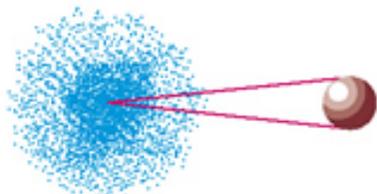


Astronomy 100
Exploring the Universe
Tuesday, Wednesday, Thursday

Tom Burbine
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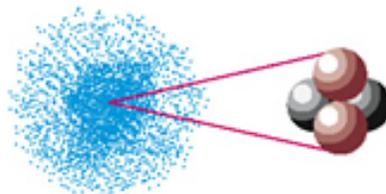
atomic number 5 number of protons
atomic mass number 5 number of protons 1 neutrons

Hydrogen (${}^1\text{H}$)



atomic number 1
atomic mass number 1
(1 electron)

Helium (${}^4\text{He}$)



atomic number 2
atomic mass number 4
(2 electrons)

Carbon (${}^{12}\text{C}$)



atomic number 6
atomic mass number 12
(6 electrons)

The number of electrons in a neutral atom equals its atomic number.

Isotopes of Carbon

carbon-12



${}^{12}\text{C}$

(6 protons 1 6 neutrons)

carbon-13



${}^{13}\text{C}$

(6 protons 1 7 neutrons)

carbon-14



${}^{14}\text{C}$

(6 protons 1 8 neutrons)

Different isotopes of a given element contain the same number of protons but different numbers of neutrons.

Definitions

- *Atomic Number – Number of protons*
- *Atomic Mass – Number of protons and neutrons*
- *${}^{235}_{92}\text{U}$ – atomic mass
92- atomic number*
- *Isotopes – Same number of protons but different numbers of neutrons*

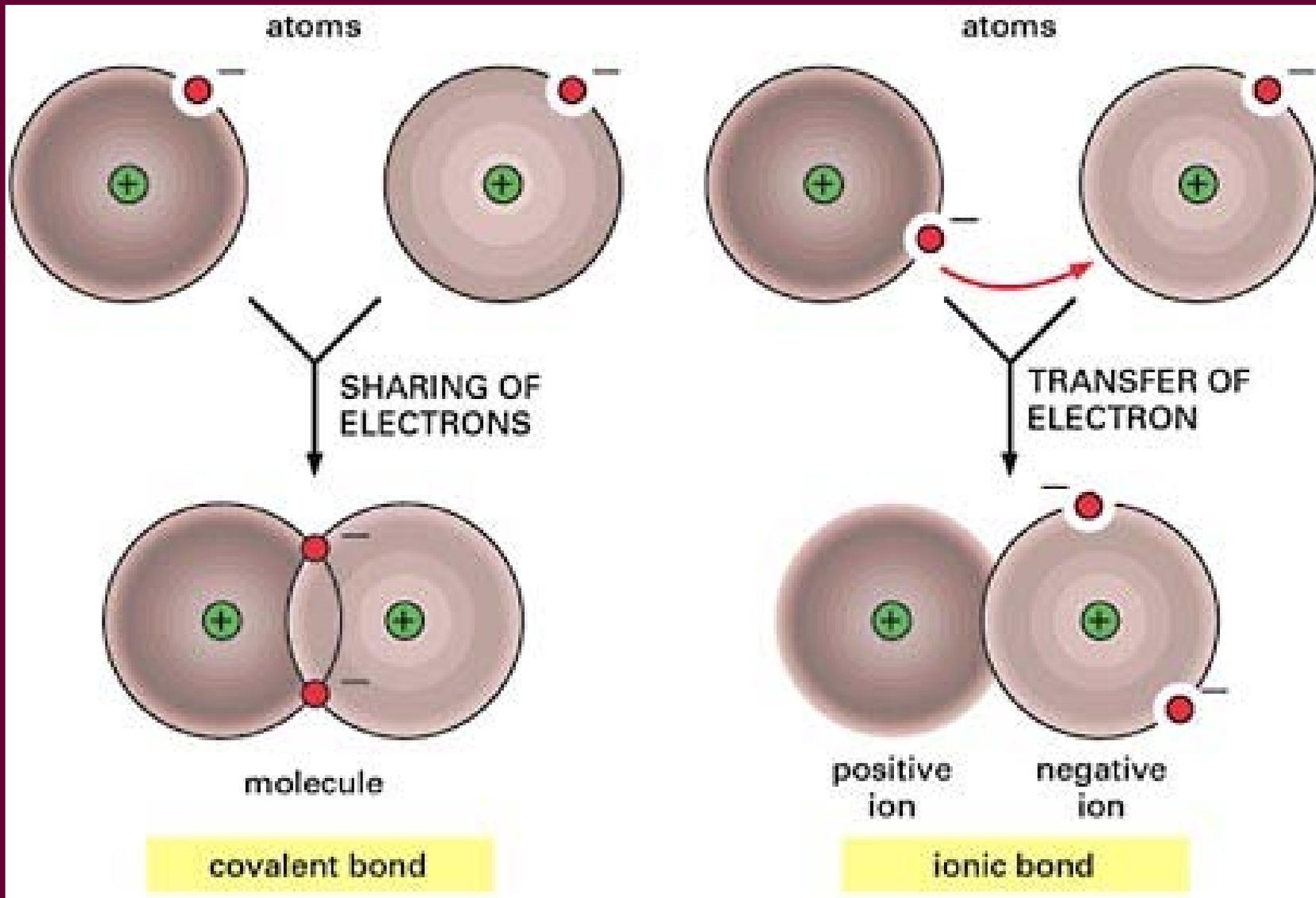
Molecules

- *an electrically neutral group of at least two atoms in a definite arrangement held together by very strong chemical bonds*

H₂O - water

CO₂ – carbon dioxide

CH₄ - methane



↑
I
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C
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S
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T
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M
P
E
R
A
T
U
R
E

millions of K



Fully ionized plasma.

Atoms in plasma become increasingly ionized.

tens of thousands of K



Plasma Phase

Free electrons move among positively charged ions.

thousands of K



Molecular dissociation into component atoms.

hundreds of K



Gas Phase

Atoms or molecules move essentially unconstrained.



Liquid Phase

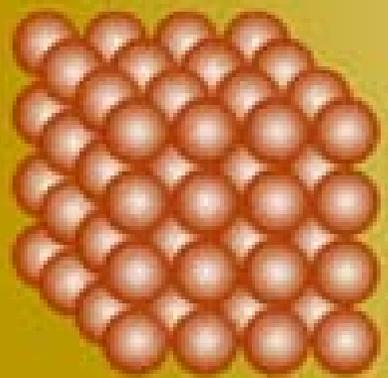
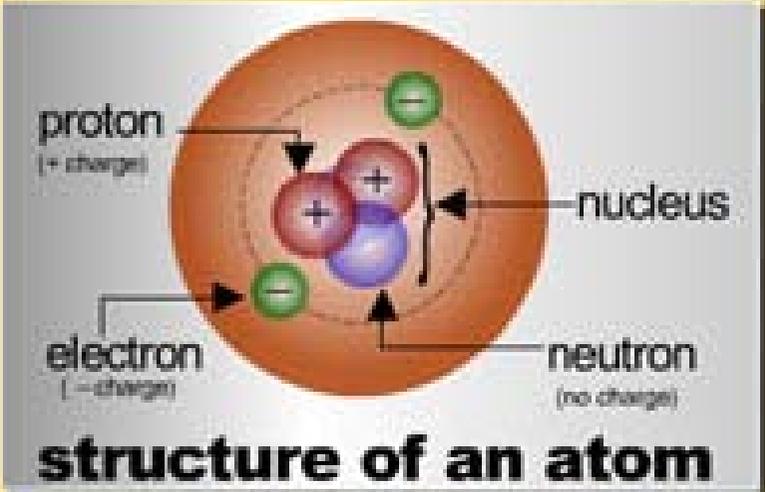
Atoms or molecules remain together but move relatively freely.



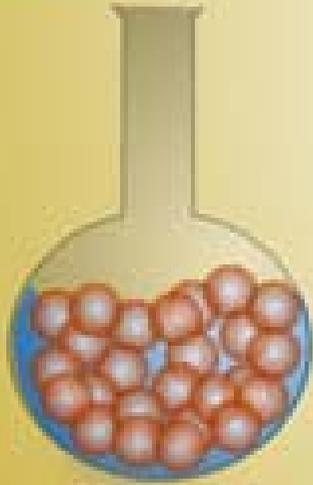
Solid Phase

Atoms or molecules are held tightly in place.

