Announcements

- HW#1 is due via UNM Learn on Thursday Jan 28 by the START of CLASS
  - After 11:00am it is late and there will be a penalty of 15% (see syllabus)

- Last day to drop with refund is Feb 5

How do we express smaller angles?

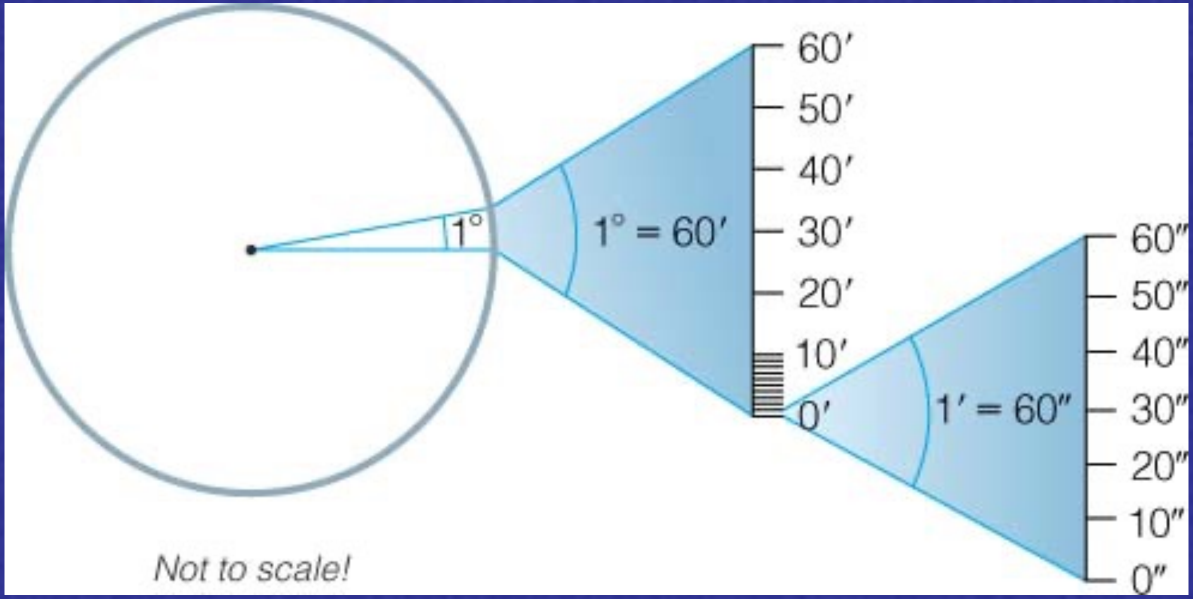
One circle has 2π radians = 360°

We subdivide the degree into 60 arcminutes (a.k.a. minutes of arc):

1° = 60 arcmin = 60'

An arcminute is split into 60 arcseconds (a.k.a. seconds of arc):

1' = 60 arcsec = 60"



Angular size - linear size - distance

Use the *small-angle formula*:

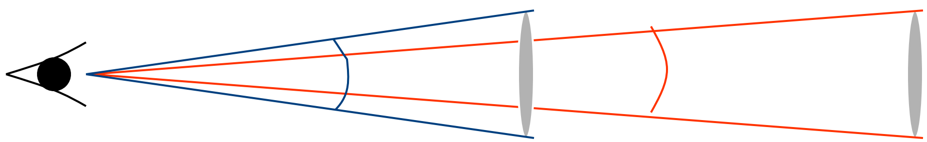
$$D = \frac{\alpha d}{206265}$$

where D = linear size of an object (any unit of length),
d = distance to the object (*same* unit as D)
α = angular size of the object (in arcsec),

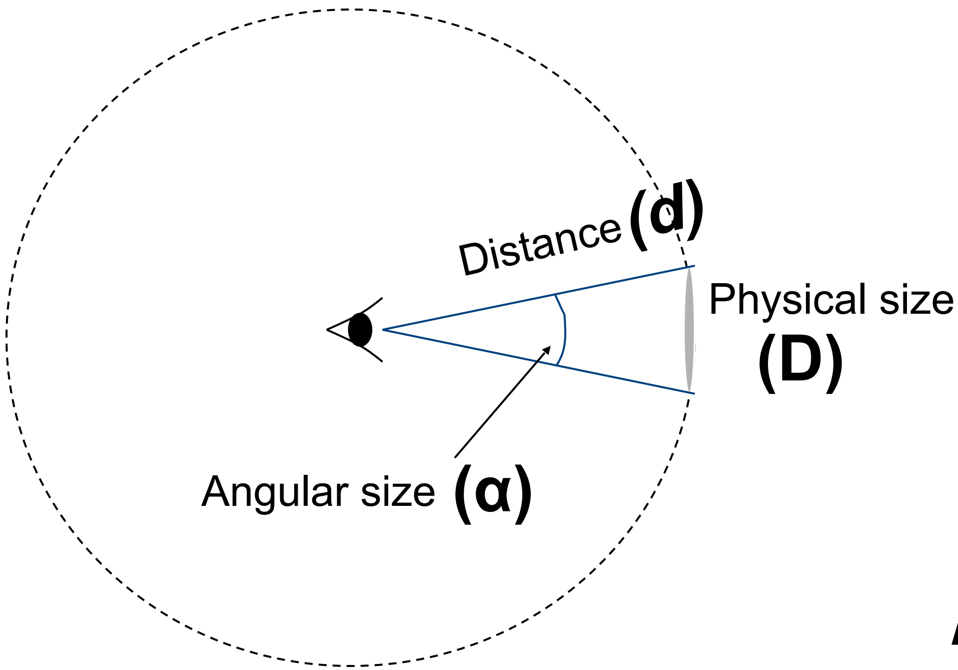
The 206,265 is required in the formula - it's the number of arcseconds in a circle divided by 2π.

Where does this formula come from?

The same idea in pictures: the angular size depends on the linear (true) size AND on the distance to the object. See Box 1-1.



Moving an object farther away reduces its angular size.

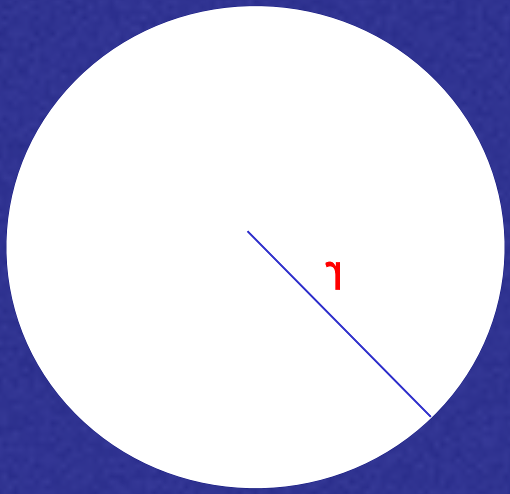


$$C = 2\pi r$$

As long as the angular size is small, we can think of the object's physical size as a small piece of a circle.

$$D = \frac{\alpha d}{206265}$$

More Basic Trig



Circle/Disk

Circumference = $2\pi r$

Area = πr^2

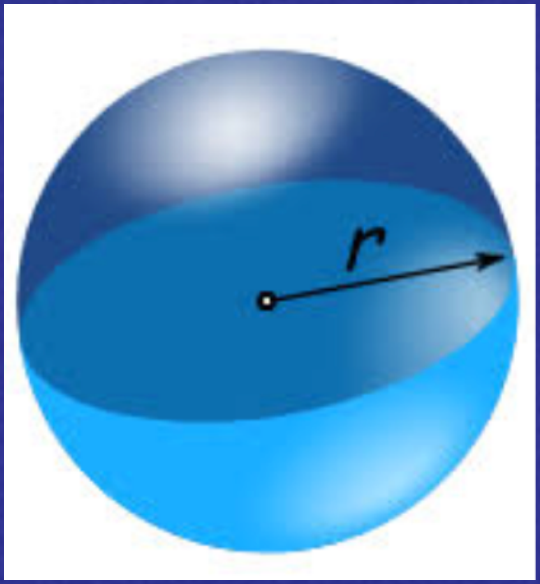
Diameter = $2r$

Sphere

Circumference = $2\pi r$

Area = $4\pi r^2$

Volume = $(4\pi r^3)/3$



Units in Astronomy

Astronomers use the normal metric system and powers-of-ten notation, plus a few “special” units.

