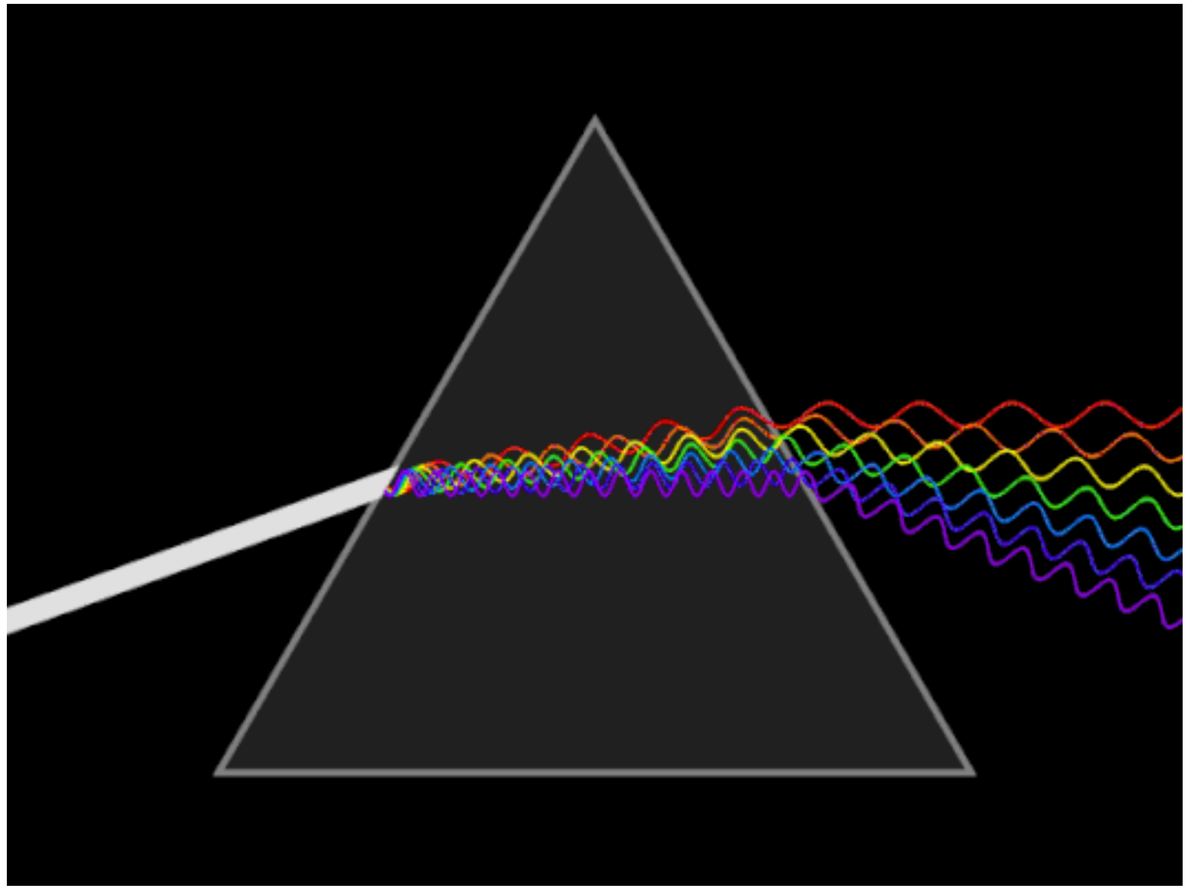
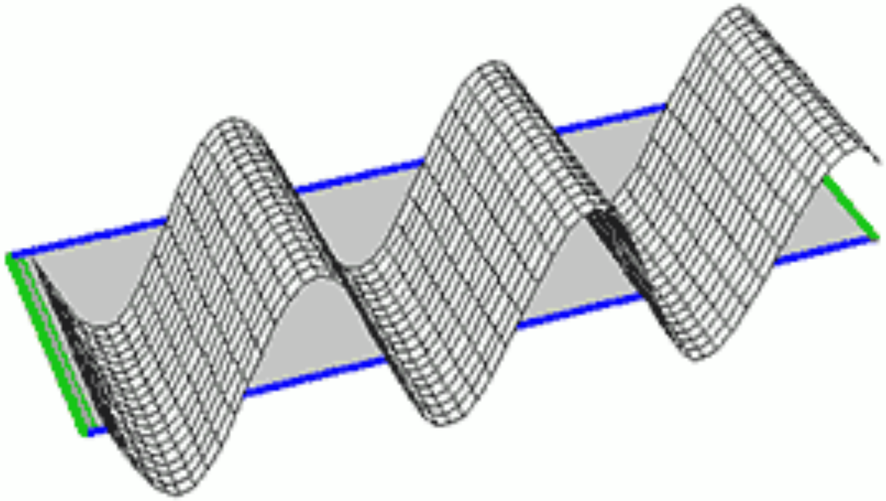
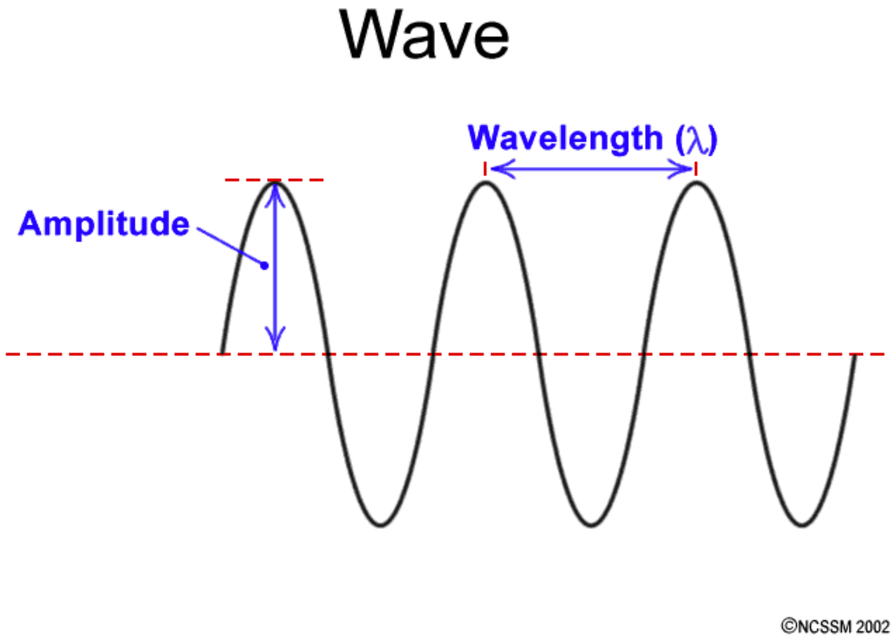
Chapter 4: Light



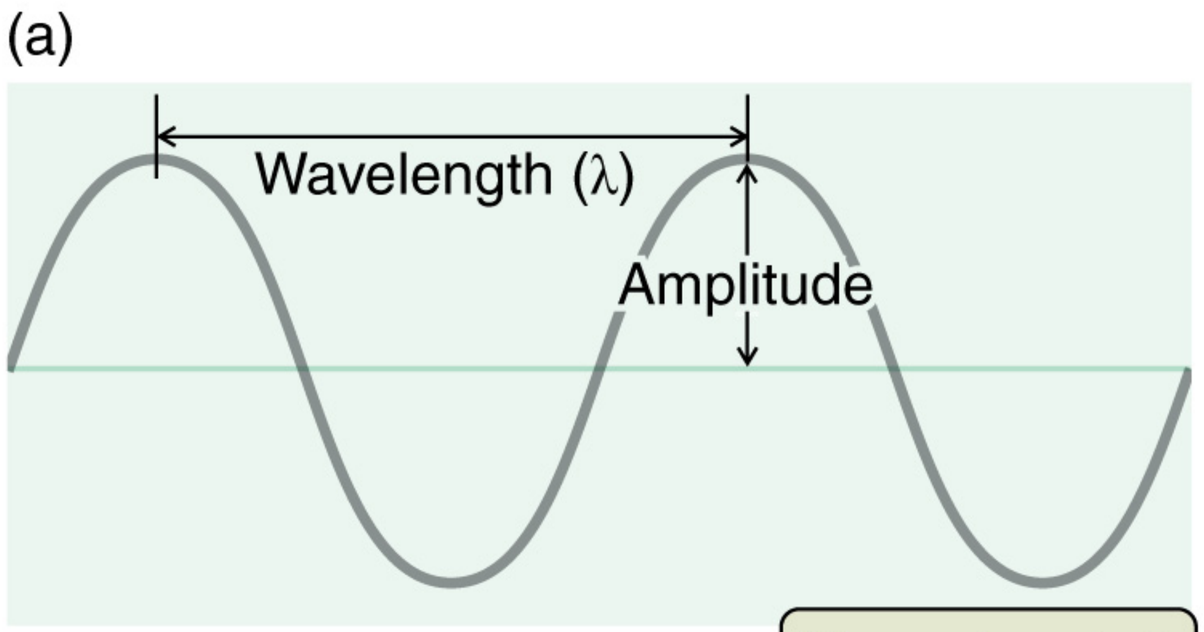
Light is a wave

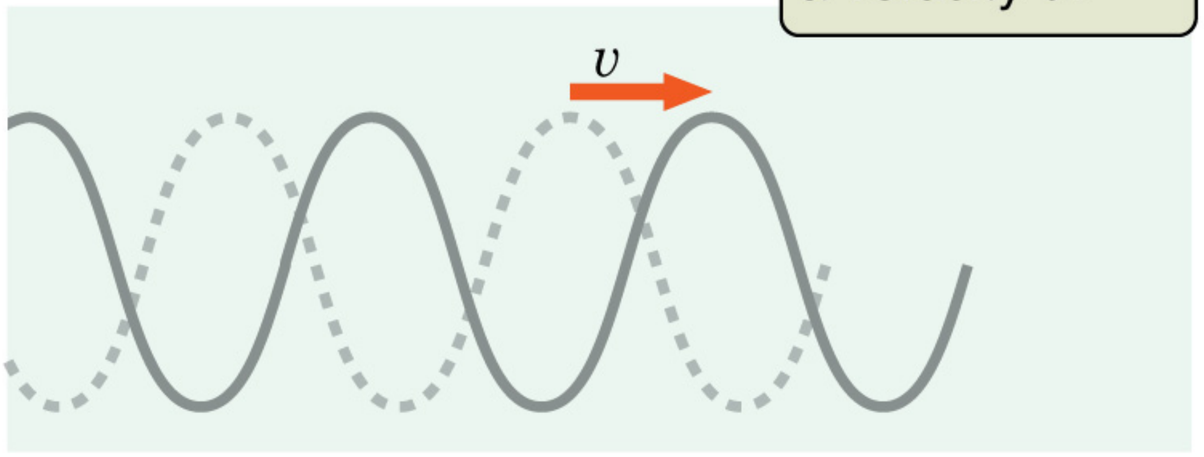




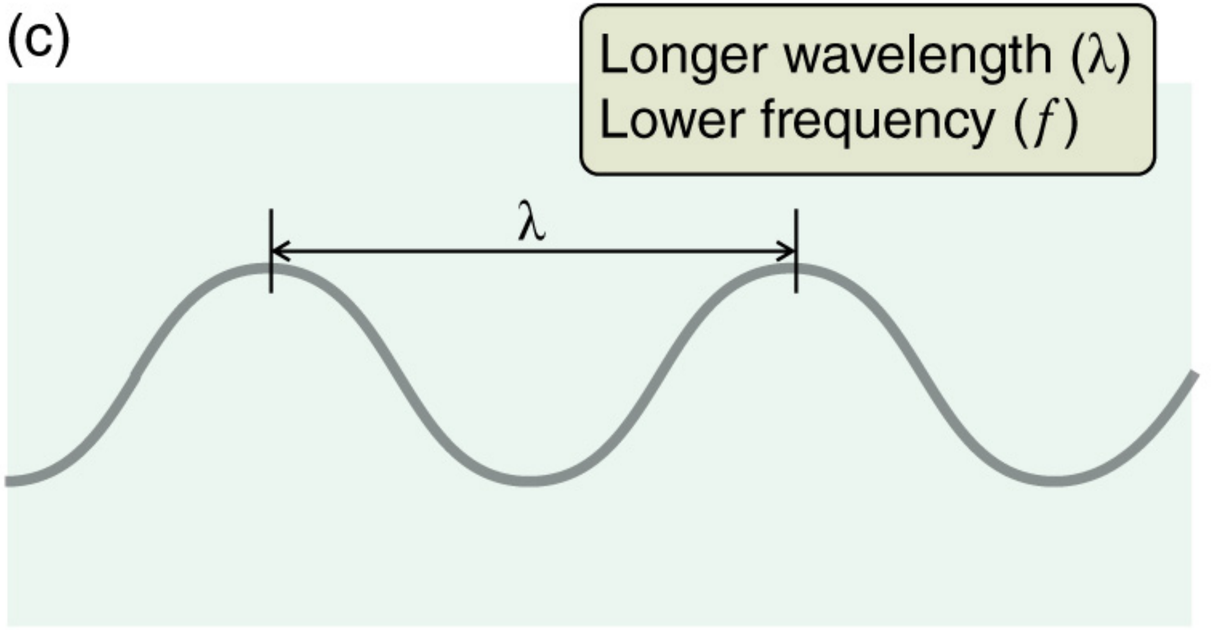
Tacoma Narrows Bridge, 1940

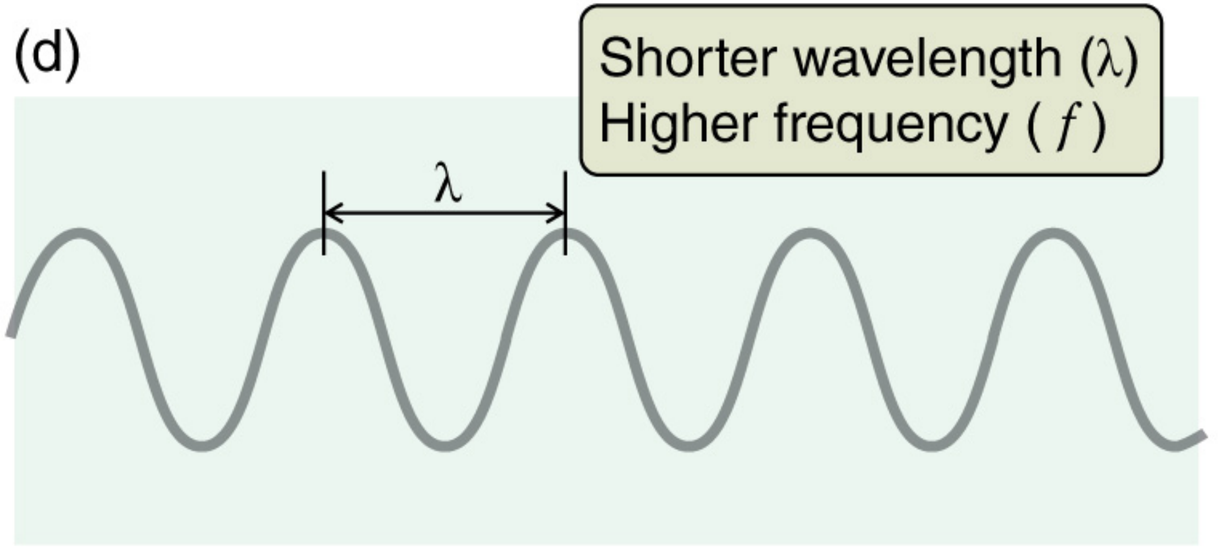
https://www.youtube.com/watch?v=XggxeuFDaDU



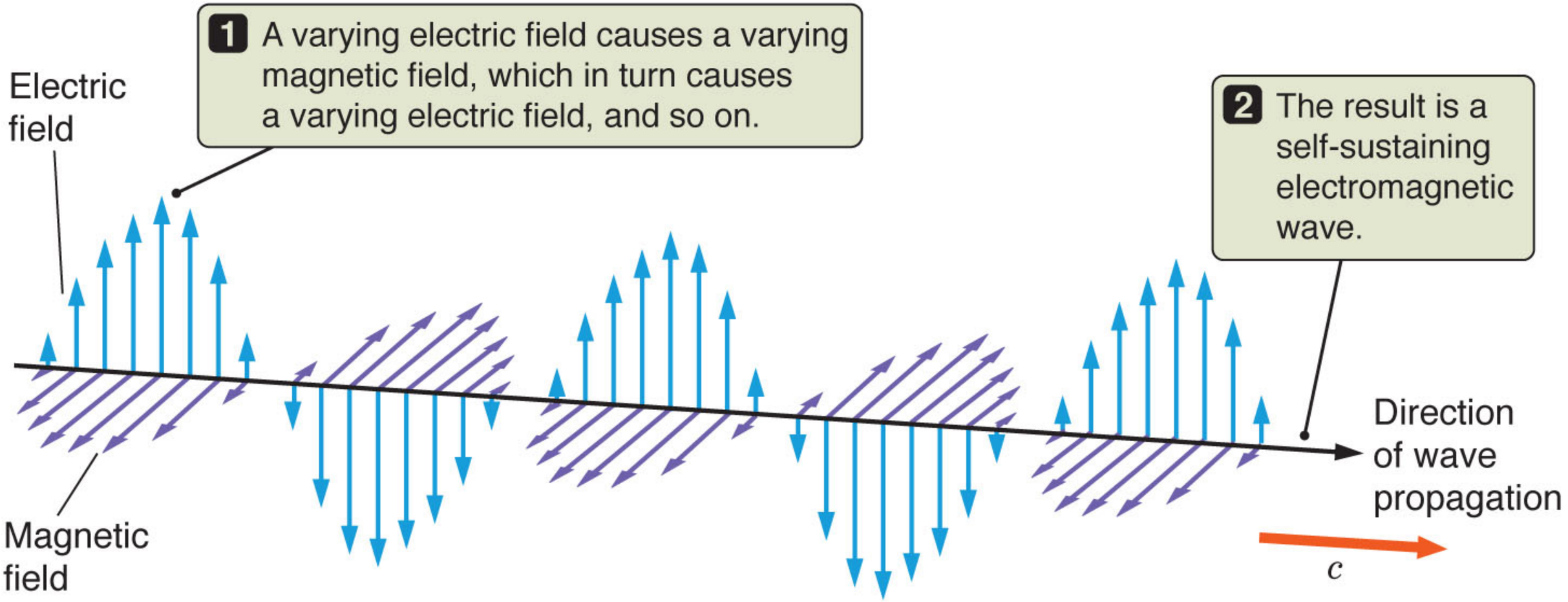


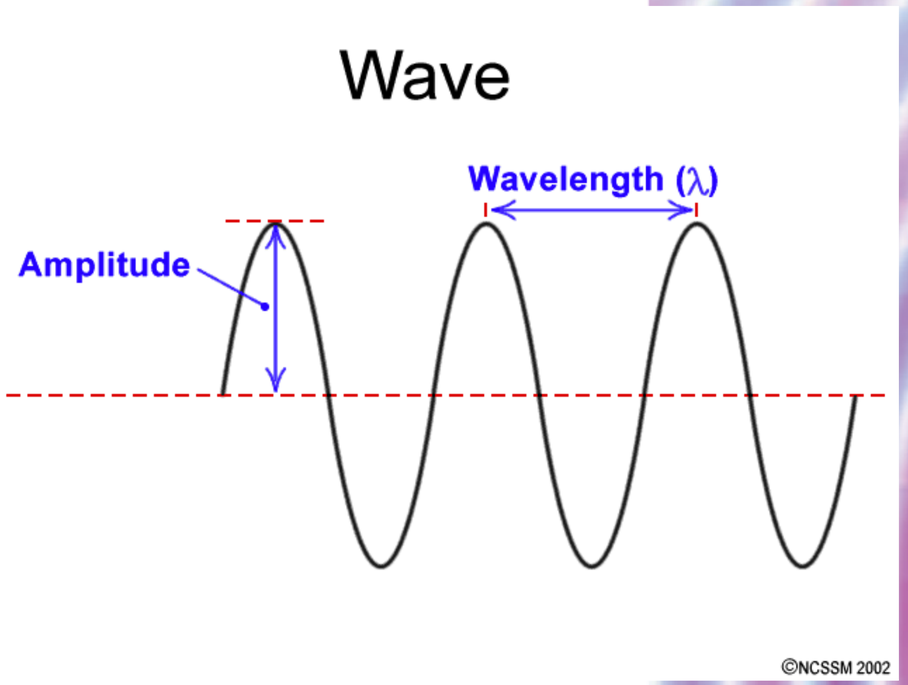
Waves travel at a velocity v.