cold



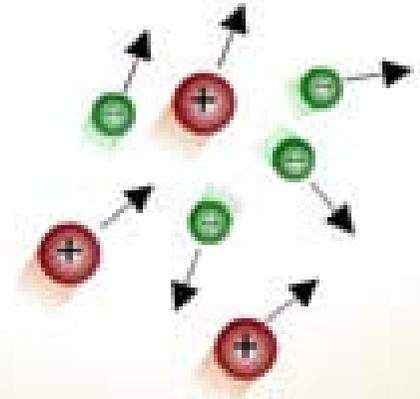
Solid



Liquid



Gas

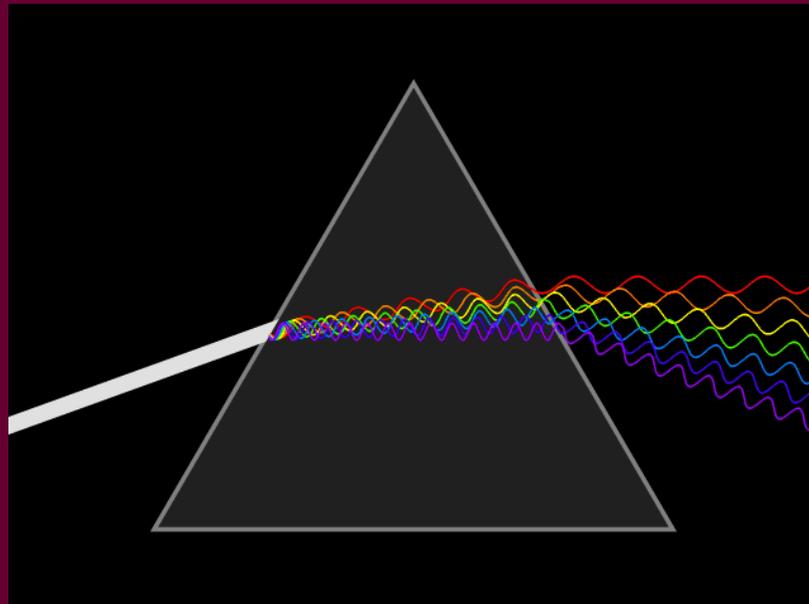


Plasma



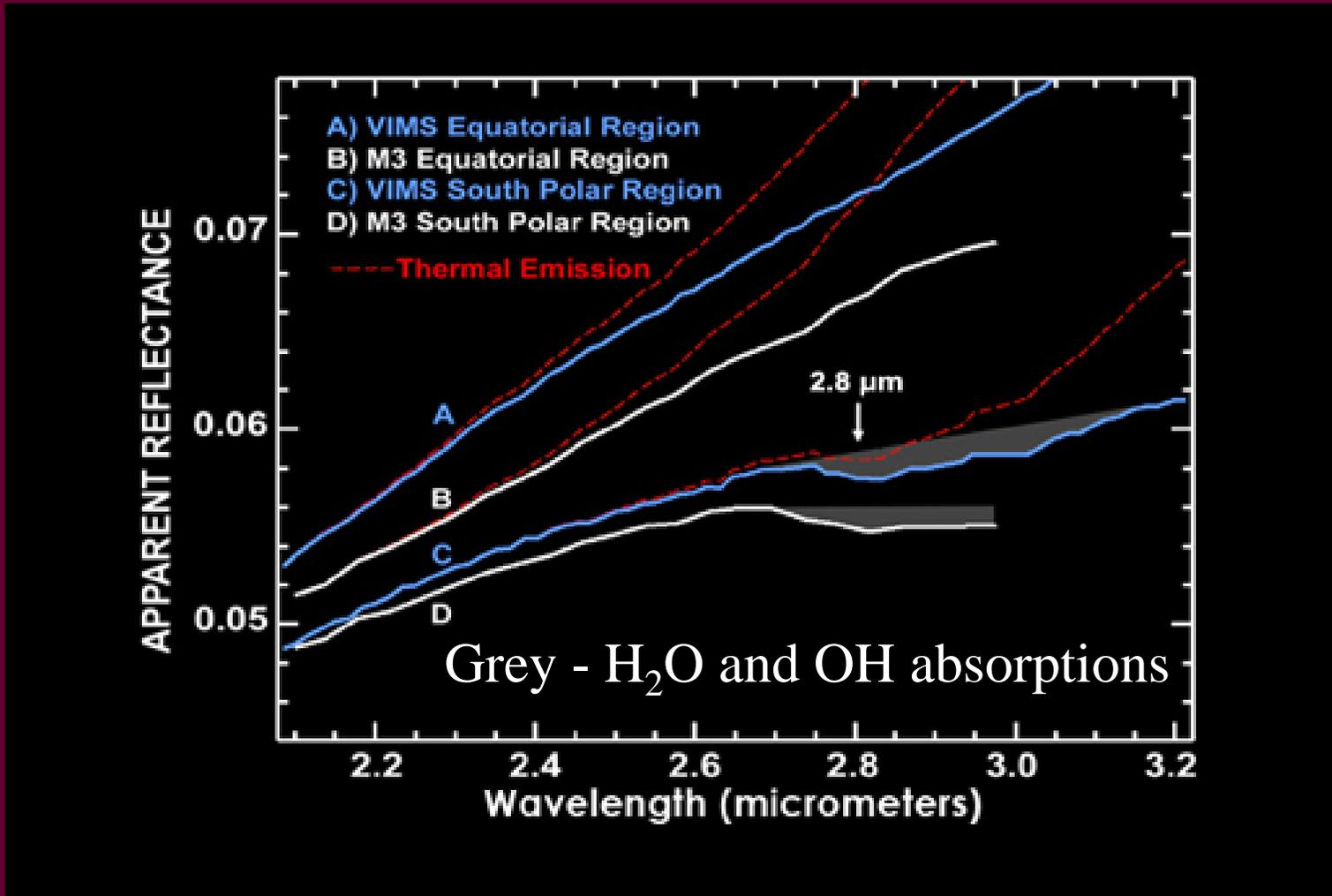
Spectroscopy

- Spectroscopy is the study of the interaction between radiation and matter as a function of wavelength (λ).
- You can use spectroscopy to determine what is in a body (planet, star, etc.) or atmosphere



- How did scientists determined that there was water on the Moon?

Water on the Moon



White line - NASA's Cassini spacecraft

Blue line - NASA's Moon Mineralogy Mapper instrument on the Indian Chandrayaan-1 spacecraft

Definitions

- Reflectance – How much light an object reflects
- Absorption – Light is absorbed and not reflected

Light cause water molecules to vibrate

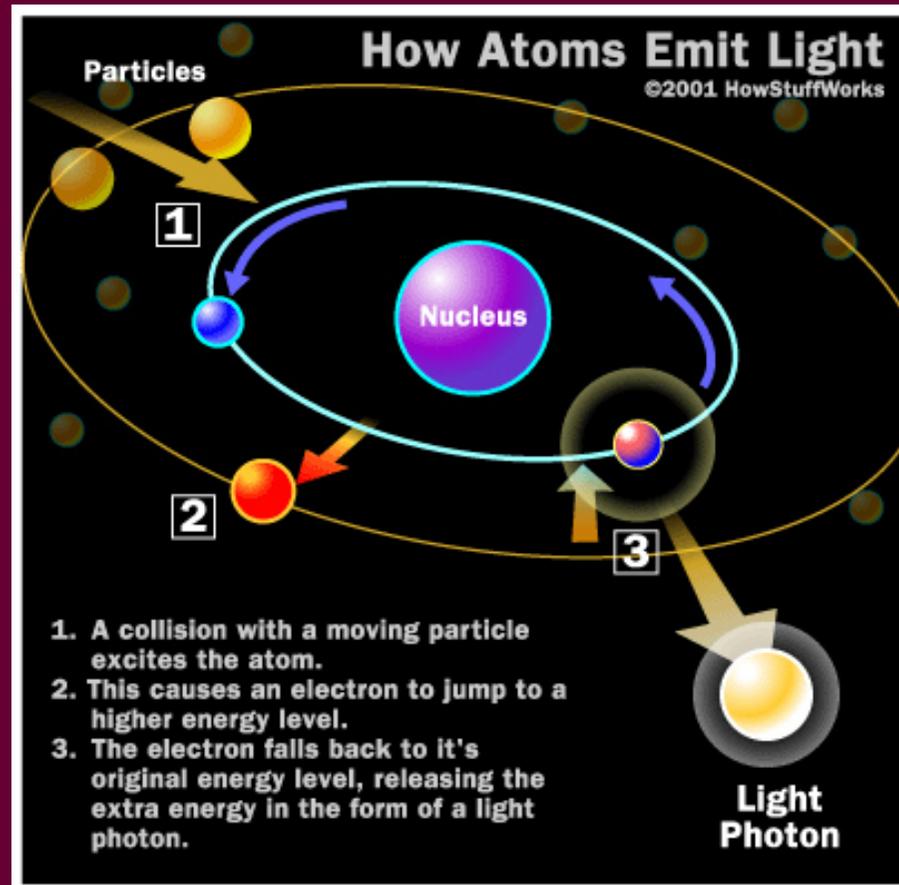
- <http://www.btinternet.com/~martin.chaplin/vibrat.html>

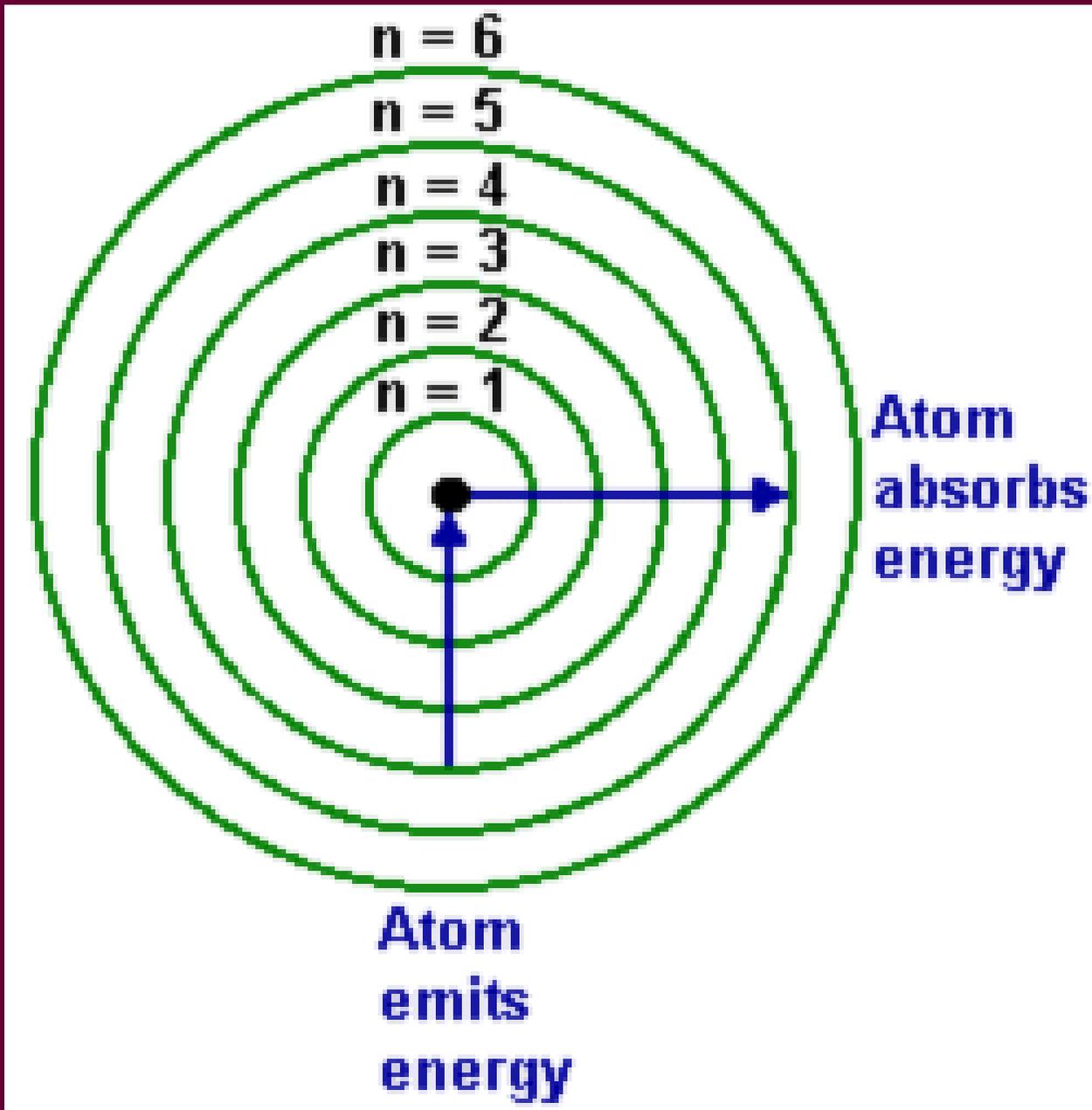
How much water?