Example: Average distance from Earth to Sun is about 1.5×10^{11} m = 1 Astronomical Unit = 1 AU

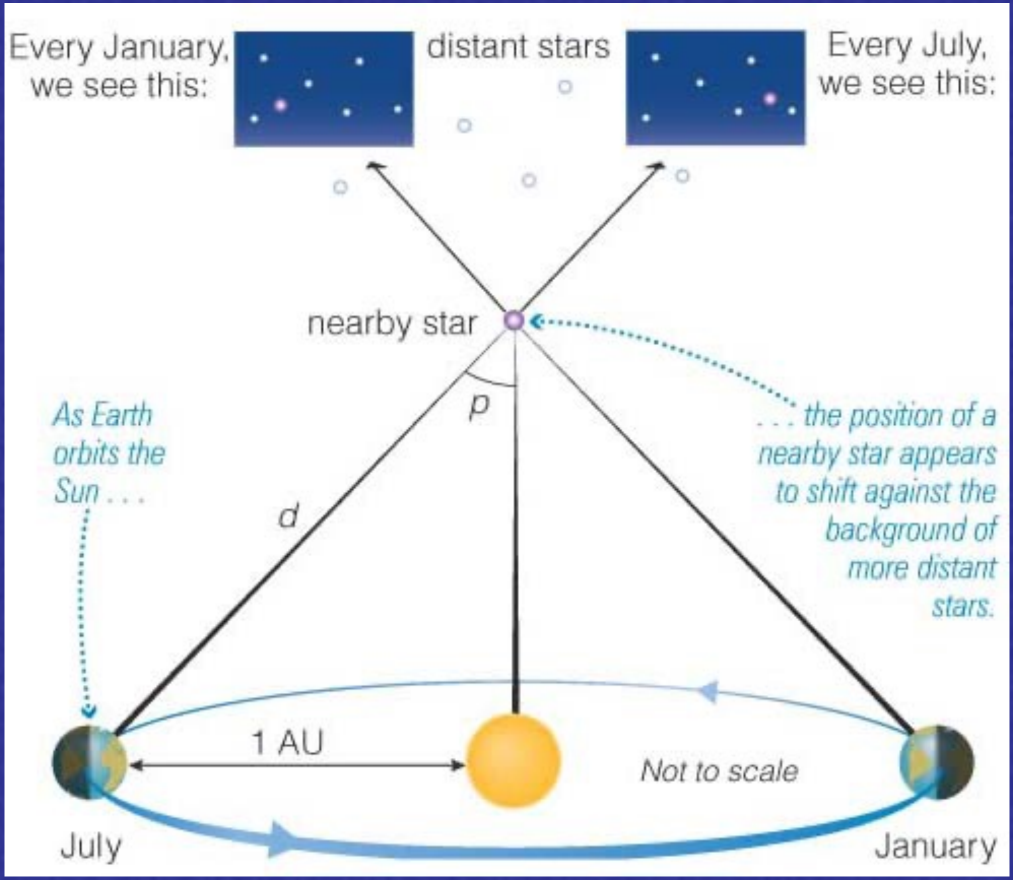
Used for distances in the Solar system.

This spring we are working on much larger scales, in which case we normally use the unit of parsec.

The parsec unit

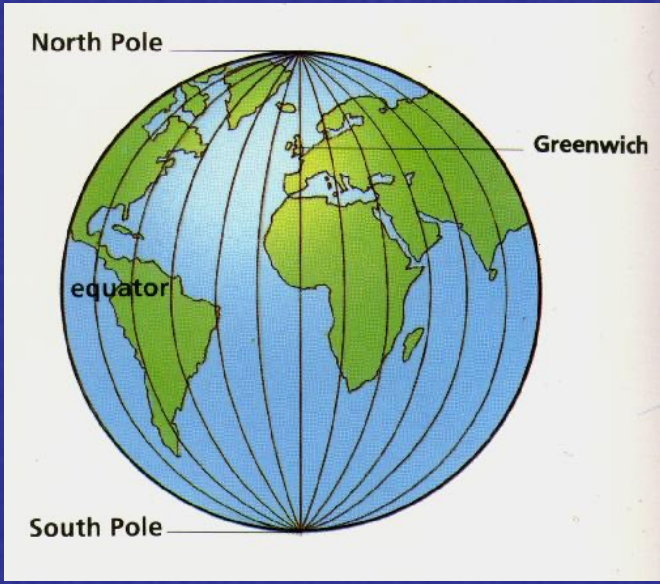
- Relation between angular size and linear distance => basic unit of distance in astronomy: the parsec
- Short for "parallax of one second of arc"
- The distance between Earth and a star at which the radius of the Earth's orbit around the Sun (1AU) subtends an angle of 1"

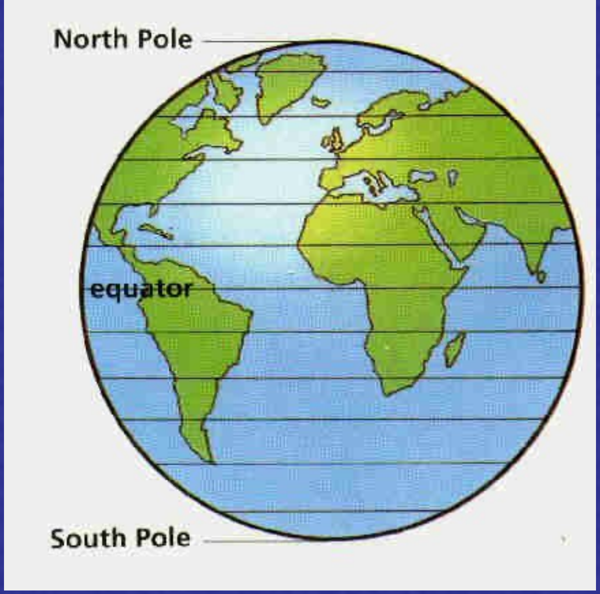
The nearest star is 1.3 pc away ($1\ pc = 3.09 \times 10^{16}\ m$)

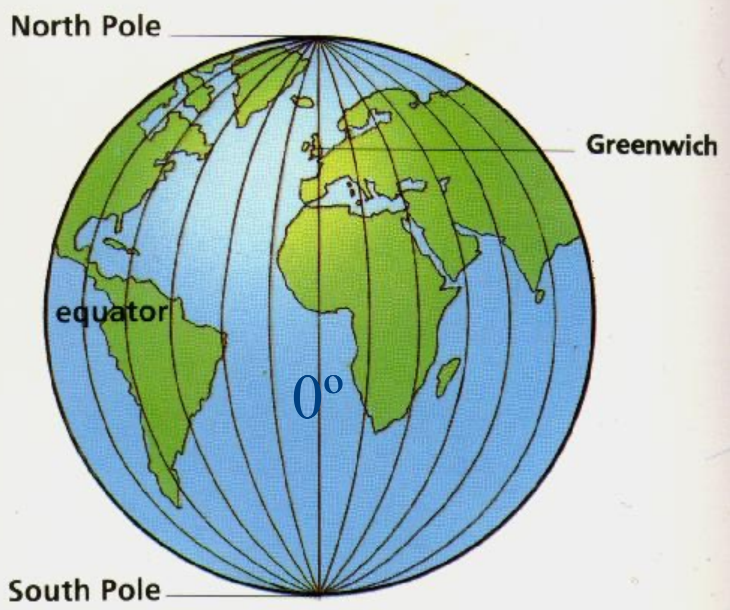


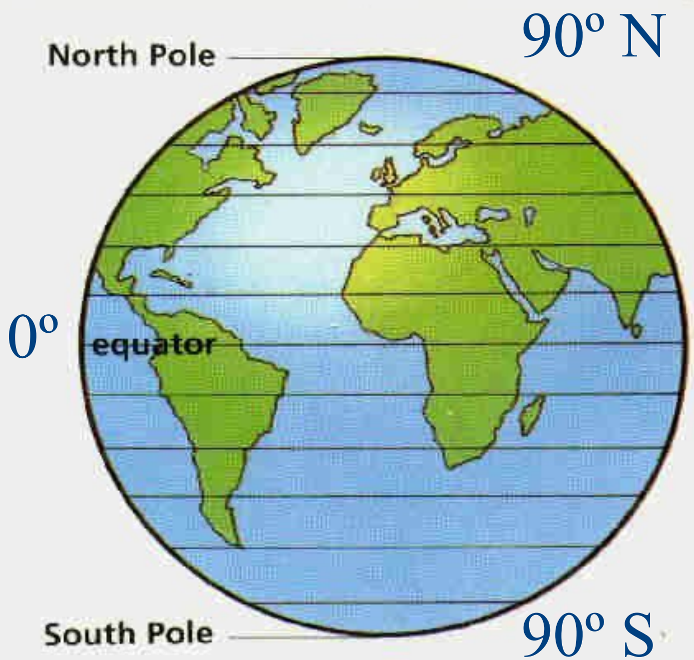
Coordinate systems (Box 2.1)