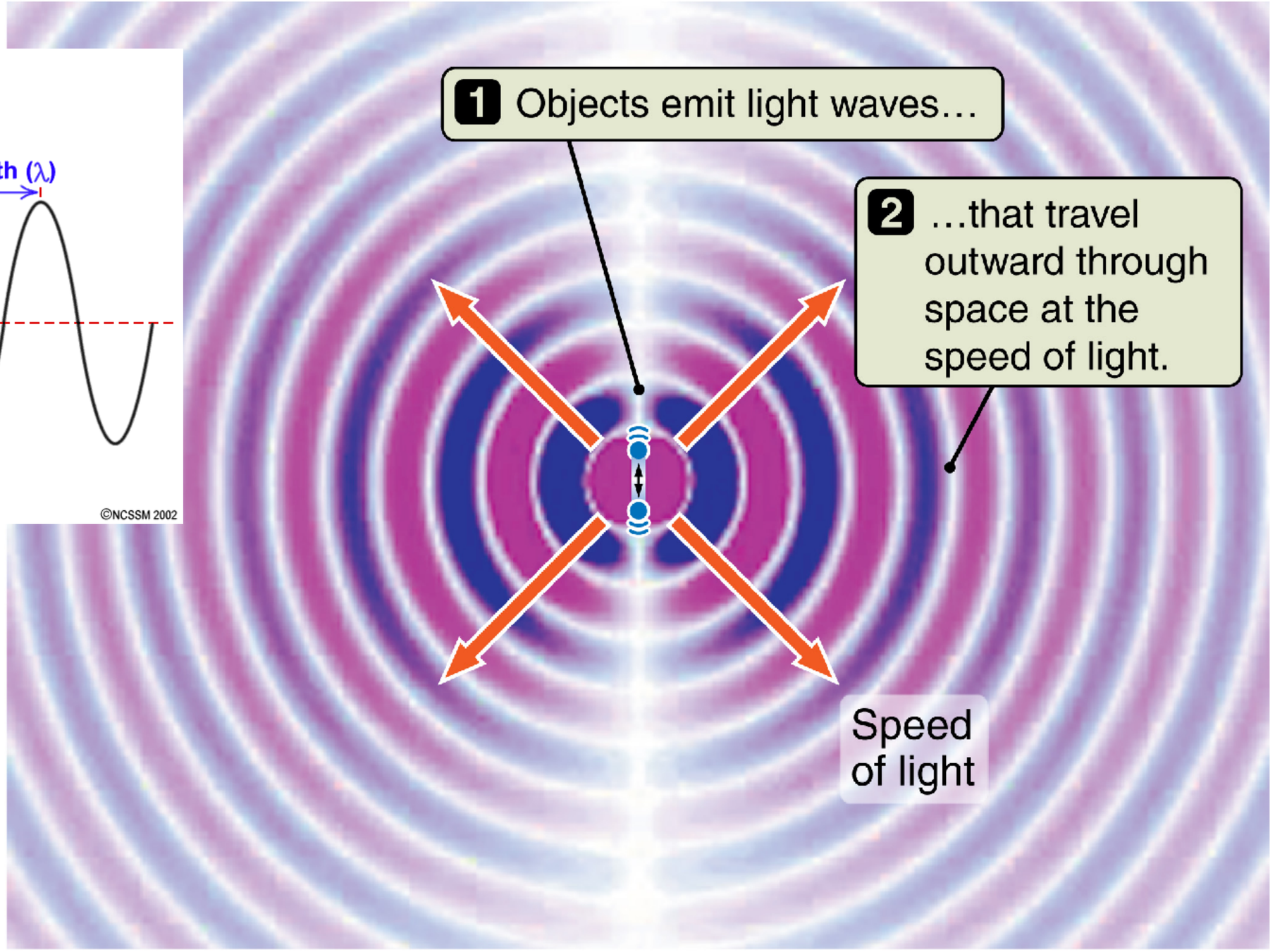




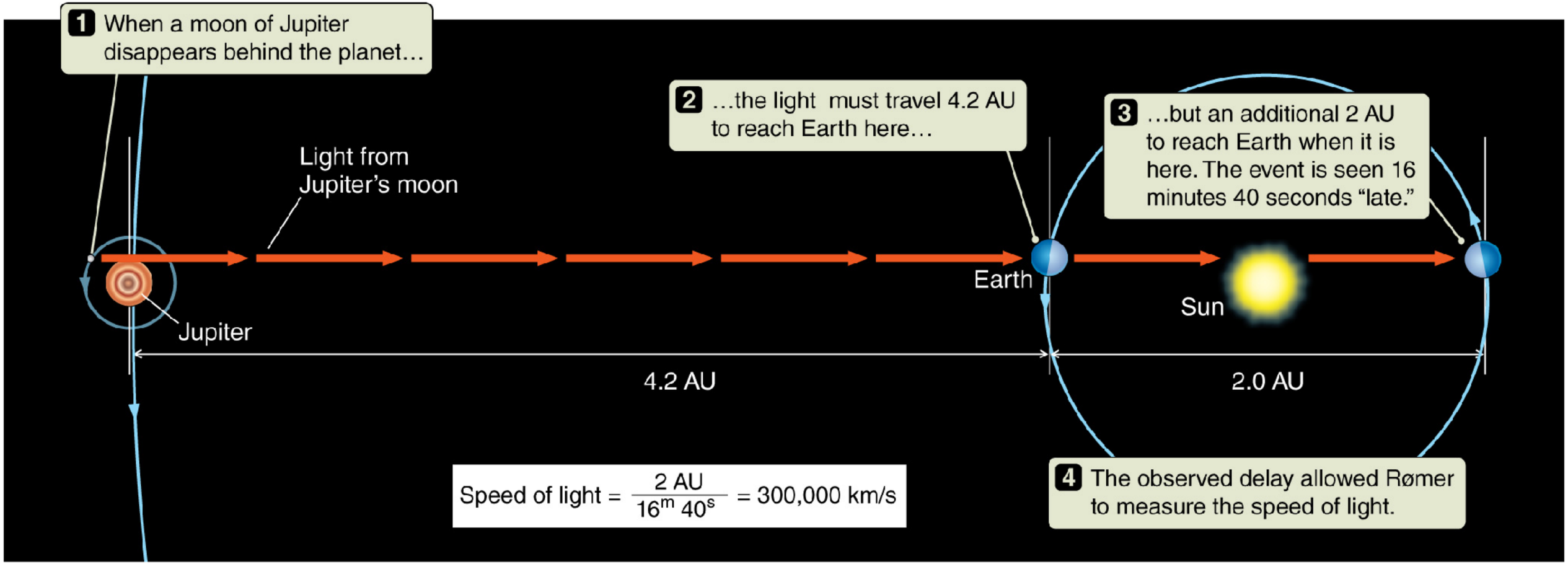
Light is an “electromagnetic wave”




Wave
Wavelength (λ)
Amplitude
©NCSSM 2002


1 Objects emit light waves…
2 …that travel outward through space at the speed of light.
Speed of light

Speed of Light: can you explain how we can measure it via this method?



A light-year is a unit of…

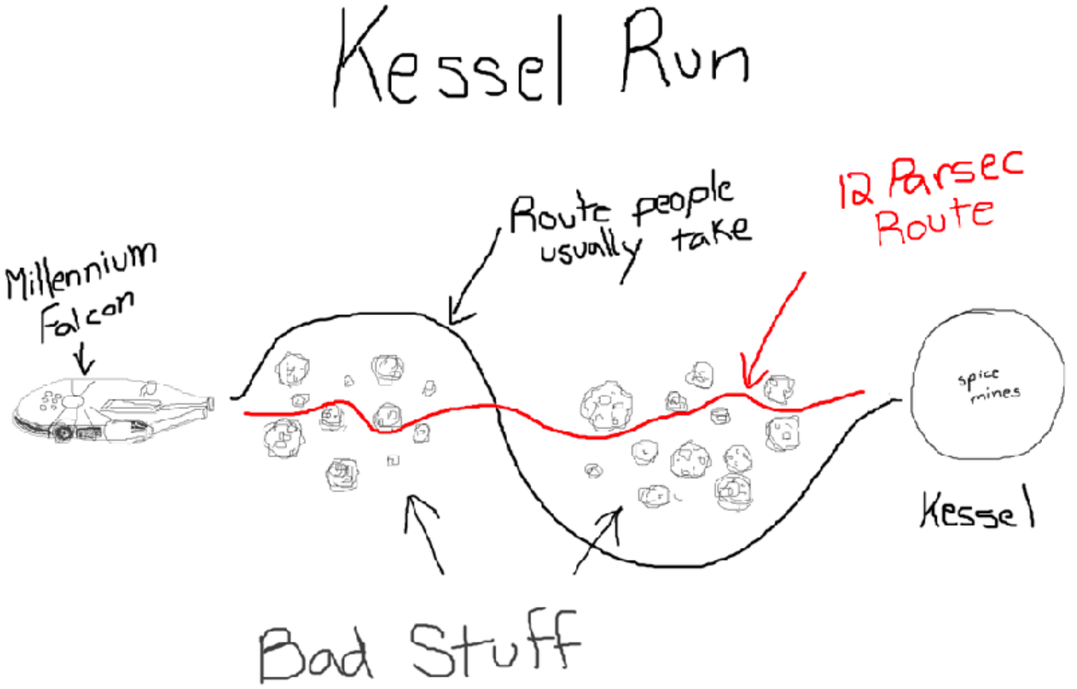
A) Energy

B) Time

C) Distance

D) Time and Distance

A light-year is like a parsec, but 3.26 times shorter



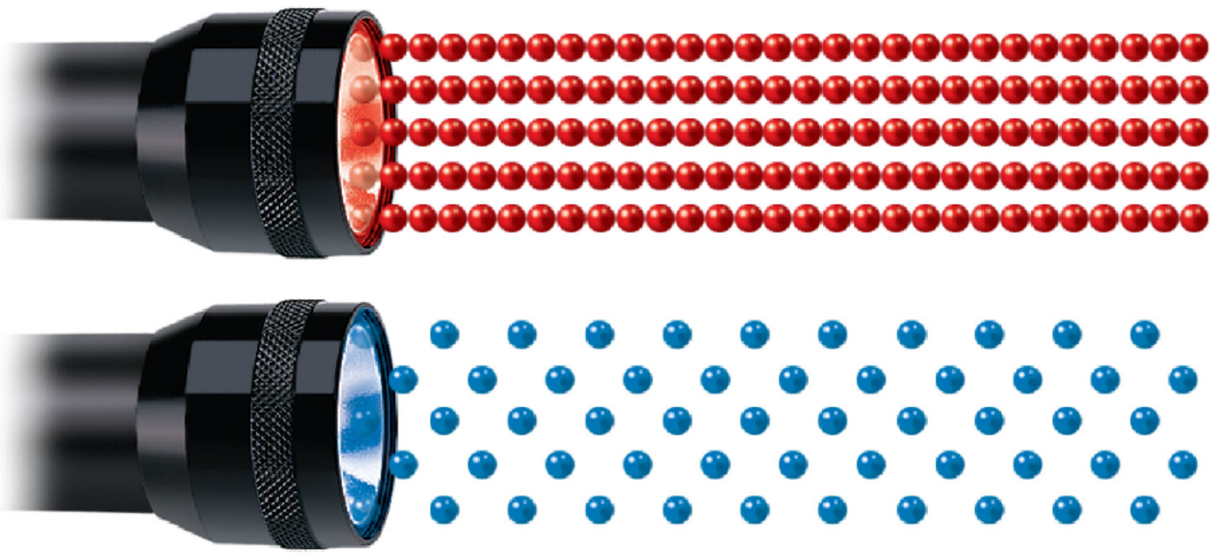
Chapter 4: Light

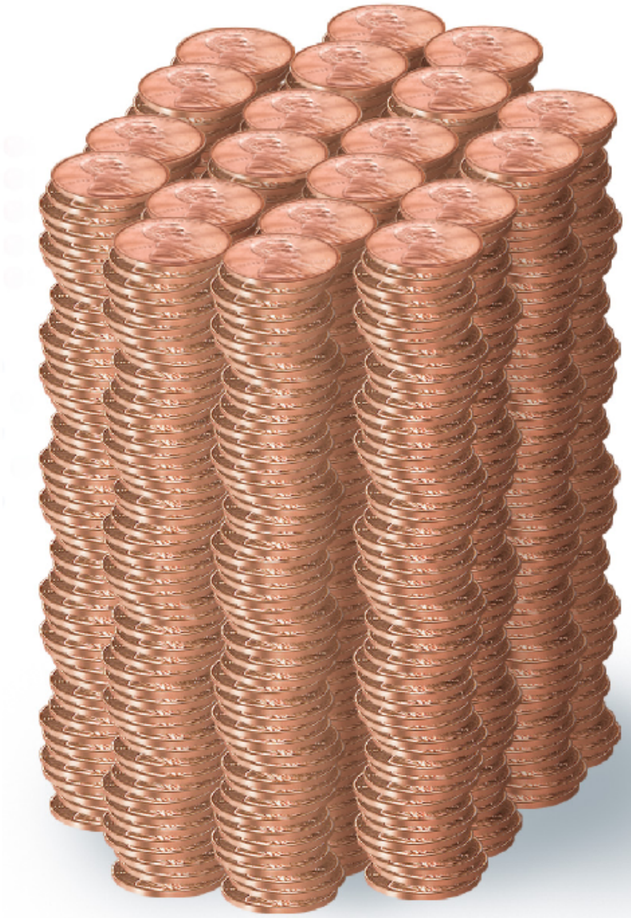
Ch. 5 Reading Quiz due this Thursday

If you will miss class, email astr1060absence@gmail.com
BEFORE the start of that class

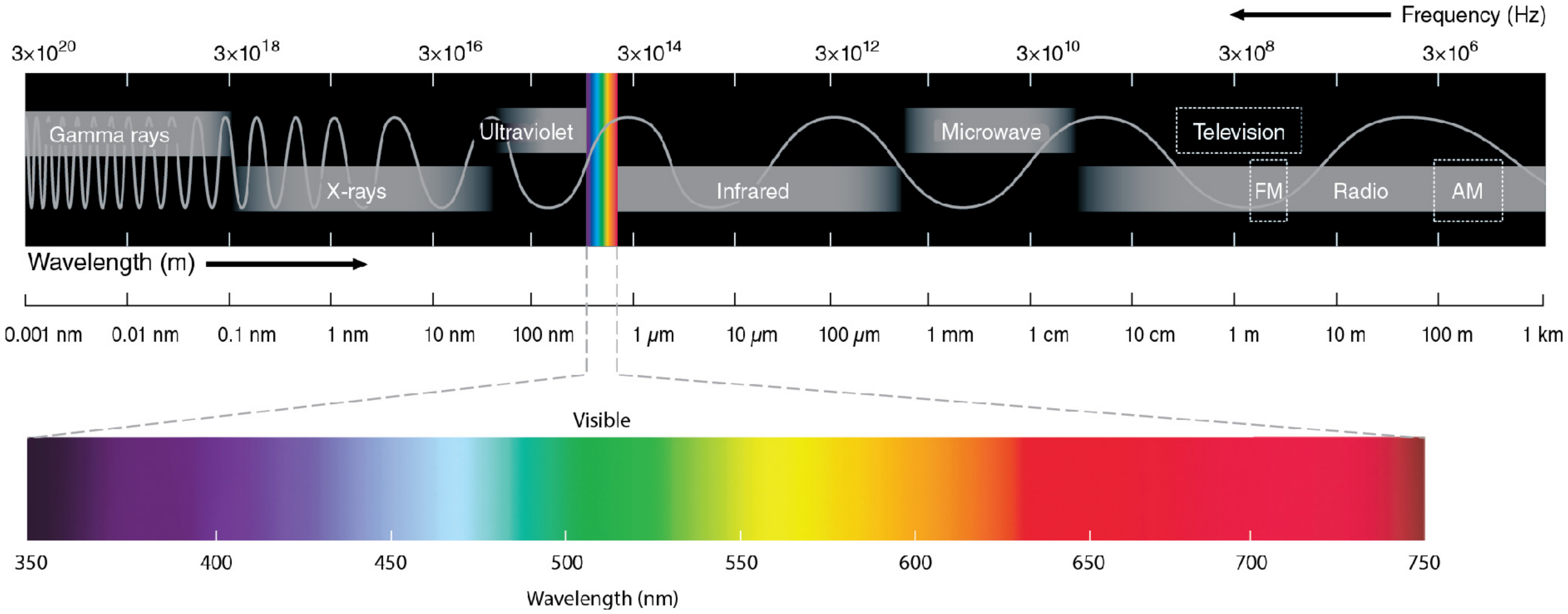
Midterm 1 Exam on Sept. 19th (1 week from Thursday)

Light is “quantized”
Its energy is proportional to frequency

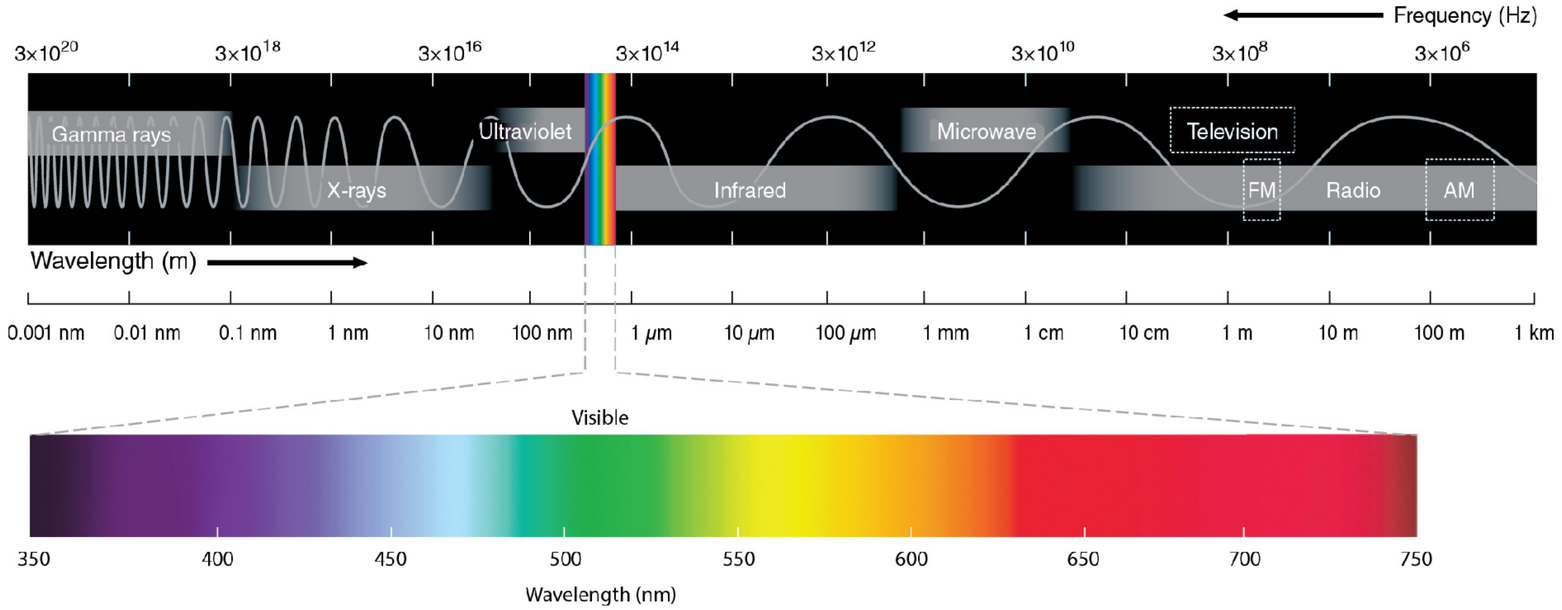




Electromagnetic Spectrum



What type of emission do we see only from the most energetic events?