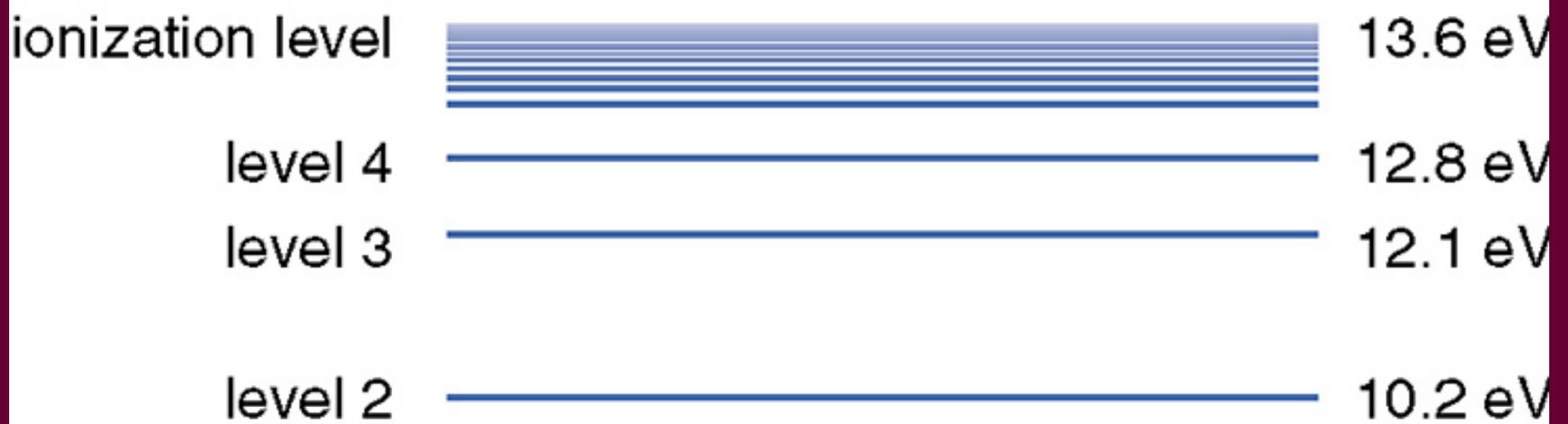
- If you had a cubic meter of lunar soil, you could squeeze it and get out a liter of water
- Water has to be near the surface

How do you use light to determine
what is in an astronomical body
like a star?

What happens when electrons absorb energy?







Energy levels where an electron can reside

To go to a higher energy level, an electron needs to gain energy

To go to a lower energy level, an electron needs to lose energy

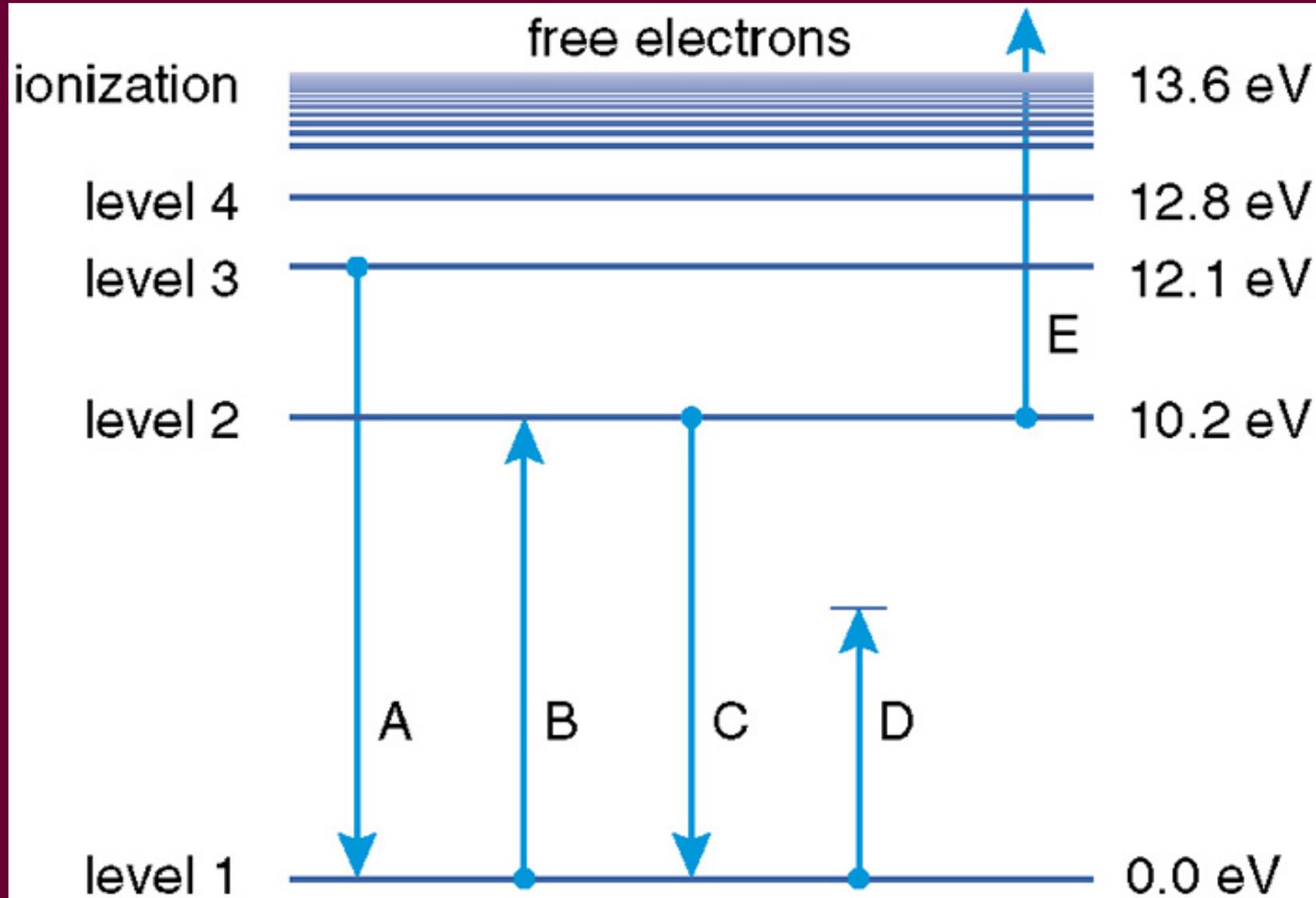


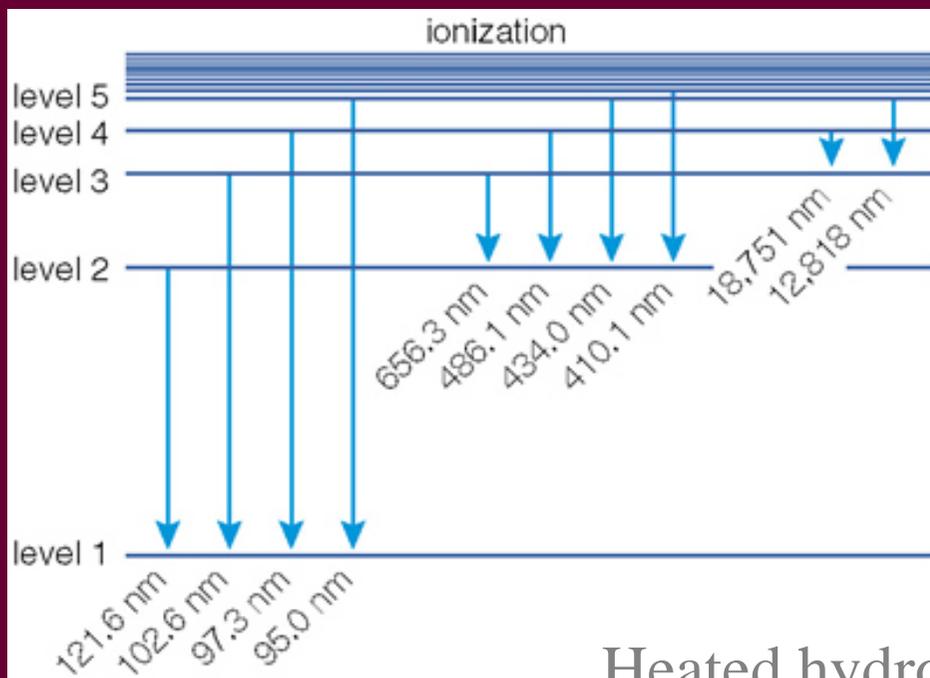
eV

- $1 \text{ eV} = 1.6 \times 10^{-19} \text{ Joules}$

Rules

- An electron can not jump to a higher energy level unless it gains energy from somewhere else
 - Absorbs a photon
 - Gains kinetic energy from an impacting particle
- To go to a lower energy level, the electron must lose energy
 - Emits a photon
- Electron jumps can occur only with the particular amounts of energy representing differences between possible energy levels





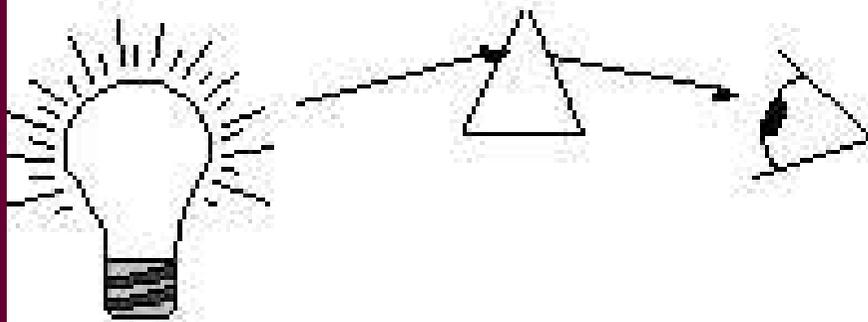
Heated hydrogen gas
Emission line spectrum