- Purpose: to locate astronomical objects
- To locate an object in space, we need three coordinates: x, y, z. Direction (two coordinates) and distance.
- At Earth we use coordinates of longitude and latitude to describe a point (ignoring altitude)









- Position in degrees:
  - Longitude: connecting the poles, 360º, or 180º East and 180º West
  - Latitude: parallel to the equator, 0-90º N and 0-90º S
  - A location is the intersect of a longitude and latitude line (virtual)
- Albuquerque:
  35º05' N, 106º39' W

Positions of celestial objects

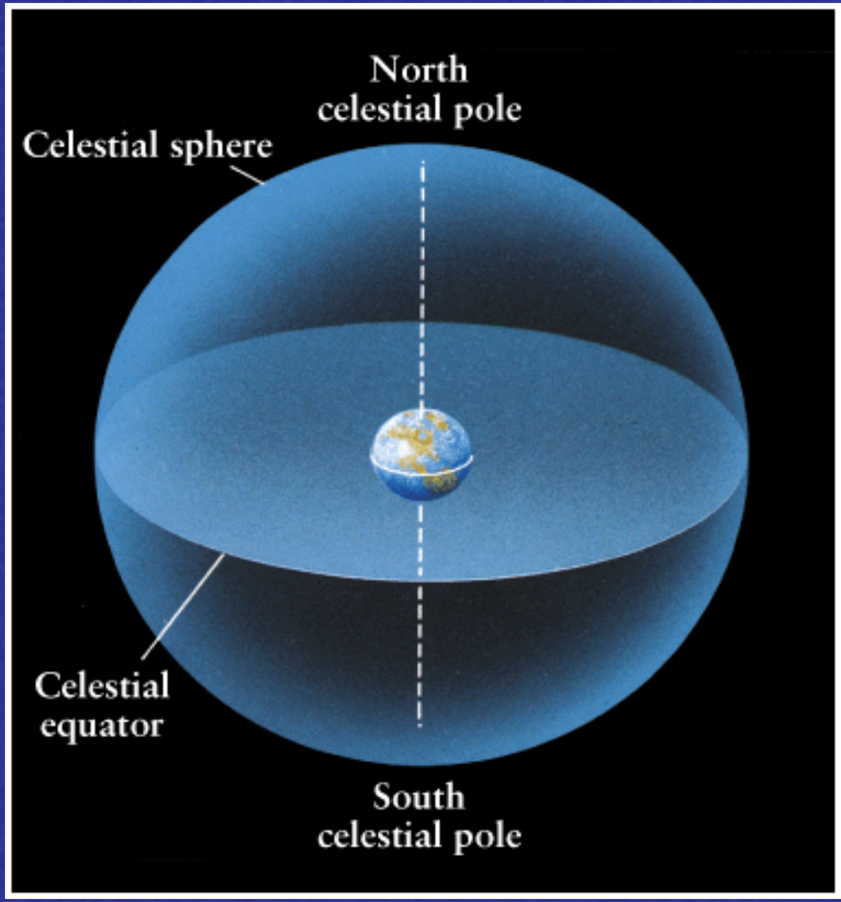
- Same idea when we describe the position of a celestial object
- The Sun, the Moon and the stars are so far away that we cannot perceive their distances - no depth perception.
- Instead, the objects appear to be projected onto a giant, imaginary sphere centered on the Earth.
- All objects seem to be on the surface of this imaginary sphere

The Celestial Sphere

- Stars are really distributed in 3-dimensional space, but they *look* like they're on a 2-dimensional sphere centered on Earth.

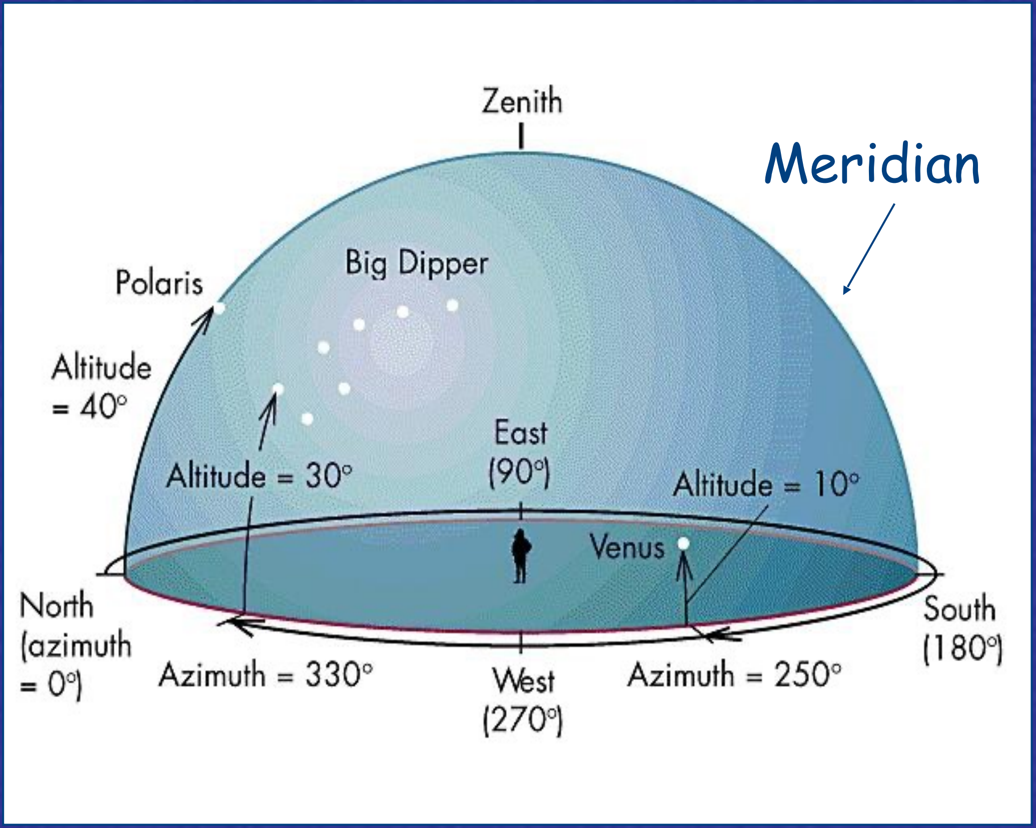
- To locate an object, two numbers (angular measures), like longitude and latitude are sufficient.

- Useful if we want to decide where to point our telescopes.



