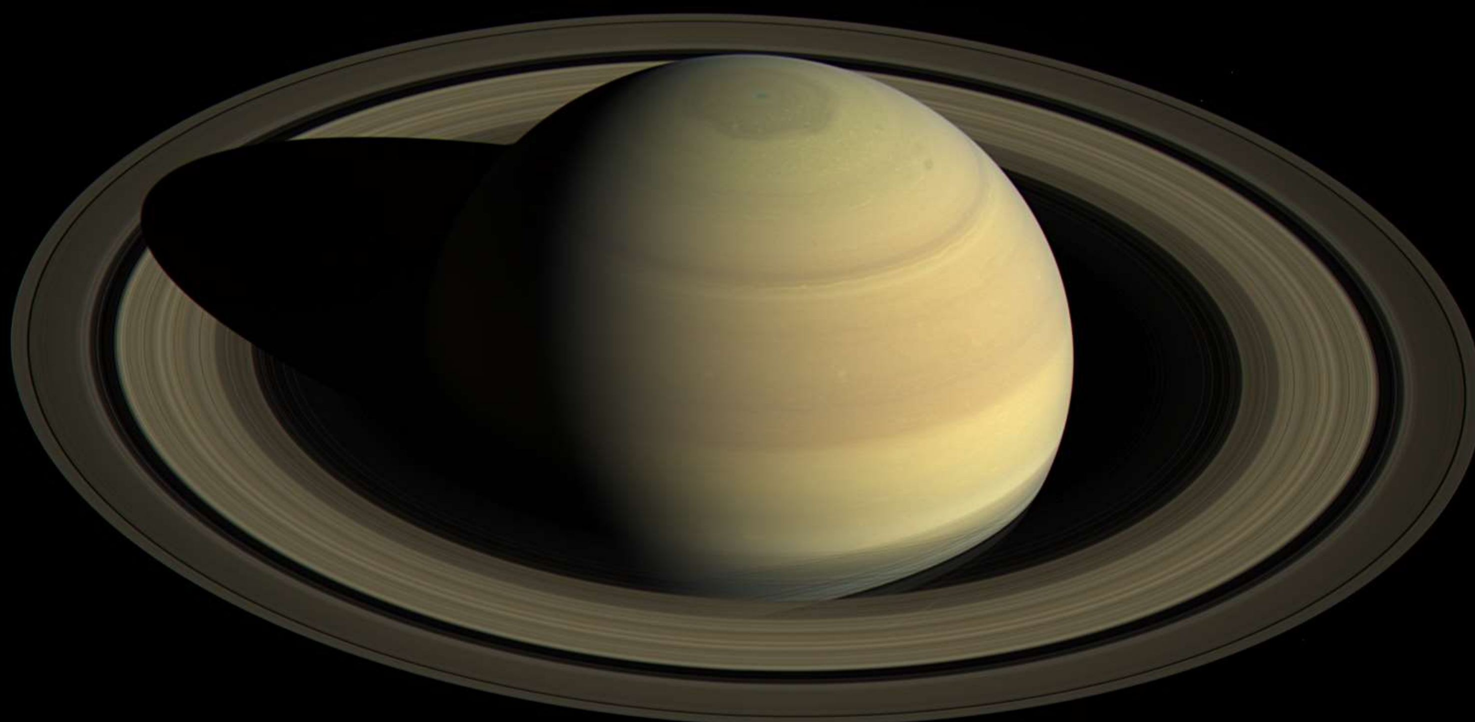
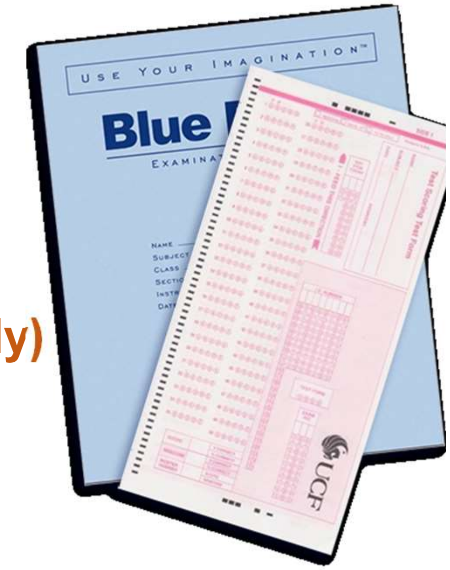
AST 2002
Introduction to Astronomy



A Few Quick Things…



Mary Hinkle, Graduate Teaching Assistant:

Office Hours: Mon 1:30-3:30pm. PSB 316 (this week only)

My office hours: Mon 3:30-4:15pm. PSB 308 (this week only)

Tue 3-4 pm. PSB 308

First Mid-term is this week, Friday 9th February.

https://ucfsga.com/services/free-scantrons-and-blue-books/

Exam Tips… Go over lecture slides! … On Wednesday will give a better idea what to expect for exams… material from Today will be on the first mid-term!

Today: Light

Last Time:

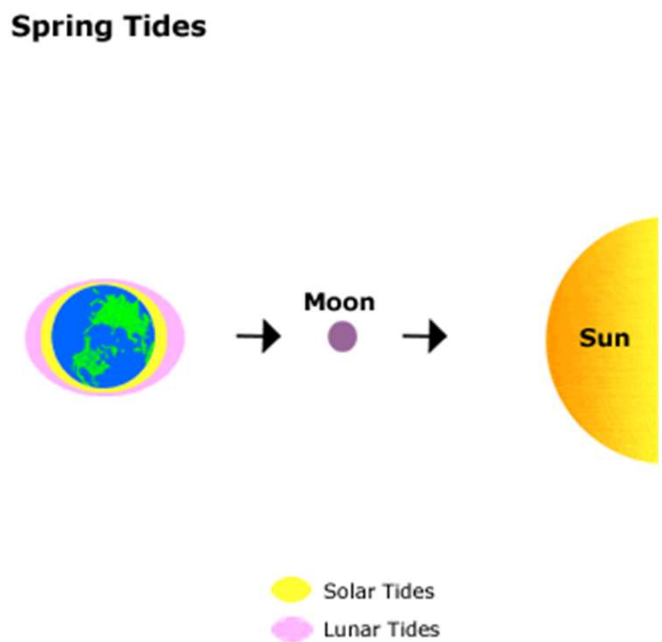
- How does gravity cause tides?
- What is light and matter, and how do they interact?
- Three types of Spectra

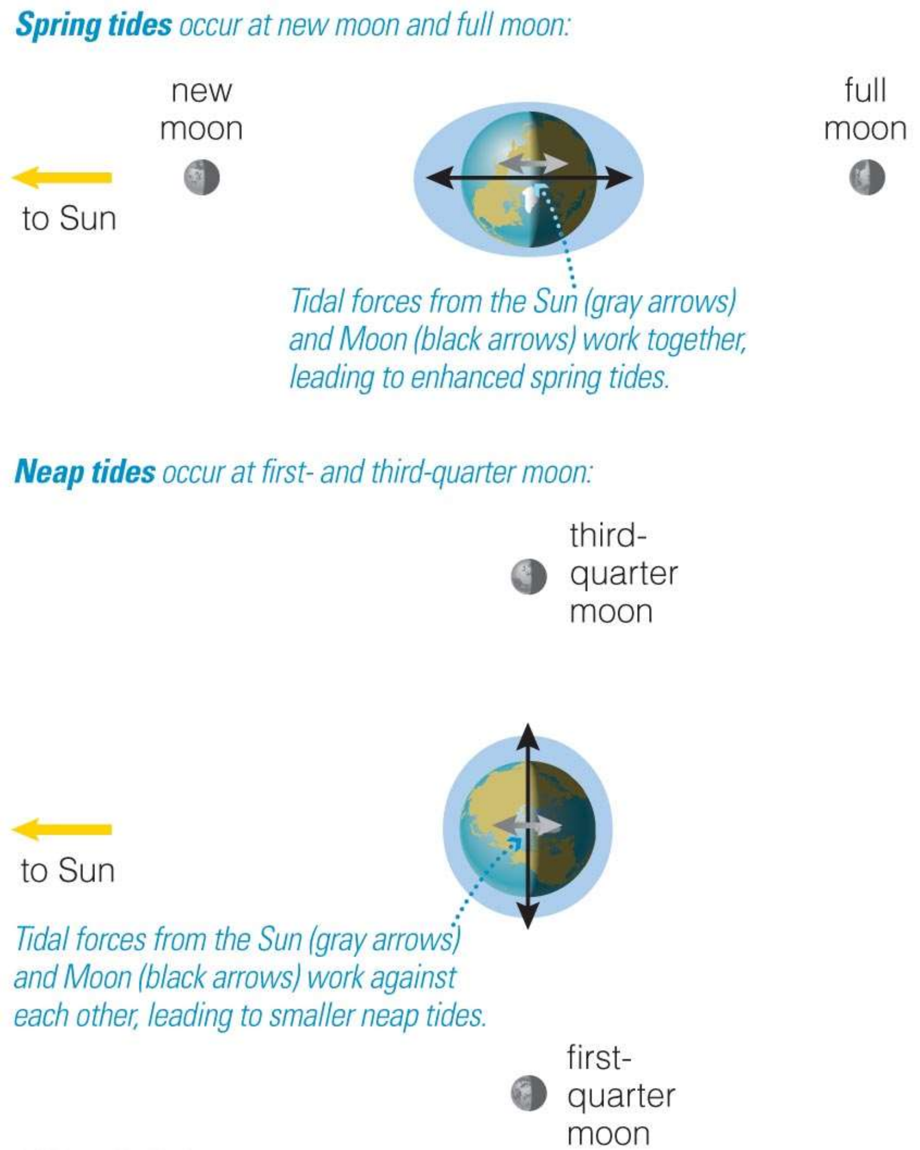
Topics Covered Today:

- What can we learn from light (composition, temperatures, and speed/distance)
- Collecting light with telescopes

Tides and Phases

Size of tides depends on the phase (relative position) of the Moon.

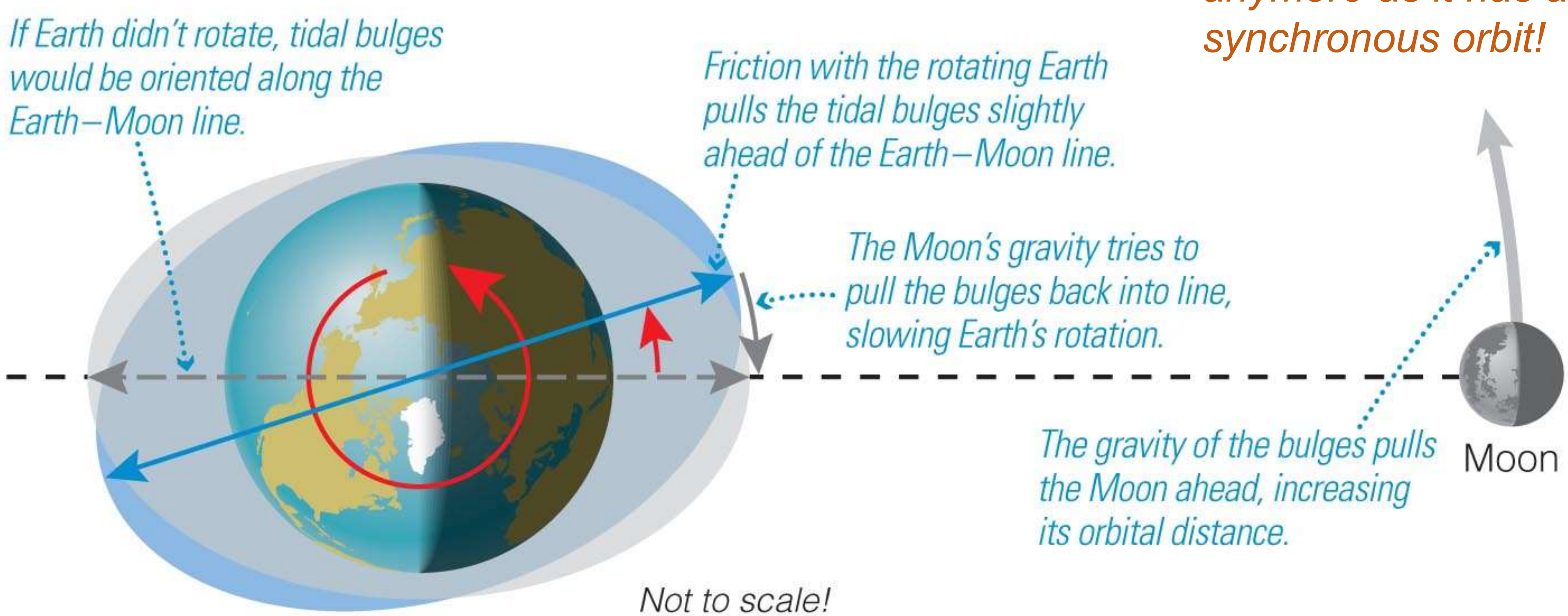




https://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html

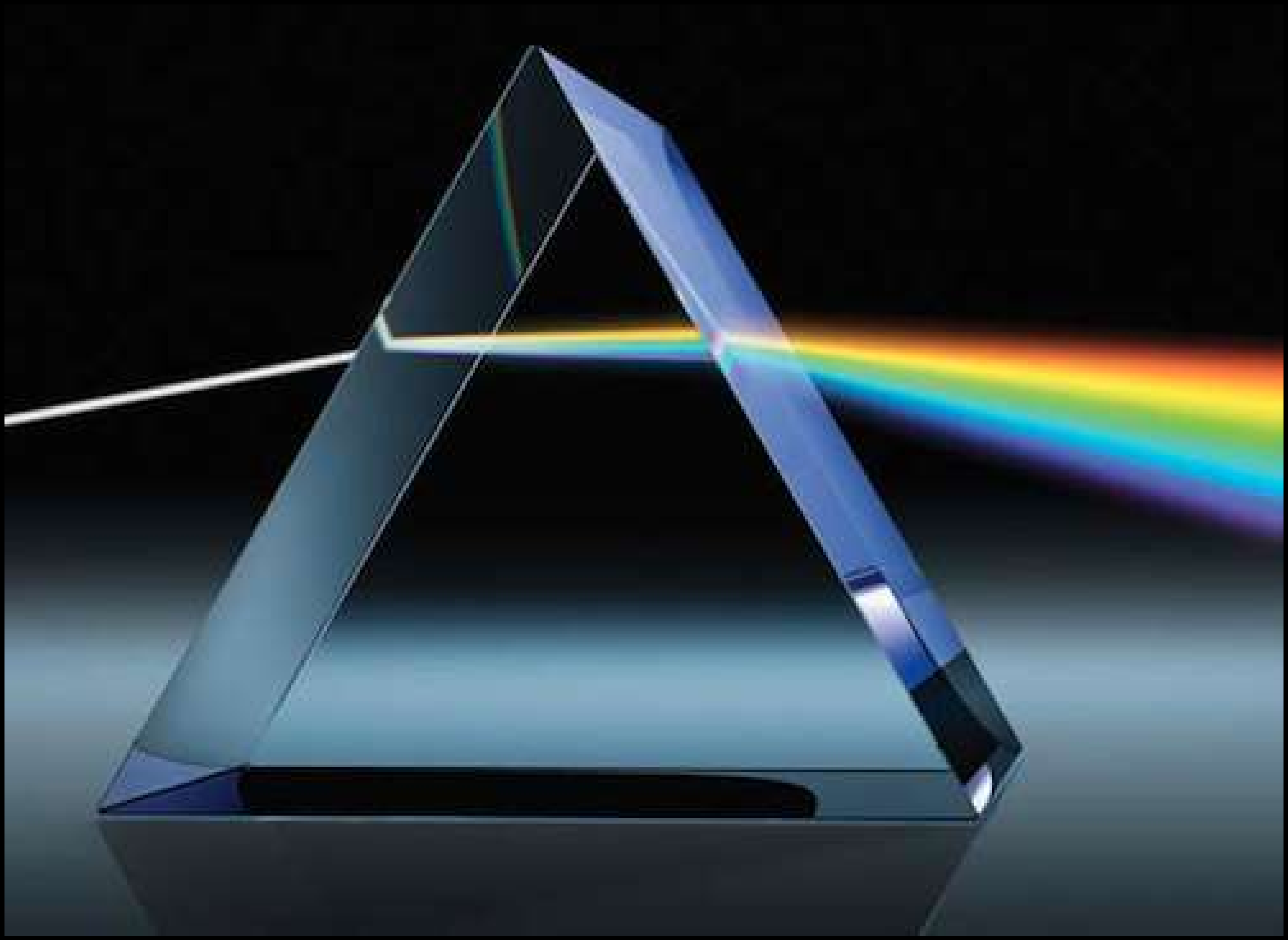
Why does the moon always show us the same face?

There is no tidal friction on the moon anymore as it has a synchronous orbit!



Energy is being transferred from the Earths rotation to the Moon's orbit

What is Light?