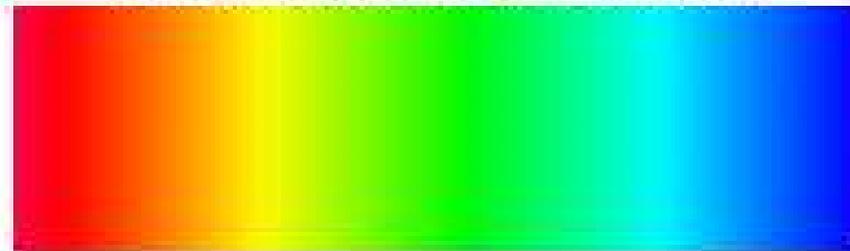
White light through cool hydrogen gas
Absorption line spectrum

Types of spectra

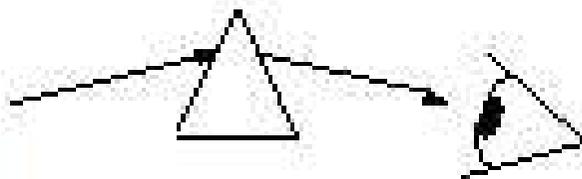
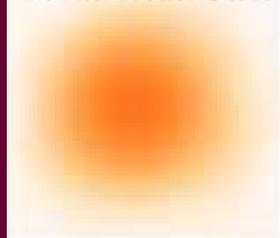
- Emission – radiation is emitted at characteristic wavelengths
 - Material is “hot” so electrons keep on bumping into each other and transferring kinetic energy to each other so they jump between particular energy levels
- Absorption – radiation is absorbed at characteristic wavelengths
 - Radiation passes through the material



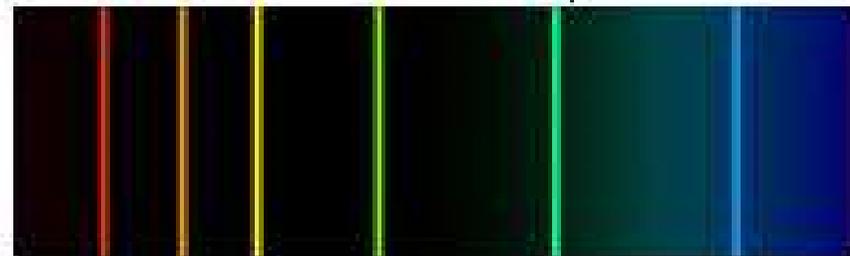
Continuum Spectrum



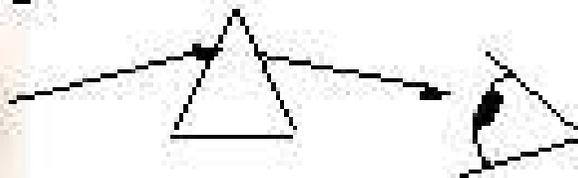
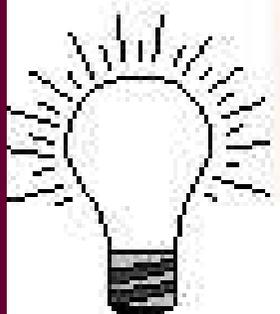
Hot Gas



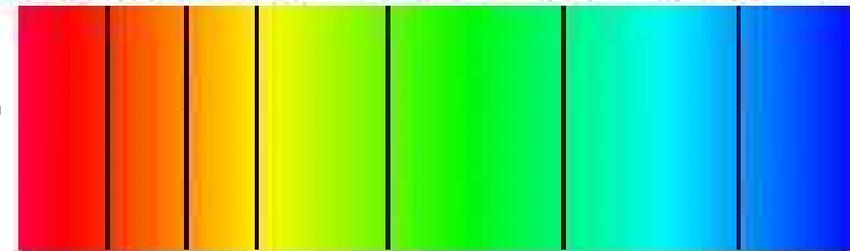
Emission Line Spectrum



Cold Gas



Absorption Line Spectrum



So why is this important

- Different elements have different number of electrons
- Different elements have different energy levels for their electrons

So

- Different elements can absorb light at specific energies
- Different elements can emit light at specific energies
- So if you can measure the wavelength of the light from an astronomical body, you can determine what's in it

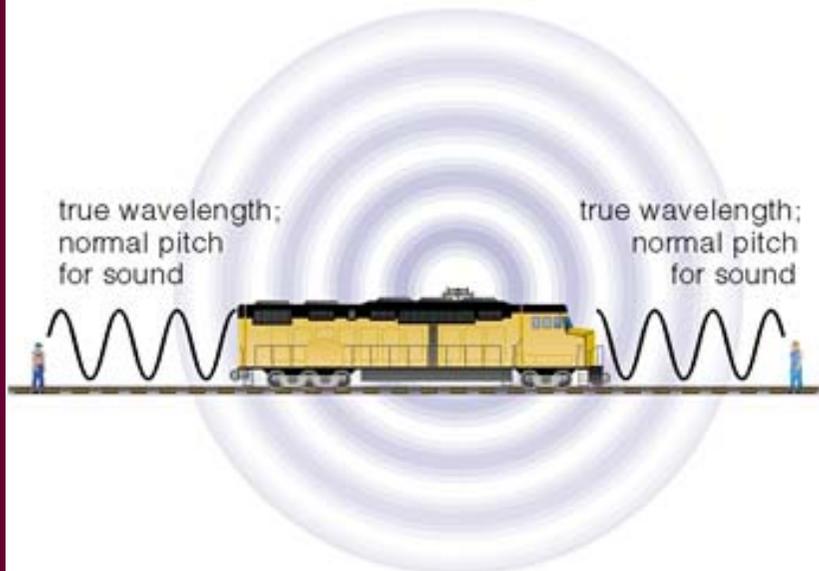
Emission line spectra



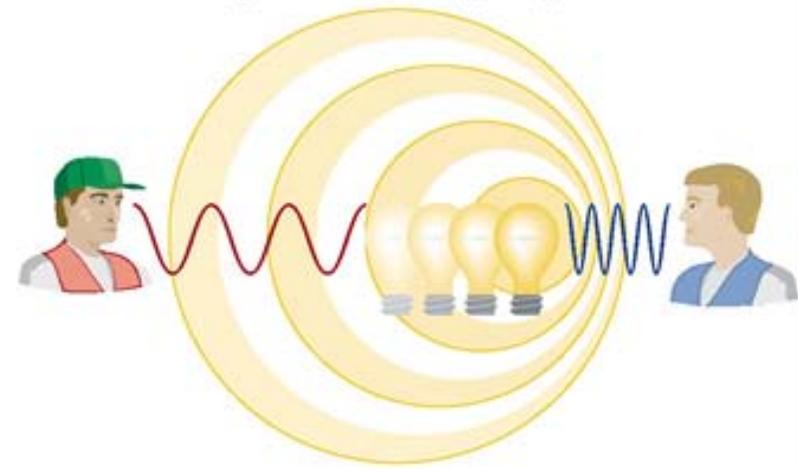
How can you determine velocities of objects?

- Doppler Shift – The wavelength of light changes as the source moves towards or away from you
- Since you know the wavelength position of emission or absorption features
- If the positions of the features move in wavelength position, you know the source is moving

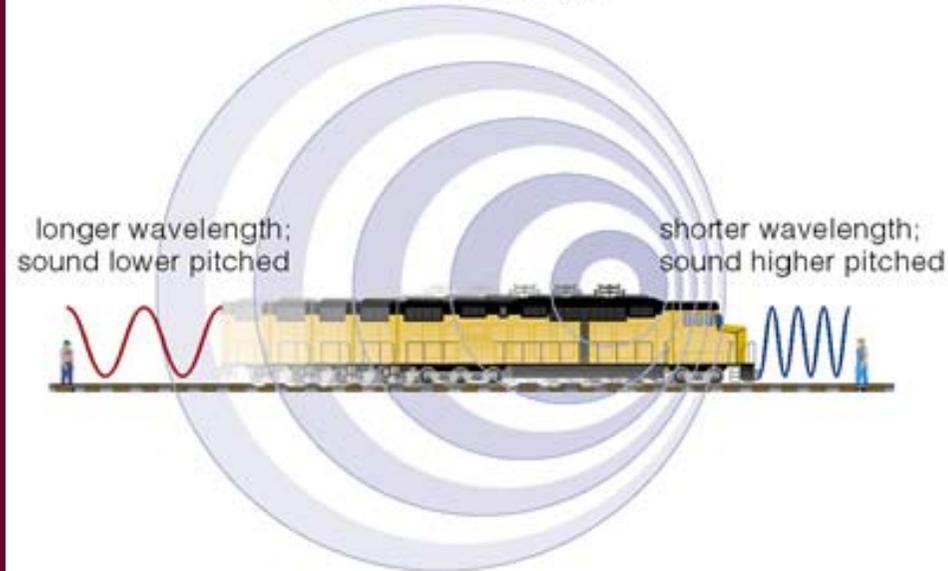
train stationary



light source moving to right



train moving to right



So

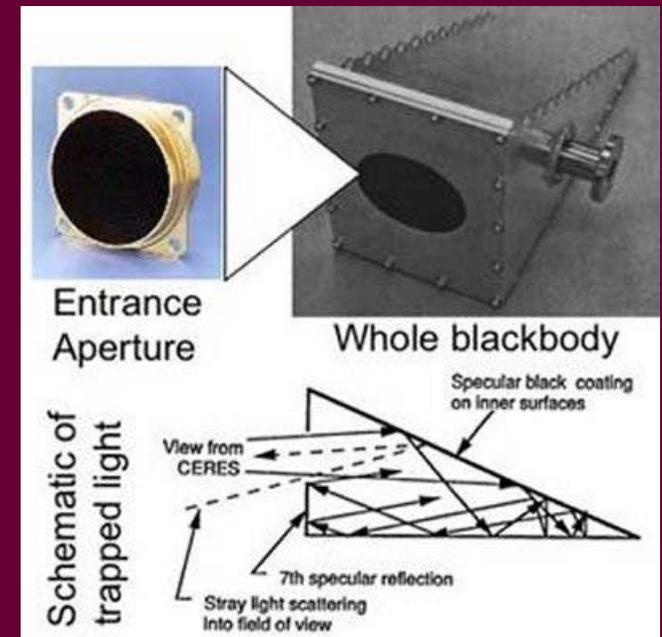
- Source moving towards you, wavelength decreases
 - blueshift
- Source moving away from you, wavelength increases
 - redshift
- <http://www.youtube.com/watch?v=-t63xYSgmKE>
- <http://www.youtube.com/watch?v=a3RfULw7aAY>