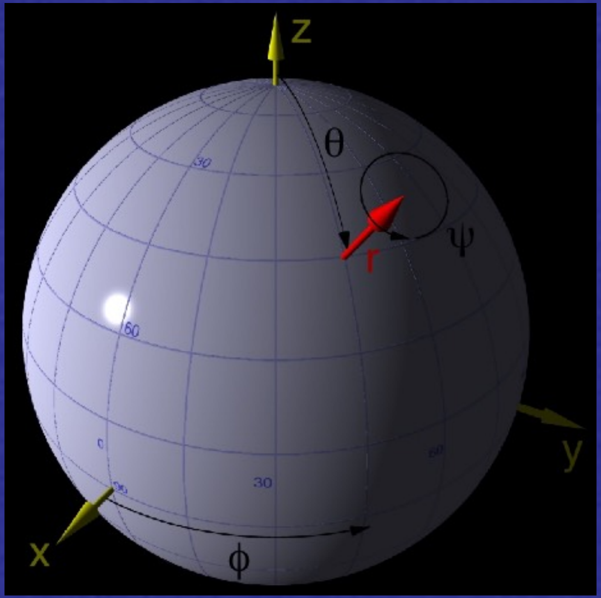
Horizon coordinate system

- The Horizon coordinate system (used for telescopes):
- Altitude
  - Angle above the horizon
  - 0-90º
  - The altitude of the north celestial pole equals the observer's latitude on Earth.
- Azimuth
  - Angle measured eastward along horizon, starting from the north
  - 0-360º



Horizon coordinate system: Pros and Cons

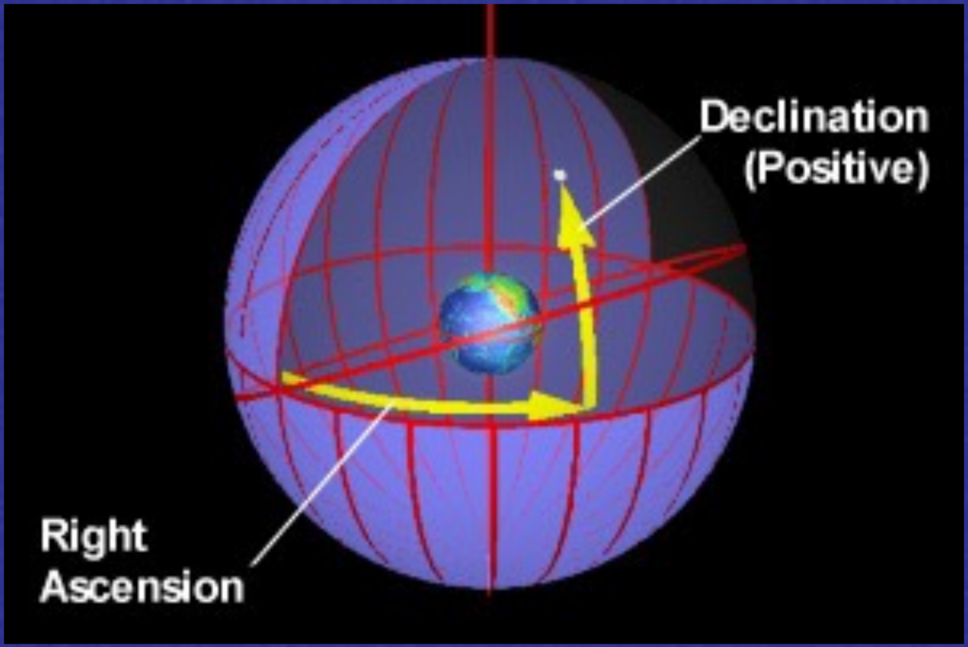
- Pros
  - Easy to tell and understand
- Cons
  - At different position on the Earth, the same object has different coordinates
  - At different times, the same object has different coordinates



The coordinates of an object change in this system!

The equatorial system

- A system in which the coordinates of an object does NOT change.
- The coordinates are called Right Ascension and Declination, and are analogous to longitude and latitude on Earth.



- The equatorial coordinate system rotates with stars and galaxies.

RA and Dec

- Declination (Dec) is measured in degrees, arcminutes, and arcseconds.
- Right ascension (RA) is measured in units of time: hours, minutes, and seconds.
- Example 1: The star Regulus has coordinates

  RA = $10^h\ 08^m\ 22.2^s$

  Dec = 11° 58' 02"

Zero point of RA: ***The vernal equinox,*** **which is the point on the celestial equator the Sun crosses on its march north - the start of spring in the northern hemisphere (cf. Greenwhich 0° longitude).**

Properties of Light
Chapter 5

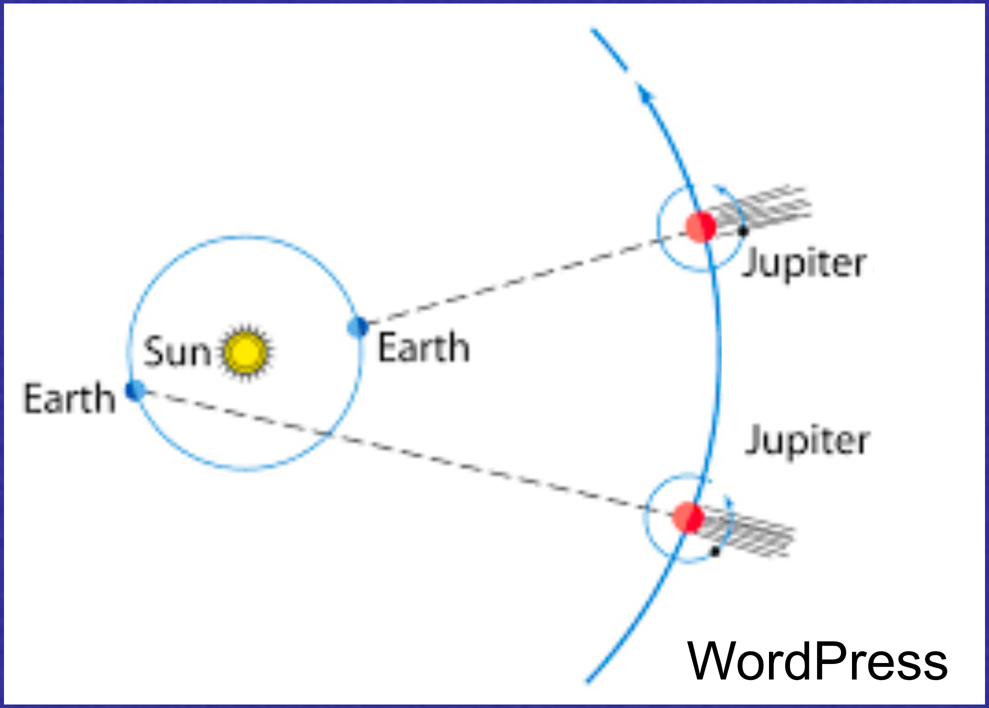
Light carries information to astronomers

- How hot is the Sun?
- How does it compare to other stars?
- What is its composition?
- Is there anything between the stars? Between galaxies?
- How do we know that the Universe is expanding?

All of this comes from the study of light!

Astronomers use telescopes to collect light of distant objects, and then extract information from this light.

The speed of light



The speed of light

c = 300 000 000 m/s (or 186 000 miles/s) = 3×10^8 m/s

It is the same everywhere in the universe in vacuum.

The speed of light is different in other media (air, water, glass, etc.)

What is a light year?

1 parsec = 3.26 light-years (like km to miles)

What is Light?

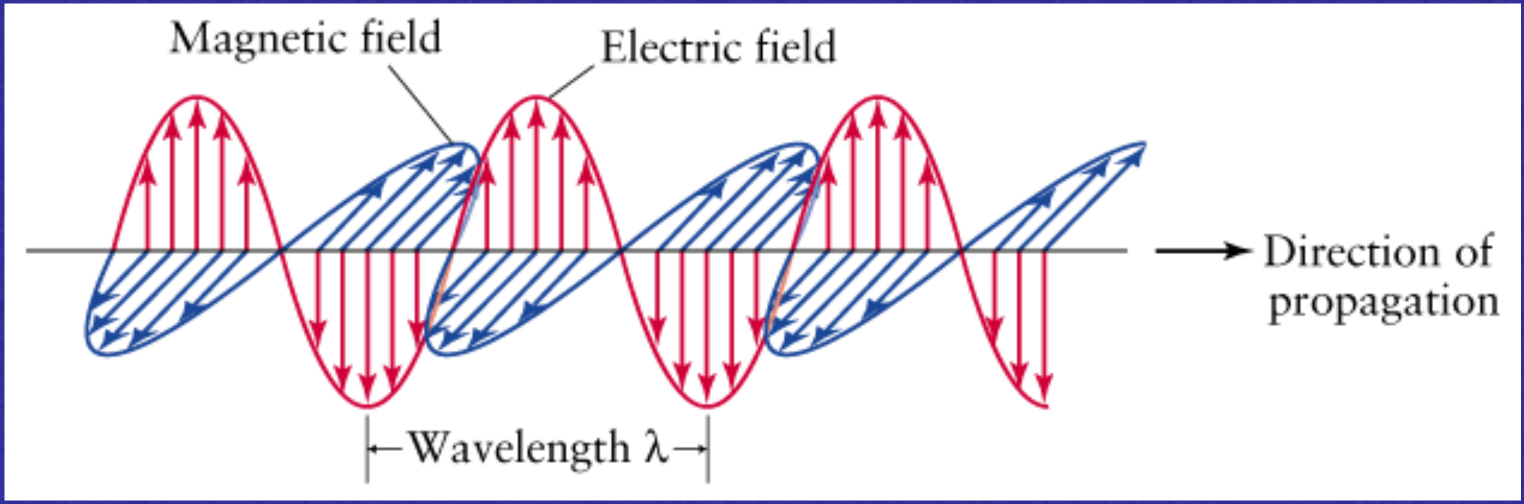
- Light is *electromagnetic (EM) radiation*
- Light can be treated either as
  - EM waves
  - Photons (particles of light)
- Both natures have to be considered to describe all essential properties of light

Light as electromagnetic waves

- EM waves: self propagating electric and magnetic fields (changes in strengths of E- and B-fields).