Wavelength, Frequency, and Energy

Relationship between frequency and wavelength:

$$\lambda \times f = c$$

λ = wavelength, f = frequency

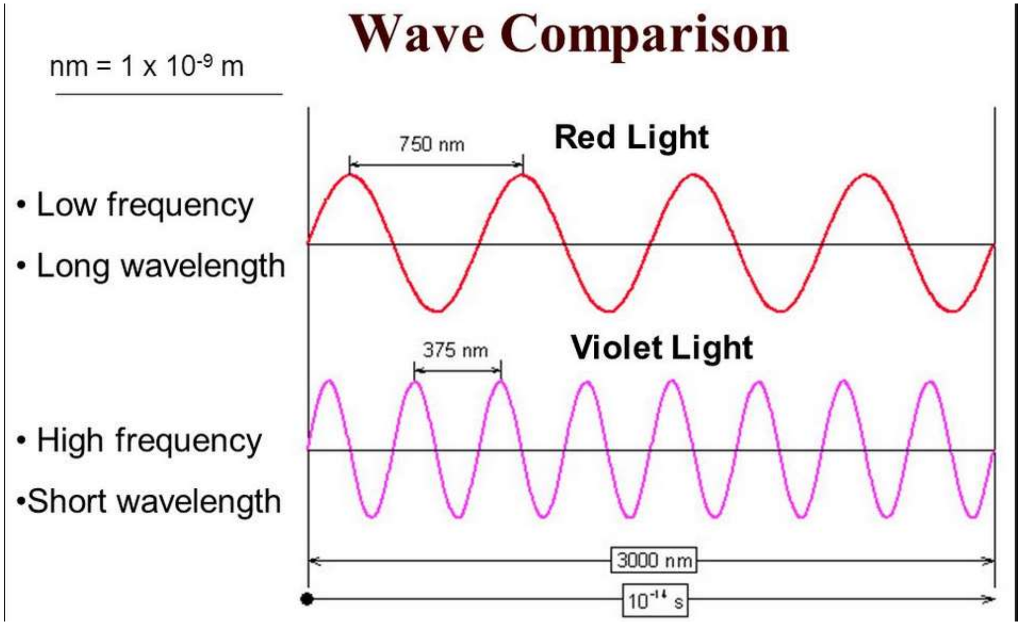
c = 3.00×10^8 m/s (speed of light)

Relationship between frequency and energy:

$E = h \times f$ = photon energy

$h = 6.626 \times 10^{-34}$ joule × s

(h = Planck's constant)



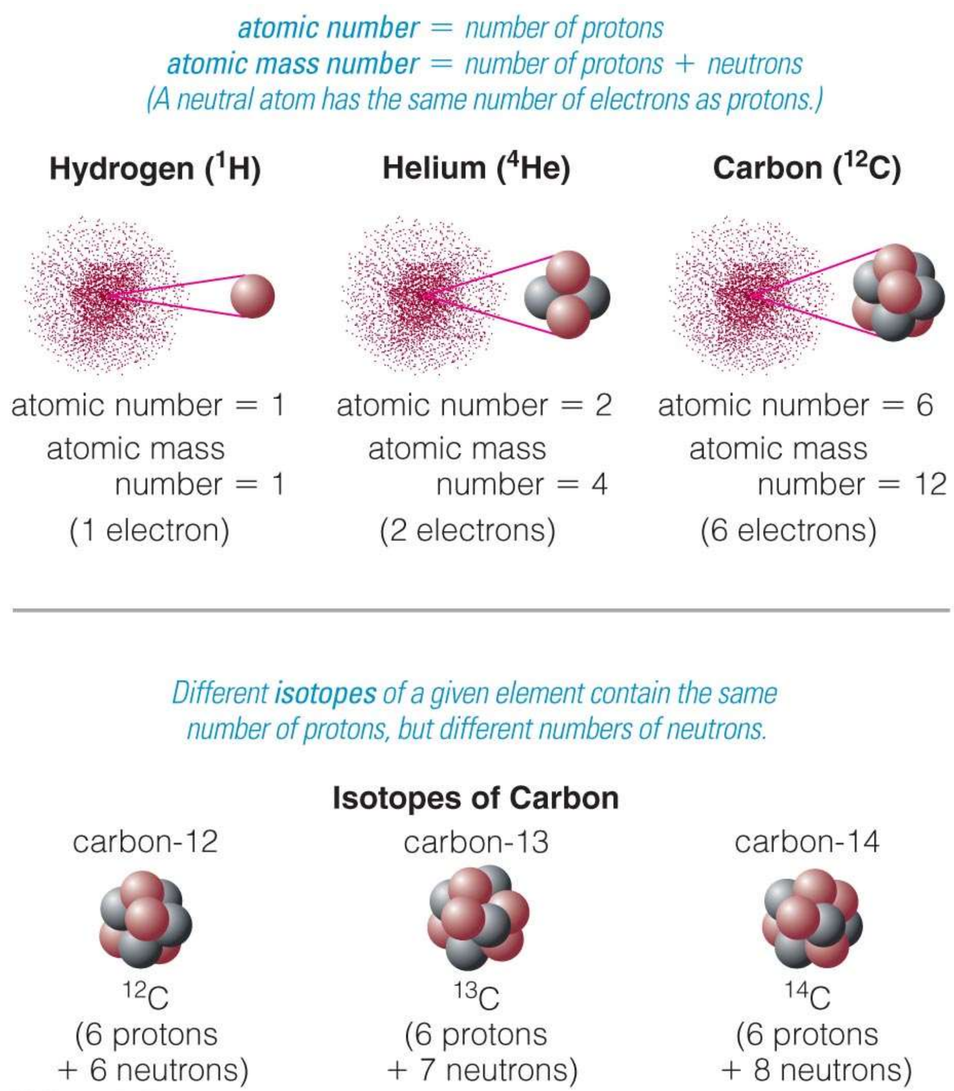
- Our eyes are sensitive to changes in wavelength (or frequency).
- We can see from ~400 nm (violet) to ~700 nm (red)
- Our eyes are most sensitive to green light (~ 530 nm)

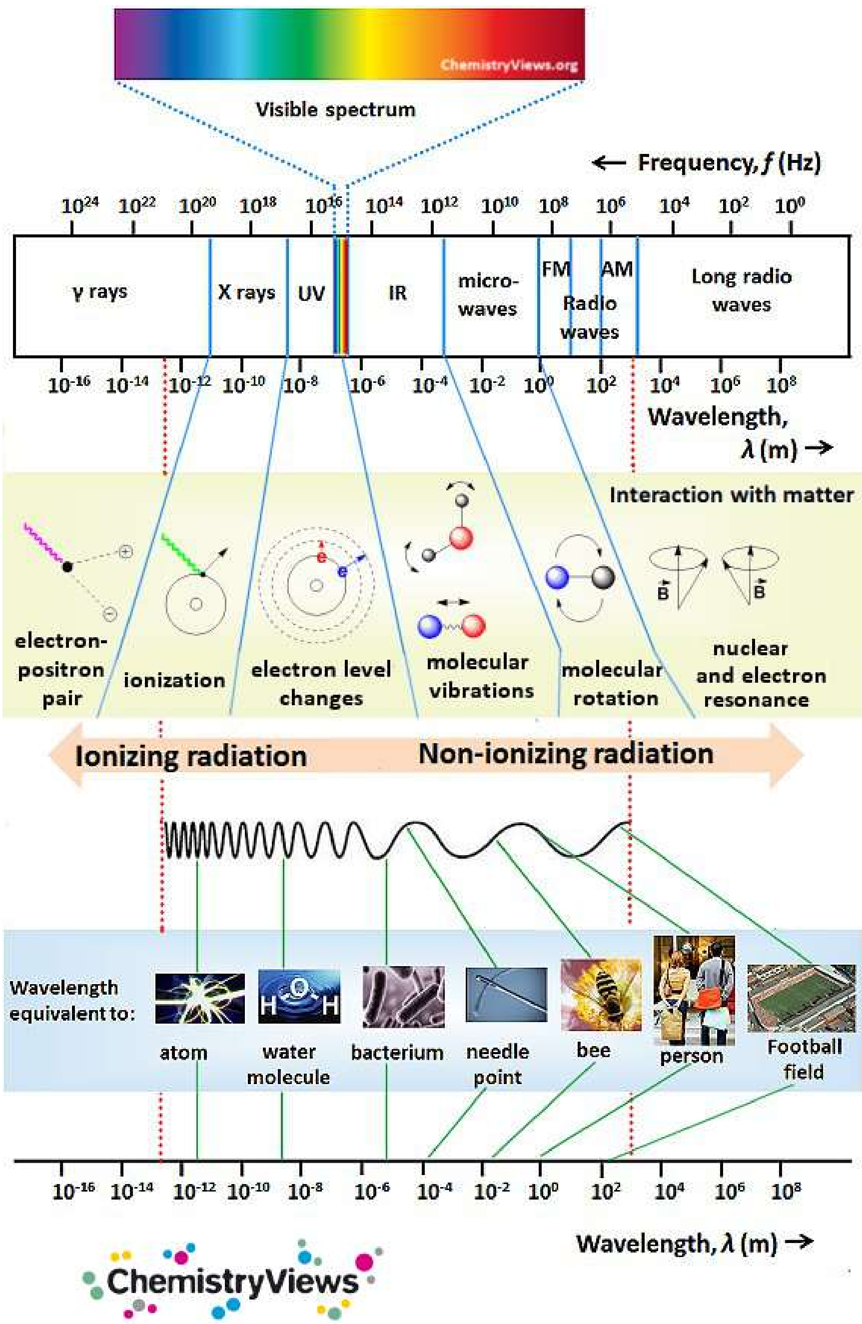
Red-shifted: Longer wavelength, lower frequency, lower energy

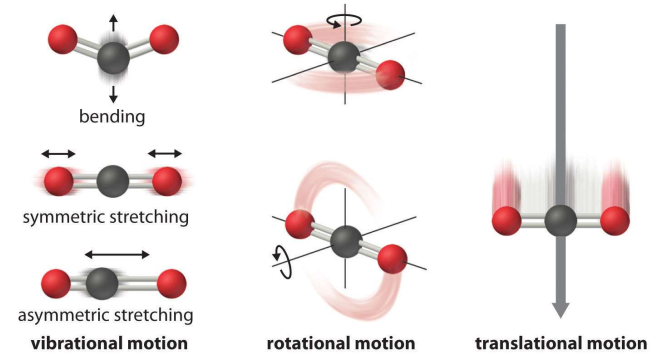
Blue-shifted: Shorter wavelength, higher frequency, higher energy

Atomic Terminology

- Atomic Number = # of protons in nucleus
- Atomic Mass Number = # of protons + # of neutrons
- Isotope: same # of protons but different # of neutrons (^4He, ^3He)
- Molecules: consist of two or more atoms (H_2O, CO_2)





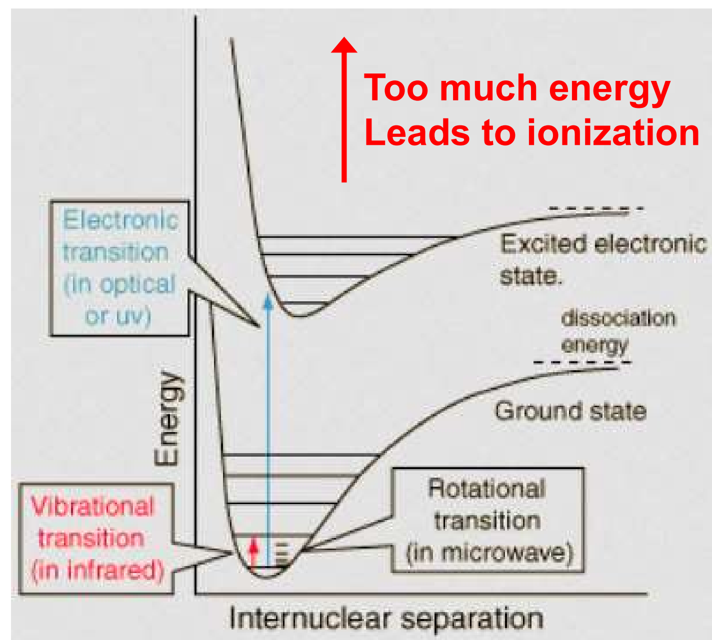


Molecular rotations don’t require much energy (microwave region)

Molecular vibrations require a bit more energy (infrared region)

Electronic transitions require more energy still (visible light and UV light)

Higher energy levels causes bonds to start breaking and ionization to occur (X-rays and UV)



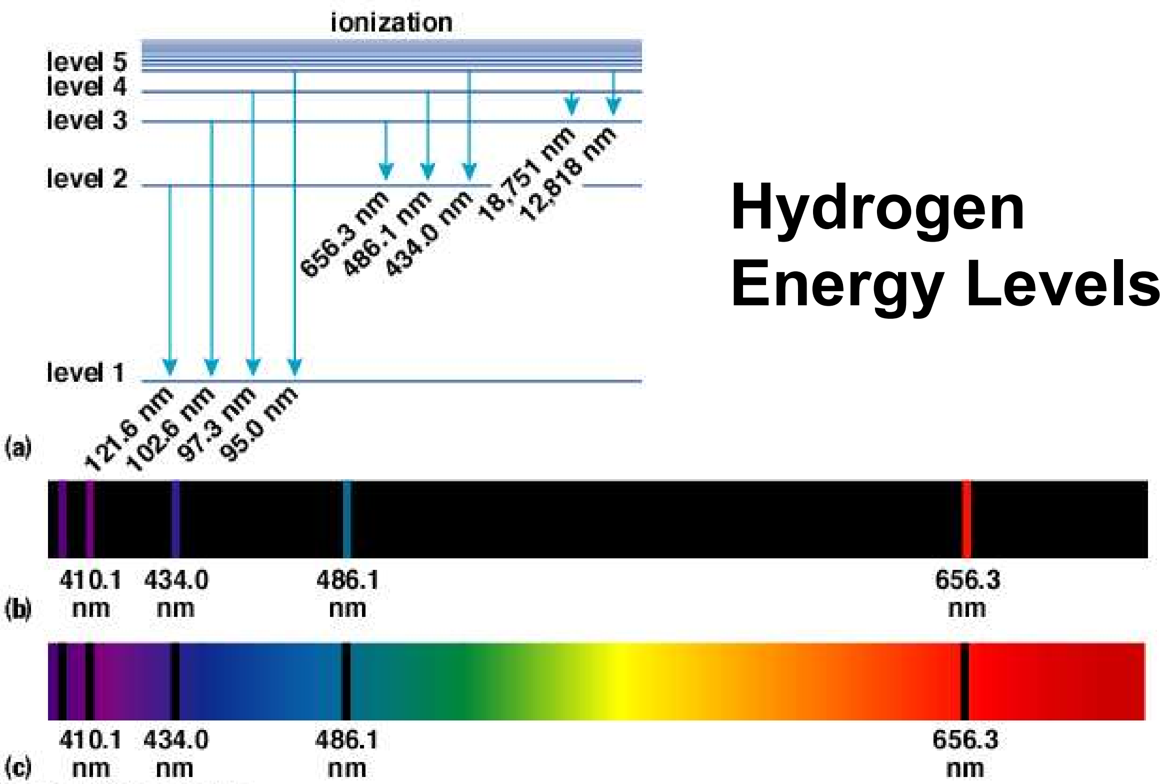
Energy Levels in Matter Are Quantized *(specific energy levels!)*

A fundamental part of the rules that govern the universe

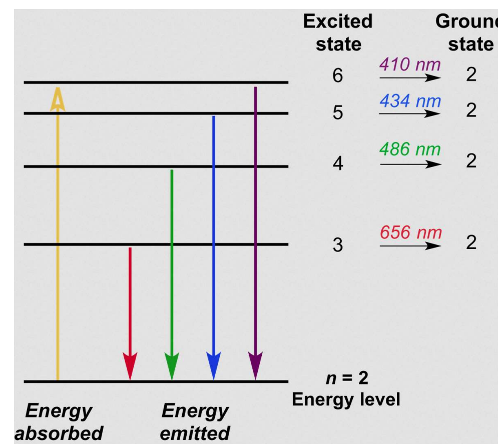
Electrons in atoms have distinct energy levels.

Each chemical element, ion, molecule, has a unique set of energy levels.