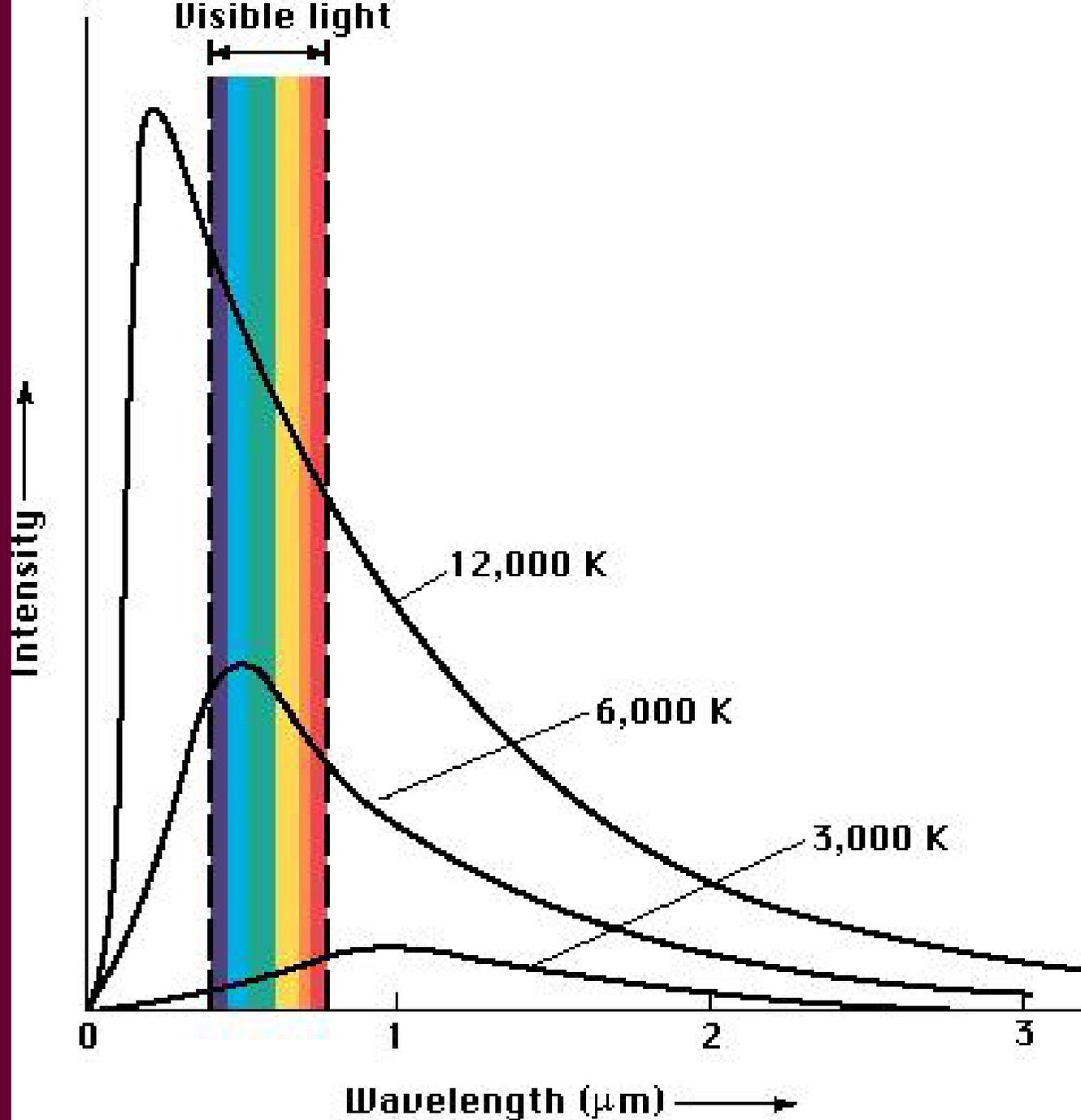
nanometer

- 1 nanometer = 1×10^{-9} meters

Blackbody

- A black body is an object that absorbs all electromagnetic radiation that falls onto it.
- Perfect emitter of radiation
- Radiates energy at every wavelength





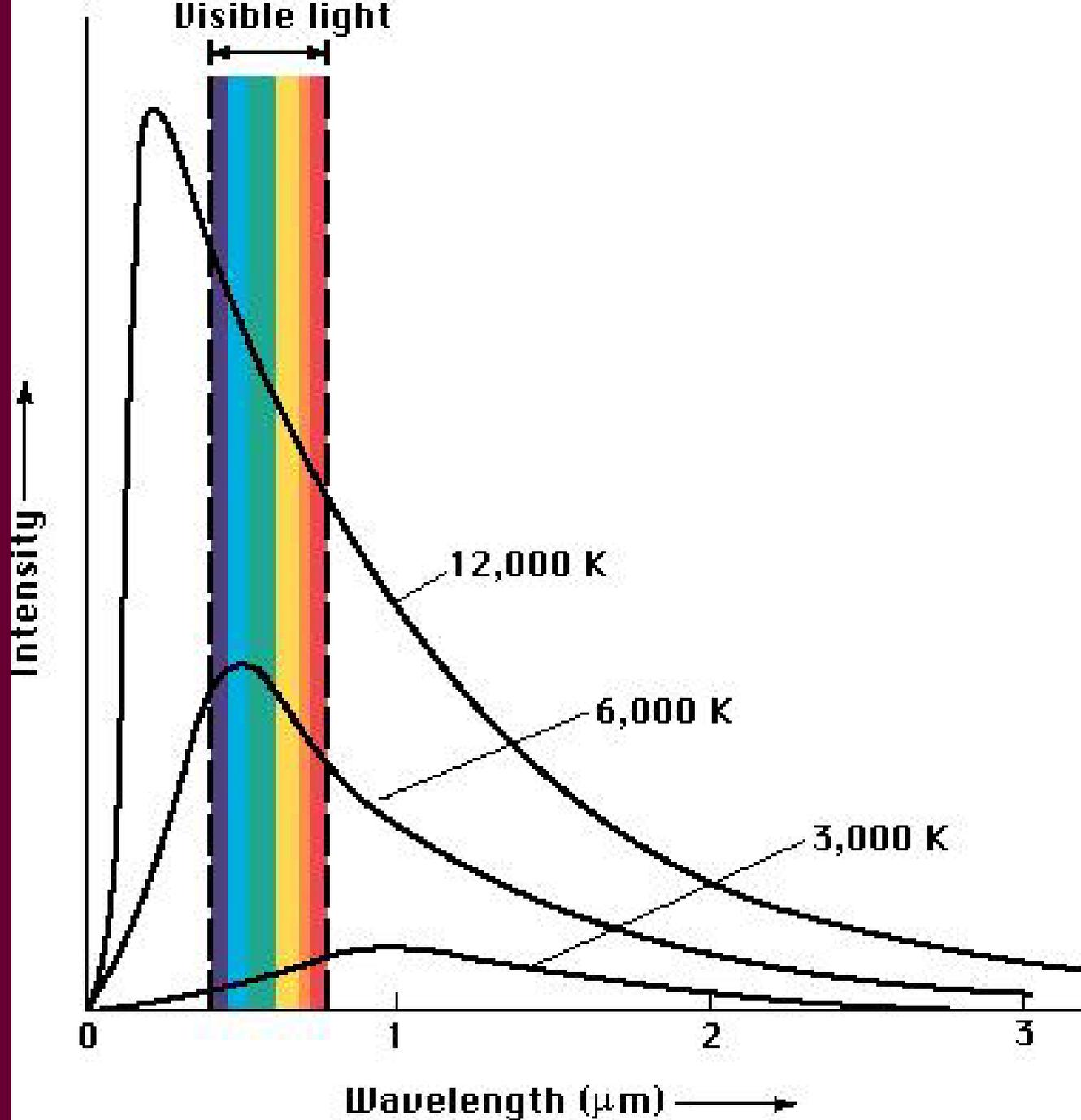
- Stars and planets act can be modeled as blackbodies

- Stefan-Boltzmann Law - The energy radiated by a blackbody per second per unit area is proportional to the fourth power of the temperature

$$\frac{\text{Energy emitted}}{\text{s} * \text{m}^2} \propto T^4$$

- Wien's Law – There is an inverse relationship between the wavelength of the peak of the emission of a black body and its temperature