- Traveling (in vacuum) at the constant speed of light

- $\nu = c/\lambda$, where ν is the frequency [Hz] and λ is the wavelength [m].

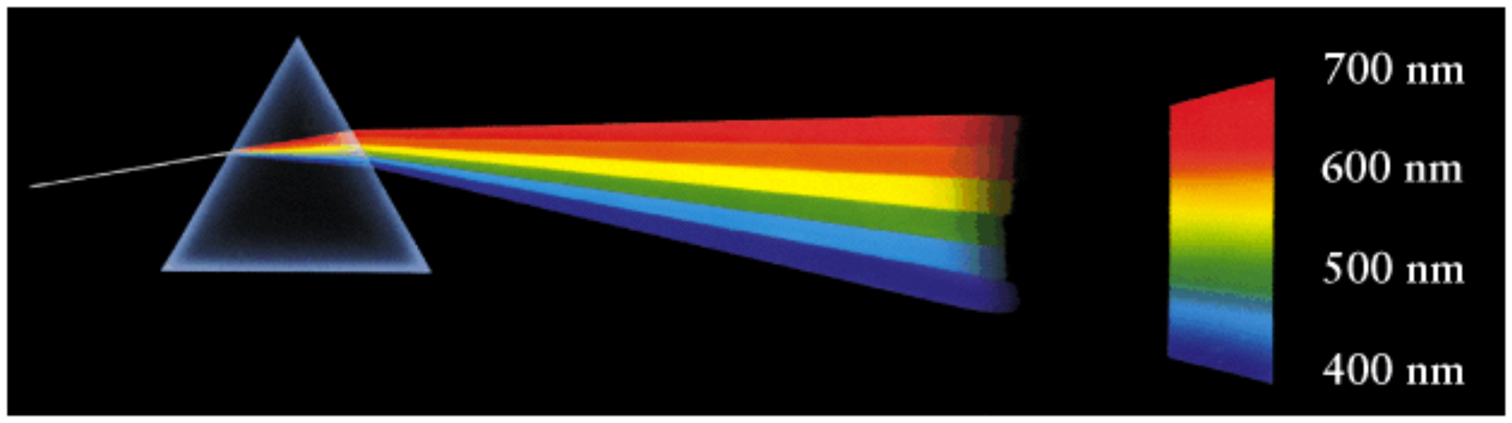


EM waves are different from other waves, since it doesn't need a medium to propagate in!

Properties of Light

- It heats up material (e.g. your skin), thus it is a carrier of energy.
  - This is radiative energy, one out of three basic categories of energy (kinetic, potential and radiative)

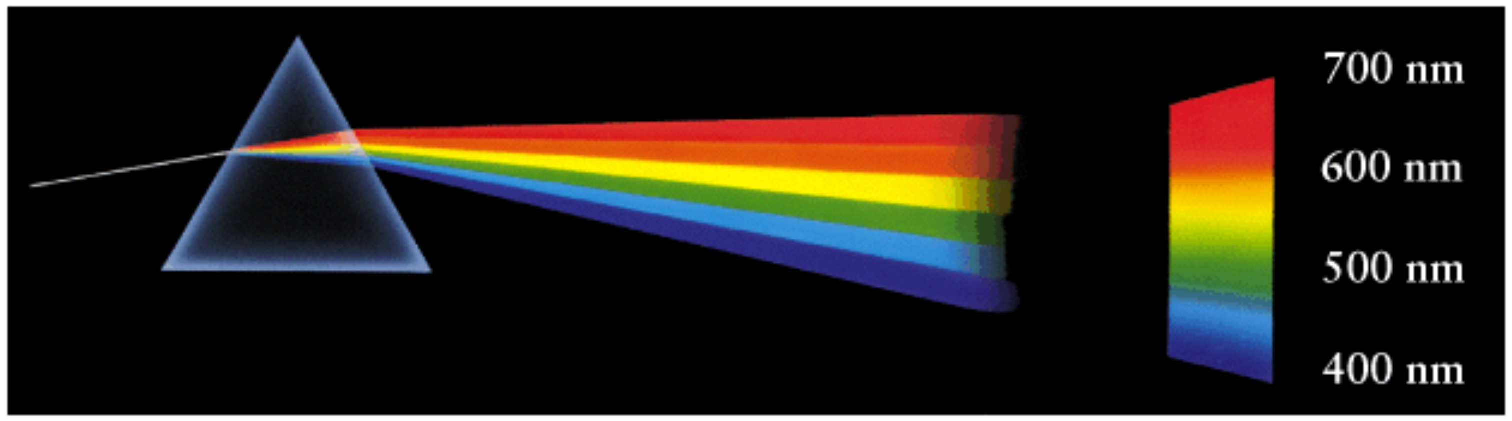
- It has a "color", especially in the visible regime you are used to the colors of the rainbow:



- The human eye is sensitive to light with colors from violet to red, which corresponds to a wavelength range:

$4{,}000\ \text{Å} < \lambda < 7{,}000\ \text{Å}$ where an Å is 10^{-10} m (Å=Ångström).

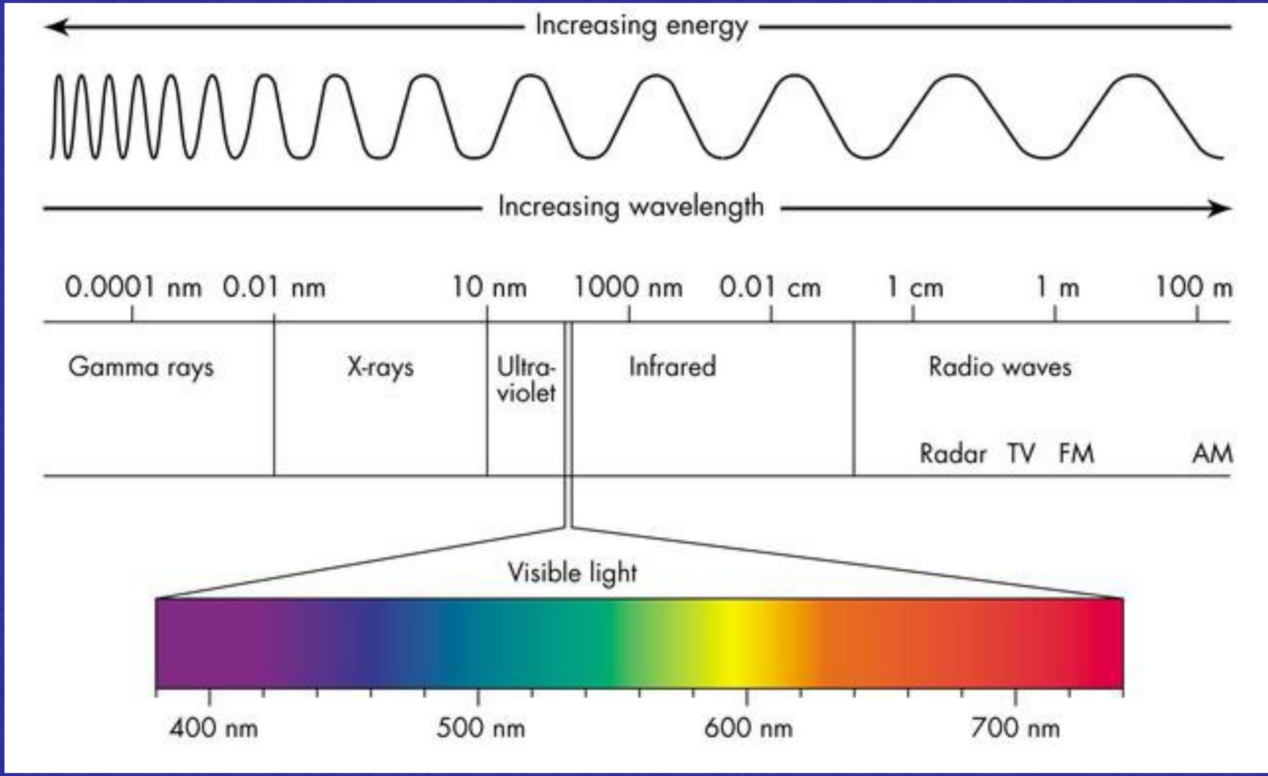
$= 400\ \text{nm} < \lambda < 700\ \text{nm}$ where 1 nm $=10^{-9}$ m.