- **Distinct energy levels lead to distinct emission or absorption lines.**



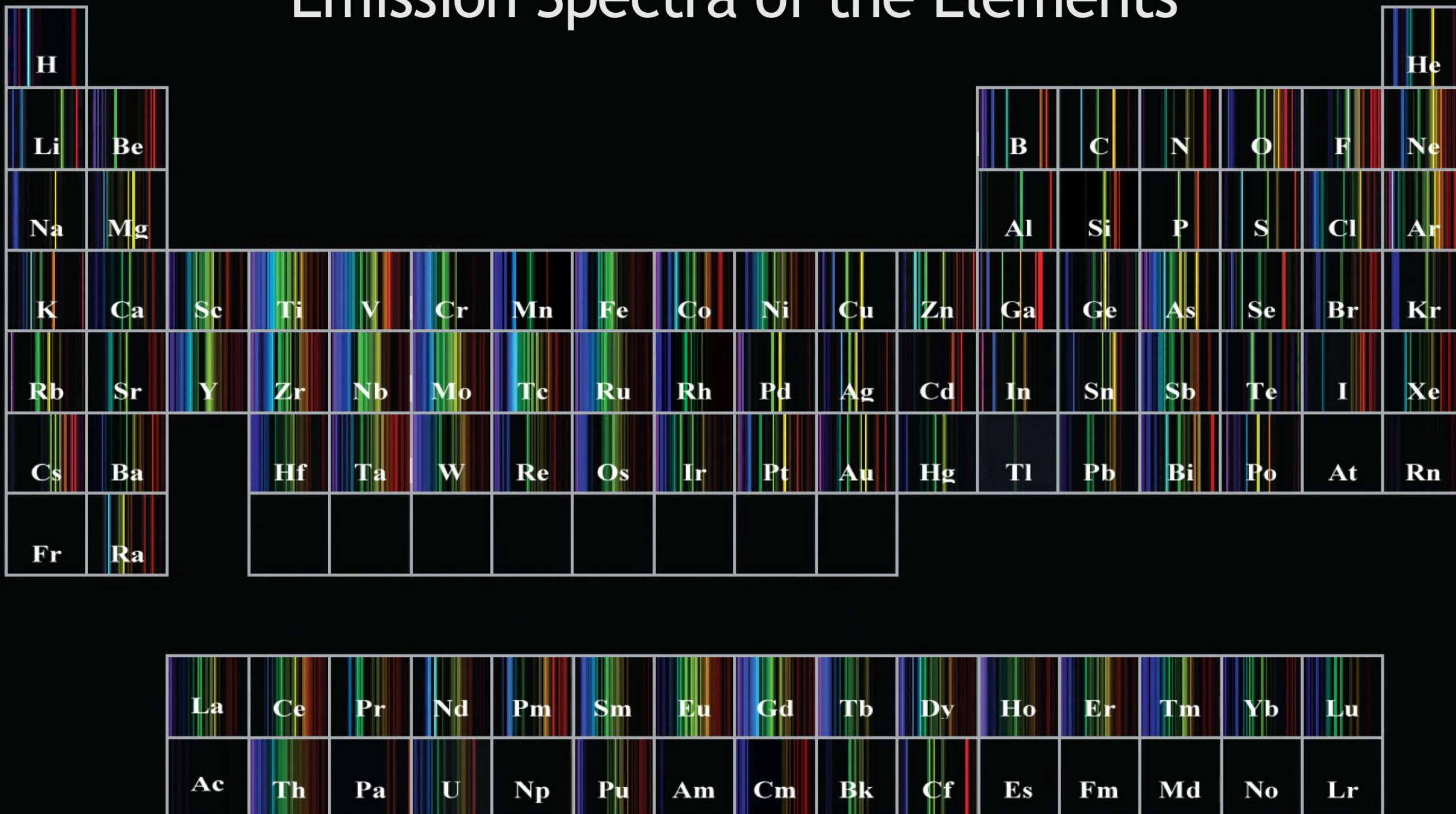
Hydrogen Energy Levels



Emission Lines
(depopulating energy levels)

Absorption Lines
(populating energy levels)

Emission Spectra of the Elements



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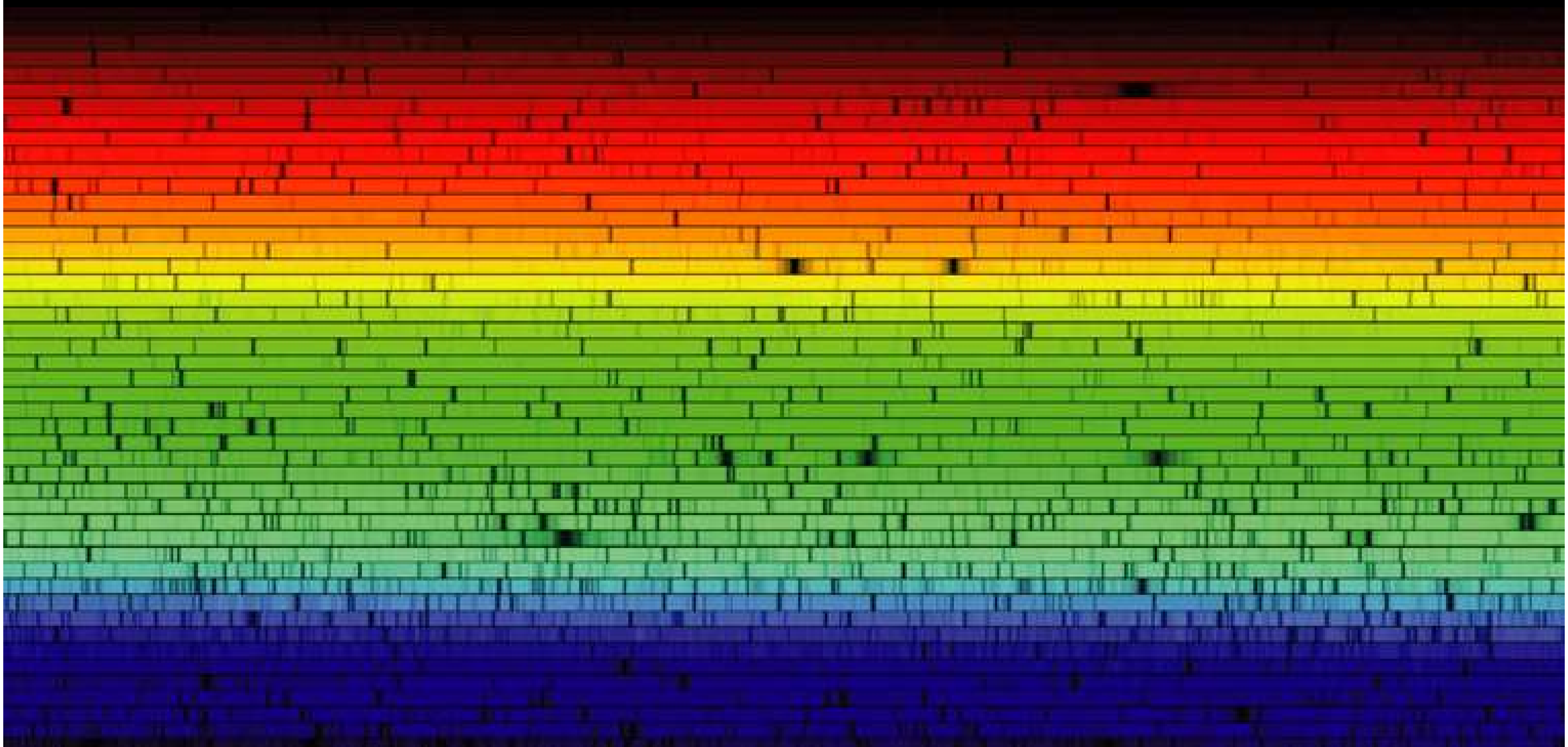
Example: Solar Spectrum



These actually indicate a combination of emission and absorption processes

iClicker Question #1

(Code = BC)

Question: Put the following kinds of light in order, according to wavelength, short to long:

A. Visible light, ultraviolet (UV), infrared (IR), radio, microwaves, X-rays, gamma rays

B. Gamma rays, X-rays, UV, visible, IR, microwaves, radio

C. X-rays, UV, visible, IR, radio, microwaves, gamma rays,

D. UV, visible, microwaves, radio, IR, gamma rays, X-rays

E. Radio, microwaves, UV, Visible, IR, X-rays, Gamma rays

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C. X-rays, UV, visible, IR, radio, microwaves, gamma rays

D. UV, visible, microwaves, radio, IR, gamma rays, X-rays

E. Radio, microwaves, UV, Visible, IR, X-rays, Gamma rays

iClicker Question #2

(Code = BC)

Question: We can't see infrared, but we can perceive it as:

A. Microwaves
B. Radar
C. Sound
D. FM
E. Heat

iClicker Question #2

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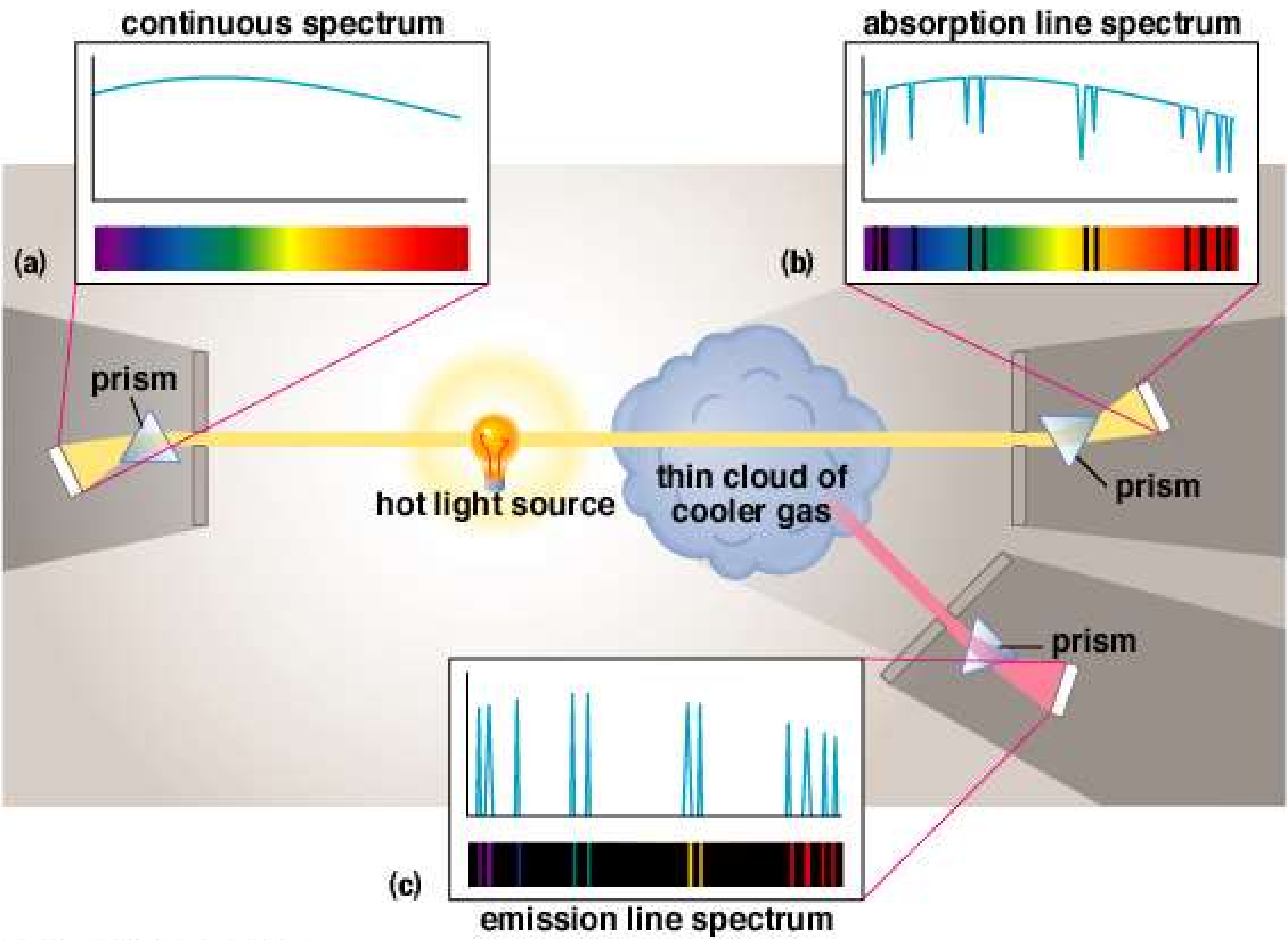
C. Sound

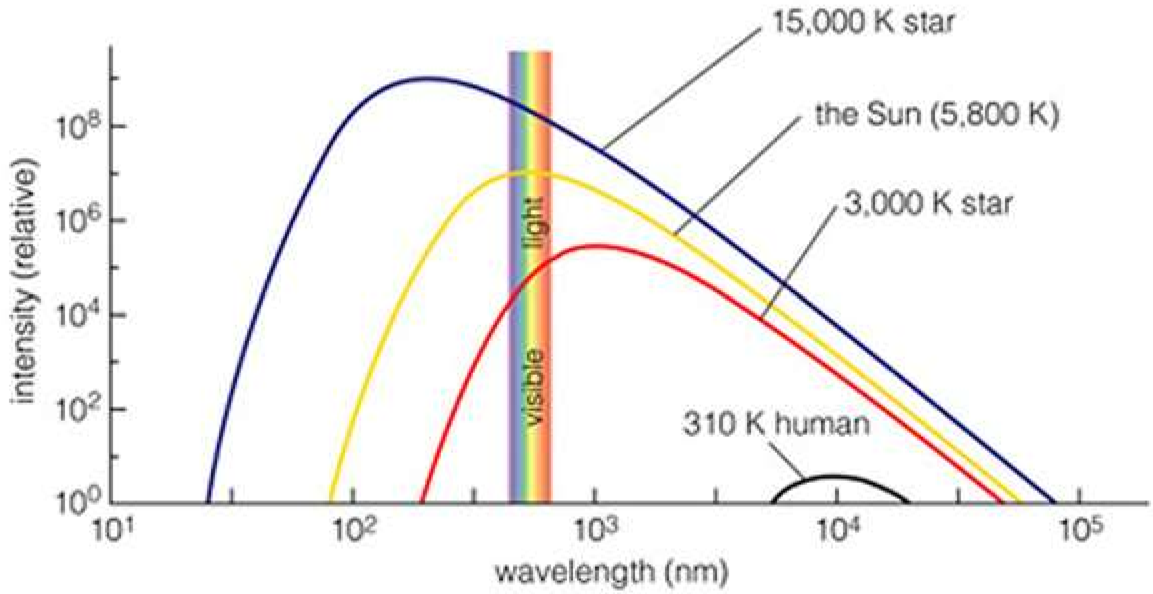
D. FM

E. Heat

What types of light spectra can we observe?



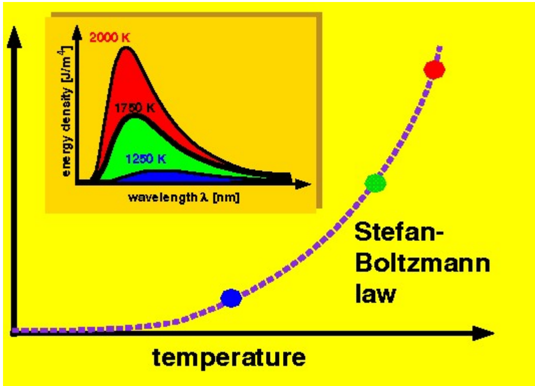
Black-Body Radiation



- The origin of the 'continuous spectrum'
- Hotter objects emit more light at all frequencies per unit area.
- Hotter objects emit photons with a higher average energy.
- We can determine from the λ_{max} the temperature of an object
- The 'ideal black-body' represents an ideal case treating all wavelengths equally, and adheres to both the 'Two Laws of Thermal Radiation' perfectly.

The Two Laws of Thermal Radiation #1) The Stefan-Boltzmann Law

The Stefan-Boltzmann Law: *As you heat an object, it emits more light at all wavelengths per square meter.*



- For example a 15,000 K star emits more light at every λ than a 3,000 K star per square meter of its surface

$$emitted\ power(Wm^{-2}) = \sigma T^4$$

σ is the Stefan Boltzmann constant, $\sigma = 5.7 \times 10^{-8} \frac{Watts}{m^2 \times K^4}$

Example: What is the power emitted per square meter for an object at 10,000 K?