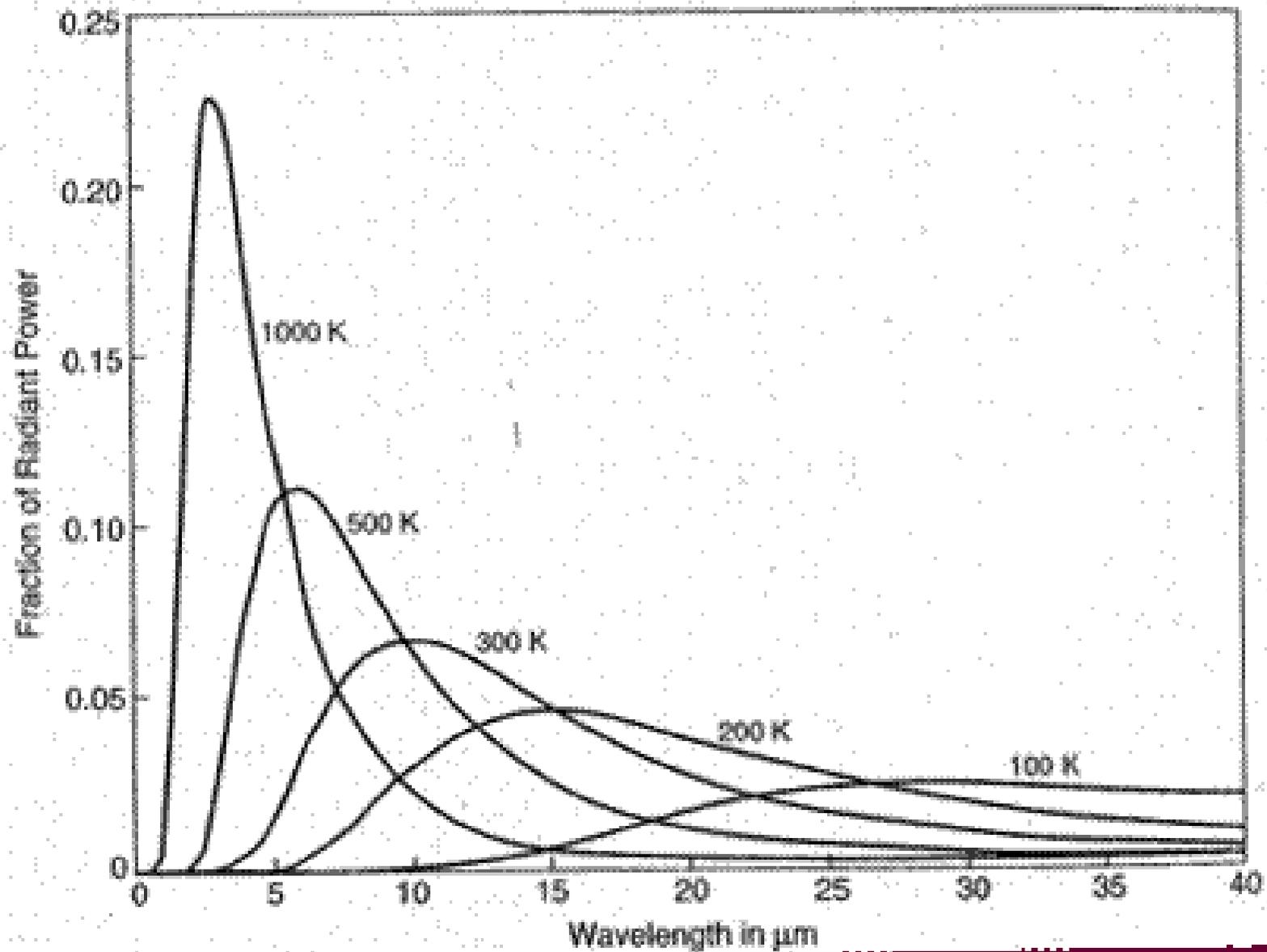
$$\text{Peak position} \propto 1/T$$

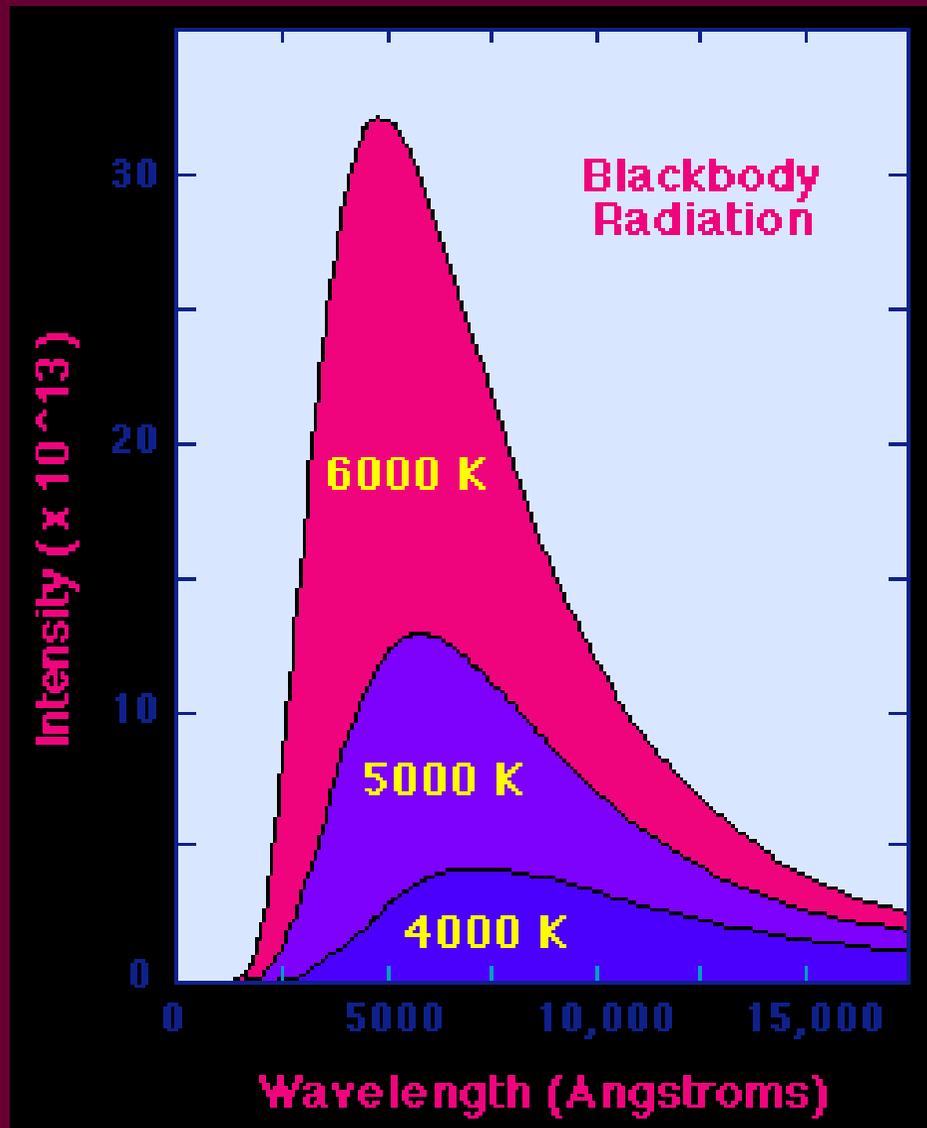


- Stars and planets act can be modeled as blackbodies

Blackbody curves

- <http://www.mhhe.com/physsci/astronomy/applets/Blackbody/frame.html>





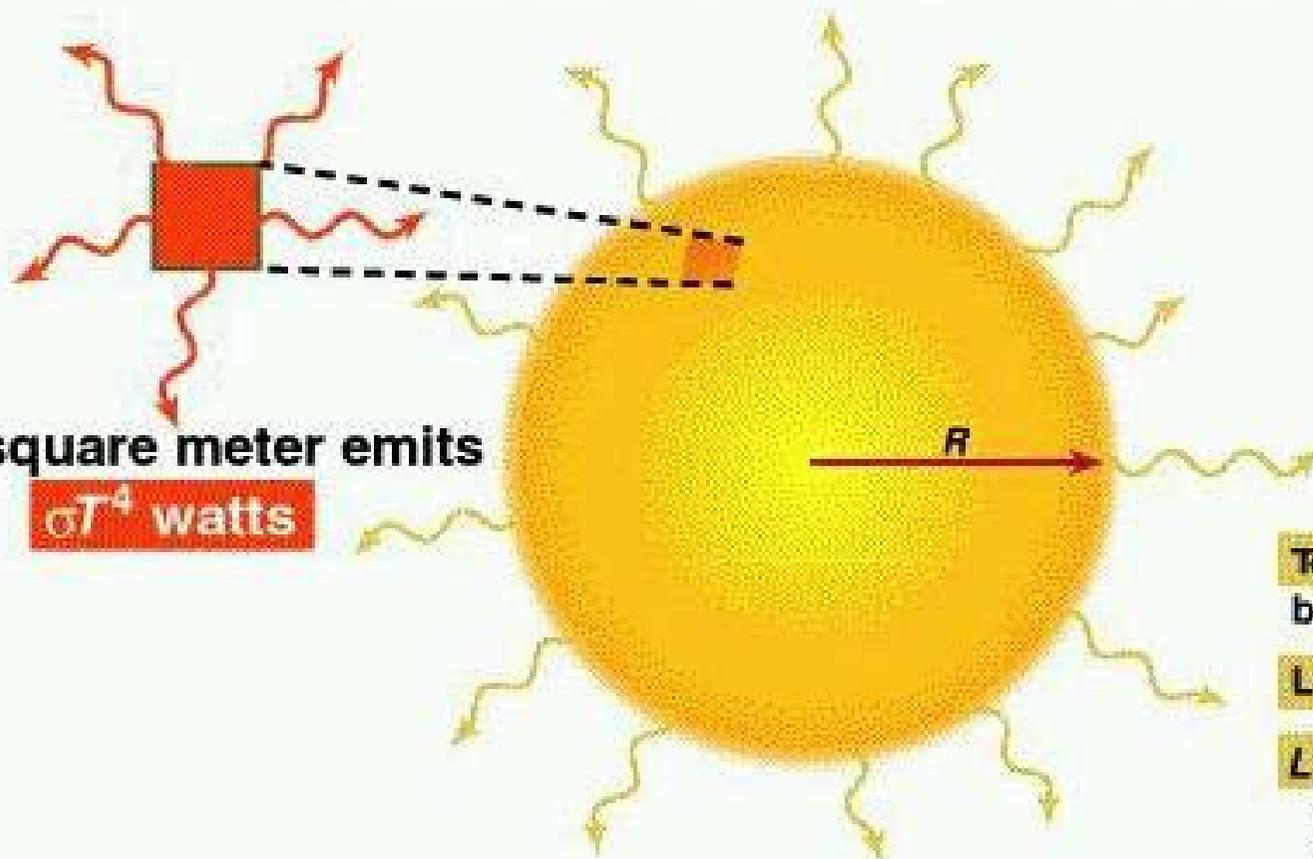
<http://csep10.phys.utk.edu/astr162/lect/light/radiation.html>

Stefan Boltzman Law

- For the same size object (same surface area), energy emitted per second is proportional to T^4
- For example if a body goes from a temperature of 1,000 to 5,000 degrees Kelvin
- How many times more energy is emitted per second from the hotter body?
 - Energy emitted per second $\propto \frac{(5000)^4}{(1000)^4} = (5)^4 = 625$ times

Luminosity

- Luminosity is in Joules/second = Watts



Total energy radiated per second by the star is its

Luminosity = L

$L =$ Energy emitted by one square meter
 x Number of square meters of its surface