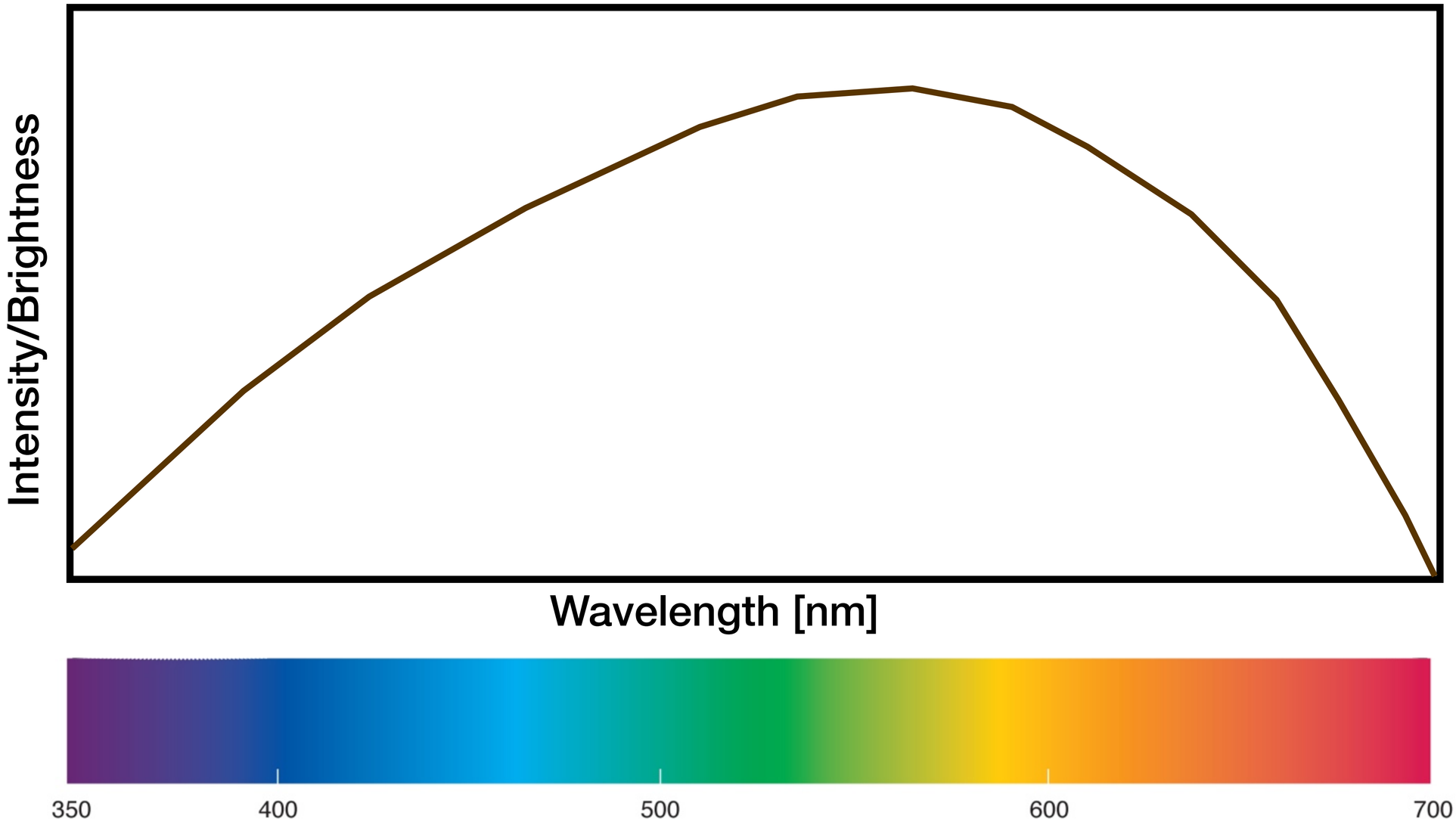
A) Visible Light

B) Radio Waves

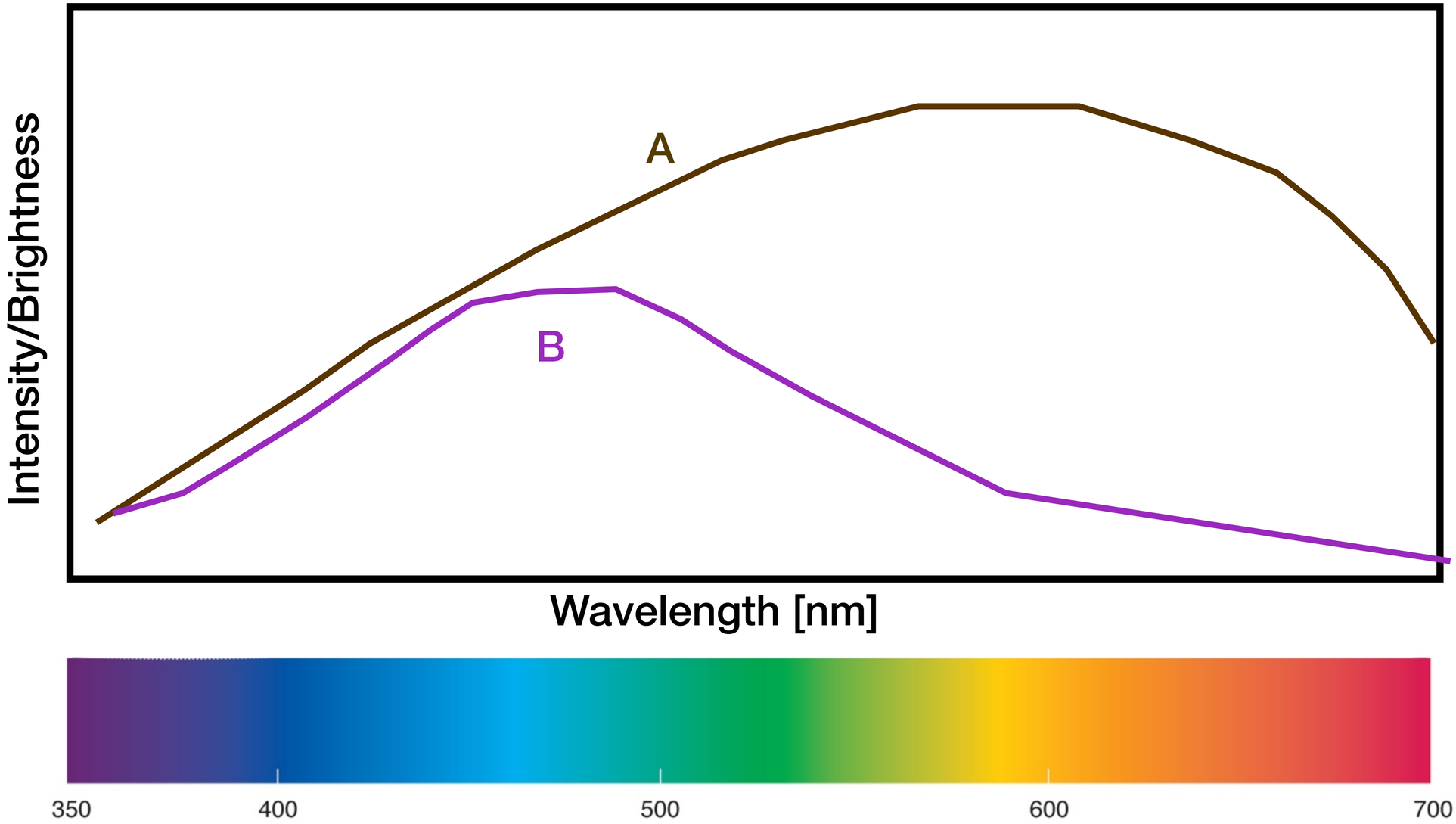
C) Ultraviolet Light

D) Gamma Rays

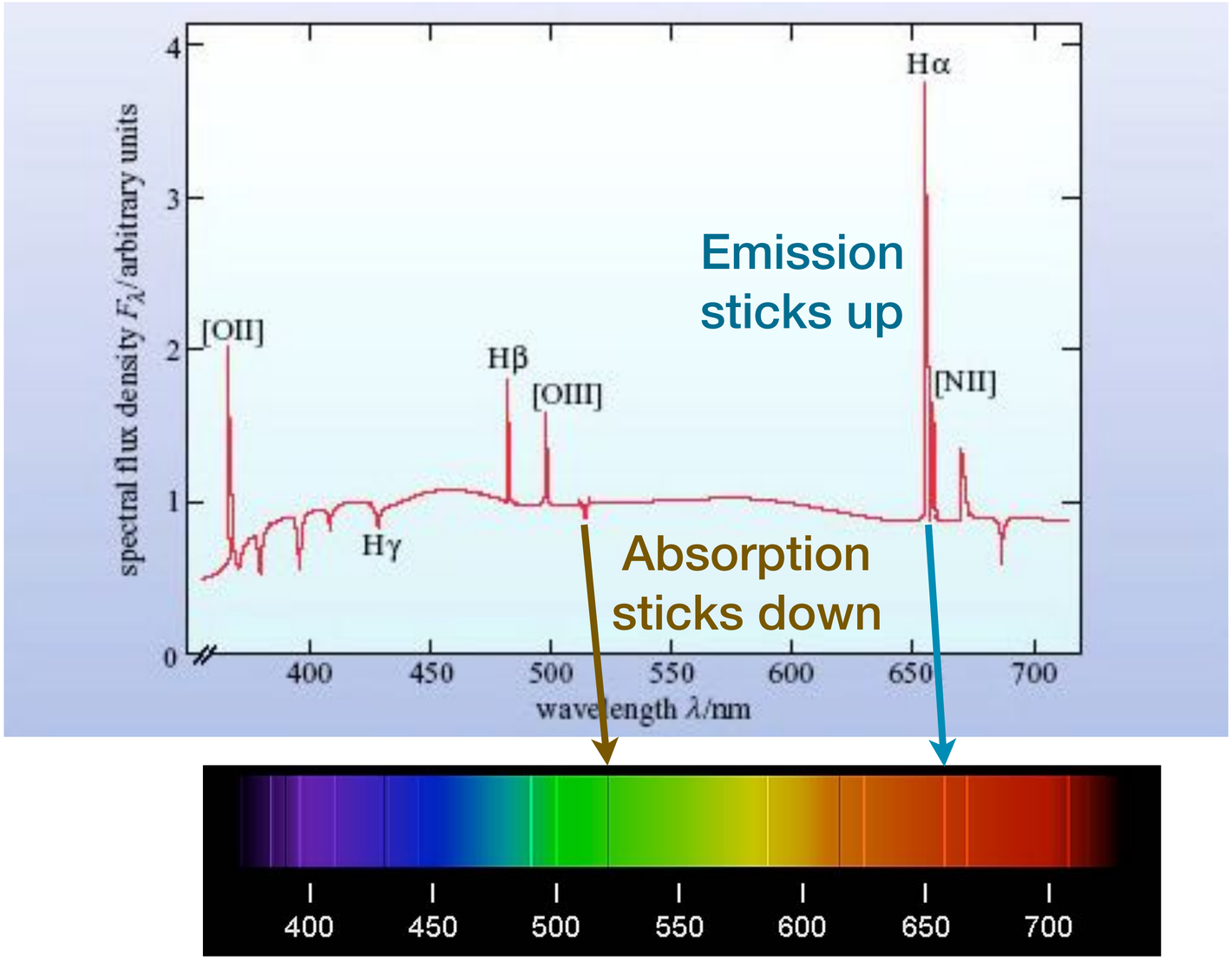
What is a spectrum?

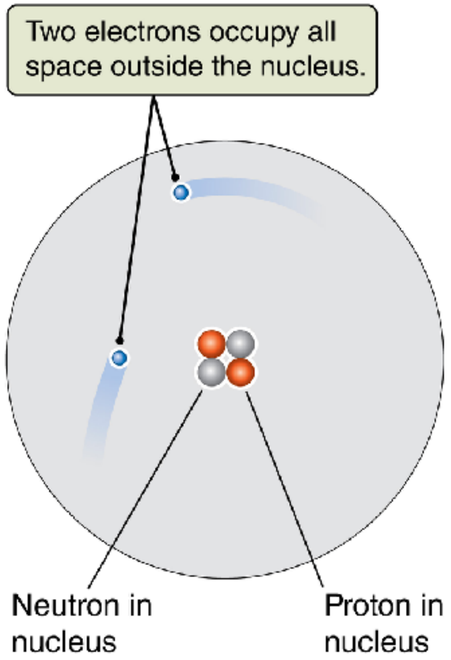


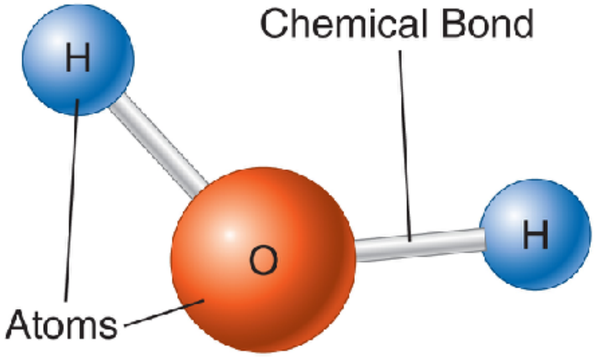
Which object would look bluer? Which object would look brighter?