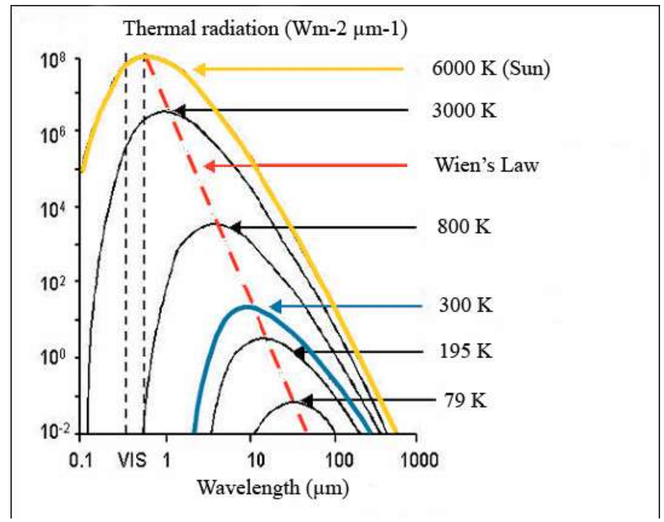
$$emitted\ power = \sigma T^4 = 5.7 \times 10^{-8} \frac{Watts}{m^2 \times \cancel{K^4}} \times (10{,}000\ \cancel{K})^4$$

$$= 5.7 \times 10^{8} \frac{W}{m^2}$$

The Two Laws of Thermal Radiation
#2) Wien's Law

Wien's Law: *Hotter objects will emit photons with a higher average energy.*

- For example, the peak λ for a 3,000 K star is in the infrared, for our sun at 5,800 K is in the visible region, and for a 15,000 K star is in the UV region.



$$\lambda_{max} = \frac{2.898 \times 10^{-3}\ (mK)}{T\ (K)}$$

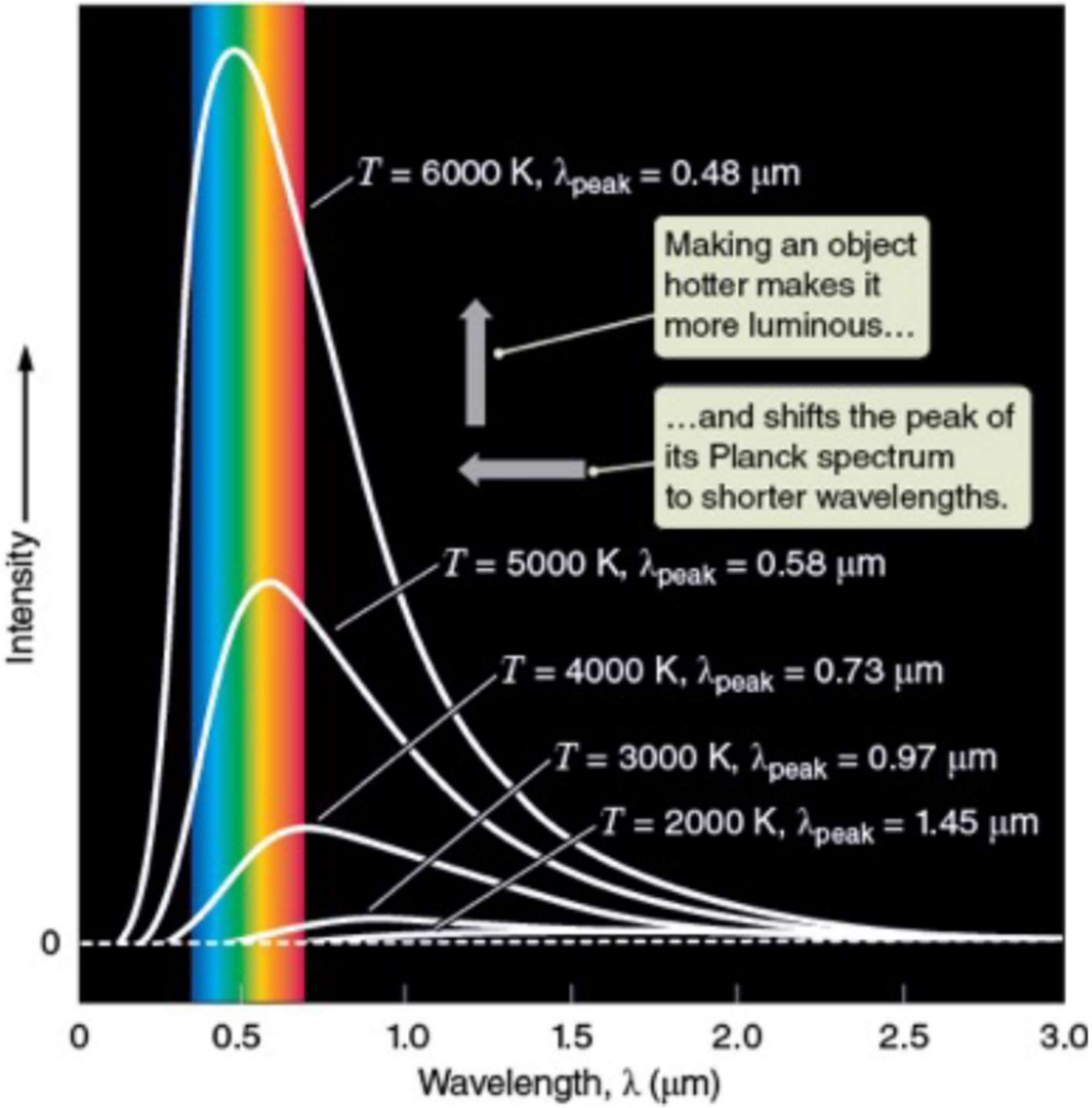
Note: this could equally be written as 2,898,000 (nm K)/T (K)

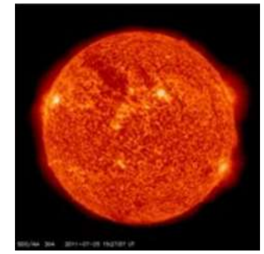
Example: What is the wavelength of peak intensity for an object at 10,000 K?

$$\lambda_{max} = \frac{2.898 \times 10^{-3}\ (m\not{K})}{10{,}000\ (\not{K})}$$

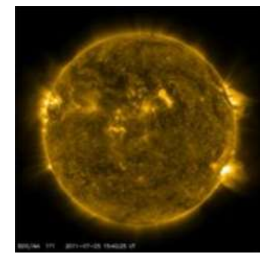
$\lambda_{max} = 2.898 \times 10^{-7}\ m$, or 289.8 nm

Thought question: Can we see this?

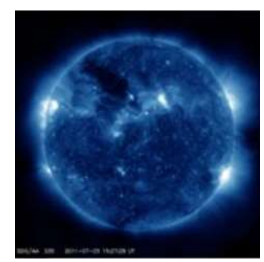




Red Star, T = 3,000 K

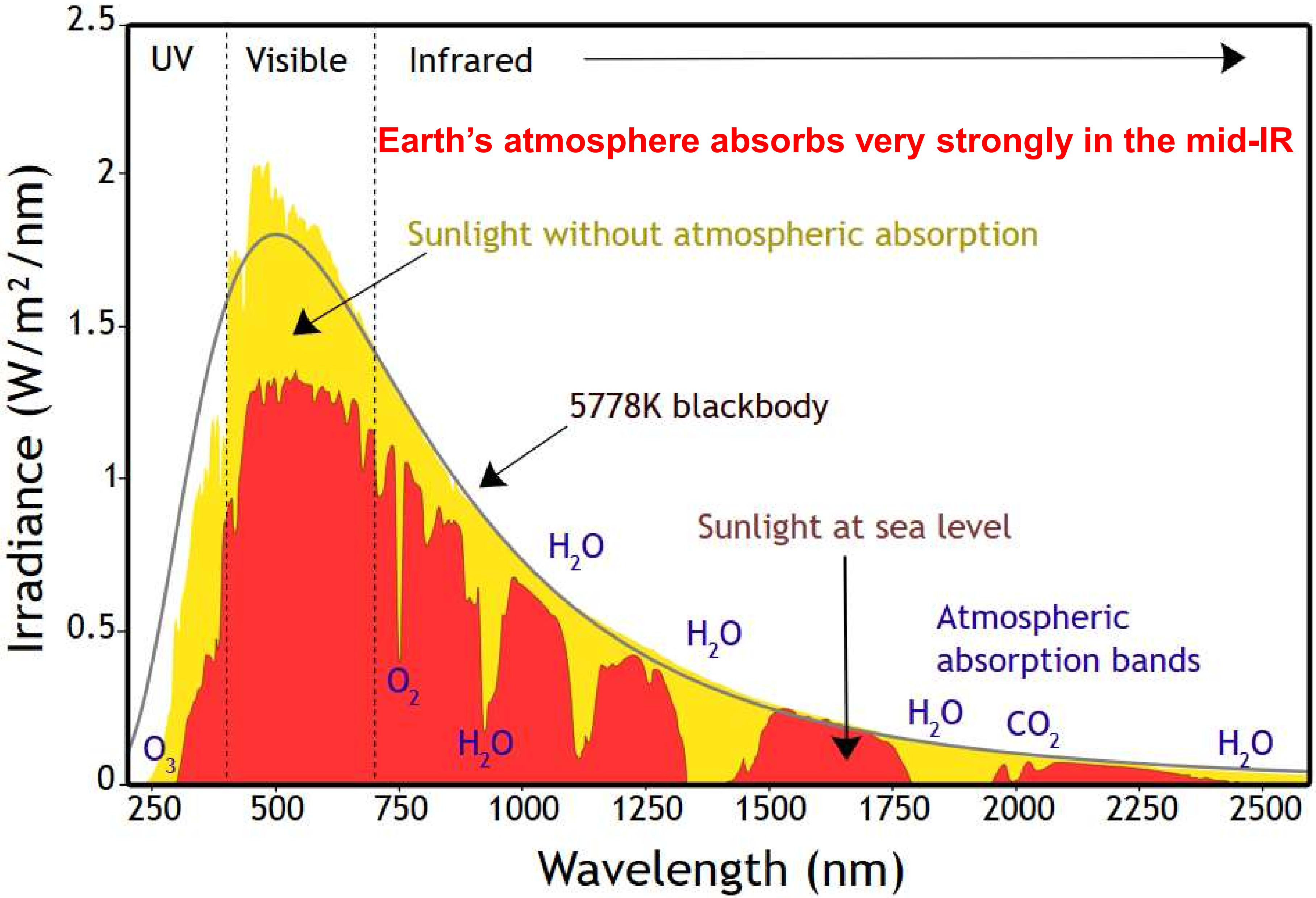


Yellow/Green Star,
T = 5,000 K

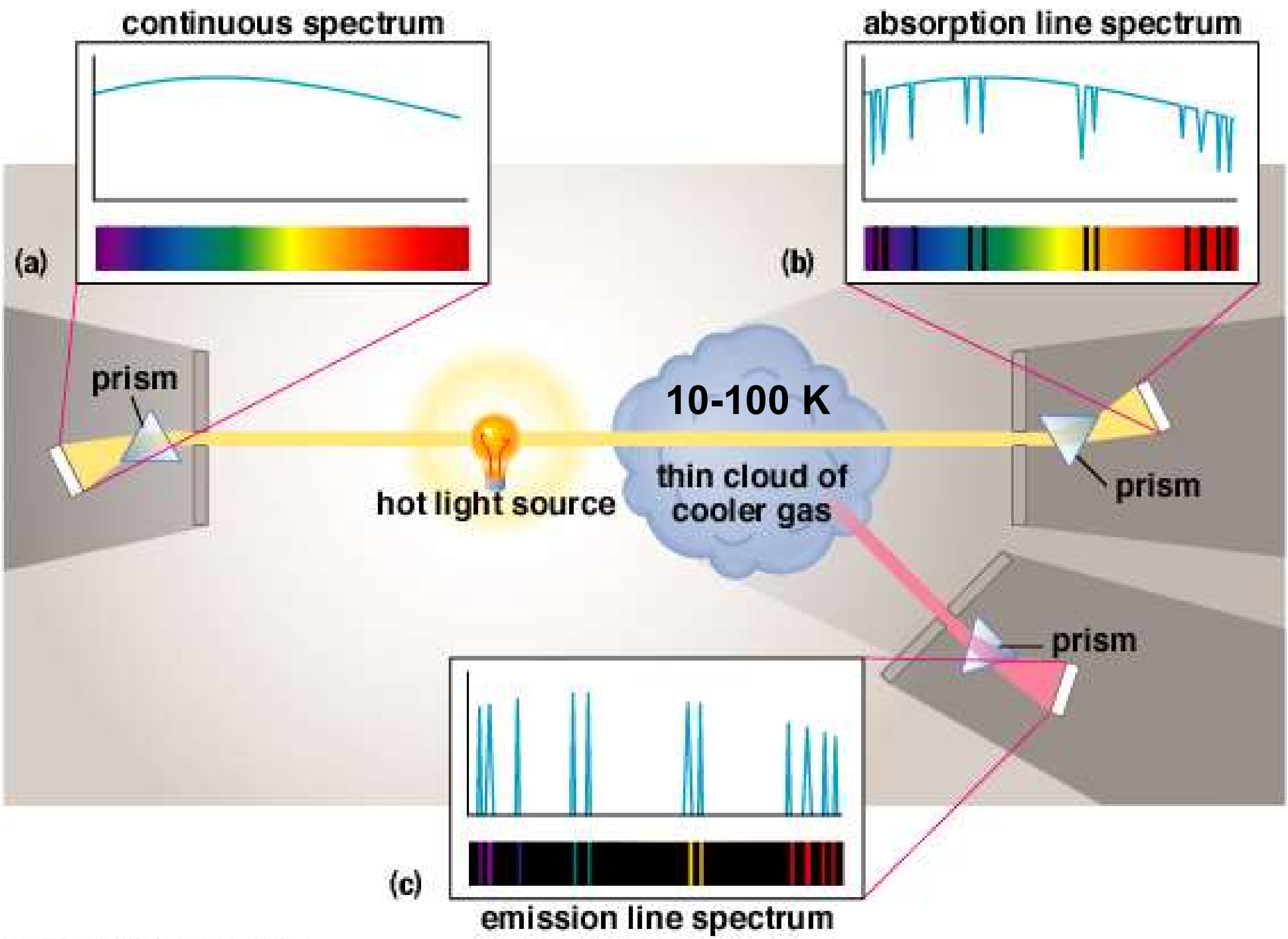


Blue Star,
T = 10,000 K

Spectrum of Solar Radiation (Earth)

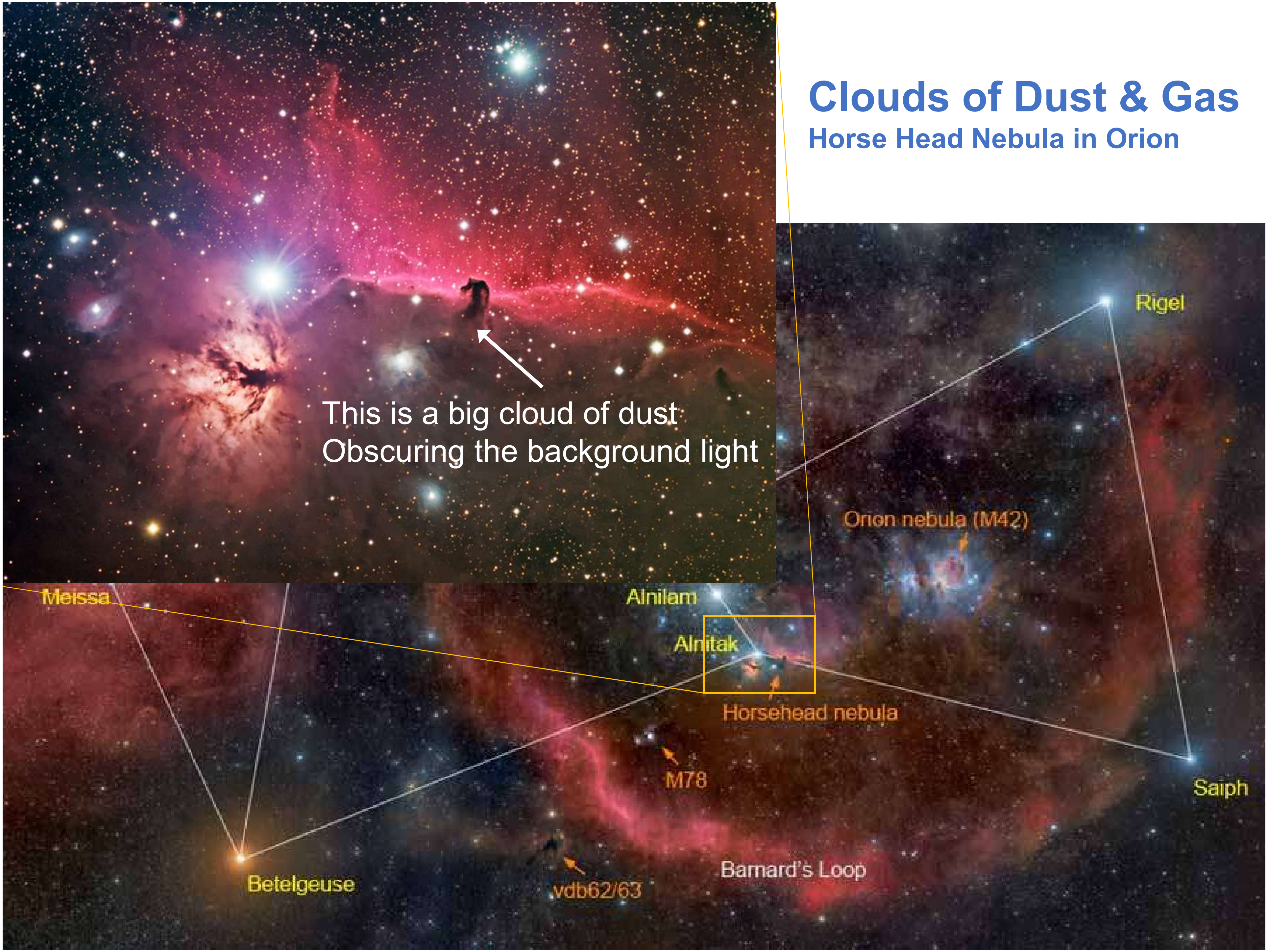


What types of light spectra can we observe?



