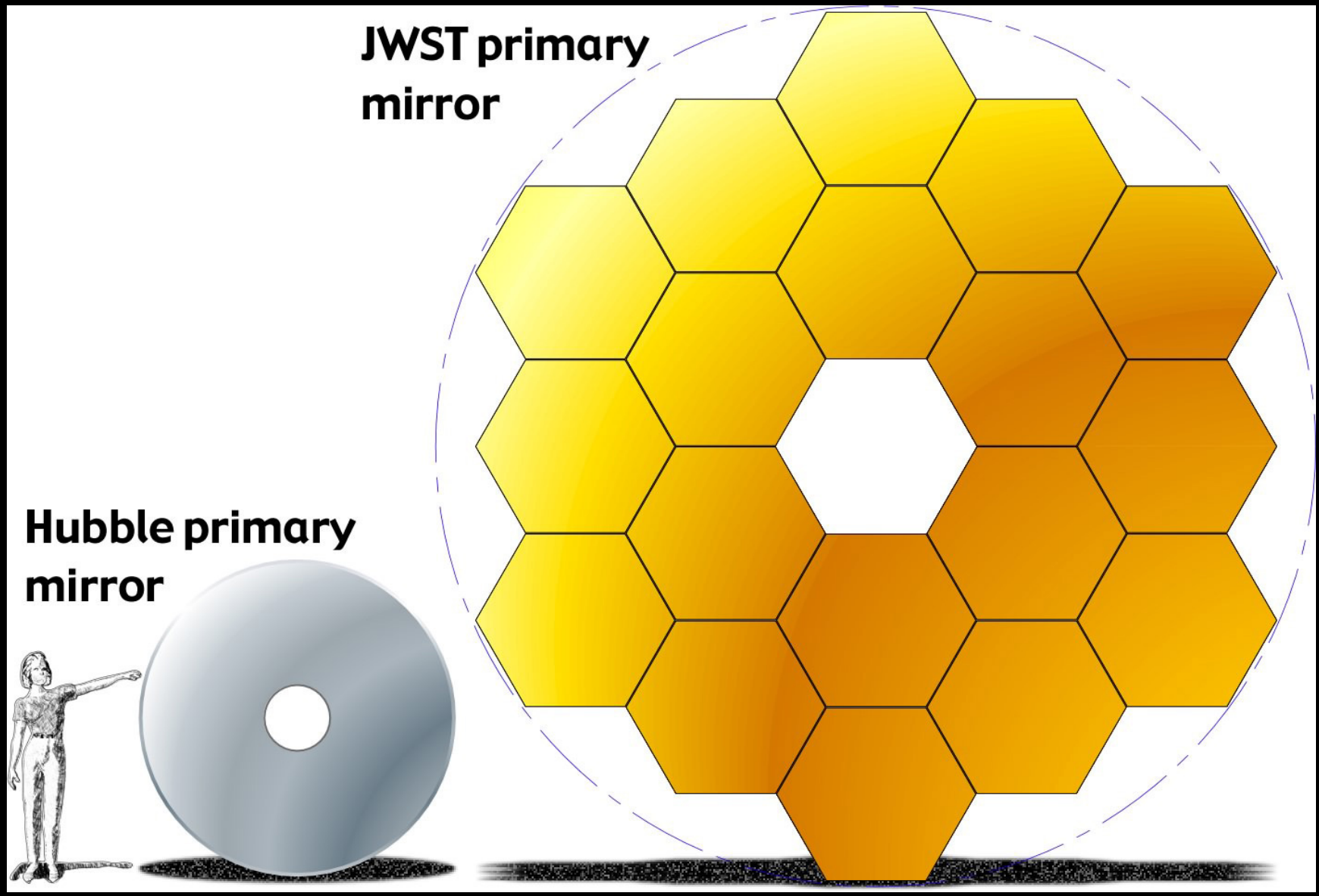




The Next Generation:
The James Webb Space Telescope (JWST)



The JWST vs. the Hubble



JWST

https://interestingengineering.com/nasas-james-webb-is-one-crucial-step-away-from-taking-its-first-images

https://www.youtube.com/watch?v=RzGLKQ7_KZQ

question for you

Imagine you're the head of a funding agency that can afford to build only one telescope. Which of the proposed telescopes below would be best to support?

A. A gamma ray telescope in Antarctica
B. A radio telescope in orbit above the Earth
C. A visible telescope located high on a mountain in Peru
D. An ultraviolet telescope located in the Mojave desert
E. I have no idea.

What did we learn in Chapter 6?

- ✓ Light is an electromagnetic wave, and its wavelength times its frequency equals the speed of light.
- ✓ Its color and energy depend on the frequency.
- ✓ Light interacts with matter by being absorbed, emitted, transmitted, or reflected.
- ✓ Earth's atmosphere is transparent to visible light and radio waves, and a small portion of UV and infrared light.
- ✓ Two primary types of telescopes: reflecting and refracting.
- ✓ Most important characteristics of telescopes:
  - Light gathering power – goes as area of mirror/lens
  - Resolving power – goes as radius of mirror/lens
- ✓ Telescopes in space are able to observe at all wavelengths without atmospheric interference.