- White light: all colors of the rainbow
- Black: no light, hence no colors

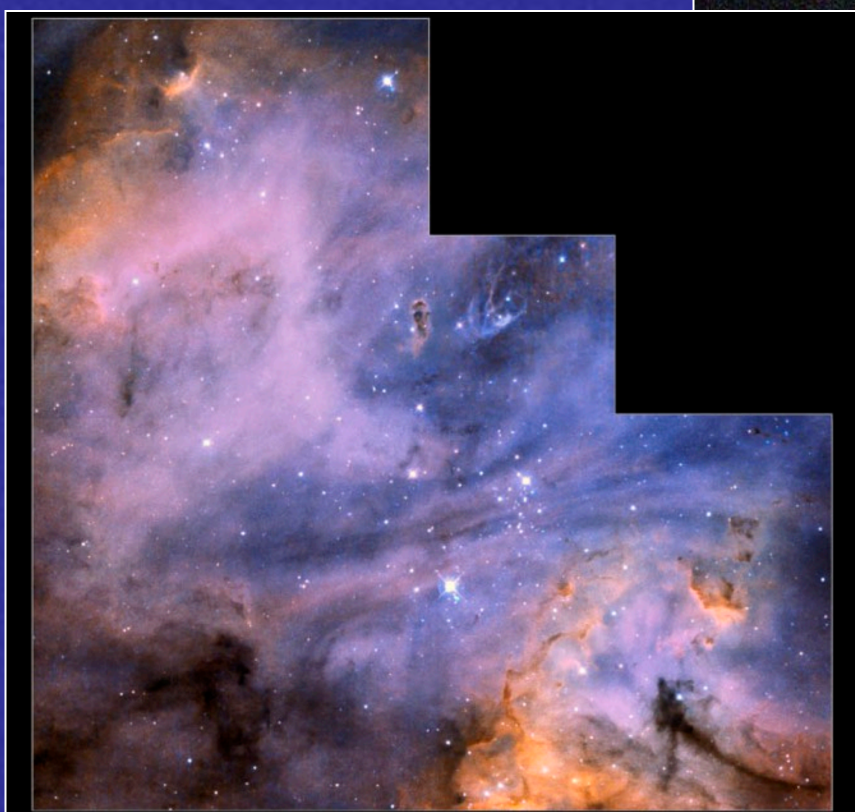
The electromagnetic spectrum

- Light extends beyond the visible regime, and the continuous and infinite distribution of wavelengths is called the electromagnetic spectrum



Light of different wavelengths interacts in different ways with matter

Different objects in the Universe give off EM radiation in different ways, depending on their physical condition.



The dual nature of light

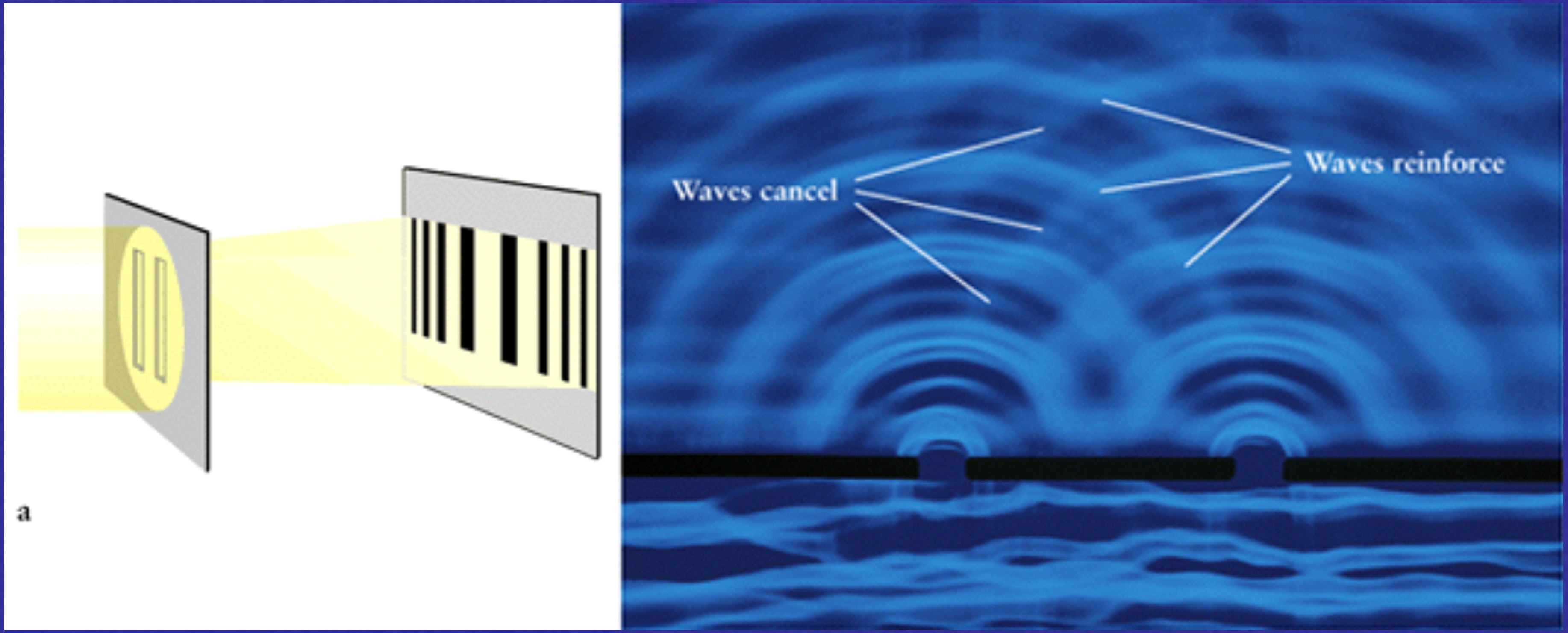
Light often acts like a wave but also can act like a particle – in interactions with atoms and molecules.

- The particles are called *photons*.
- A photon is a mass-less particle that carries energy E at the speed of light.
- $E = hc/\lambda = h\nu$ where $h = 6.6 \times 10^{-34}$ J s (Planck's constant)

Question: which has more energy, a photon of blue light, or of red light? UV or radio?

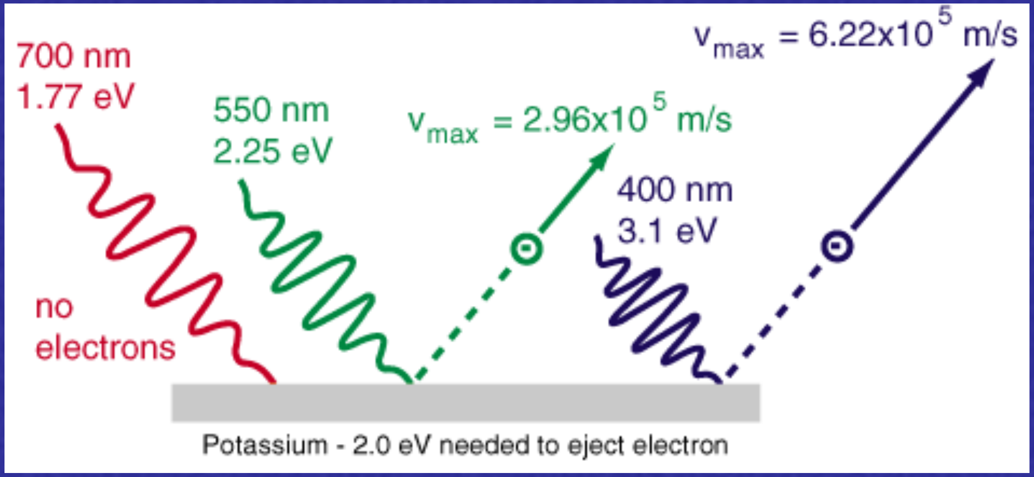
Young's double slit experiment

- Demonstrates the wave-like nature of light:
- Like water waves (right), EM waves can interfere.