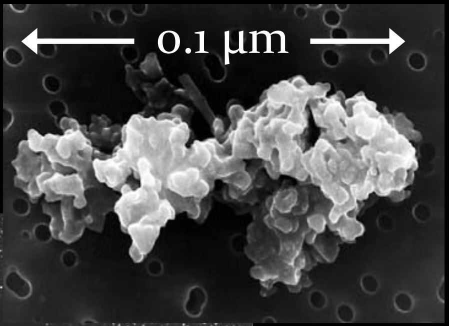
Clouds of Dust & Gas

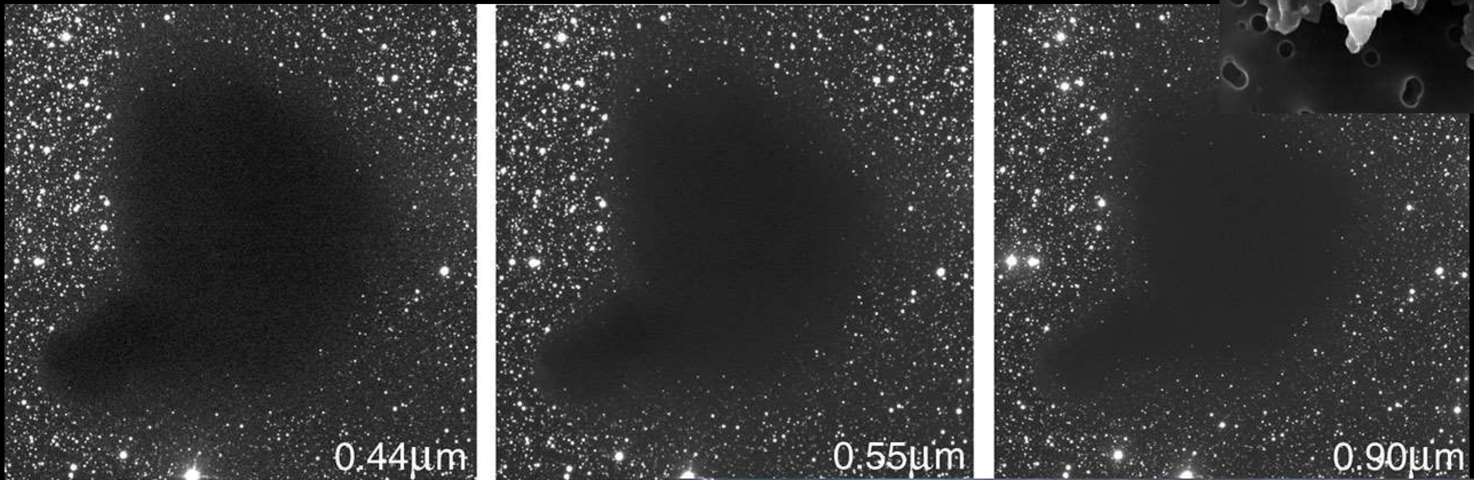
Horse Head Nebula in Orion

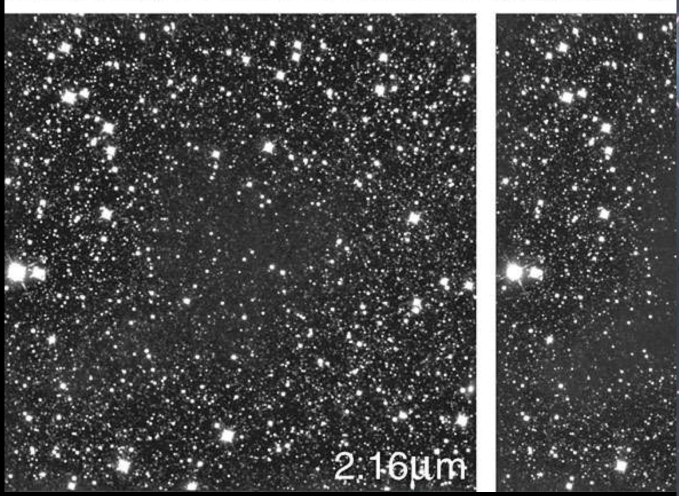


2nd Example of a Molecular Cloud - Barnard 68

We an see through the dust could at infrared wavelengths, but the light is scattered more at visible wavelengths that are comparable to the size of the interstellar dust grains…





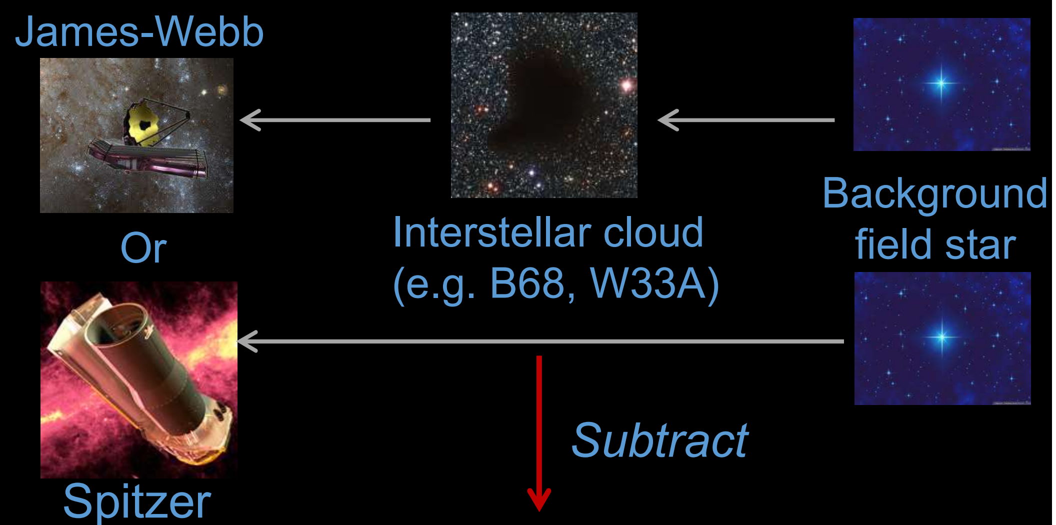


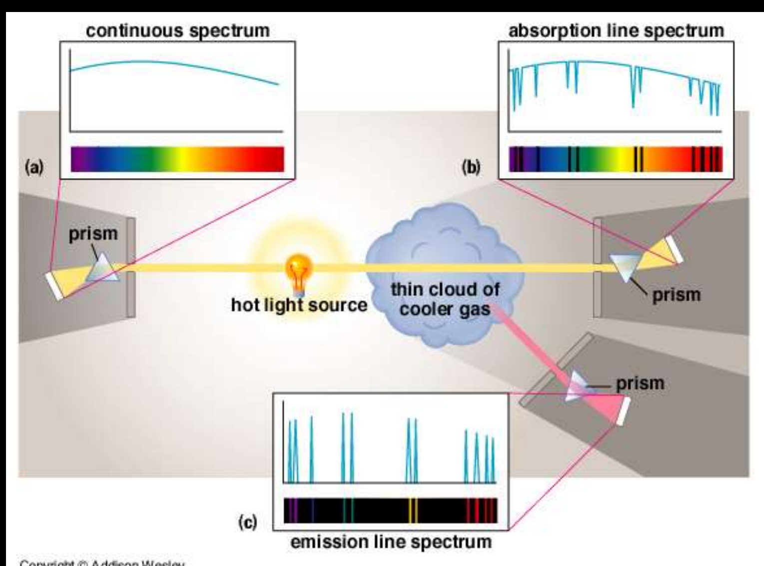
Absorption spectroscopy can tell us the composition of Interstellar Clouds

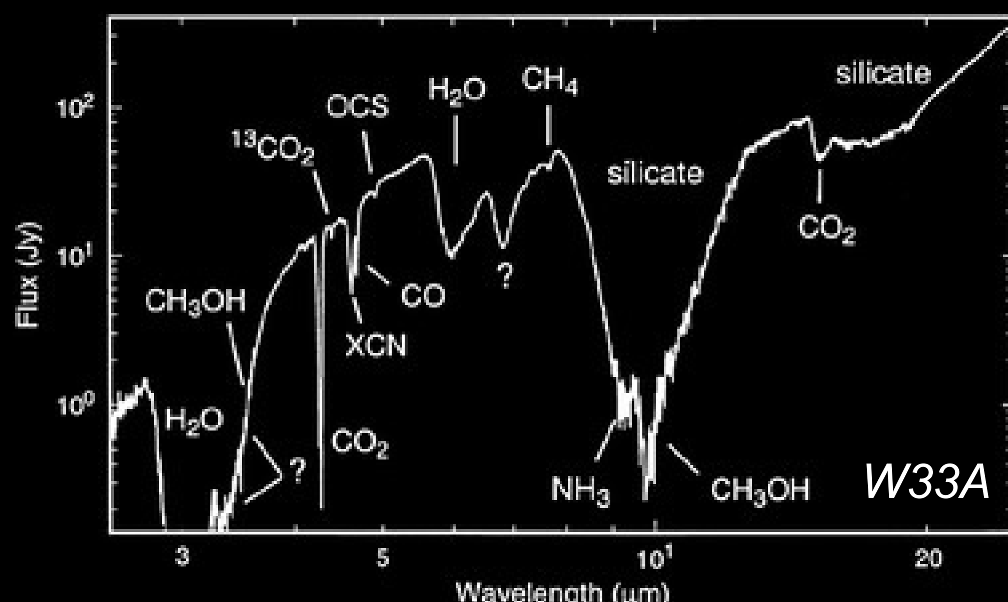
We can use a background field star as a black-body hot light source

Photons corresponding to discrete vibrational levels of molecular species present within the ices absorb the infrared light. Clouds are often 10-30 K

Orbiting spacecraft detect a continuous spectrum of the field star with dips in intensity where light was absorbed



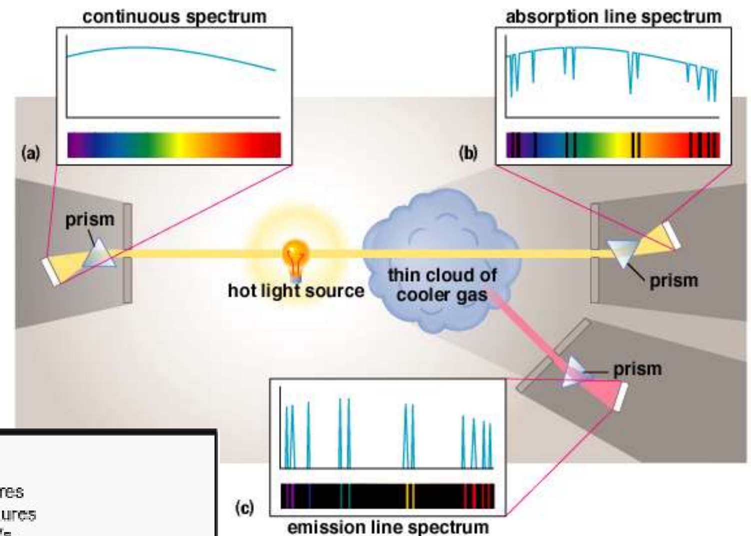


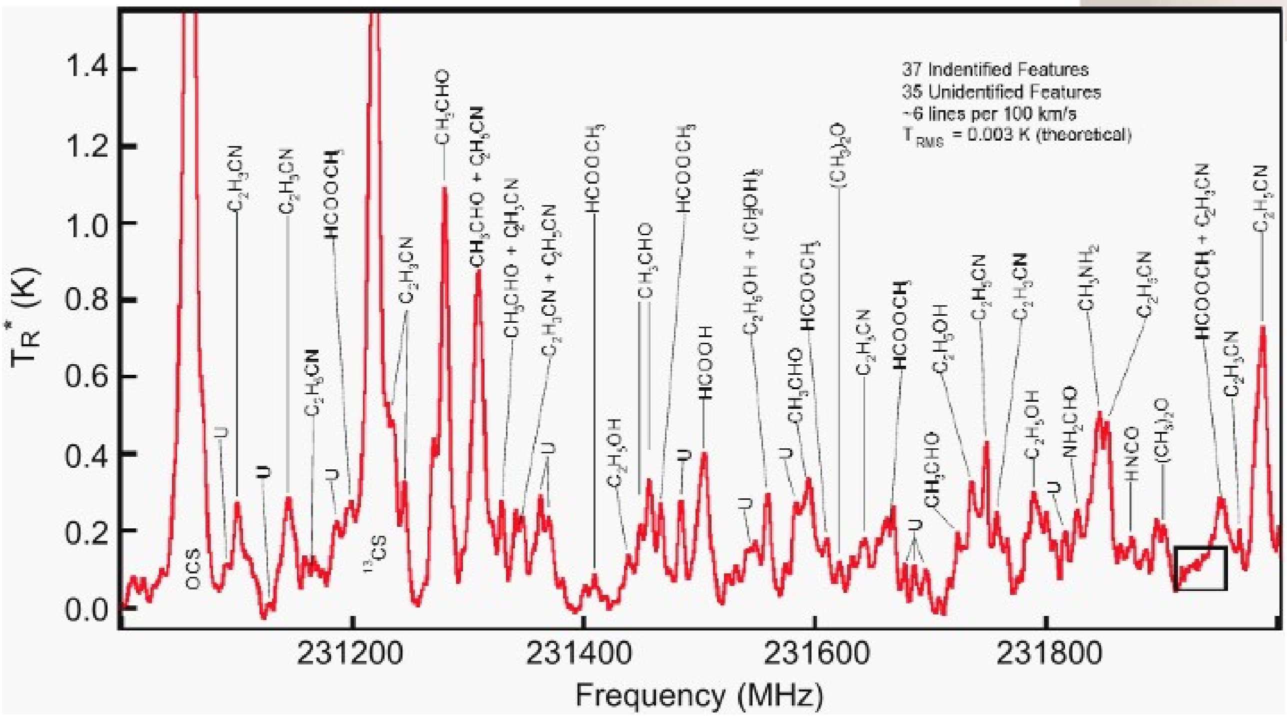


Emission Spectroscopy from Interstellar Clouds

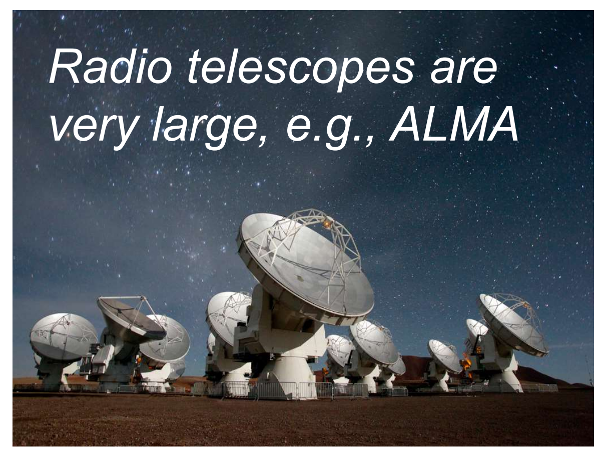
Stars and other hot objects often give off a combination of continuous, absorption and emission lines

Most interstellar clouds are too cold (<200 K) to observe anything but rotational levels