$= \sigma T^4$ x Star's surface area

For a spherical star of radius R , the surface area is $4\pi R^2$

Thus, $L = \sigma T^4$ x $4\pi R^2$

or

$L = 4\pi R^2 \sigma T^4$

A

B

Stefan-Boltzman Law

- Luminosity of star = $4\pi R^2 \sigma T^4$
- Temperature in Kelvin
- $\sigma = 5.7 \times 10^{-8} \text{ Watt}/(\text{m}^2 \cdot \text{K}^4)$

Wien's Law

- Wavelength of Maximum intensity of the blackbody curve peak = 2,900,000 nm

T (Kelvin)

- $\lambda_{\max} = 2,900,000/10,000$ nm
- $\lambda_{\max} = 290$ nm
- 1 nanometer = 1×10^{-9} meters
- $\lambda_{\max} = 290$ nm = 2.0×10^{-7} meters

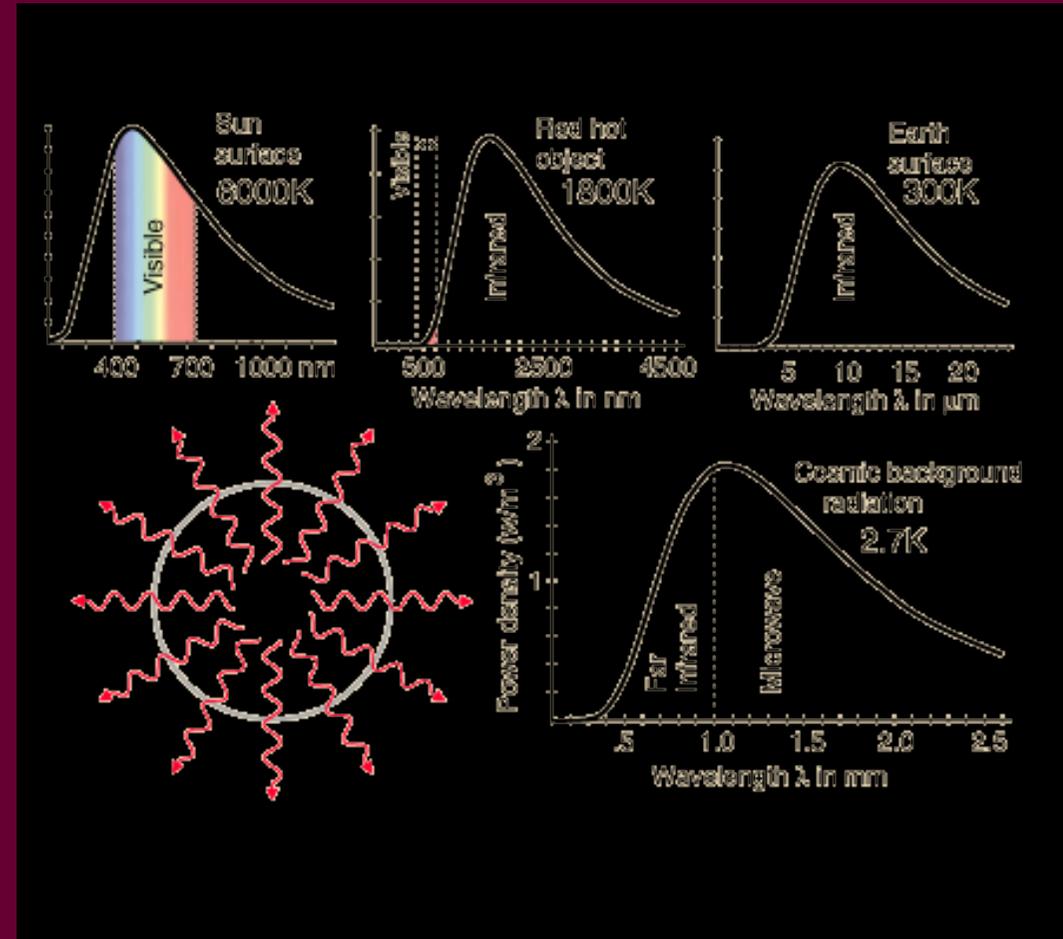
New Rings around Saturn

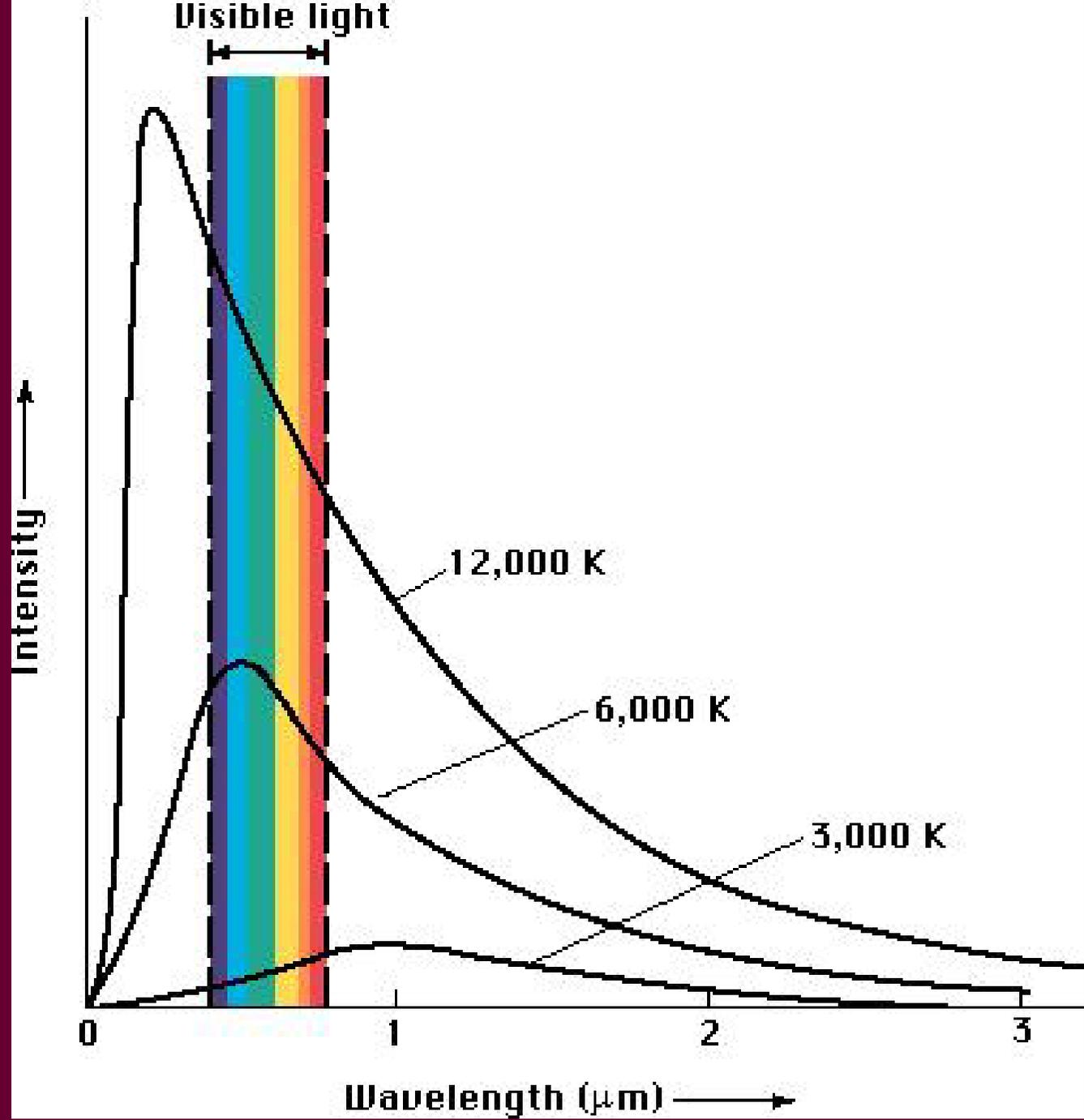


- Seen in the infrared by the Spitzer Telescope
- Made of dust and ice; Dust is 80 Kelvin
- Lies some 13 million km from the planet
- Tilted 27 degrees from main ring plane
- 50 times more distant than the other rings and in a different plane.
- Probably made up of debris kicked off Saturn's moon Phoebe by small impacts.

Why infrared for dust?

- Cold things give off more light in infrared than visible





When you observe an astronomical body

- You measure intensity
- Intensity – amount of radiation

When you see an object in the sky

- You measure its brightness
- Its brightness is a function of its
 - Distance from Earth (can be calculated from orbit)

If star:

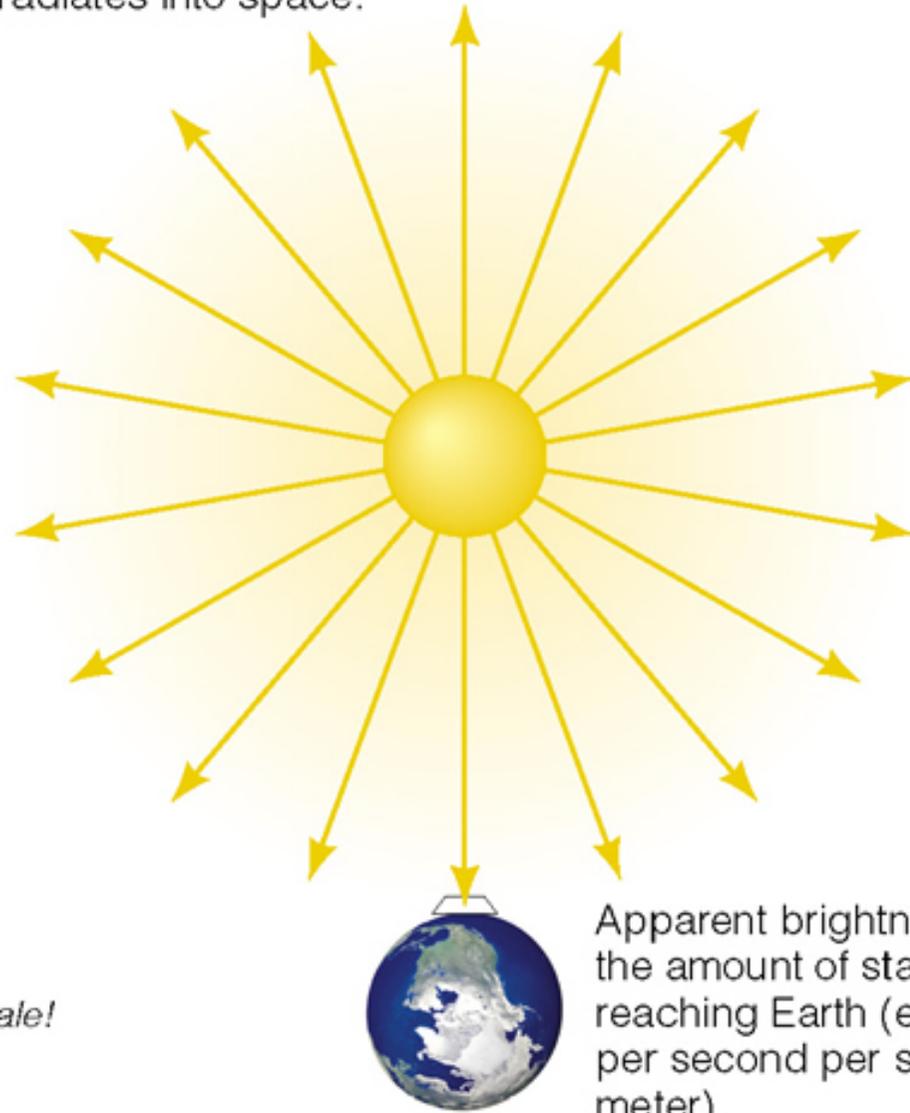
-Luminosity - is the amount of energy a body radiates per unit time

If planet

– Albedo

– Size

Luminosity is the total amount of power (energy per second) the star radiates into space.