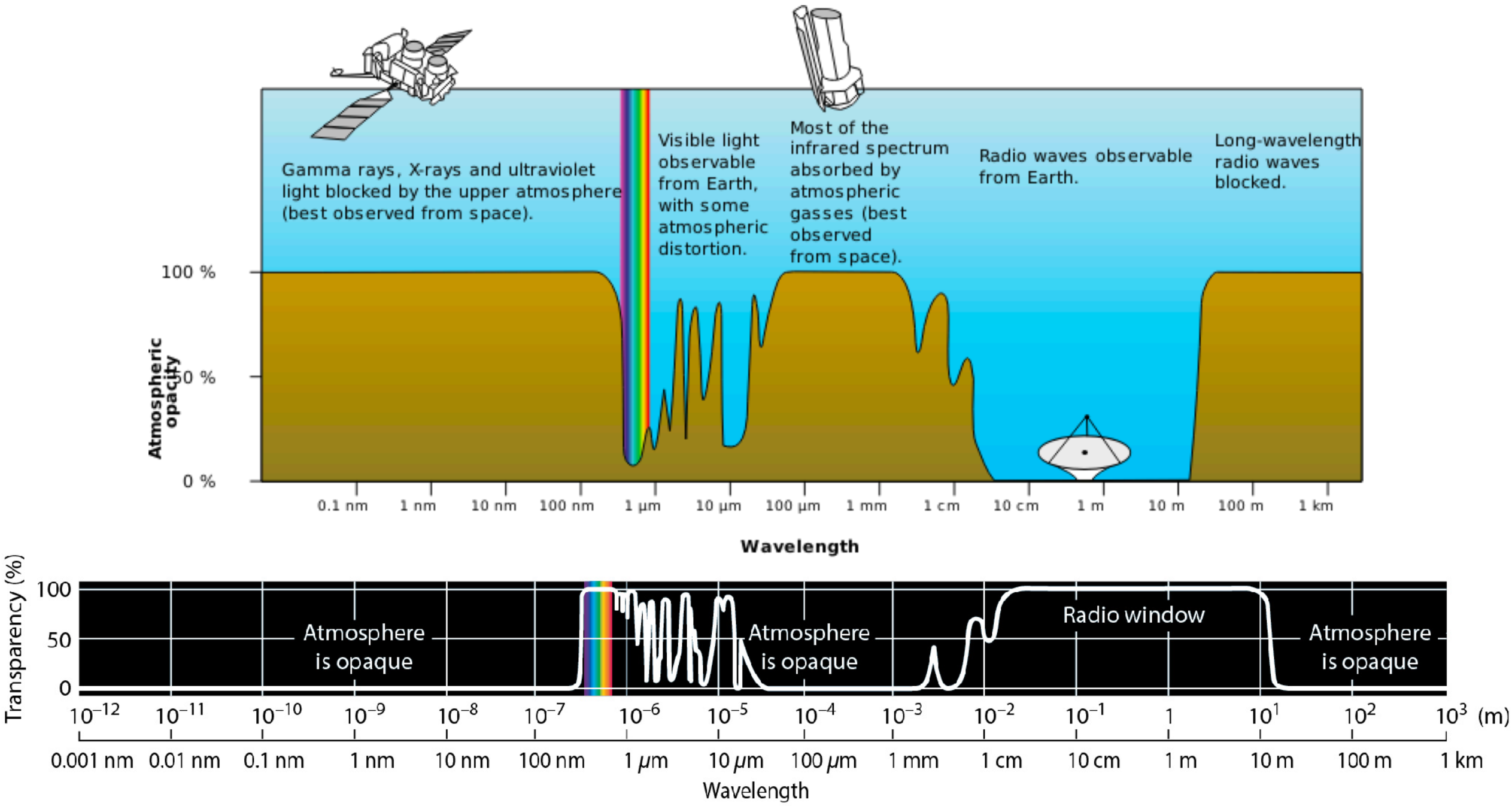


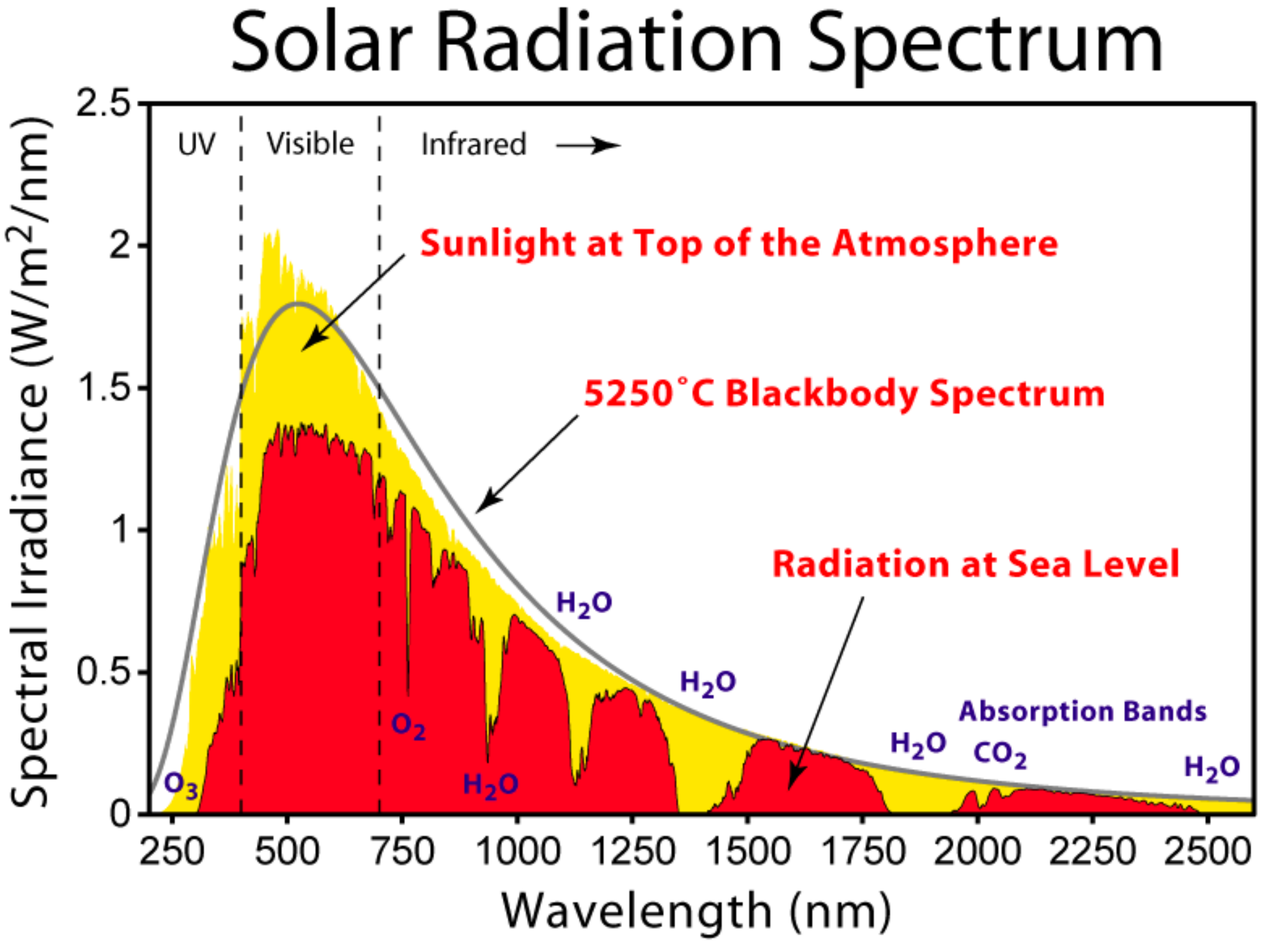
Emission and Absorption Lines

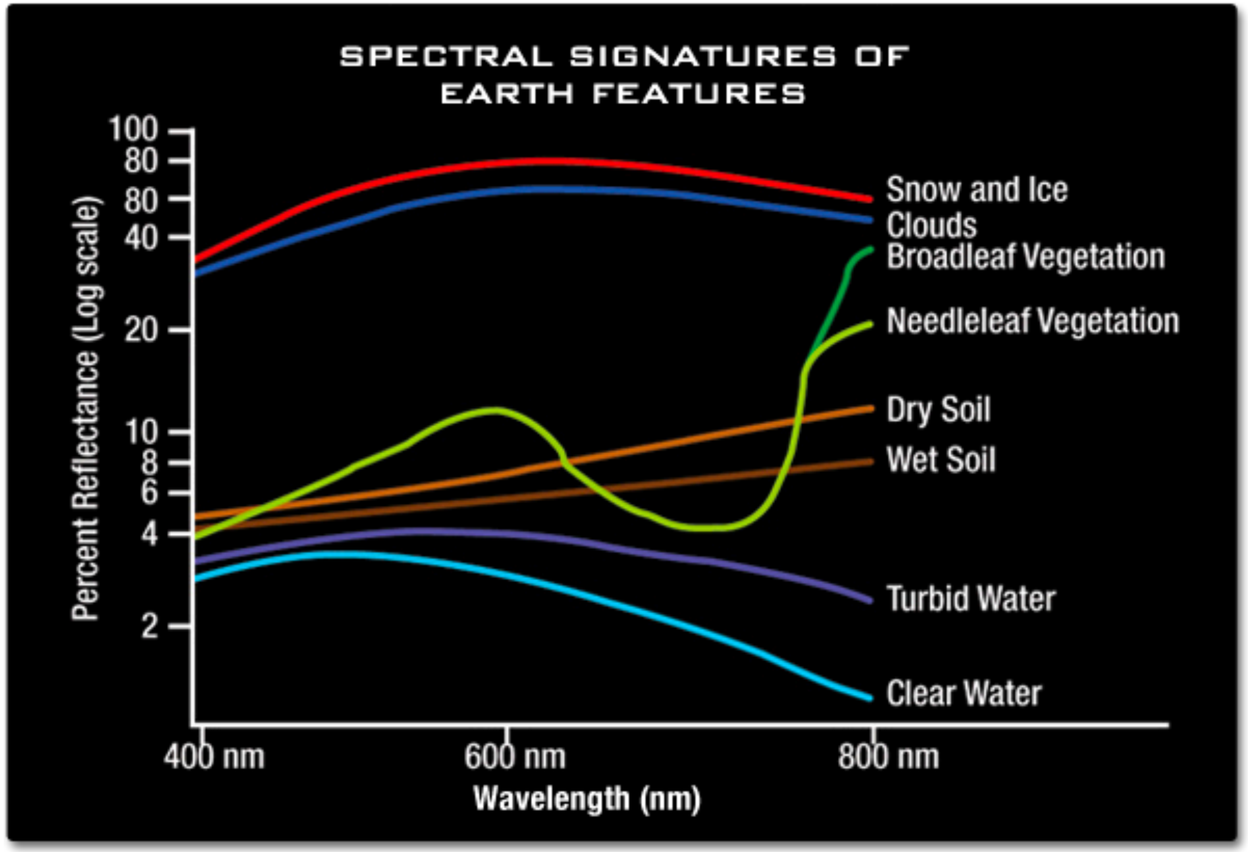






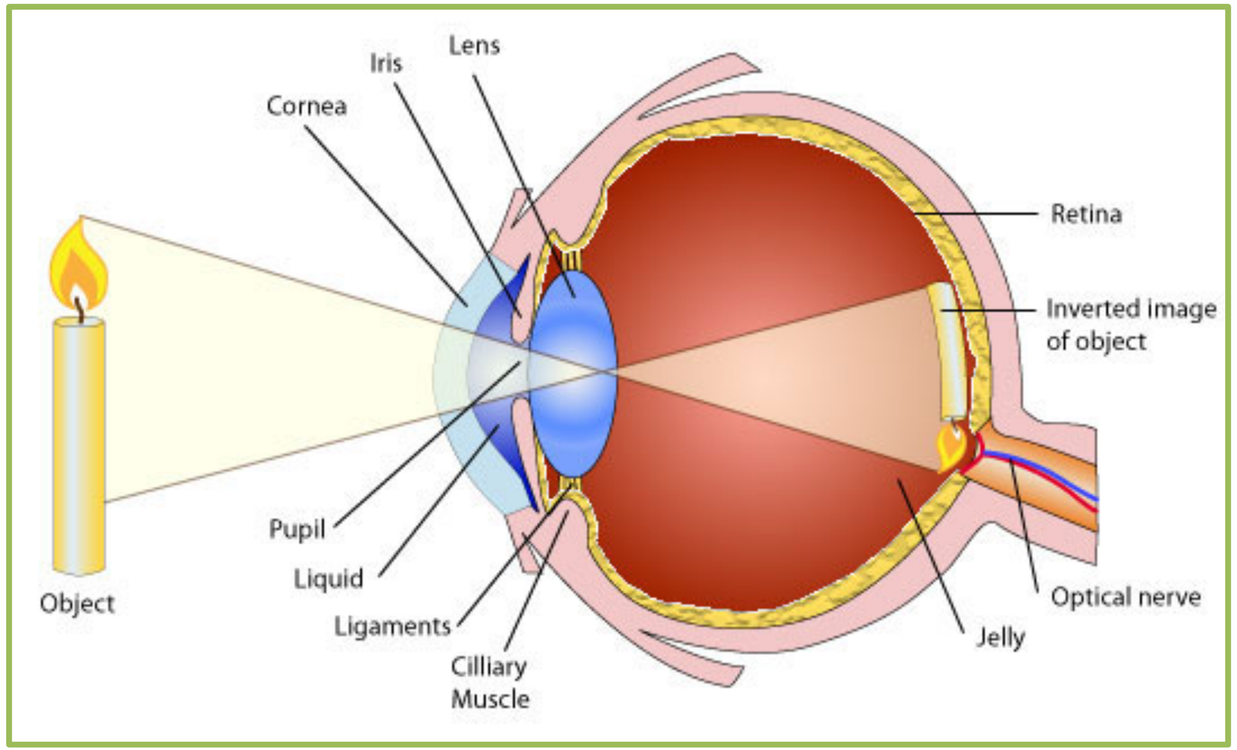

Gamma rays, X-rays and ultraviolet light blocked by the upper atmosphere (best observed from space).
Visible light observable from Earth, with some atmospheric distortion.
Most of the infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio waves observable from Earth.
Long-wavelength radio waves blocked.
100 %
50 %
0 %
Atmospheric opacity
0.1 nm
1 nm
10 nm
100 nm
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
Transparency (%)
100
50
0
Atmosphere is opaque
Atmosphere is opaque
Radio window
Atmosphere is opaque
10^{-12} 10^{-11} 10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^{1} 10^{2} 10^{3} (m)
0.001 nm 0.01 nm 0.1 nm 1 nm 10 nm 100 nm 1 μm 10 μm 100 μm 1 mm 1 cm 10 cm 1 m 10 m 100 m 1 km
Wavelength

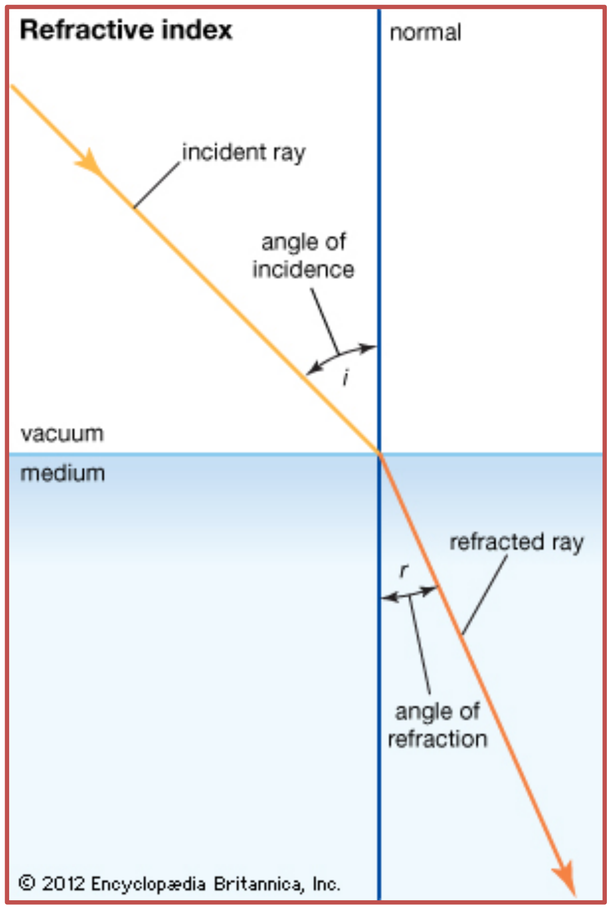

Solar Radiation Spectrum
Spectral Irradiance (W/m²/nm)
2.5
2
1.5
1
0.5
0
UV
Visible
Infrared
Sunlight at Top of the Atmosphere
5250˚C Blackbody Spectrum
Radiation at Sea Level
Absorption Bands
O_3
O_2
H_2O
H_2O
H_2O
H_2O
CO_2
H_2O
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)

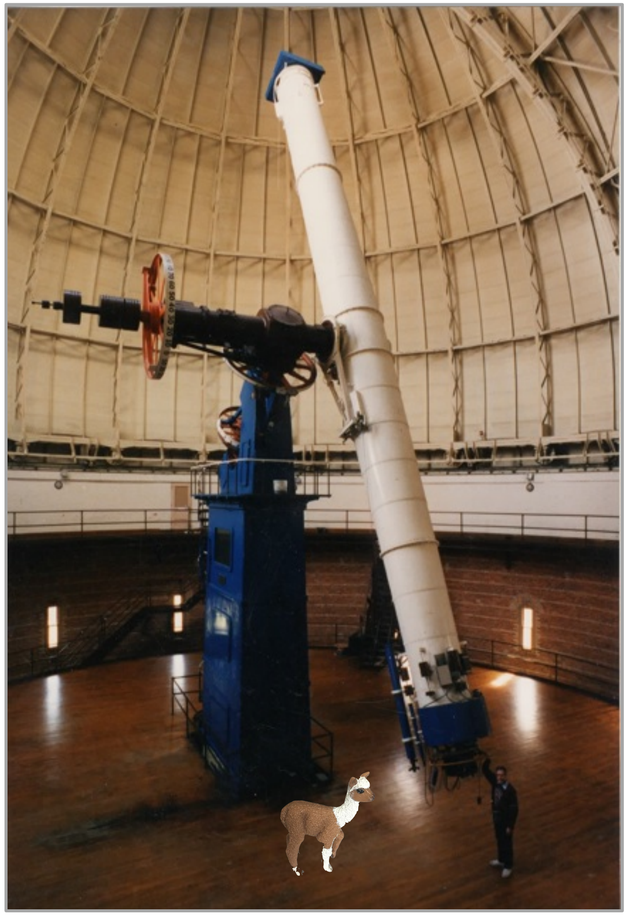

SPECTRAL SIGNATURES OF EARTH FEATURES
Percent Reflectance (Log scale)
100
80
80
40
20
10
8
6
4
2
Snow and Ice
Clouds
Broadleaf Vegetation
Needleleaf Vegetation
Dry Soil
Wet Soil
Turbid Water
Clear Water
400 nm
600 nm
800 nm
Wavelength (nm)

Our eyes are telescopes!