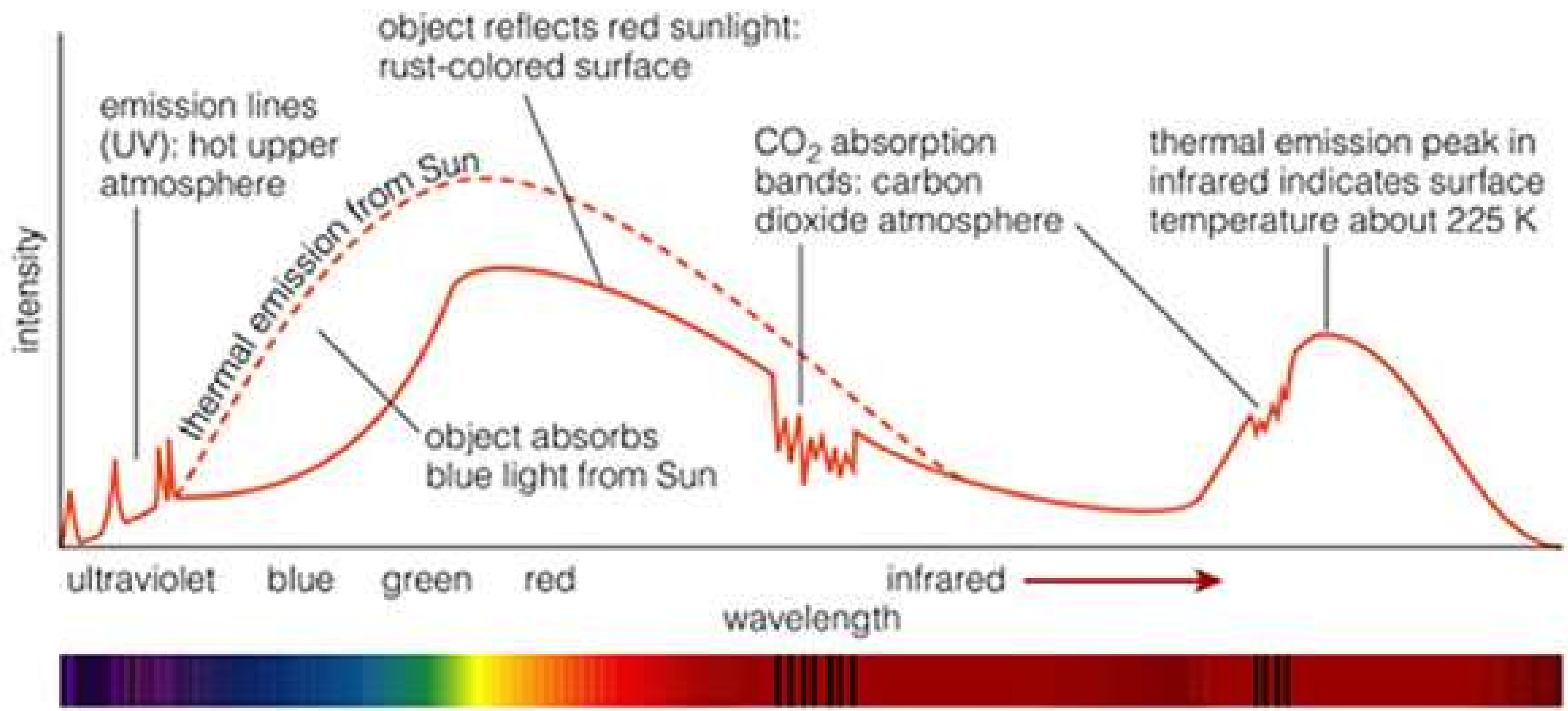


We have observed >150 molecules in interstellar clouds



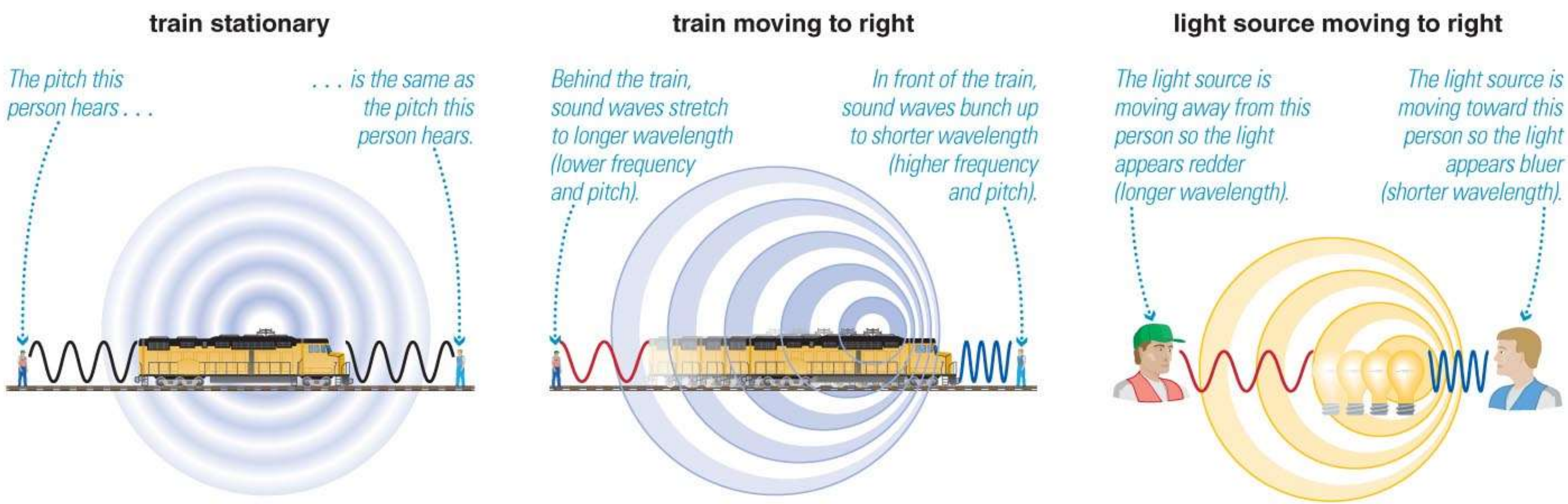
Putting it all Together - Interpreting an Actual Spectrum

What object is this spectrum from?



These features are consistent with MARS!

What is the Doppler Effect?



a The whistle sounds the same no matter where you stand near a stationary train.

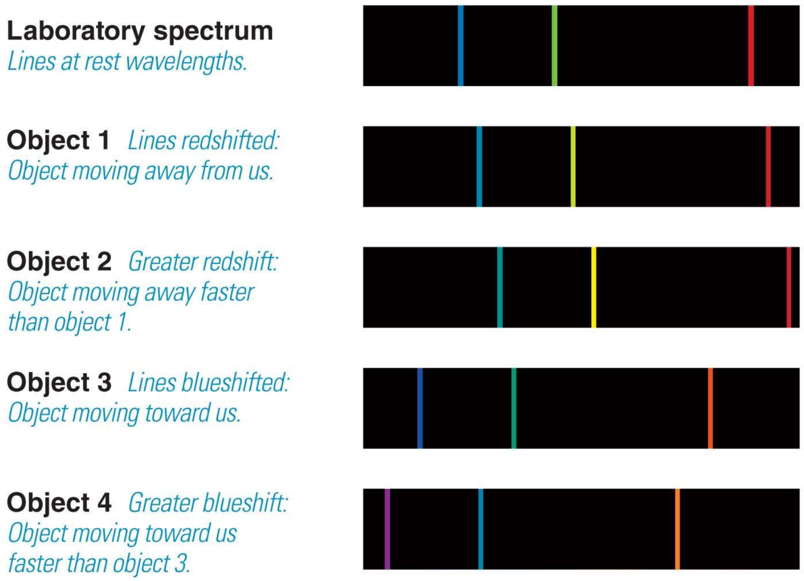
b For a moving train, the sound you hear depends on whether the train is moving toward you or away from you.

c We get the same basic effect from a moving light source (although the shifts are usually too small to notice with our eyes).

Objects moving away from you appear to have longer wavelengths → Red-shifted

Objects moving towards you appear to have shorter wavelengths → Blue-shifted

How Can We Use the Doppler Effect to Determine the Speed of an Object?



Objects with this spectrum are stationary

Red-shifted. Object is moving away

Very red-shifted. Object moving away fast

Blue-shifted. Object is moving towards

Very blue-shifted. Object moving towards fast

Example Calculation: One of the visible lines of hydrogen has a rest wavelength of 656.285 nm, but it appears in the spectrum of the star Vega at 656.255 nm. What is the velocity of Vega relative to us?

$$v_{rad} = \frac{\lambda_{shift} - \lambda_{rest}}{\lambda_{rest}} \times c$$

$$v_{rad} = \frac{656.255\ nm - 656.285\ nm}{656.285\ nm} \times (3.00 \times 10^{5} km\ s^{-1})$$

$$v_{rad} = -4.6 \times 10^{-5} \times (3.00 \times 10^{5} km\ s^{-1}) = -13.8\ km\ s^{-1}$$

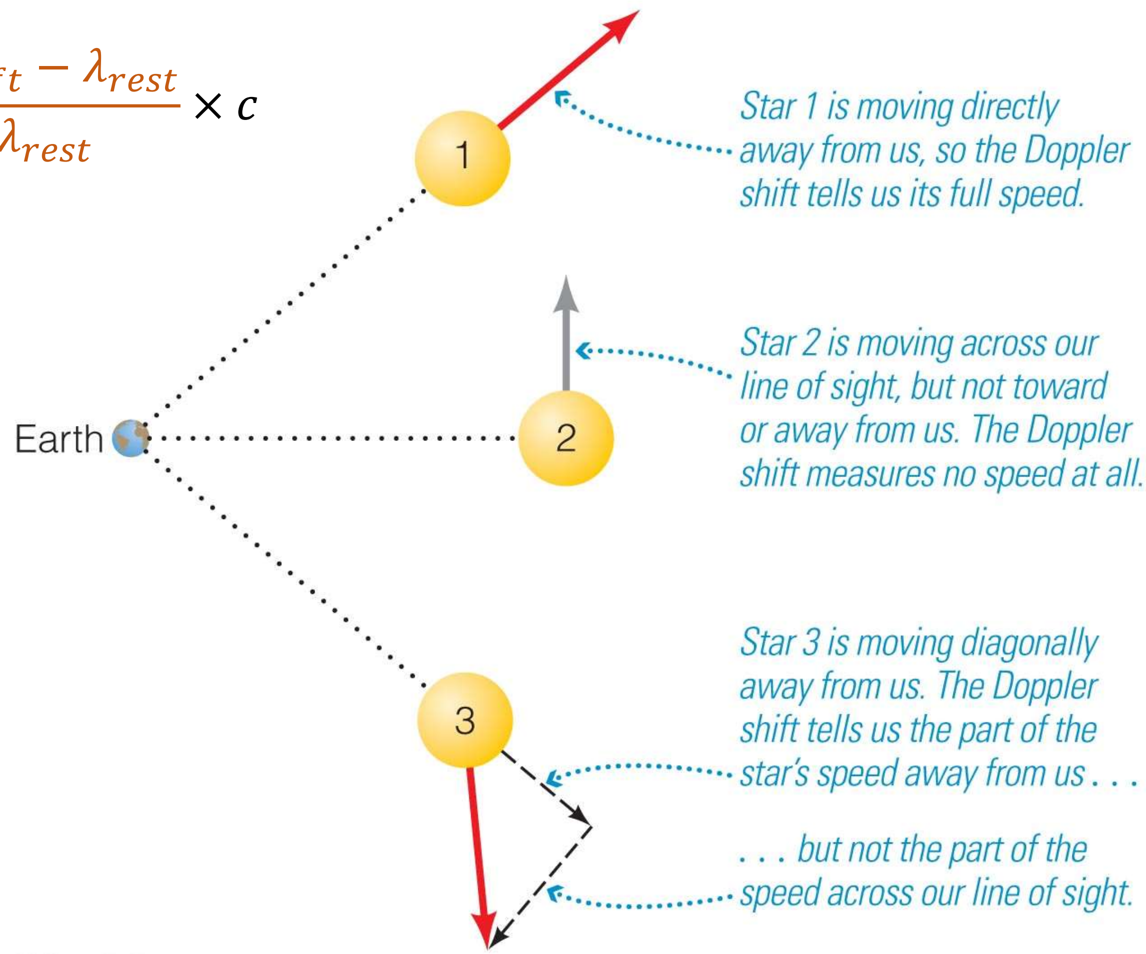
Orange part is just % difference. Units cancel…

Negative value indicates Vega is moving towards us

Doppler shift tells us ONLY about the part of an object's motion toward or away from us.

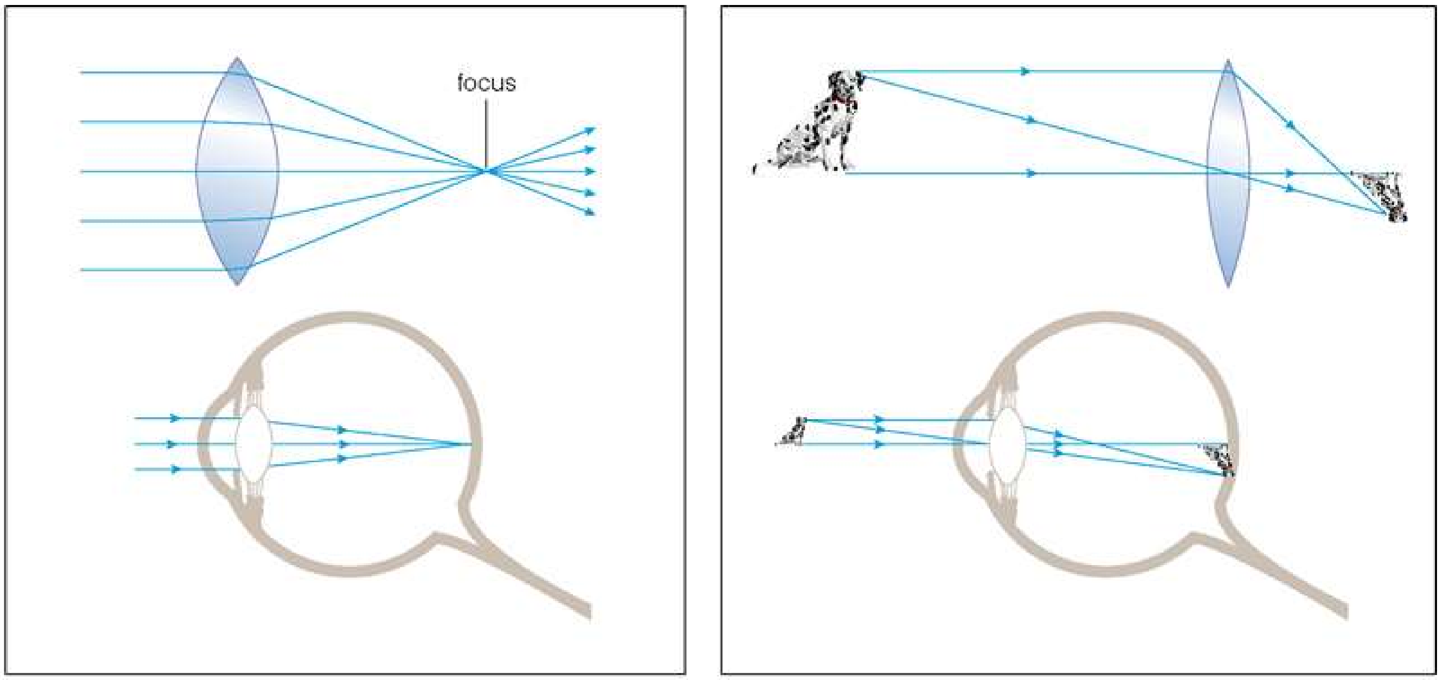
This is conveyed by use of the term 'radial velocity', V_{rad} in the equation

$$v_{rad} = \frac{\lambda_{shift} - \lambda_{rest}}{\lambda_{rest}} \times c$$



The Bending of Light

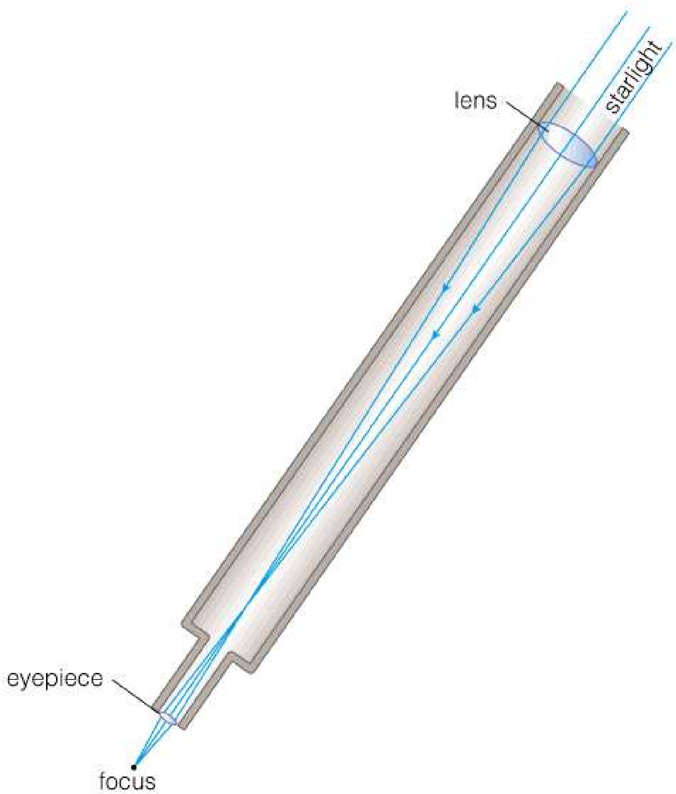
What Telescopes do is to collect and focus light, just like your eye….



Light rays which come from different directions converge at different points to form an *image*.