The photoelectric effect

- Illustrates the particle nature of light: Photons hitting a piece of metal will knock out single electrons, but only if they have enough energy.
- Above this energy level the kinetic energy of the photon does NOT depend on the intensity of the incident radiation, but on the frequency.



- IF light had only wave-nature, the kinetic energy of ejected electrons should depend on the amplitude (intensity) of the wave, but instead it depends on the frequency ($E=h\nu$)

The photoelectric effect

CCD
(charge-coupled device)

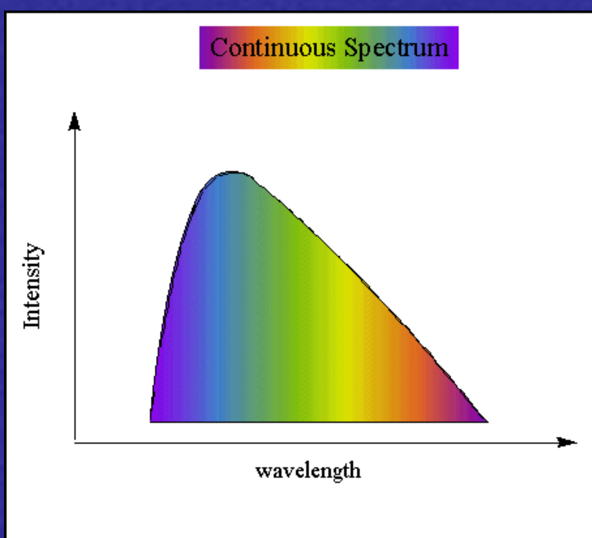
How do light and matter interact?

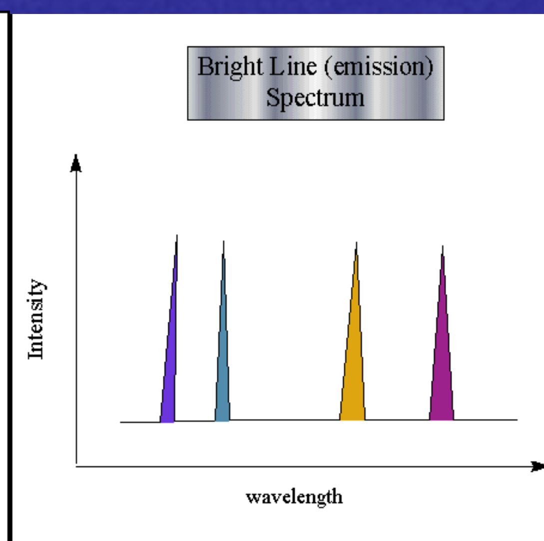
- Emission - light bulb, star
- Absorption - your skin can absorb light, in turn the absorbed energy heats your skin
- Transmission - glass and air lets the light pass through
- Reflection and scattering - light can bounce off matter leading to reflection (same direction of reflected light) or scattering (random direction of reflected light)

Materials that transmit light are *transparent.*
Materials that absorb light are *opaque.*

Three basic types of spectra

- Kirchoff's laws of spectroscopy:
  1. A hot, opaque body, or a hot, dense gas produces a continuous spectrum.
  2. A hot, transparent gas produces an emission line spectrum.
  3. A cool, transparent gas in front of a source of a continuous spectrum produces an absorption line spectrum.