Not to scale!

Apparent brightness is the amount of starlight reaching Earth (energy per second per square meter).

Inverse Square Law

- The apparent brightness varies inversely by the square of the distance ($1/d^2$)
- If the Earth was moved to 10 Astronomical Units away, the Sun would be 1/100 times dimmer
- If the Earth was moved to 100 Astronomical Units away, the Sun would be 1/10000 times dimmer

If the Earth was moved to 1×10^8 Astronomical Units away, the Sun would be ...

- A) 1×10^{-12} times dimmer
- B) 1×10^{-14} times dimmer
- C) 1×10^{-16} times dimmer
- D) 1×10^{-18} times dimmer
- E) 1×10^{-20} times dimmer

If the Earth was moved to 1×10^8 Astronomical Units away, the Sun would be ...

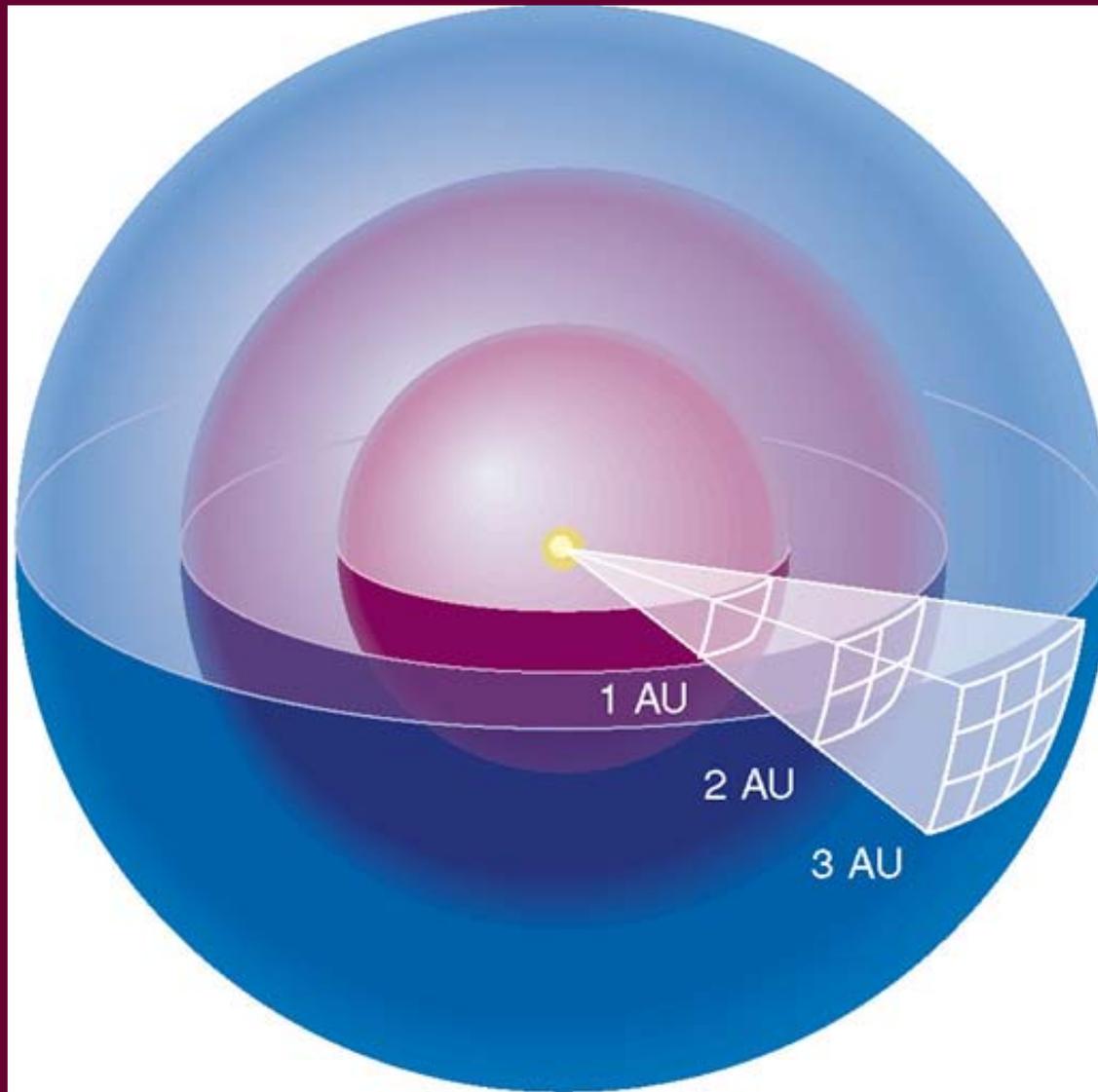
- A) 1×10^{-12} times dimmer
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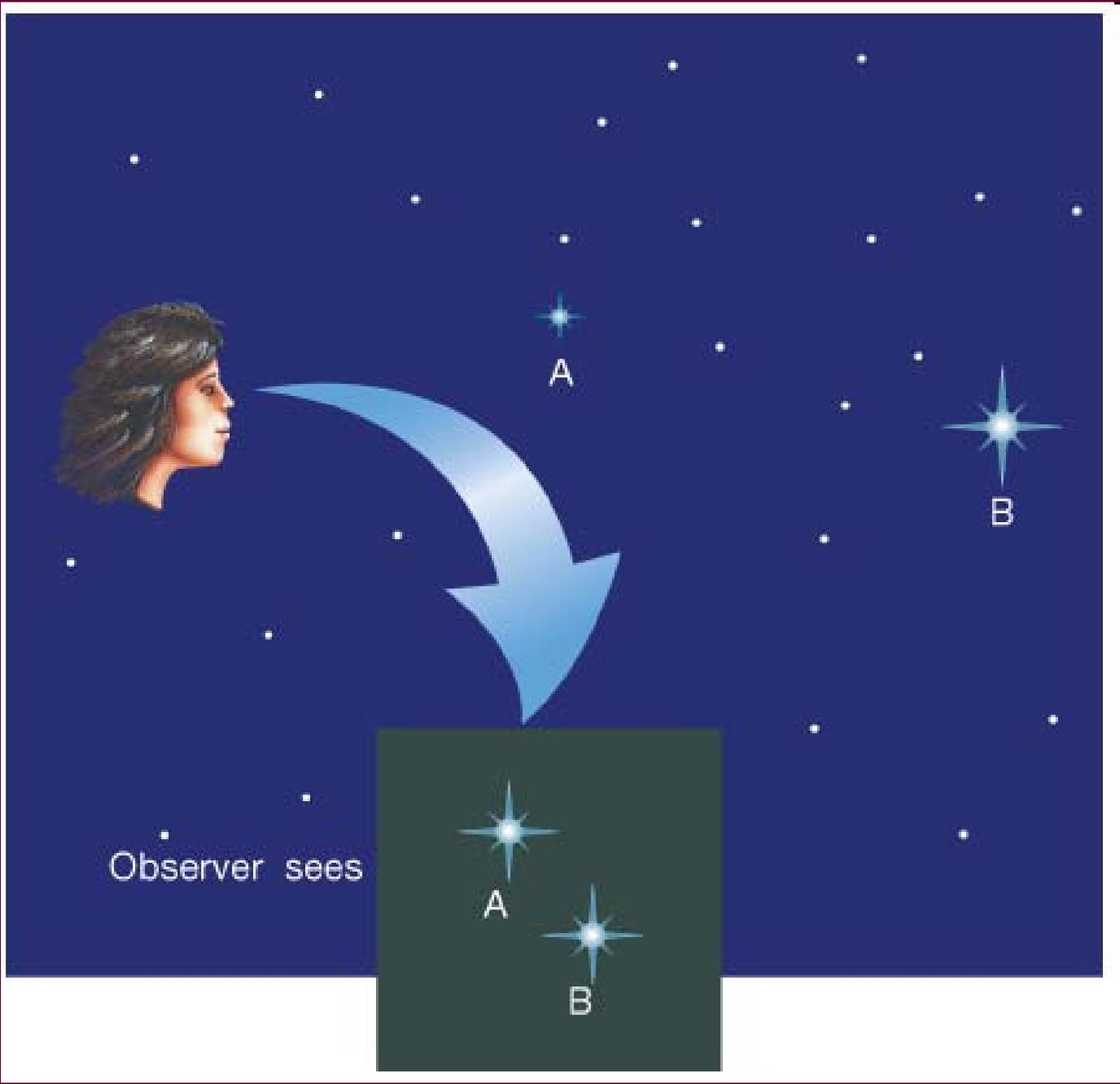
Luminosity-Distance Formula

- Apparent brightness = $\frac{\text{Luminosity}}{4\pi \times (\text{distance})^2}$

Usually use units of Solar Luminosity

$$L_{\text{Sun}} = 3.8 \times 10^{26} \text{ Watts}$$





Any Questions?