Basic Telescope Design

- Refracting: **lenses**

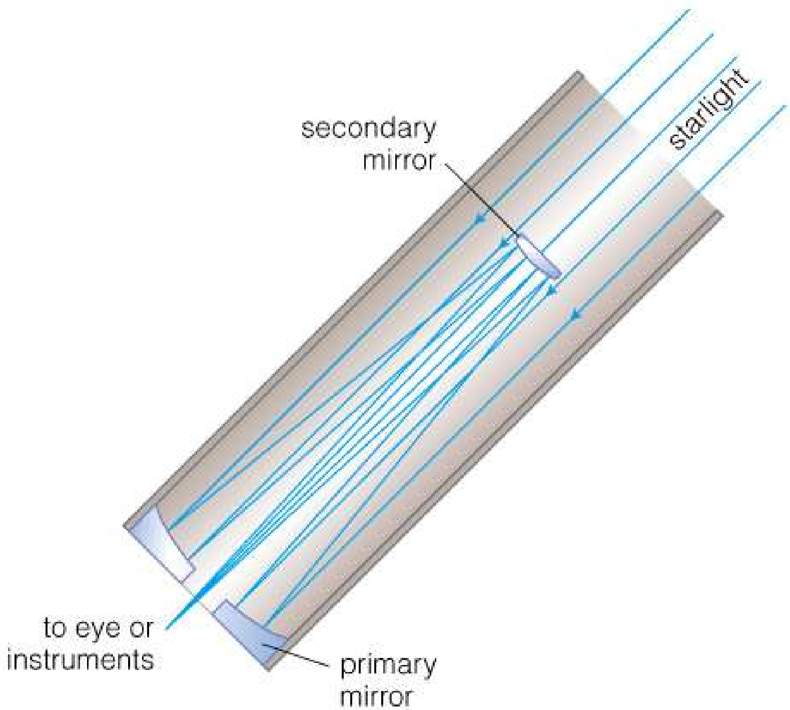


Refracting telescope

Yerkes 1-m refractor

Basic Telescope Design

- Reflecting: **mirrors**
- Most research telescopes today are reflecting



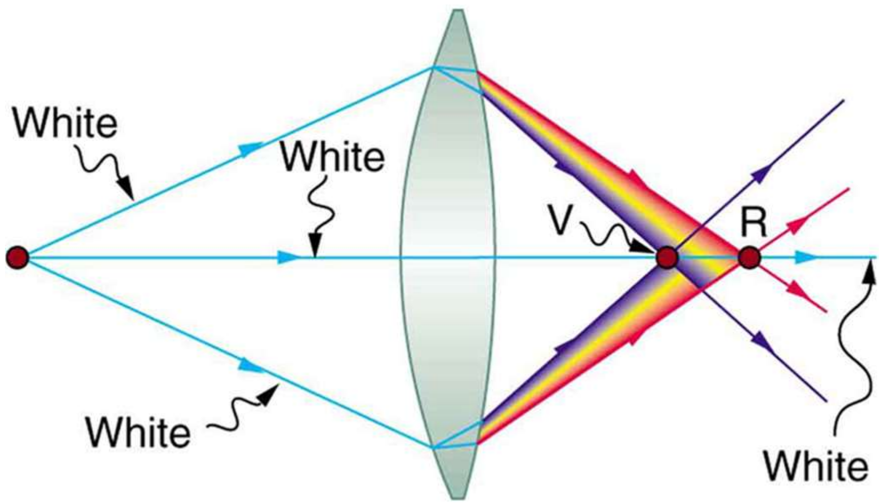
Reflecting telescope

Gemini North 8-m

Refracting or Reflecting Telescopes?

Refracting telescopes

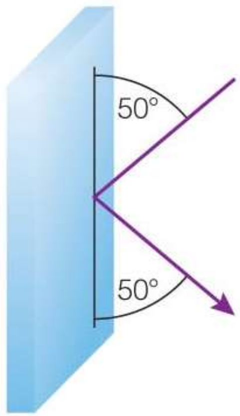
- Telescopes that use lenses to gather and focus light
- Objective lens that bends light that passes through it and focuses the light to be magnified to an eyepiece
- Disadvantages:
  - Chromatic aberrations
  - Size limited due to objective of lens



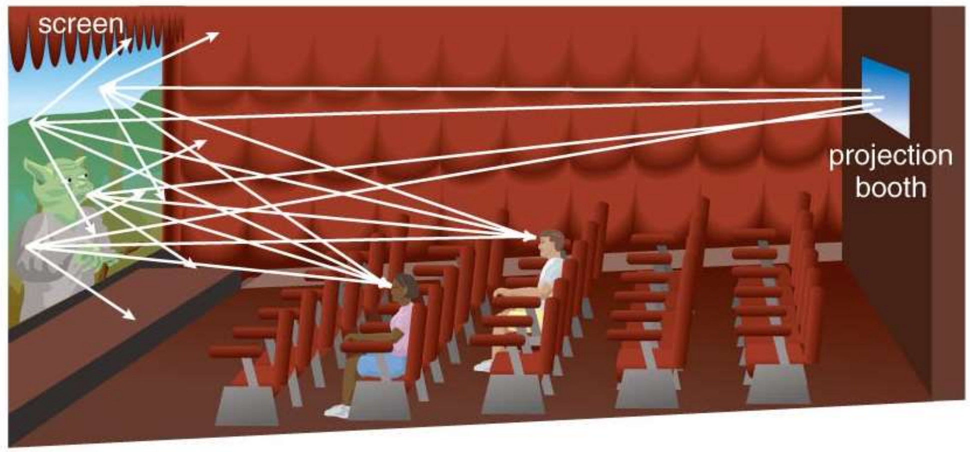
Reflecting telescopes

- Telescope that uses a curved (parabolic) mirror to gather and focus light
  - Light enters the telescope and is reflected from a large curved mirror to a flat mirror
  - Flat mirror focuses the image and reflects the light to be magnified
- Advantages
  - Mirrors can be very large
  - Prevents light from entering the glass
  - All colors have the same focal point
- Disadvantages
  - Can’t see vampires

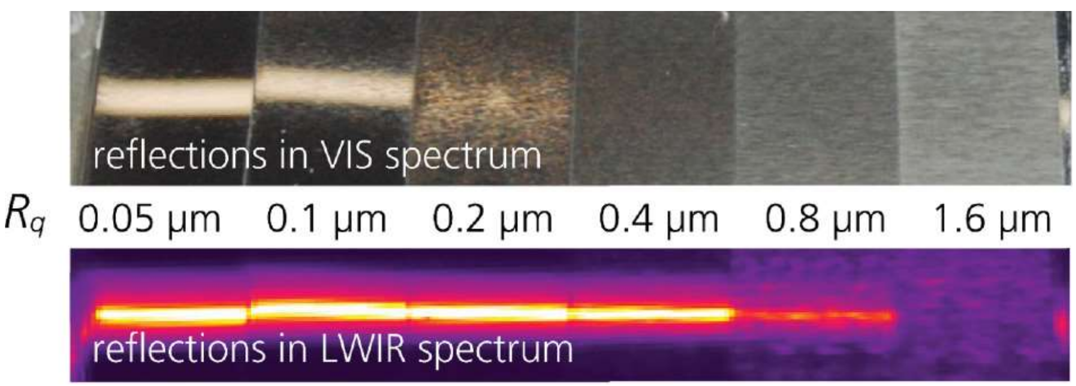
Reflection *vs.* Scattering



Mirror reflects light in a particular direction.



Movie screen scatters light in all directions.



Mirrors must have less surface roughness (they area flatter) to reflect shorter wavelength light, this matters far less for IR and microwaves/radiowaves

- Surface finish should be ~ order of λ

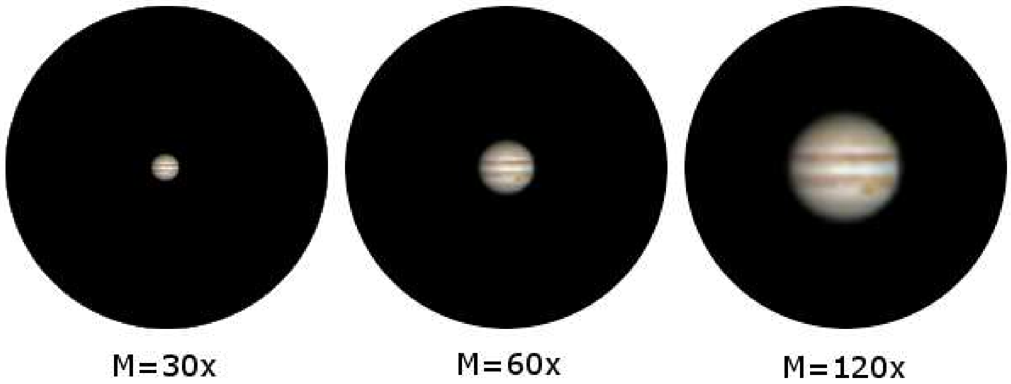
More important for UV-VIS spectroscopy

We don't have mirrors for XUV or X-rays! (See Chandra Observatory later)

Important Considerations for Telescope Design

In order of Importance:

1. Light Gathering Power
2. Resolving Power
3. Magnifying Power, M



Magnifying Power is actually the ***least*** important of these three. **Why?**

Magnifying Power Equation, $M = \frac{Focal\ Length\ of\ Objective}{Focal\ Length\ of\ Eyepiece}$

- The same # of photons are collected, but are dispersed over a wider area
- This leads to fainter, more blurry looking images

Resolving Power

Resolving Power: The ability of an optical instrument to produce two separate images of two objects very close together.

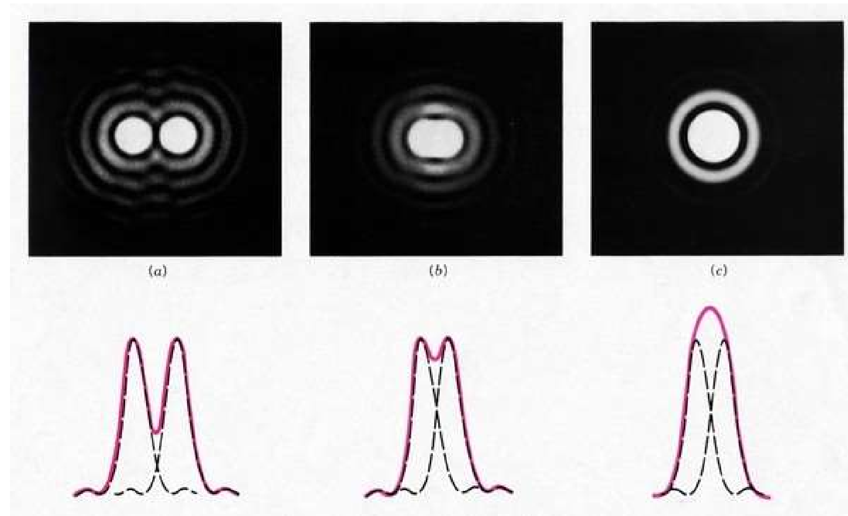
- The resolving power, α (in arc seconds) is given by:

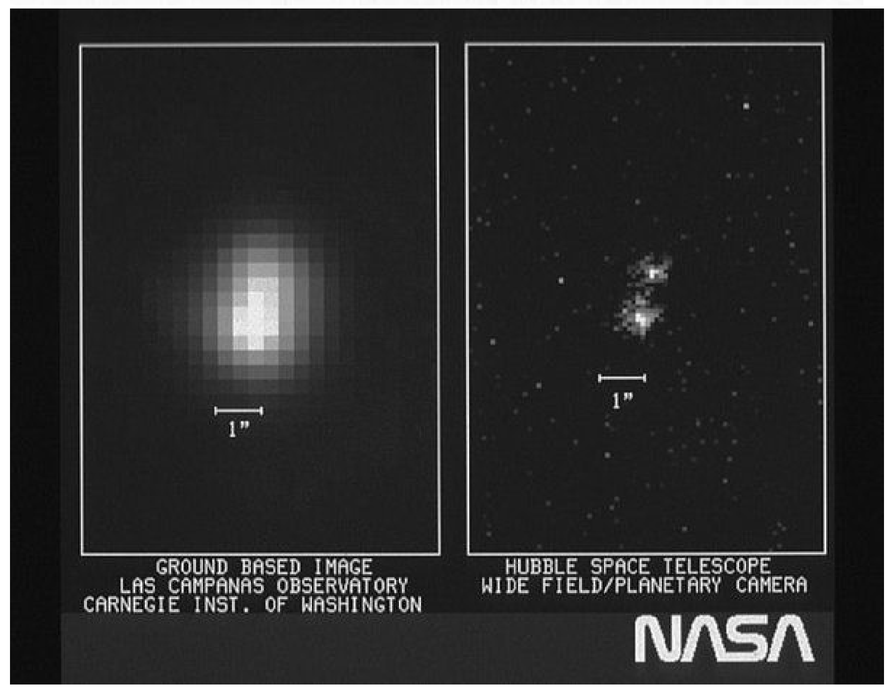
$$\alpha = \frac{11.6}{D}$$

Where *D* is the diameter of the telescope in centimeters.

This is also wavelength dependent, so the resolving angle, dθ may be given as:

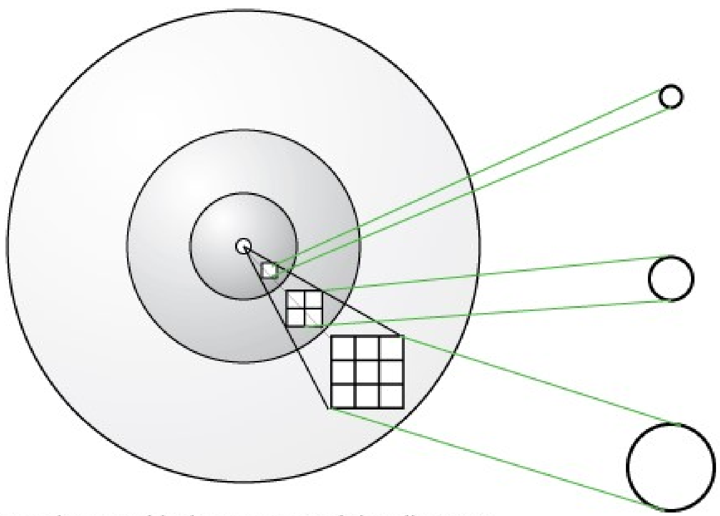
$$d\vartheta = \frac{1.22\lambda}{D}$$



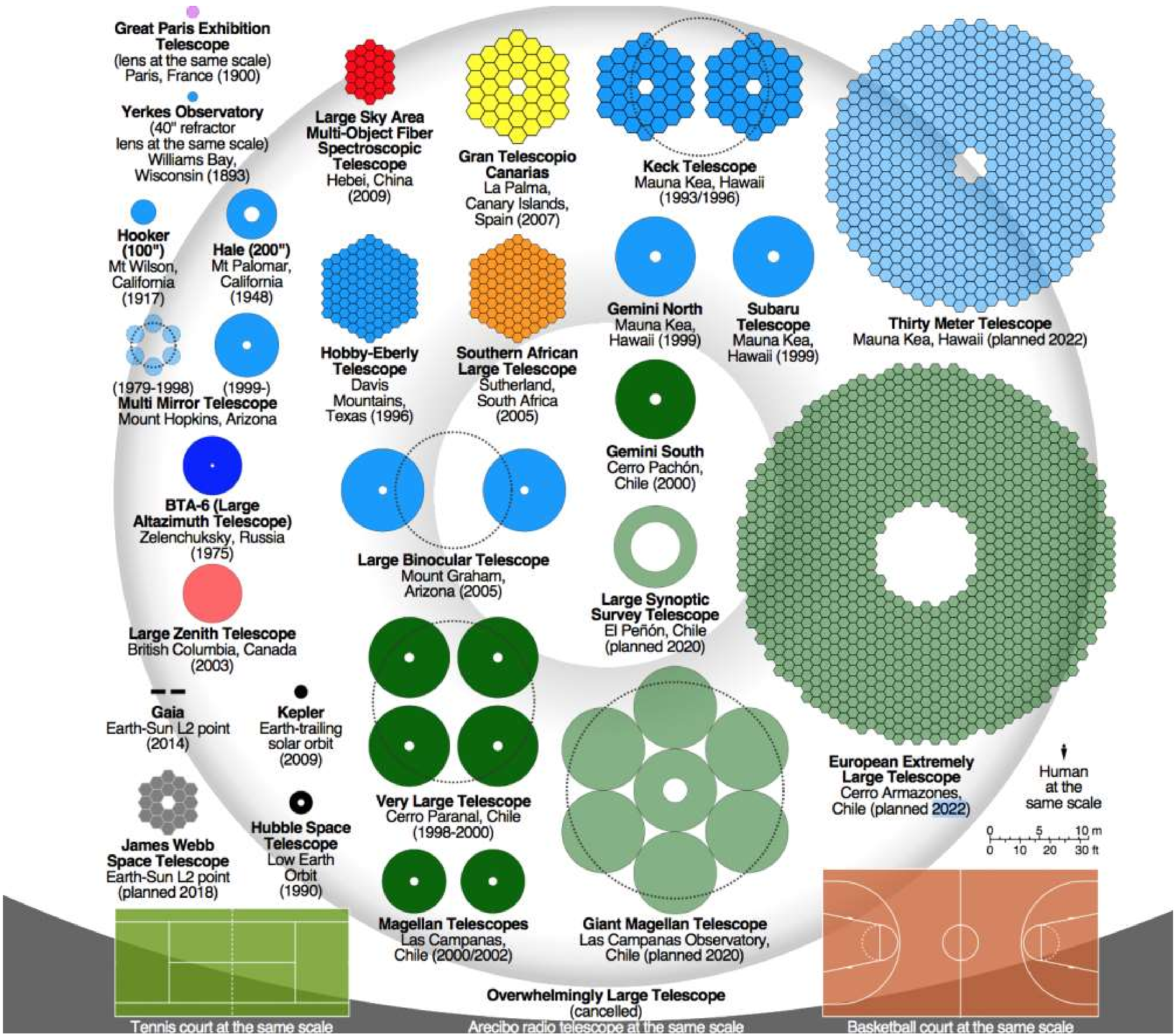


Light Gathering Power

- Astronomers often refer to telescopes as “Photon-buckets”
- The bigger the bucket, the more photons you collect.
- Your pupils dilate when it is dark to gather more light
- Based on the surface area
  - Most telescopes are circular
  - E.g., a 40 cm telescope collects 4x as much light as a 20 cm telescope!



Light spreads out with the **square** of the distance. Through a sphere twice as large, the energy covers an area **four** times larger. Through a sphere three times as large, the energy covers an area **nine** times larger.