Works like a refractor

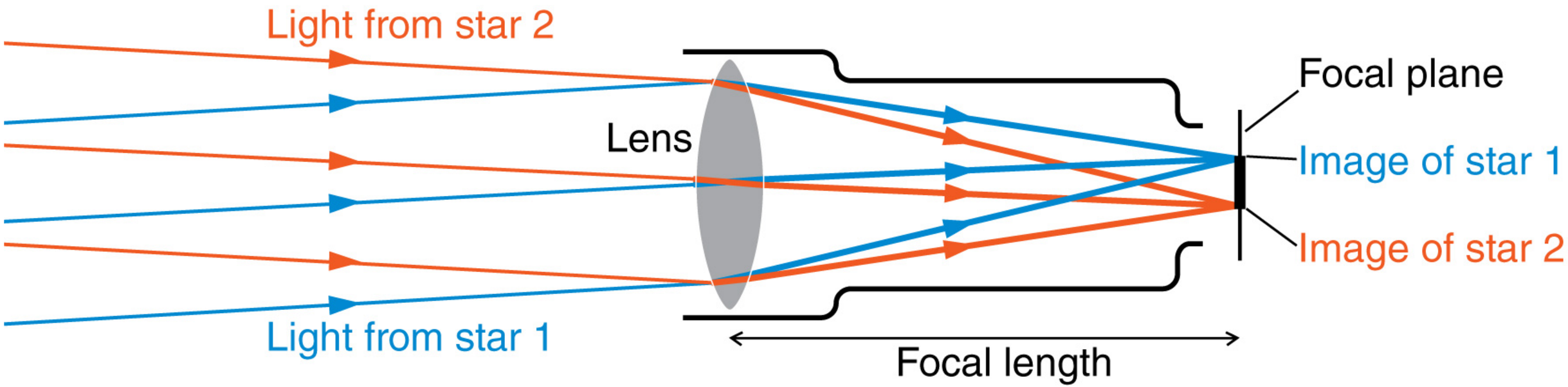




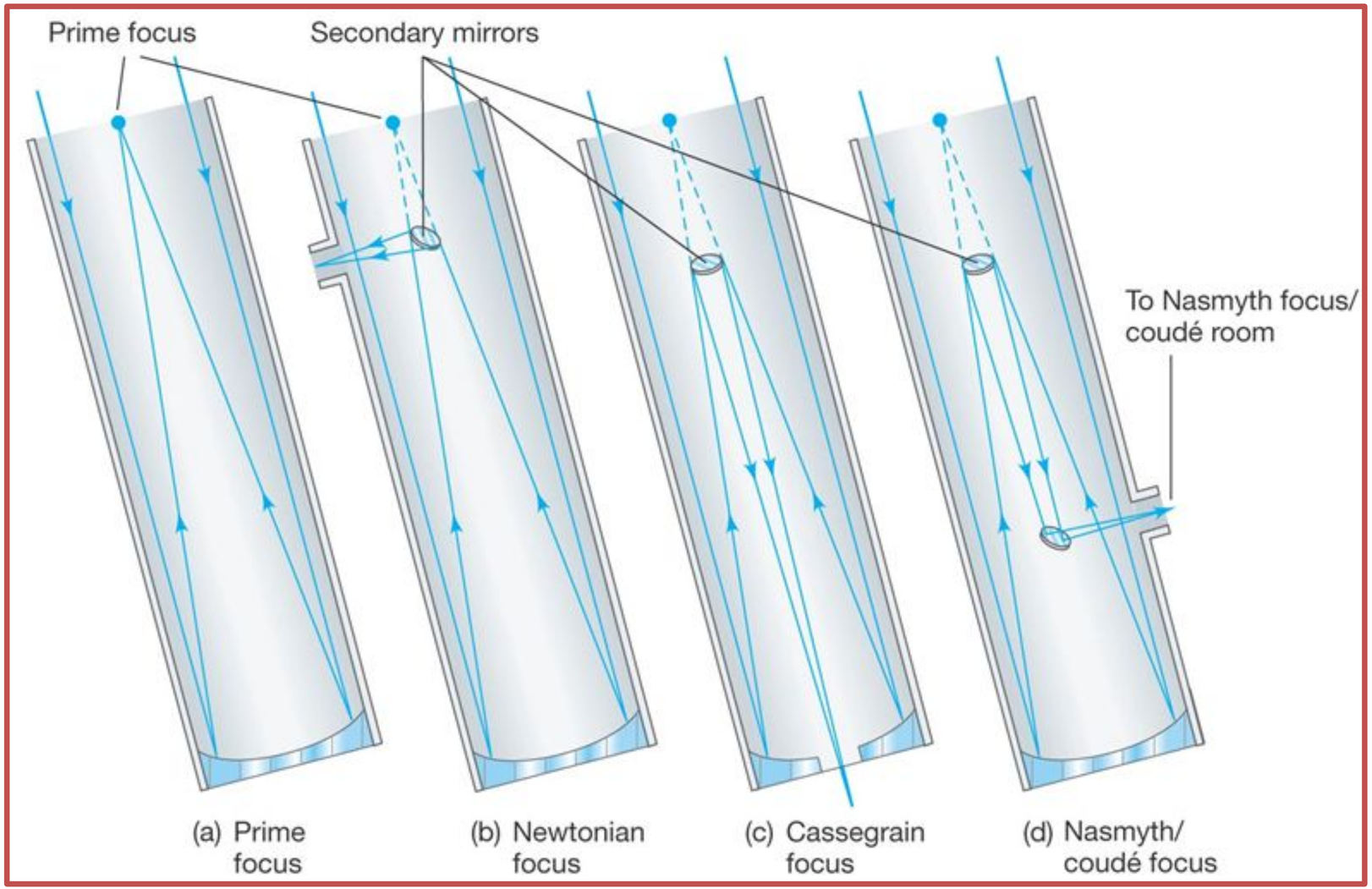


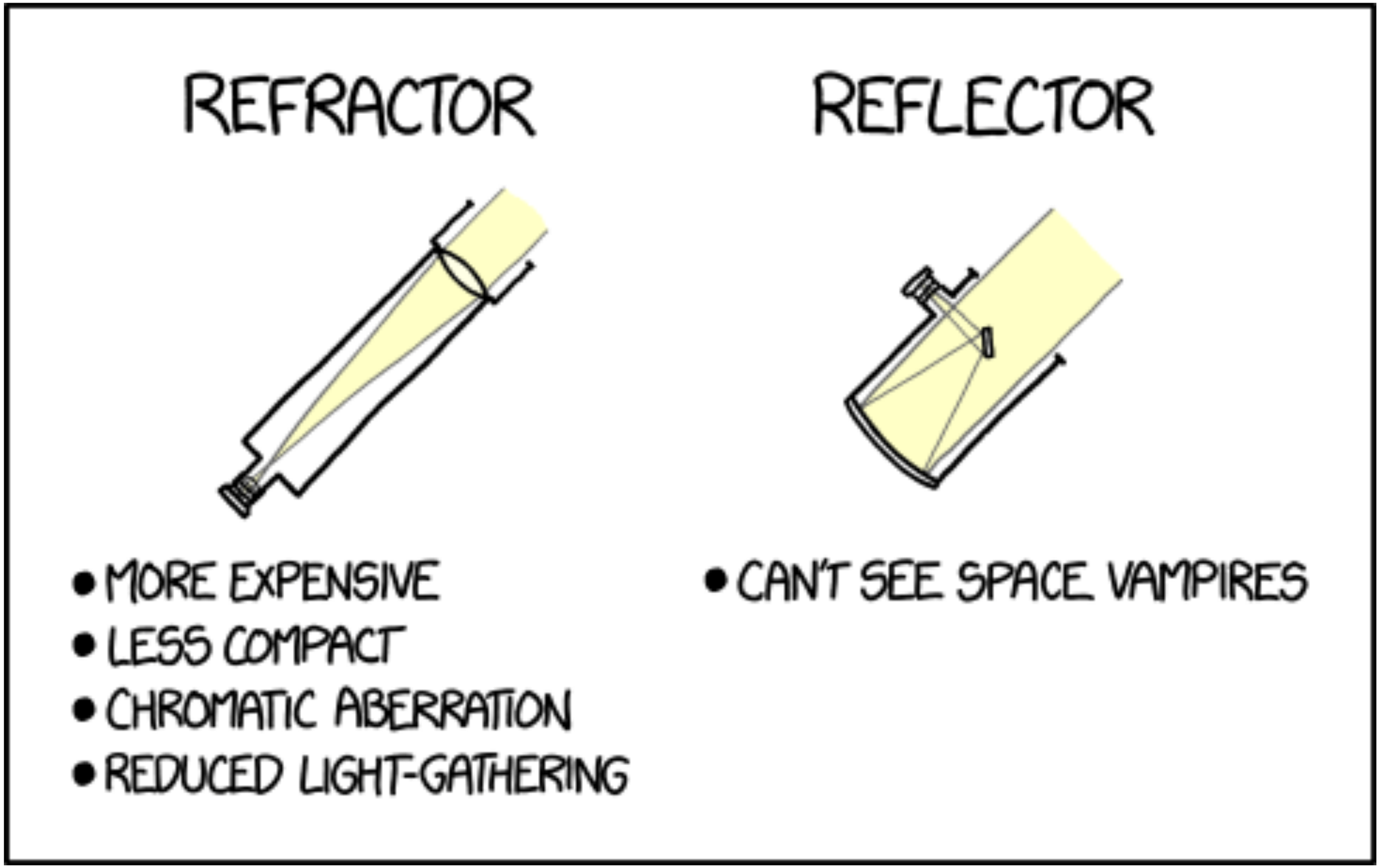
amount of refraction depends on the wavelength of light —
cannot focus red and blue light at the same time!

Astronomical Sources are “infinitely” far away



Use reflecting telescopes due to less chromatic aberration and easier to build large ones




REFRACTOR
REFLECTOR
• MORE EXPENSIVE
• LESS COMPACT
• CHROMATIC ABERRATION
• REDUCED LIGHT-GATHERING
• CAN'T SEE SPACE VAMPIRES

xkcd.com

Why do astronomers keep making telescopes bigger?

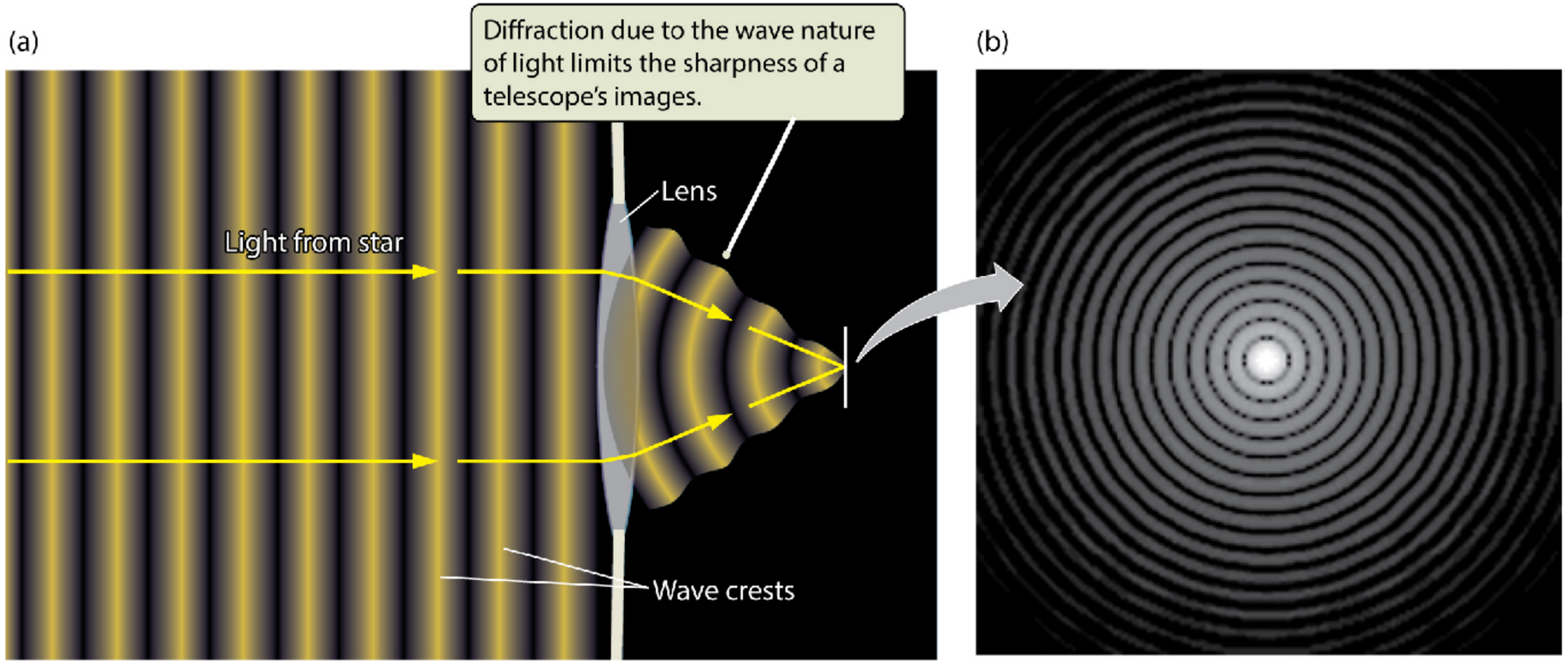
A) Increase the field of view of a single observation

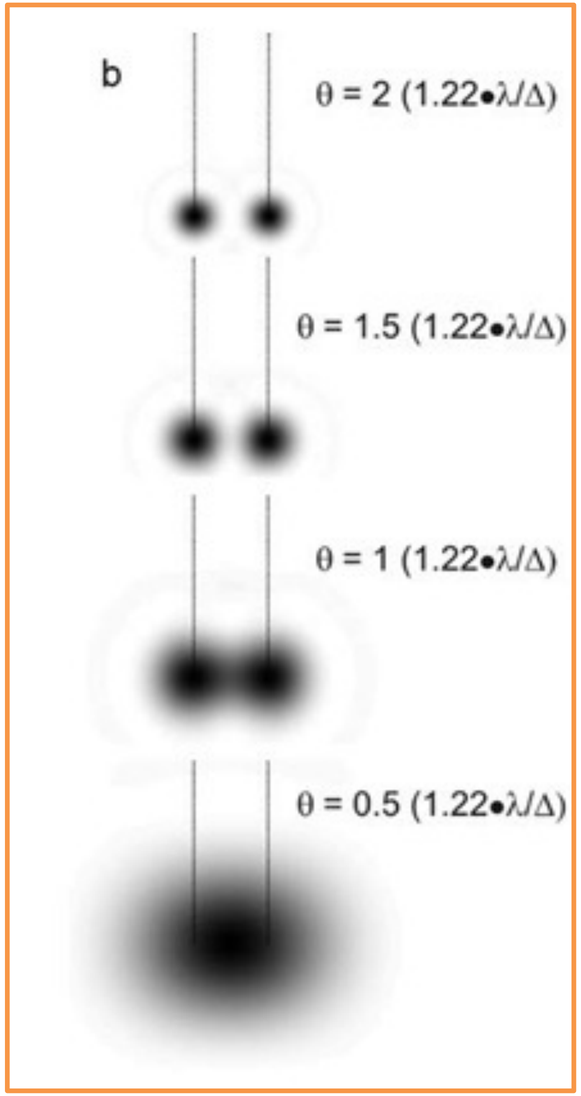
B) Resolve finer details (better image resolution)

C) Collect more light

D) Astronomers need to compensate for something

Telescope Resolution





$$\text{angular resolution} = 206265 \text{ arcseconds} \frac{\text{wavelength}}{\text{telescope diameter}} \longrightarrow \theta \propto \frac{\lambda}{D}$$

What is “angular resolution”?

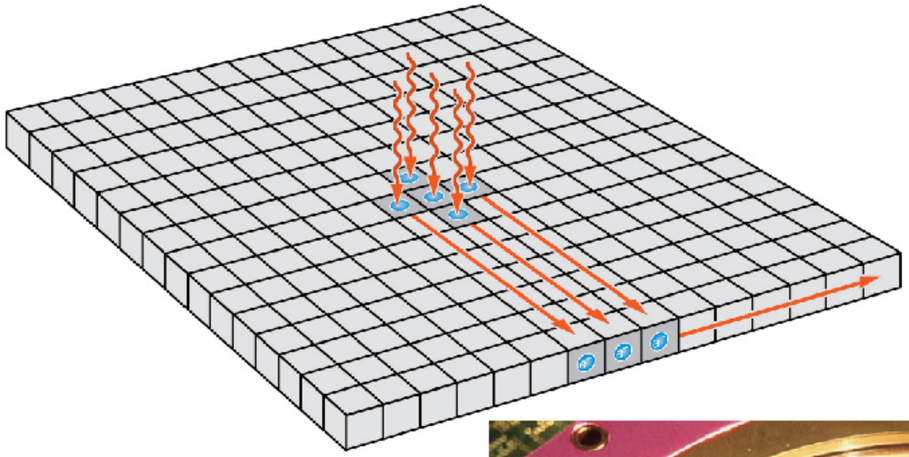
A) The angular size of a pixel of a CCD or any detector

B) The smallest resolving power of a telescope’s mirrors

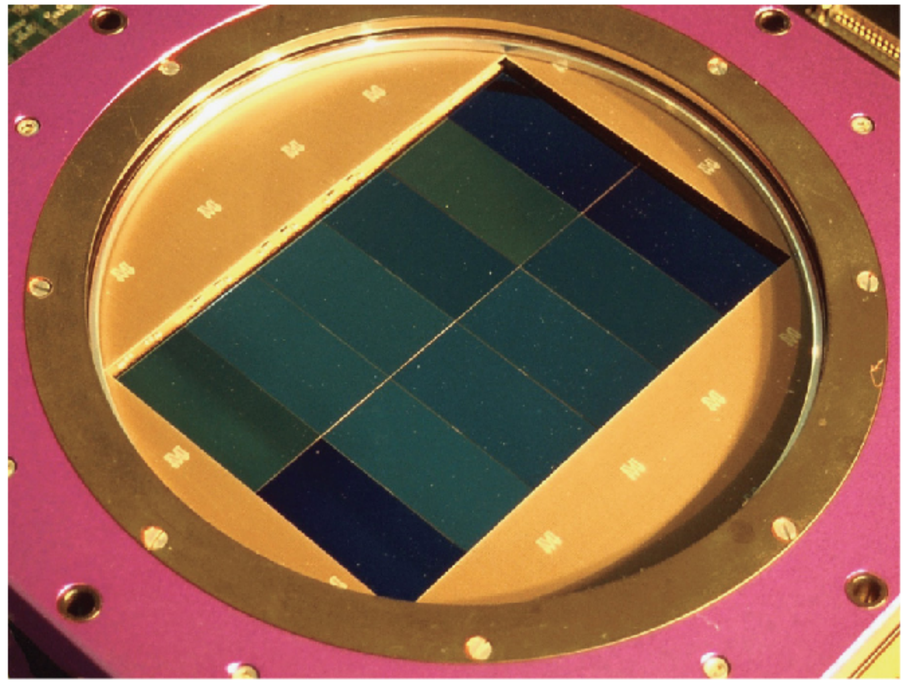
C) The angles light must be bent by mirrors