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)
Hooker (100")
Mt Wilson, California (1917)
Hale (200")
Mt Palomar, California (1948)
(1979-1998)
(1999-)
Multi Mirror Telescope
Mount Hopkins, Arizona
BTA-6 (Large Altazimuth Telescope)
Zelenchukskу, Russia (1975)
Large Zenith Telescope
British Columbia, Canada (2003)
Gaia
Earth-Sun L2 point (2014)
Kepler
Earth-trailing solar orbit (2009)
James Webb Space Telescope
Earth-Sun L2 point (planned 2018)
Hubble Space Telescope
Low Earth Orbit (1990)
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)
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)
Gemini South
Cerro Pachón, Chile (2000)
Large Binocular Telescope
Mount Graham, Arizona (2005)
Large Synoptic Survey Telescope
El Peñón, Chile (planned 2020)
Very Large Telescope
Cerro Paranal, Chile (1998-2000)
Magellan Telescopes
Las Campanas, Chile (2000/2002)
Giant Magellan Telescope
Las Campanas Observatory, Chile (planned 2020)
European Extremely Large Telescope
Cerro Armazones, Chile (planned 2022)
Human at the same scale
0 5 10 m
0 10 20 30 ft
Overwhelmingly Large Telescope
(cancelled)
Tennis court at the same scale
Arecibo radio telescope at the same scale
Basketball court at the same scale

Some Very Large Telescopes

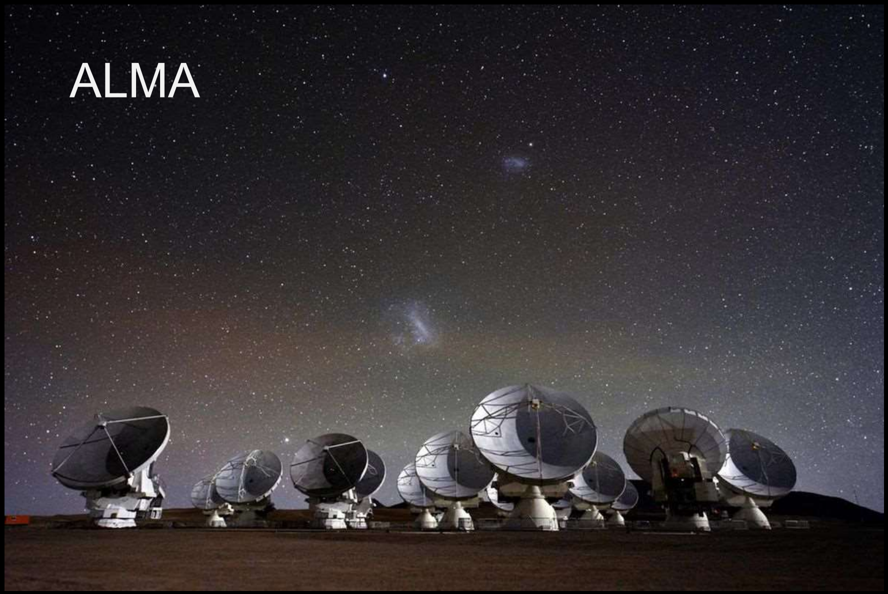
Arecibo 305m FAST radio telescope

China's 500m FAST radio telescope

Interferometry

Recall $\alpha = \frac{1.22\lambda}{D}$

- Radio telescopes typically have very poor angular resolution, since λ is large.
- Interferometry Combines the signals from several smaller telescopes to simulate one larger one.
- Has the same resolving power as the larger telescope.



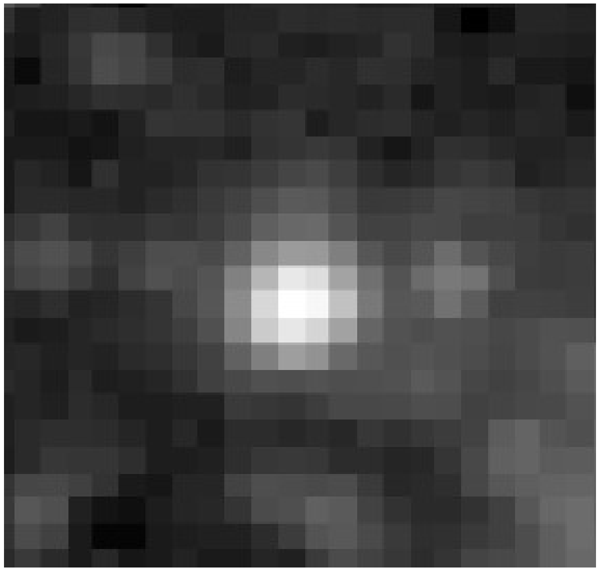
Problems Observing Space from Earth

Problem #1: Stray light causes air-glow which makes it harder to see dim objects. Light pollution from city lights often overwhelms telescopes, particularly making spectroscopy much more difficult

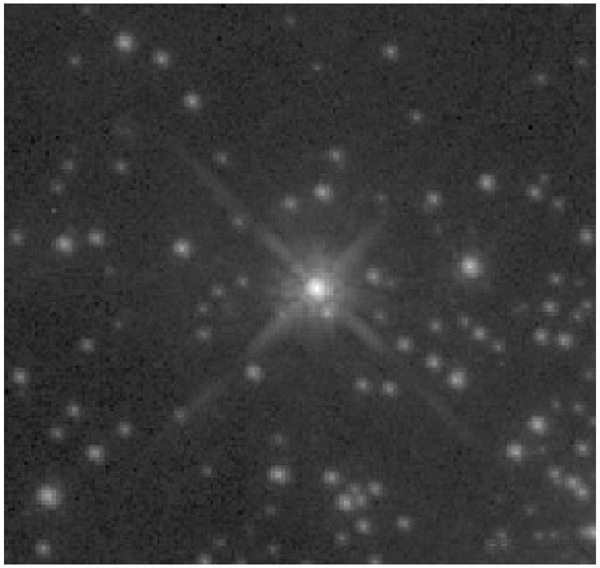
The Bortle Dark-Sky scale →

Problems Observing Space from Earth

Problem #2: Microchanges in air density due to movement of packets of warm/cold air causes turbulence in the atmosphere. The light takes slightly different paths causing its position to seem to vary, or twinkle, blurring images



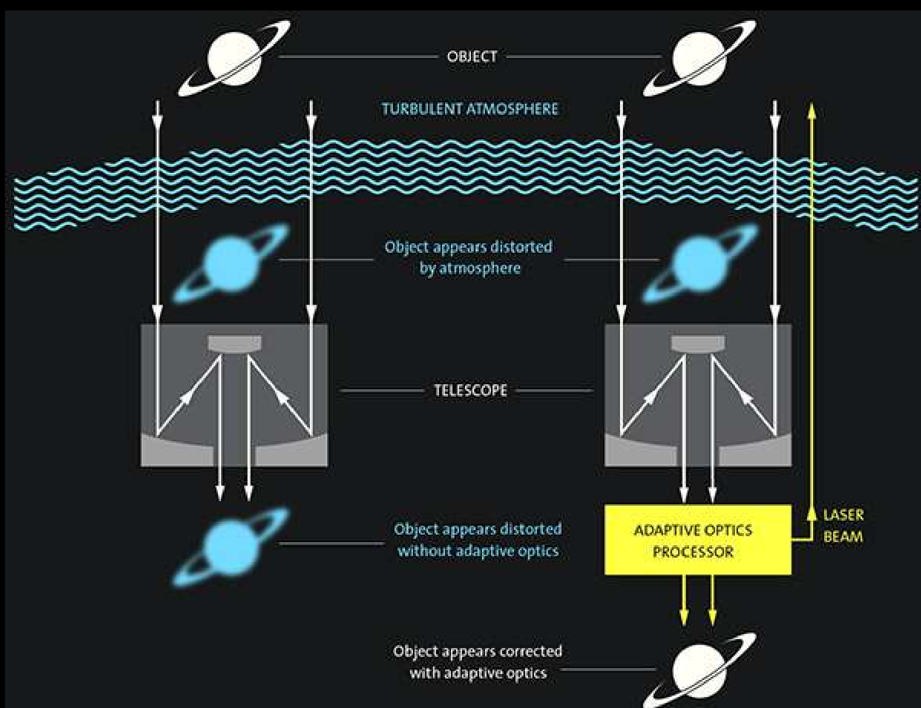
Star viewed with ground-based telescope



View from Hubble Space Telescope

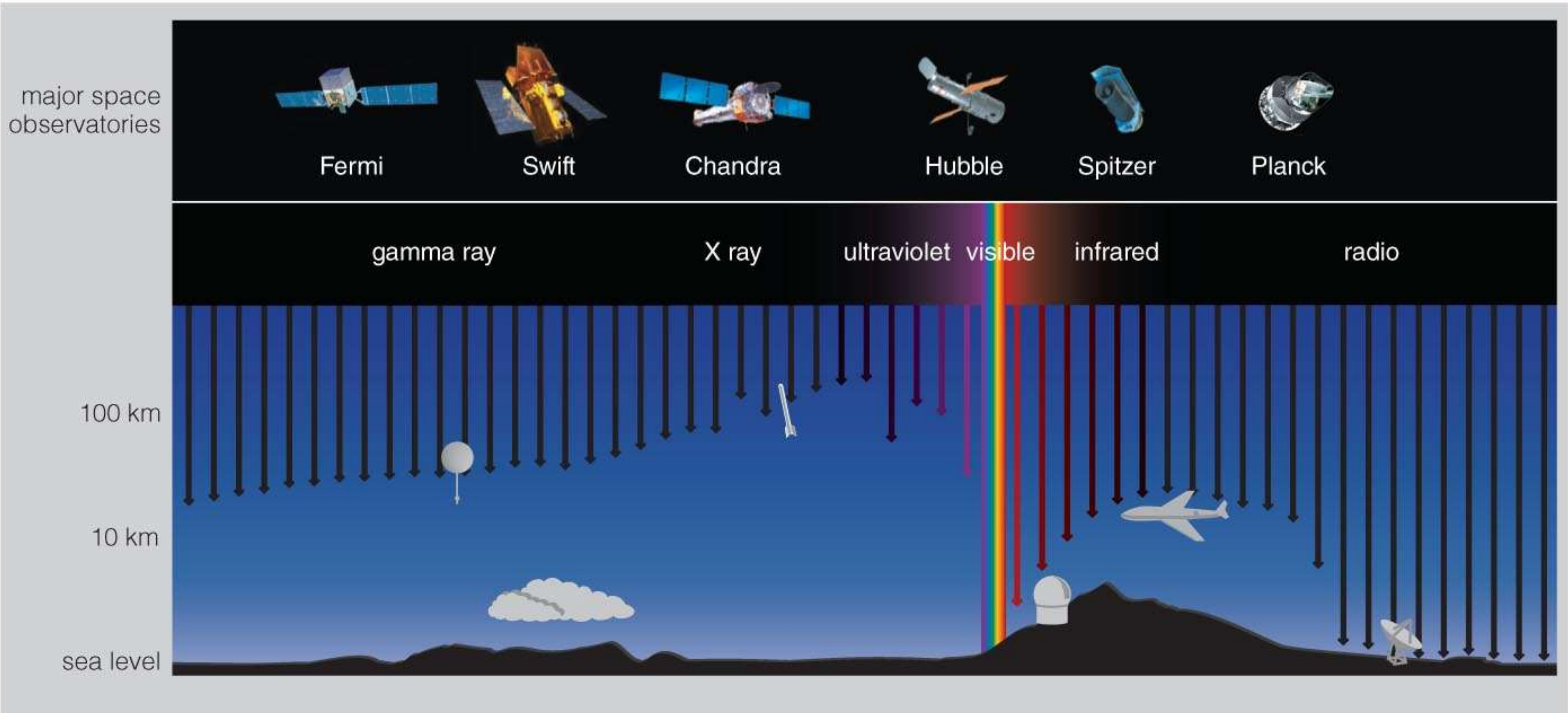
Adaptive Optics

Uses a feedback system and rapidly changes the mirror shape to compensate for atmospheric distortions



Problems Observing Space from Earth

Problem #3: The Atmosphere - absorbs most of the electromagnetic spectrum, including all UV and X ray and most of the infrared.

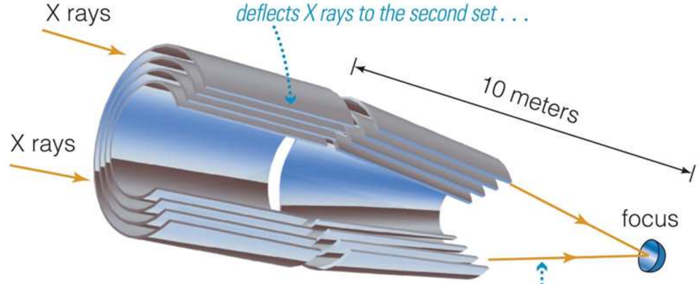



Observatories on Mauna Kea, 4,205 m (13,796 ft)

Telescopes in space solve all three problems.

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

X-rays graze metal sheet mirrors slowly being guided into focus



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.

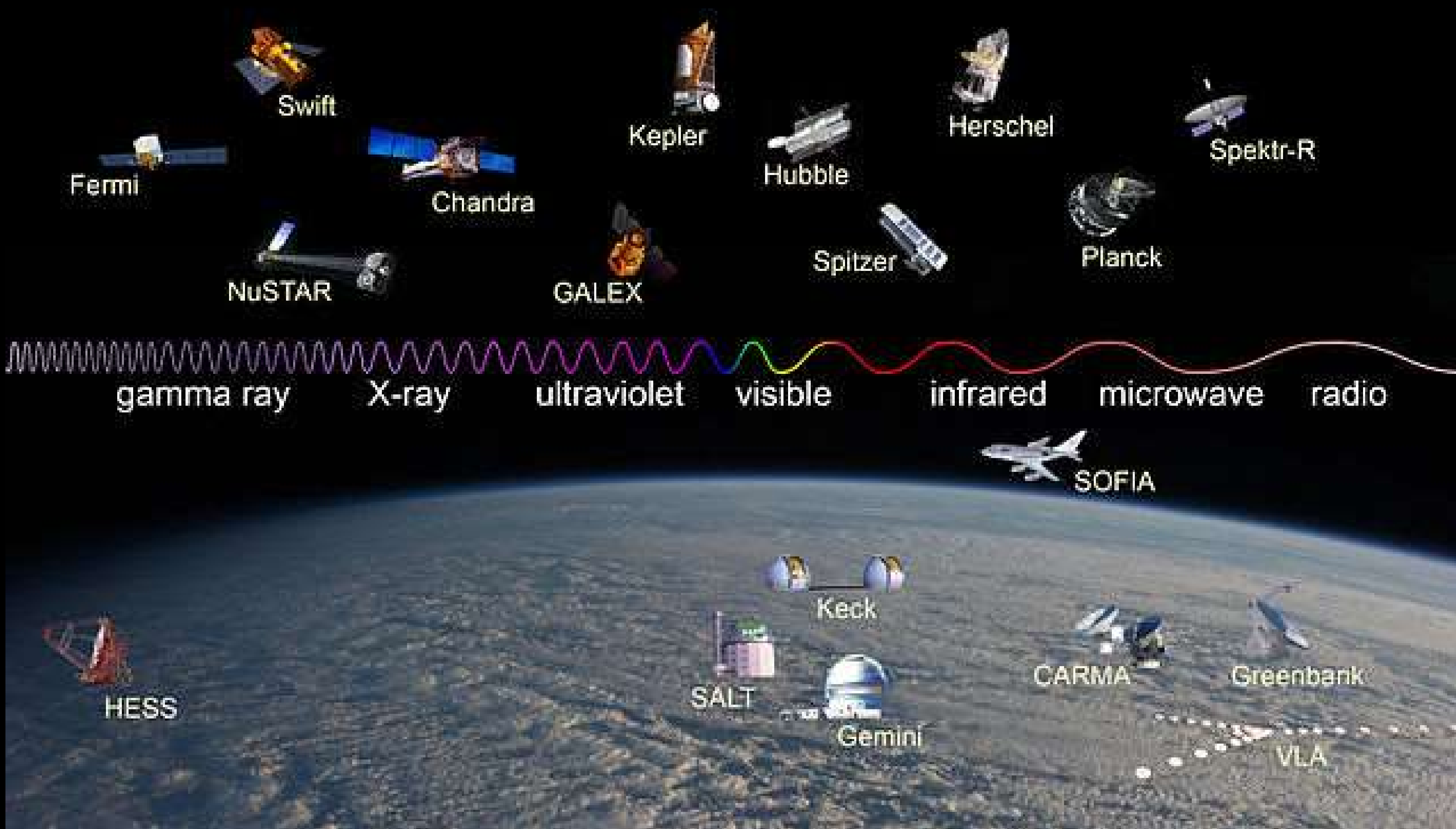
Chandra X-Ray Observatory

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

James Webb Space Telescope

The James Webb Space Telescope, a full-scale model of which is shown here, is set to launch in October 2018.

Summary of Space Borne (or High-Altitude) Telescopes



End of Todays Lecture