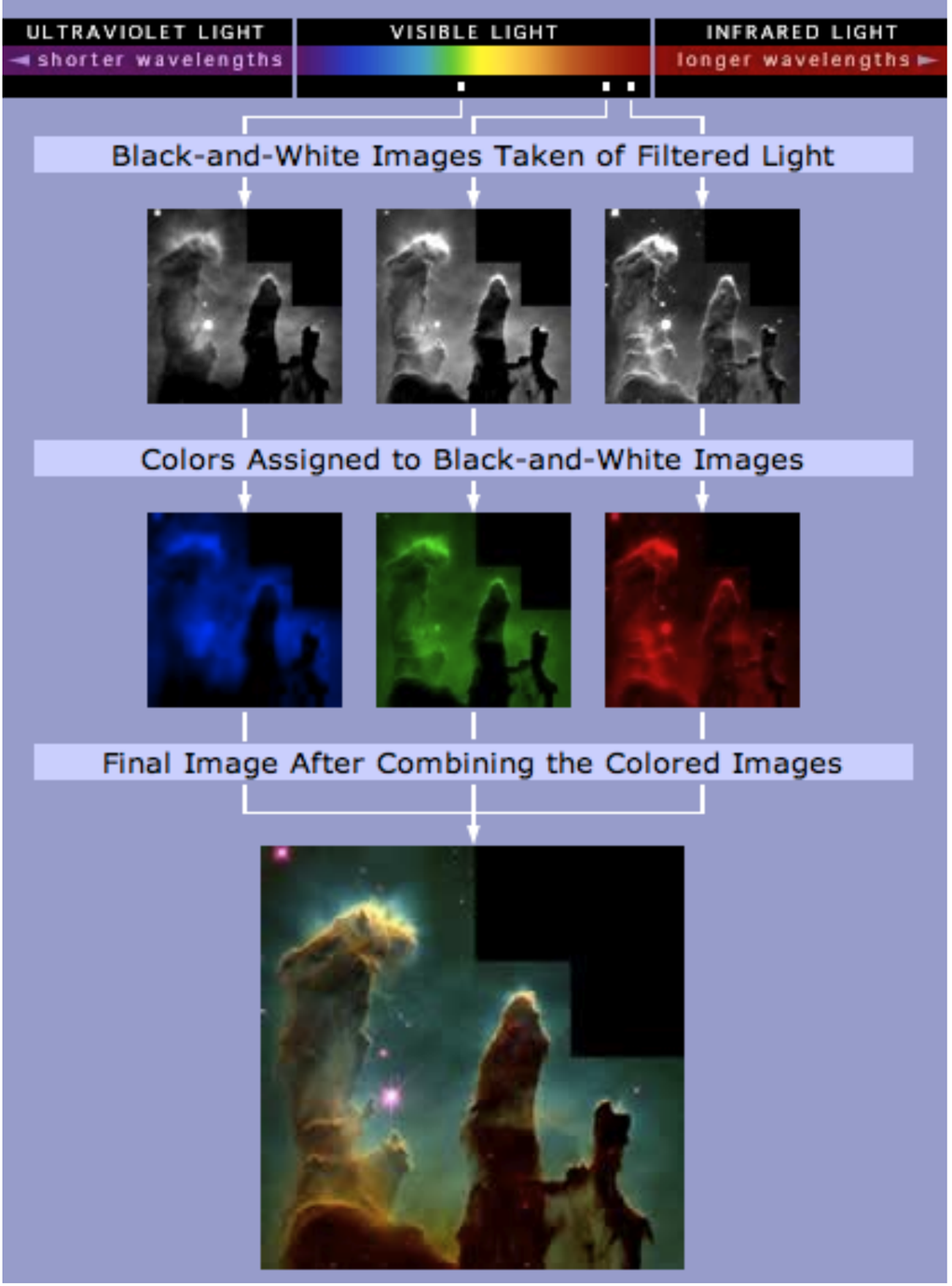
D) A solution to a tricky problem in optical design

Making Images



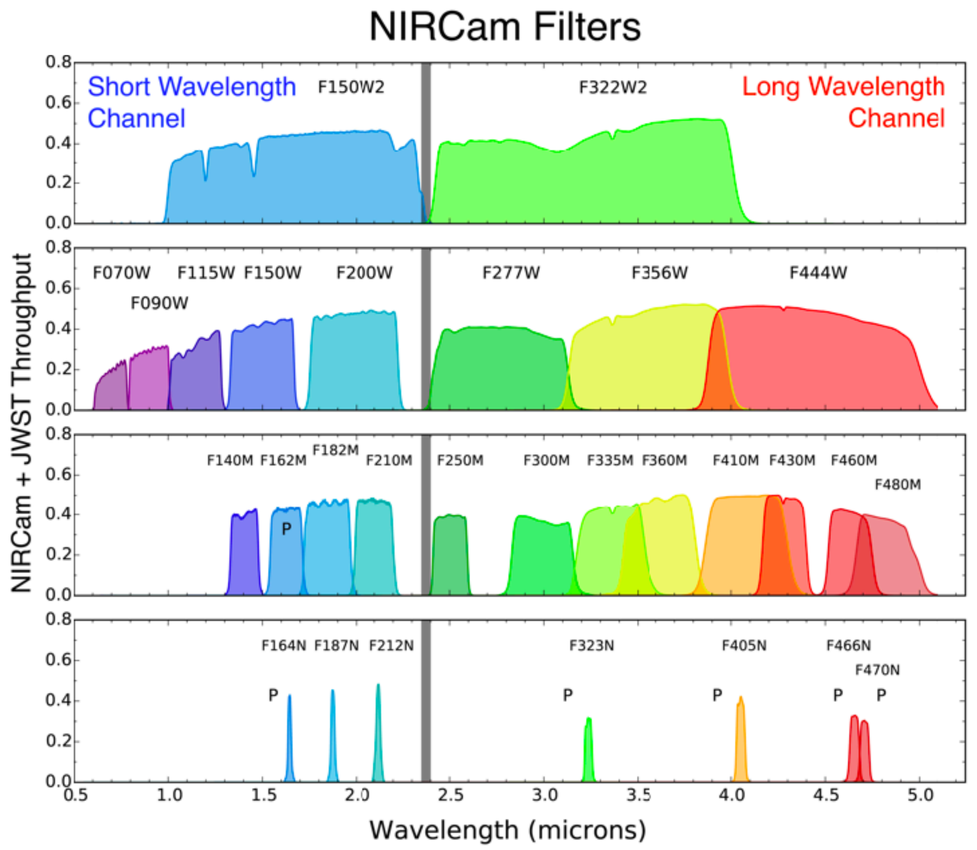
Charged Coupled Devices (CCDs)



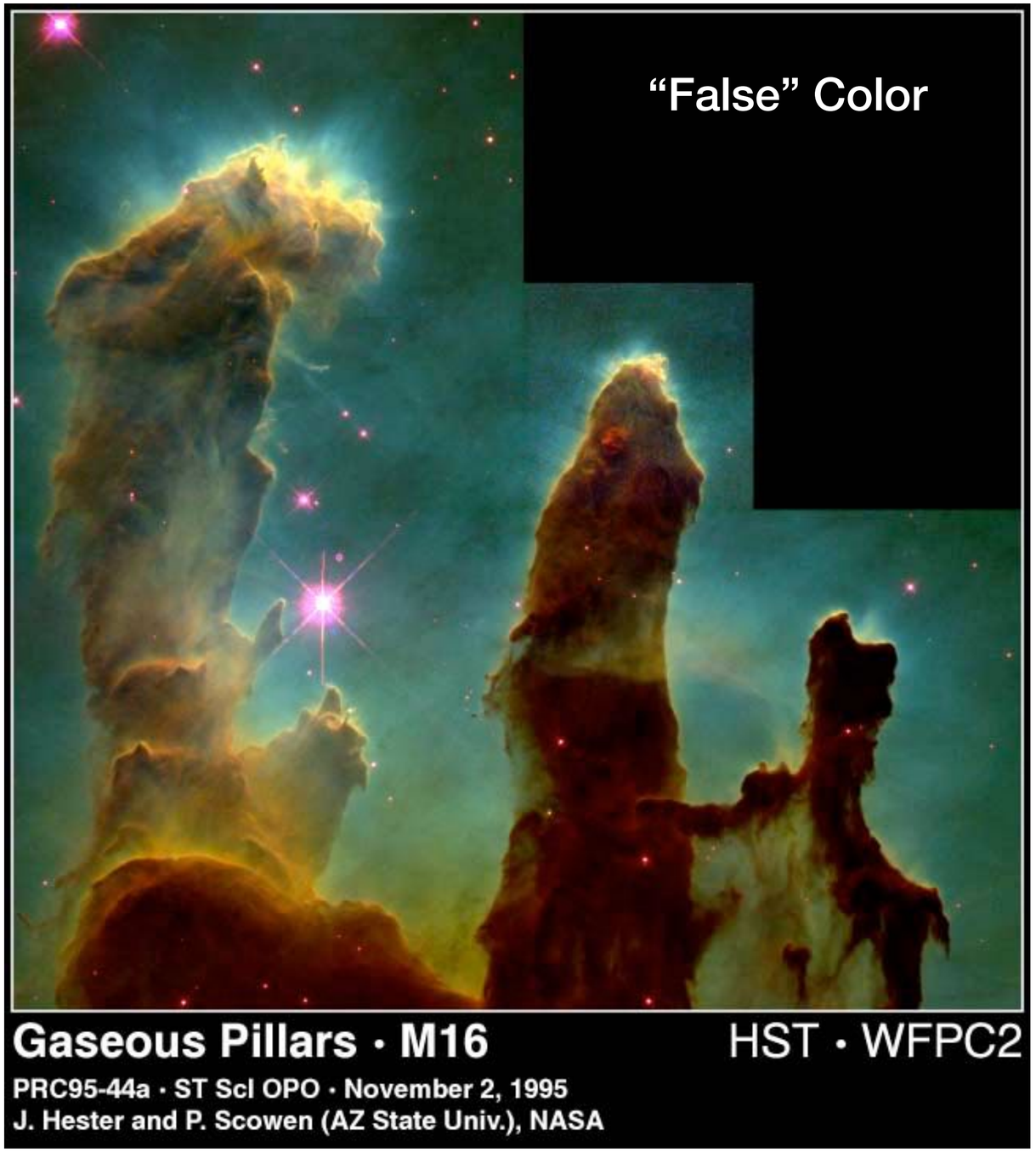

ULTRAVIOLET LIGHT
shorter wavelengths
VISIBLE LIGHT
INFRARED LIGHT
longer wavelengths
Black-and-White Images Taken of Filtered Light
Colors Assigned to Black-and-White Images
Final Image After Combining the Colored Images

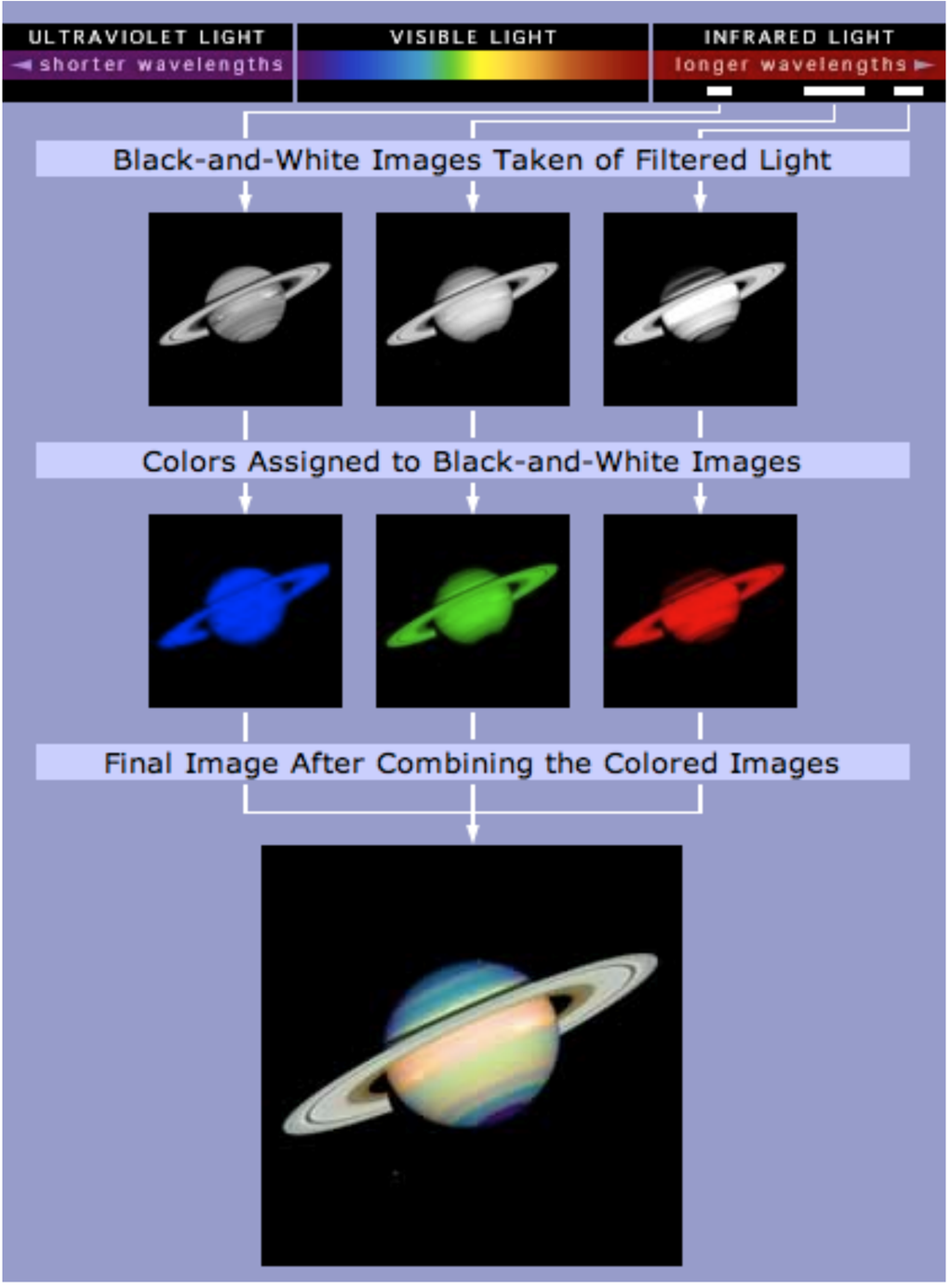
Filters


No.25 Red
No.58 Green
No.15 Yellow
No.80A Blue

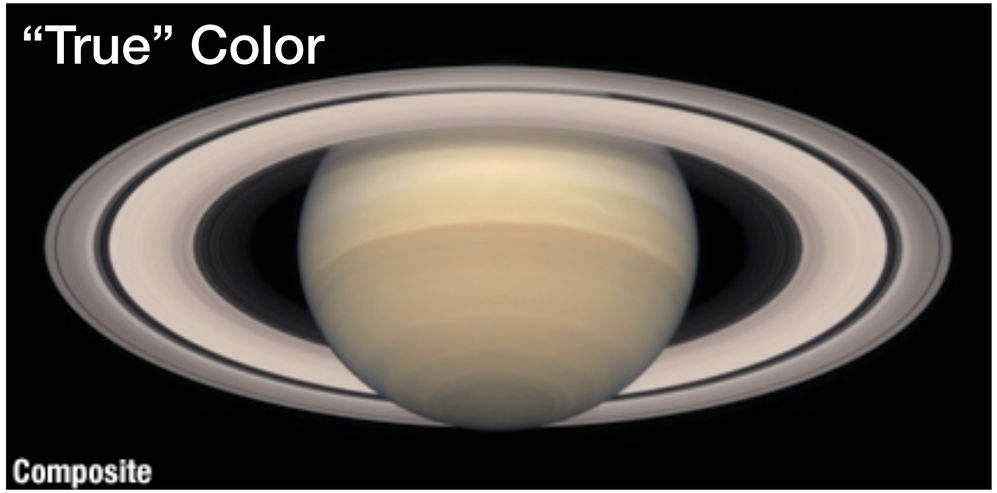

NIRCam Filters
Short Wavelength Channel
Long Wavelength Channel
F150W2
F322W2
F070W
F090W
F115W
F150W
F200W
F277W
F356W
F444W
F140M
F162M
F182M
F210M
F250M
F300M
F335M
F360M
F410M
F430M
F460M
F480M
F164N
F187N
F212N
F323N
F405N
F466N
F470N
P
NIRCam + JWST Throughput
Wavelength (microns)

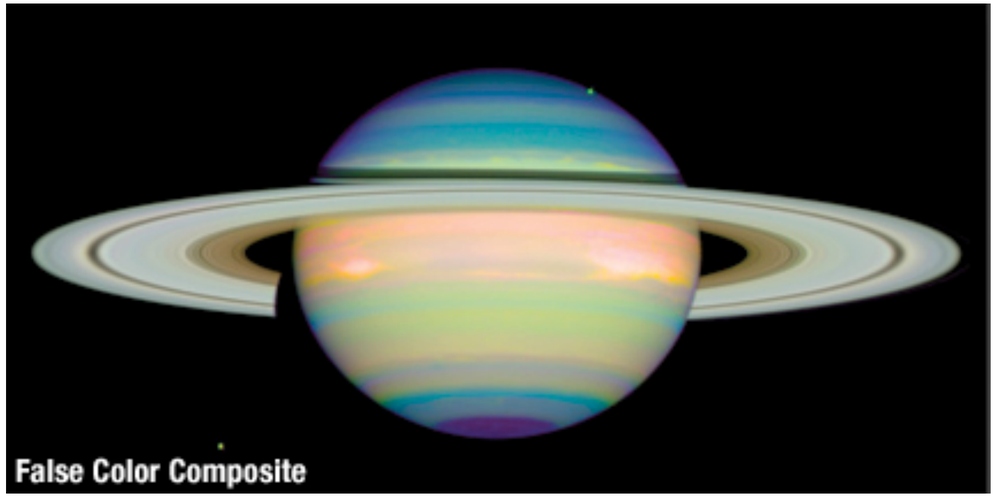
“True” Color


“False” Color
Gaseous Pillars • M16
HST • WFPC2
PRC95-44a • ST ScI OPO • November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA



False color images can be made using light at any wavelength, from radio to gamma ray



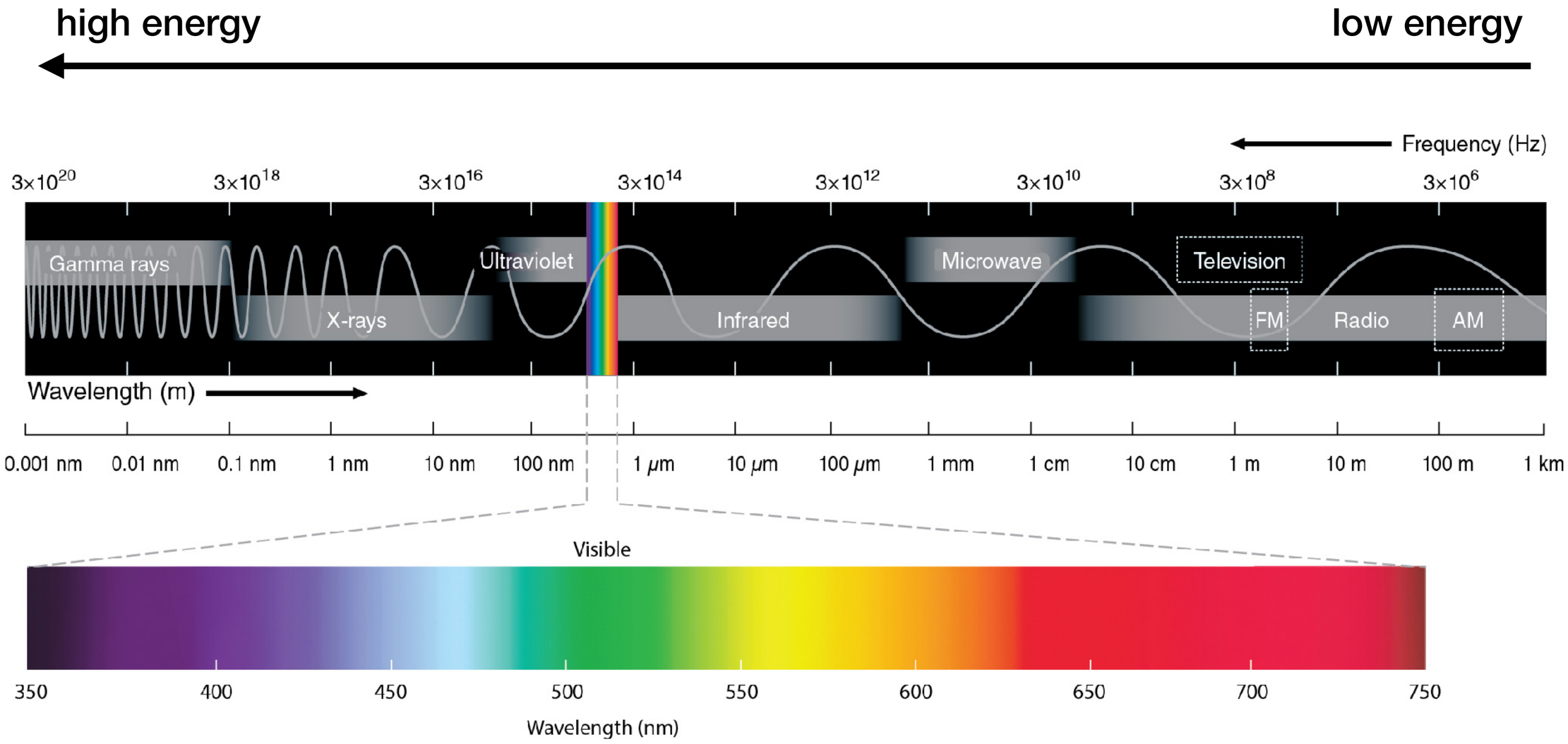


If you were designing a telescope to survey the entire sky to study the brightest stars in several colors over the course of a year, what features would you want it to have?

large/small FOV? large/small mirrors (collecting area)?
1 big telescope vs. several smaller telescopes?
a refracting or reflecting design?

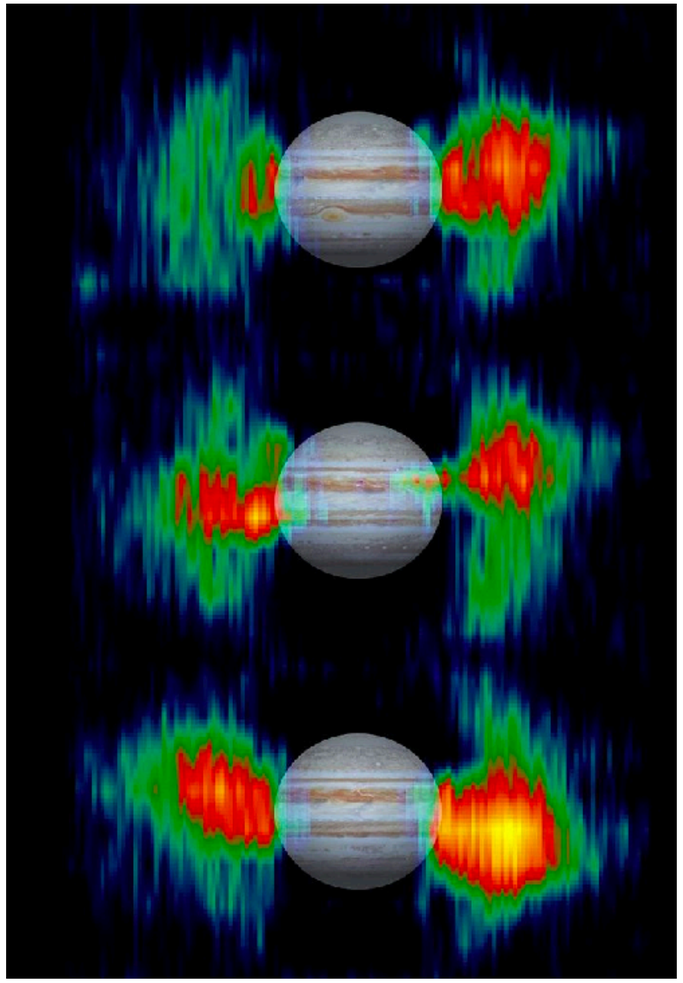
Discuss in small groups!

Brief Tour of the Universe at Different Wavelengths

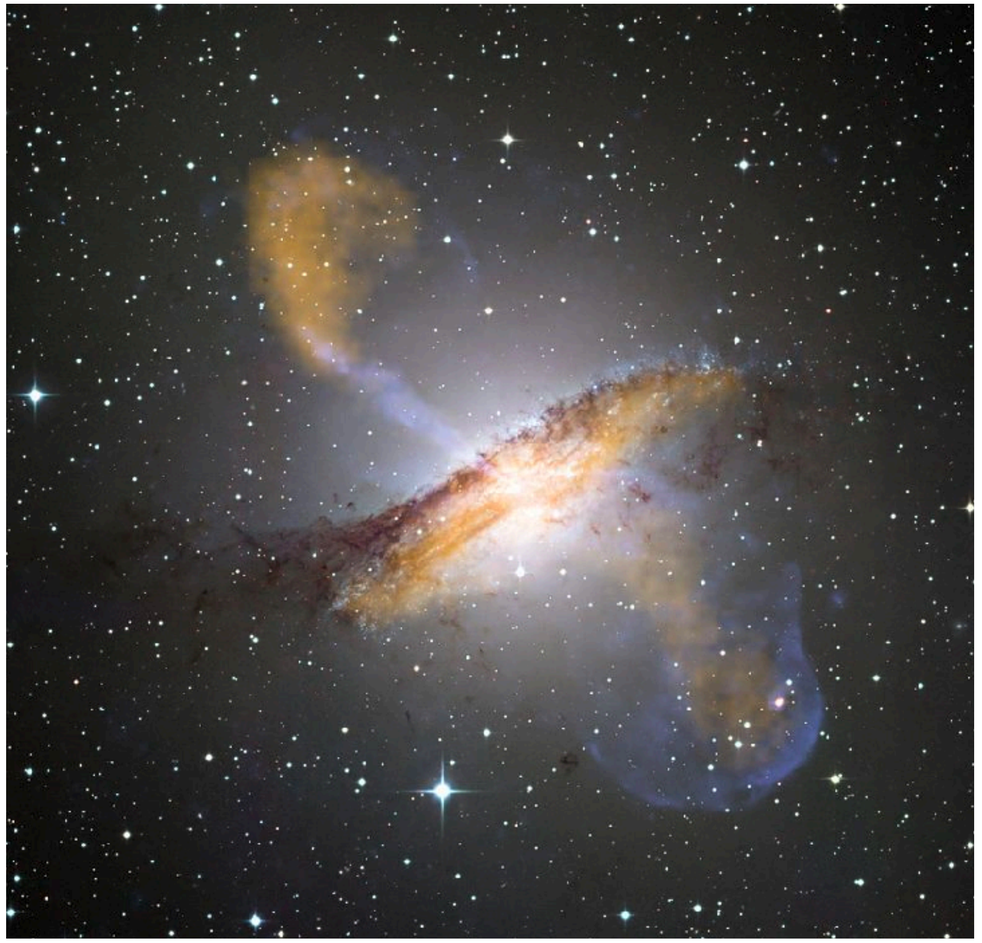


Radio (broad band)

Jupiter
Captured charged particles from the Sun



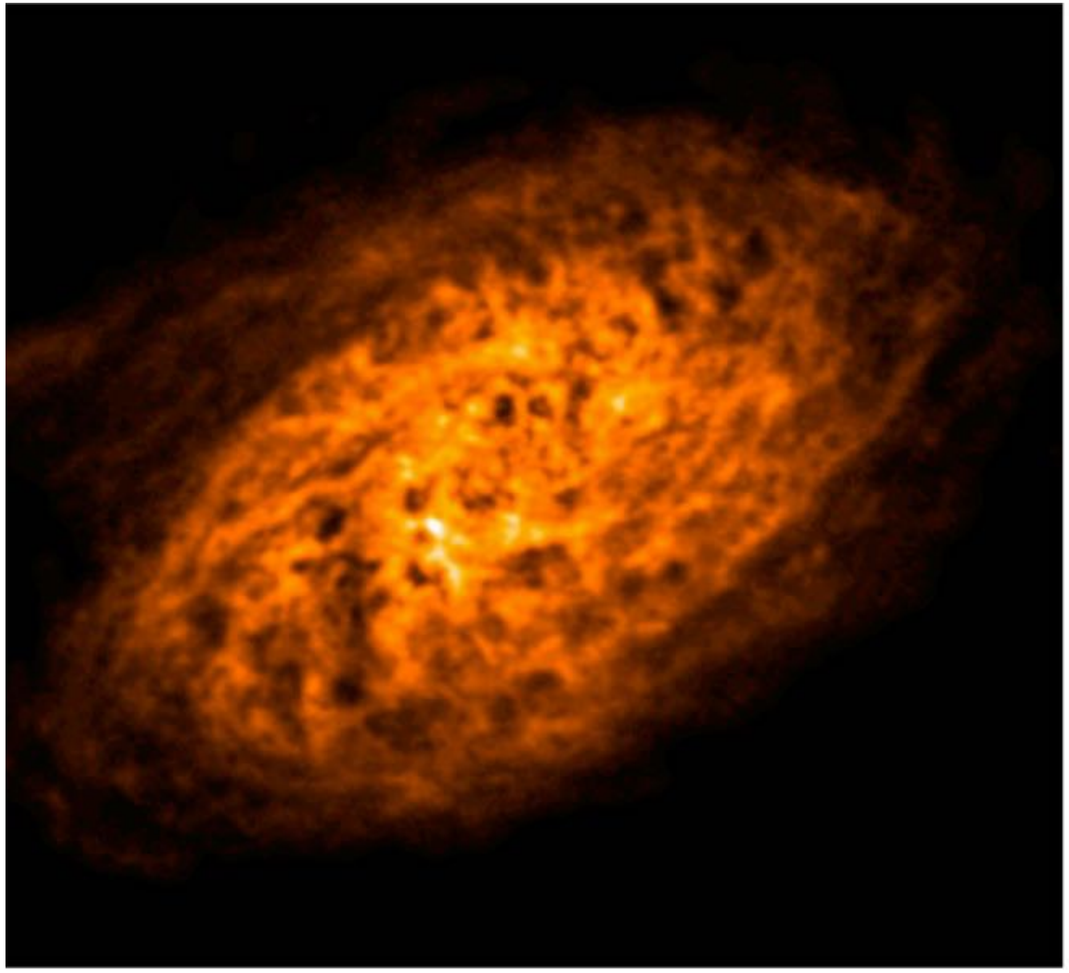
Centaurus A Galaxy
Jets accelerated by a supermassive black hole



Radio (narrow band)

Spiral Galaxy

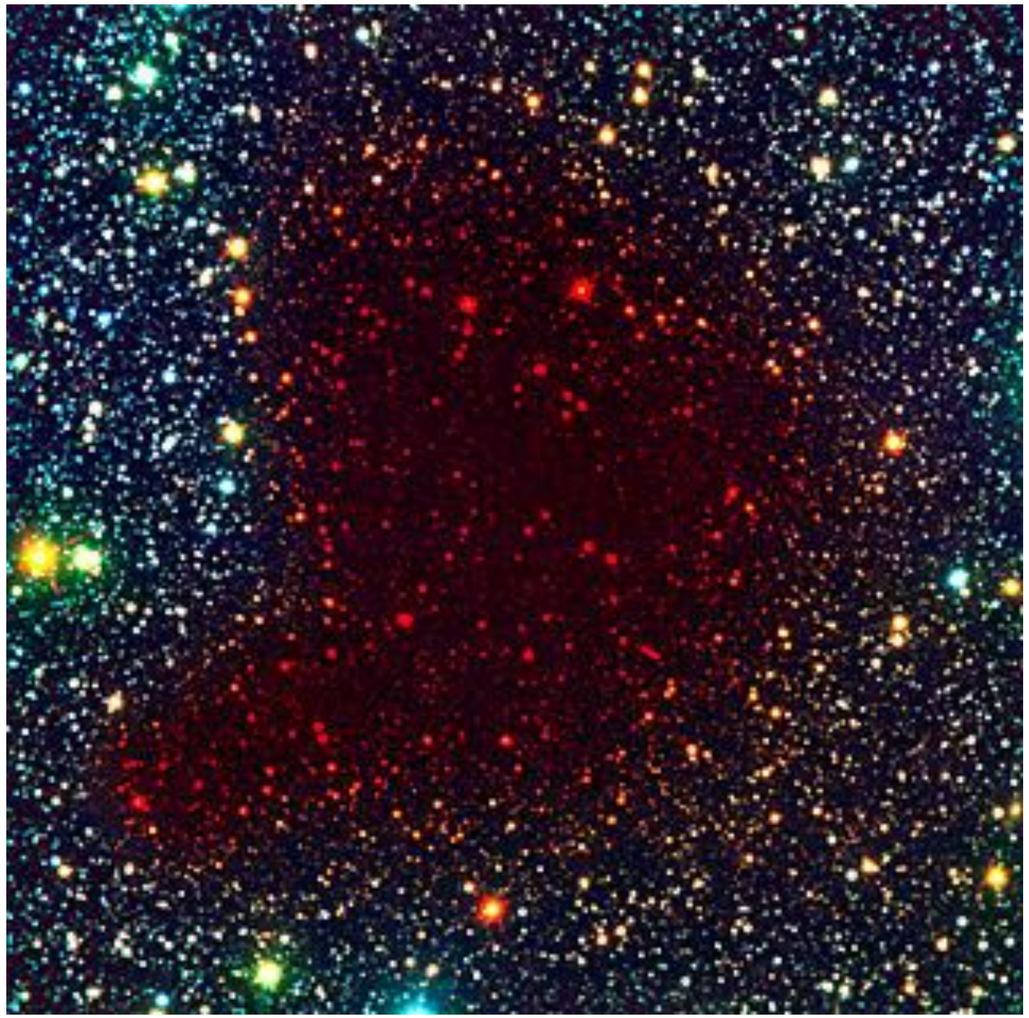
Hydrogen gas through emission line at 21 cm



Visible light (stars - images at the same scale)

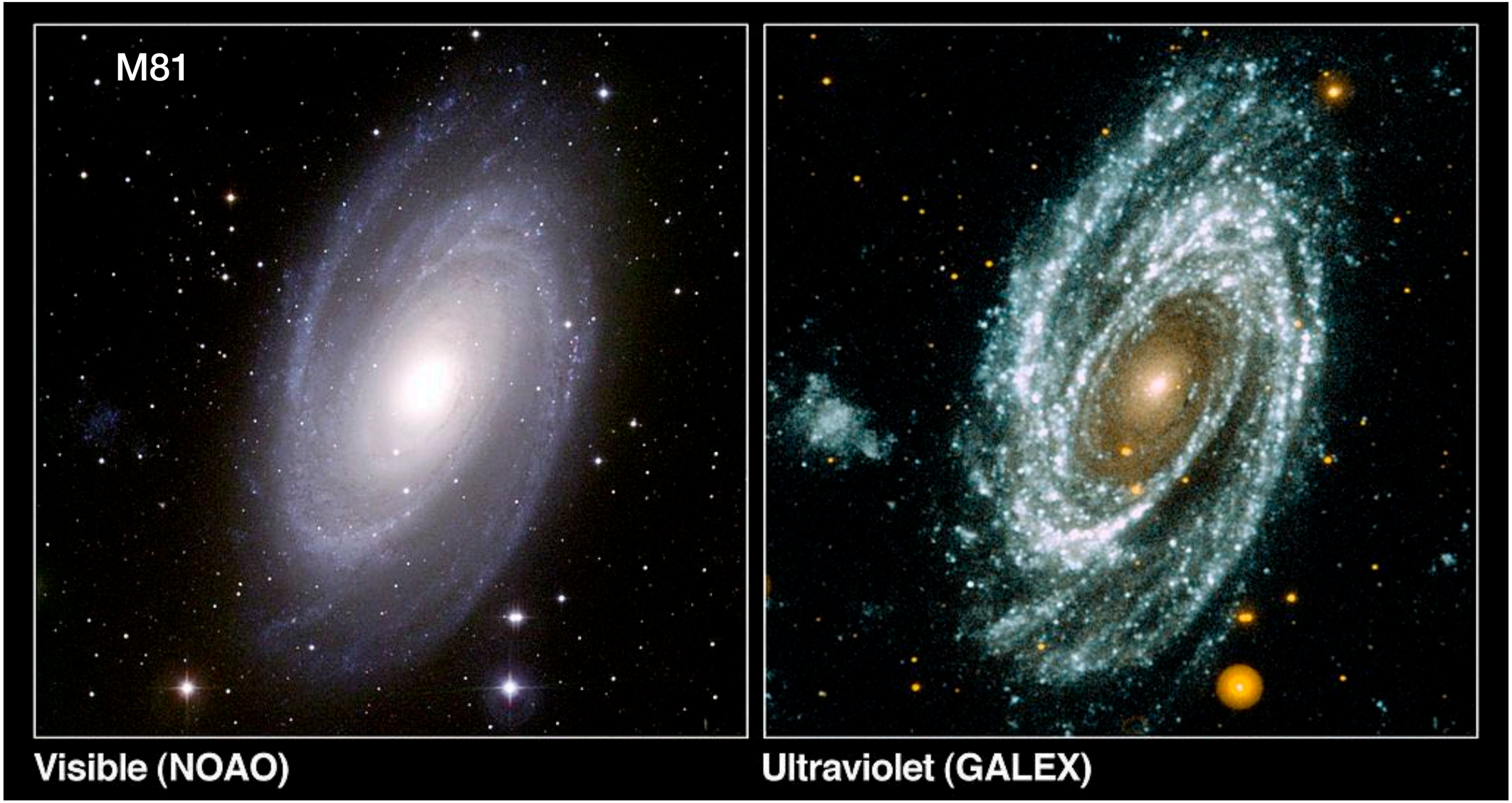
Infrared - Dust Clouds

Visible Light



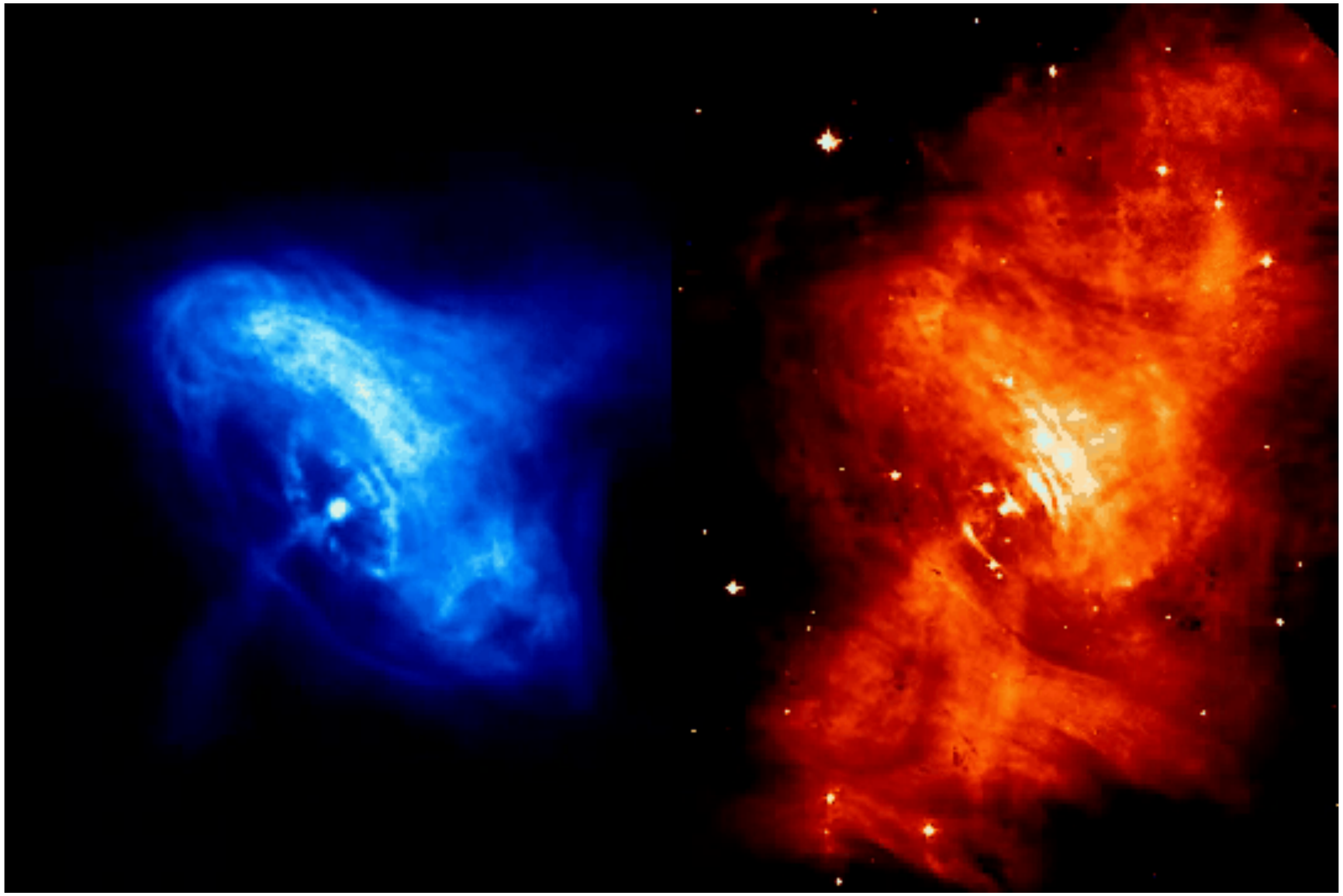
Infrared Light (1-2 μm)

Ultraviolet - Massive Stars

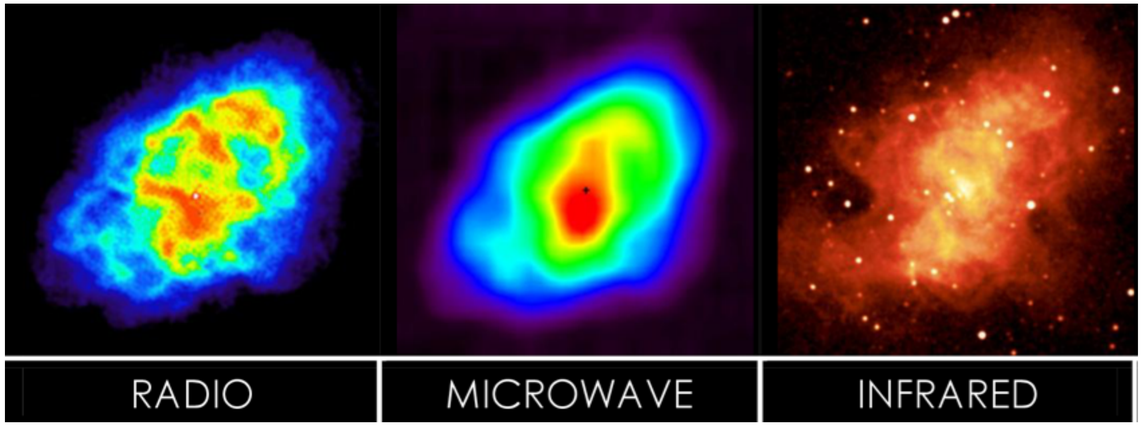


X-ray - Dead Stars

X-ray
(Chandra)

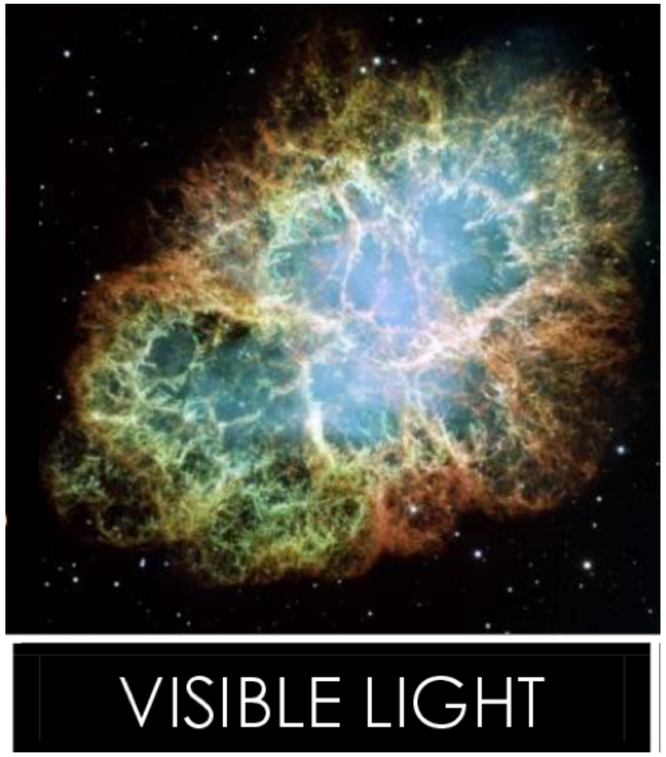


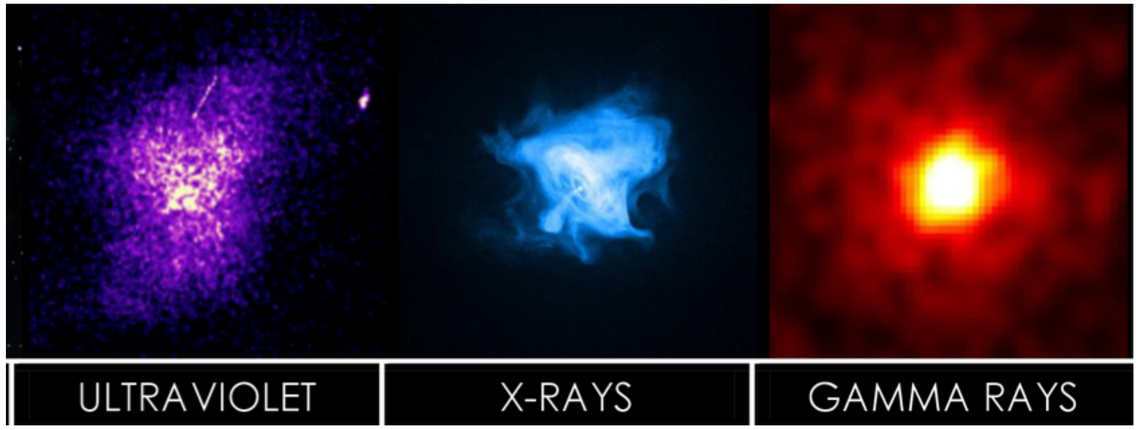
Infrared
(Hubble)



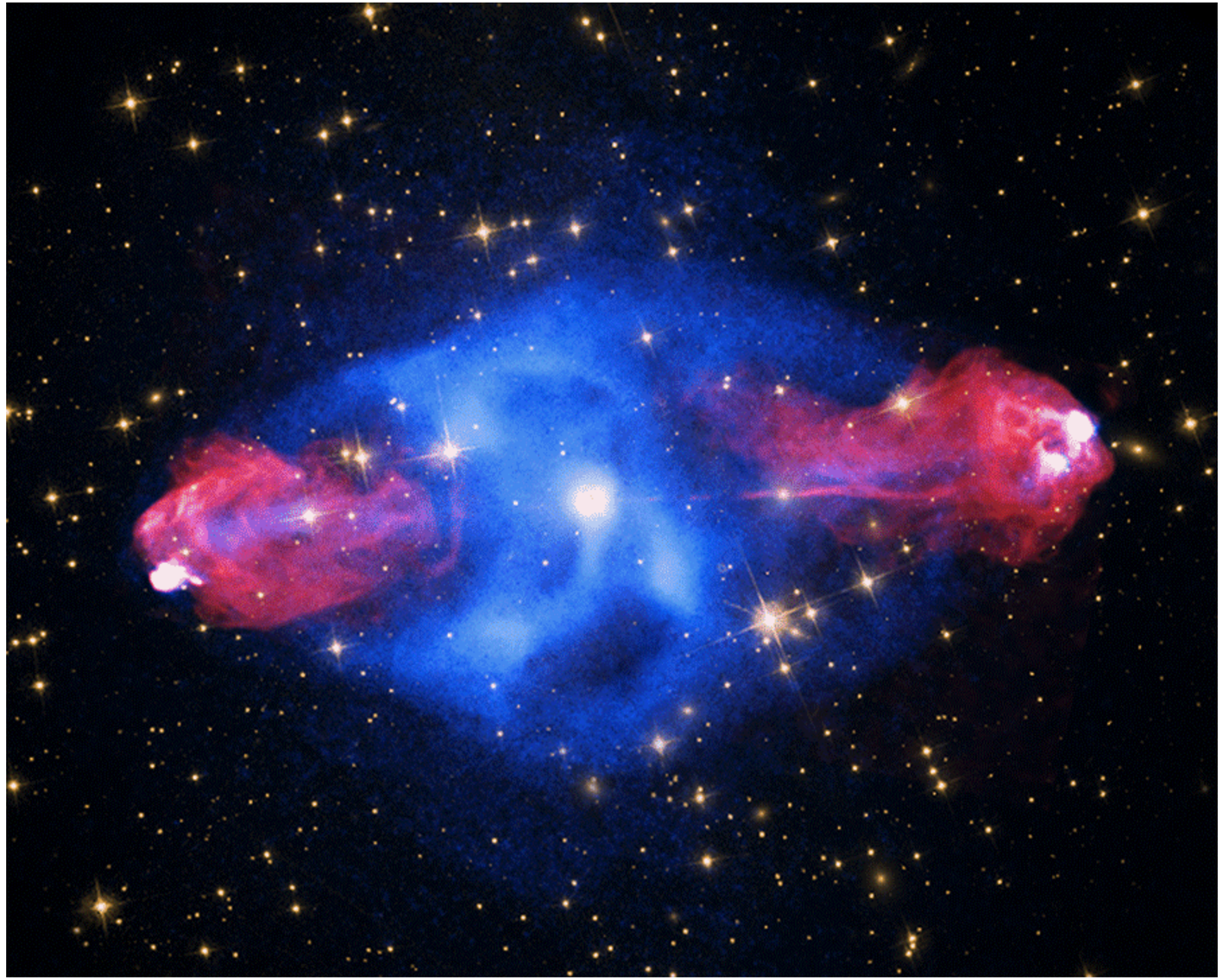
Crab Nebula

supernova explosion left a pulsar at the center that energizes surrounding gas



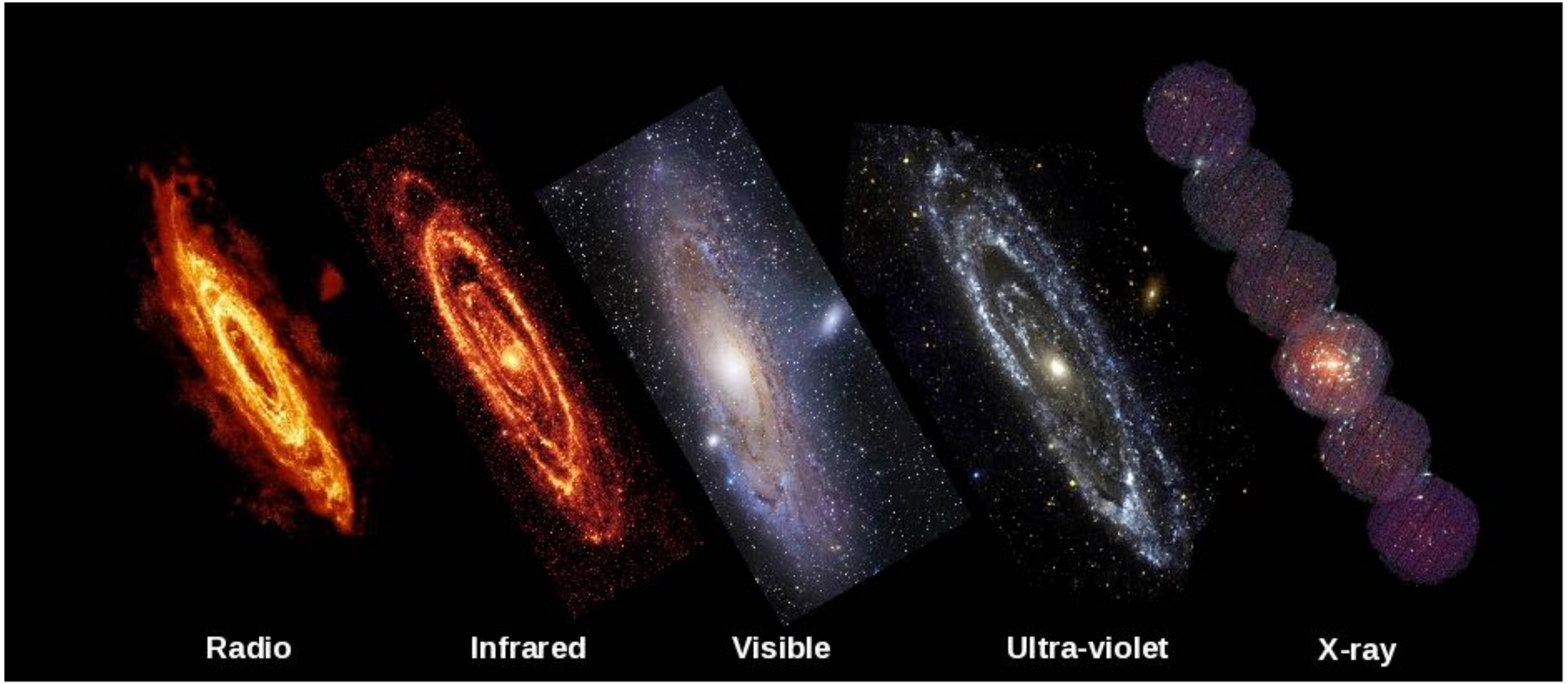


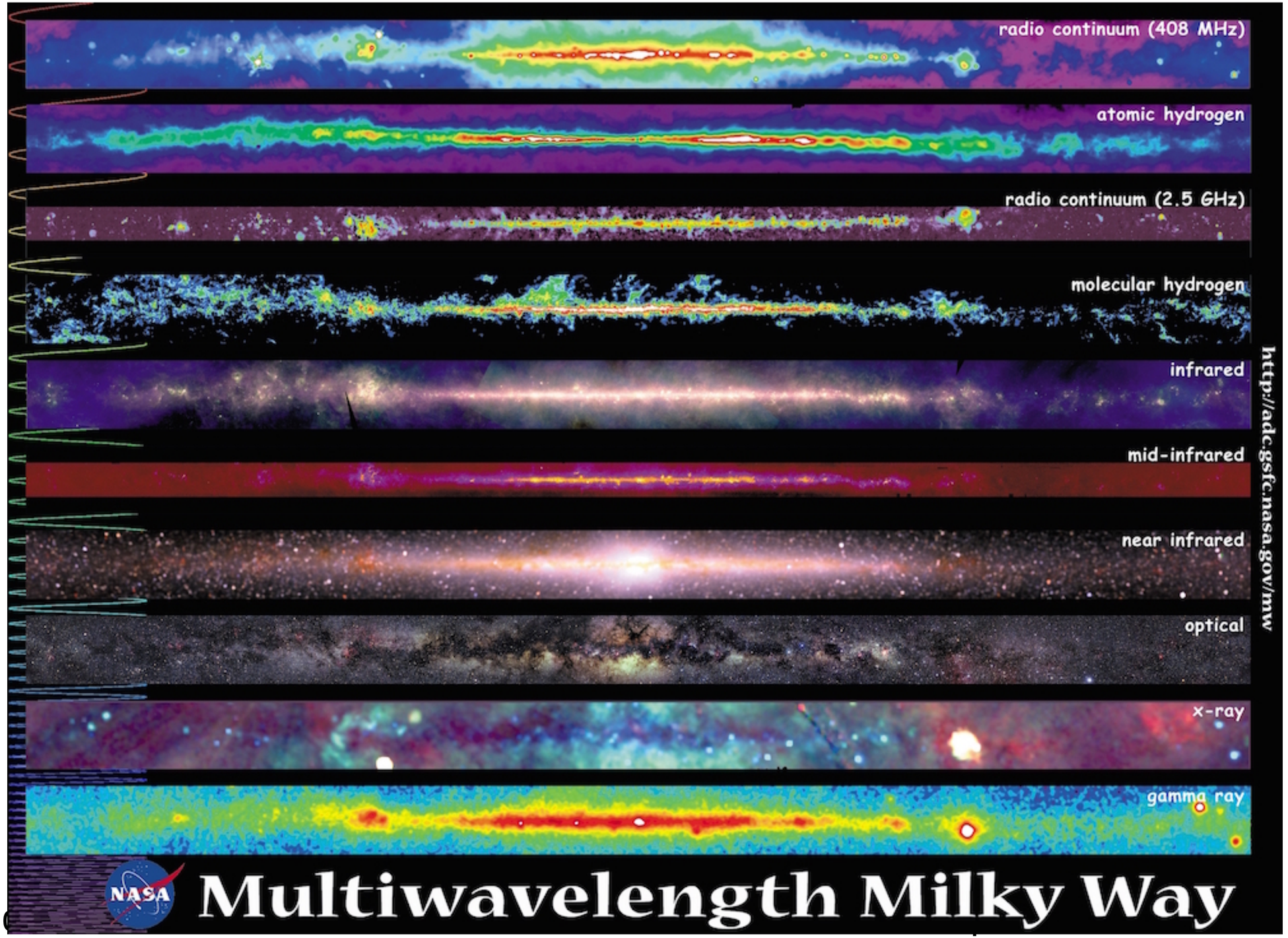
Radio/X-ray - Million Degree Gas in Galaxy Clusters



Red = Radio
Yellow = Visible
Blue = X-ray

Andromeda Galaxy - Our Nearest Neighbor




radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multiwavelength Milky Way