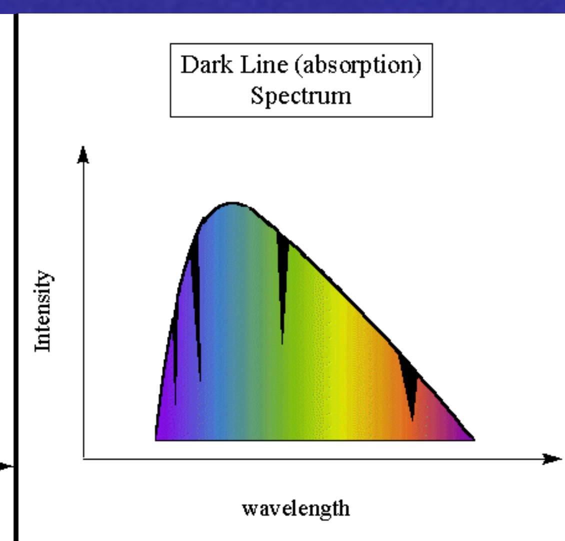
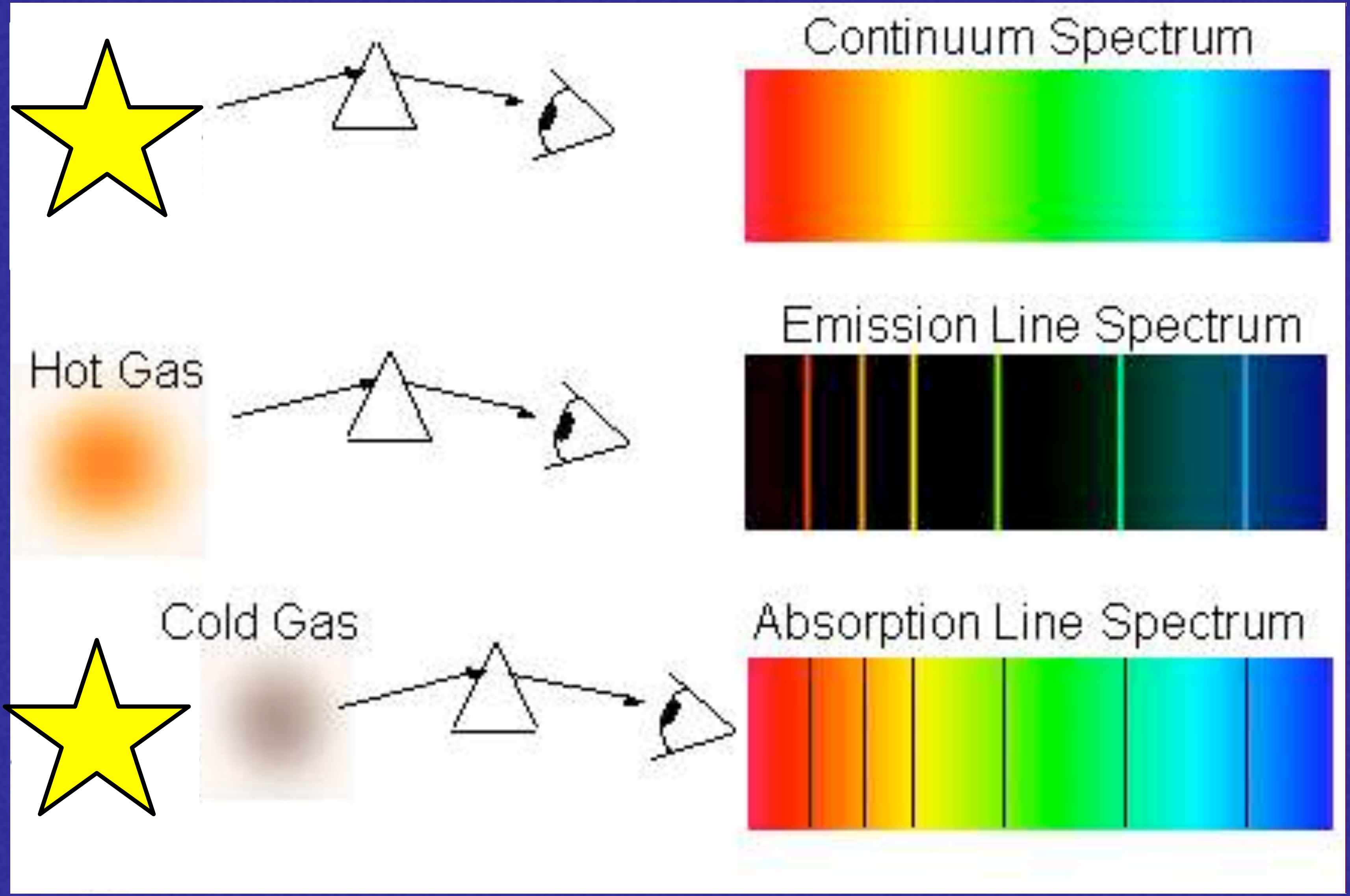
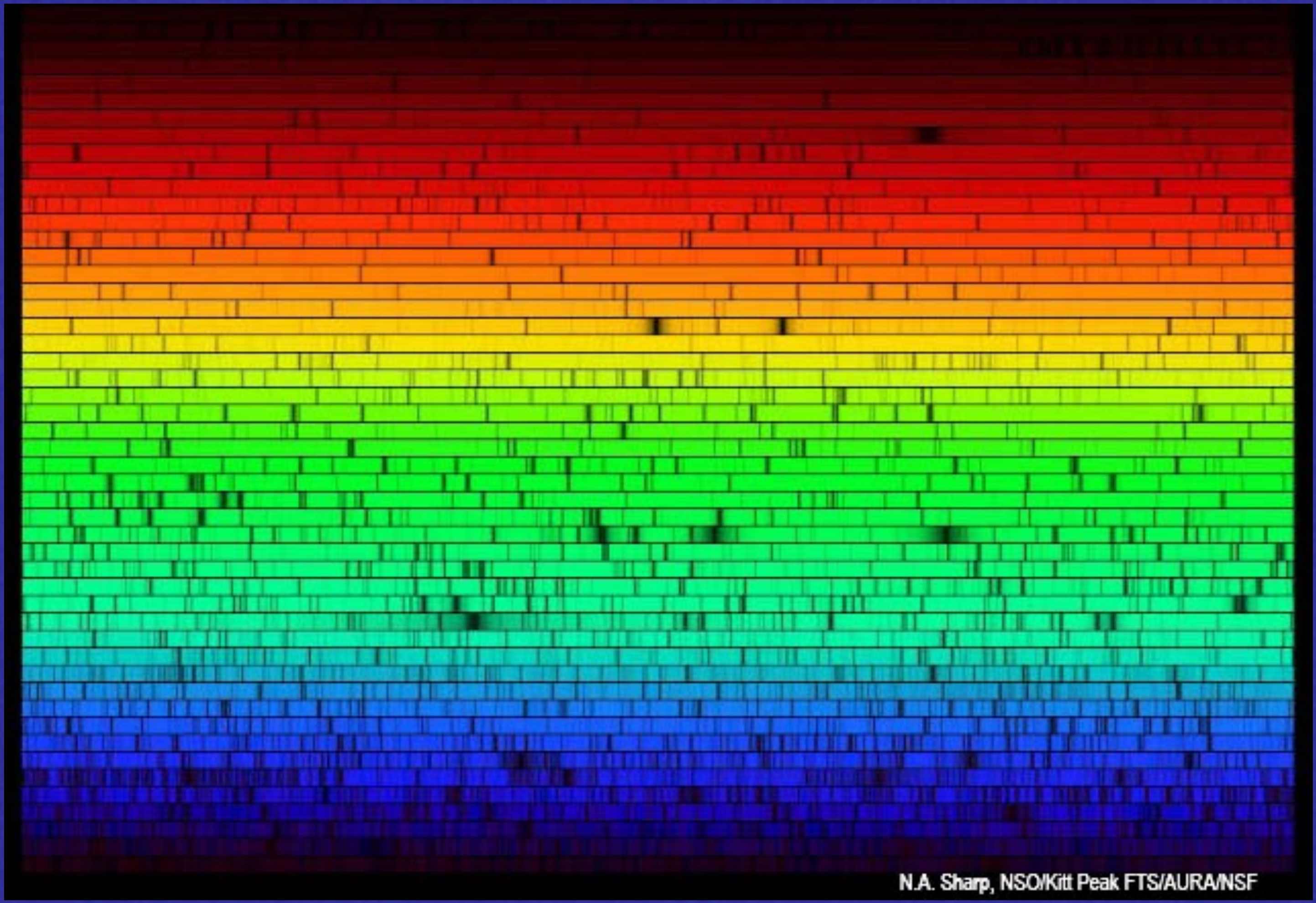
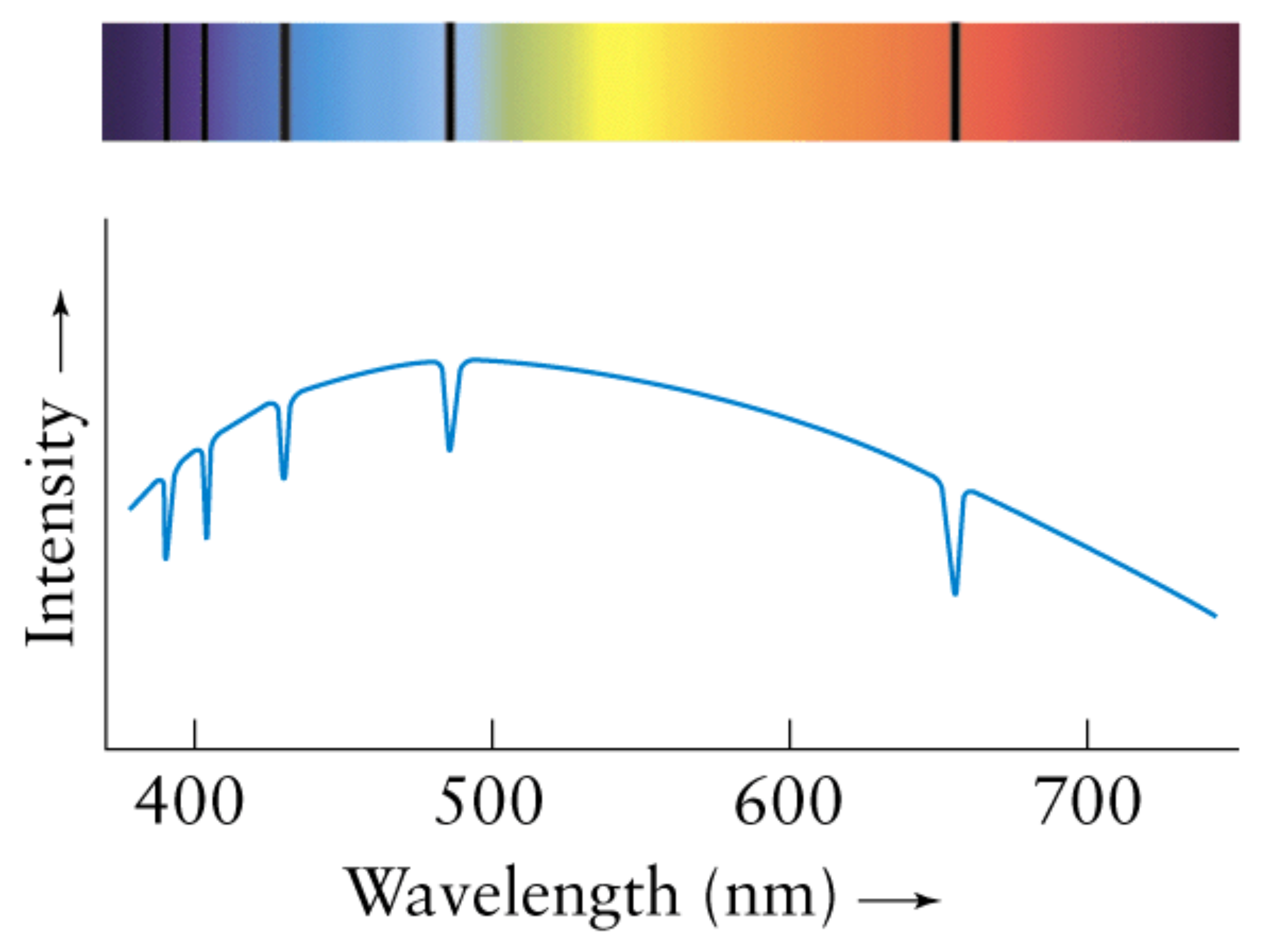


Illustration Kirchoff's laws

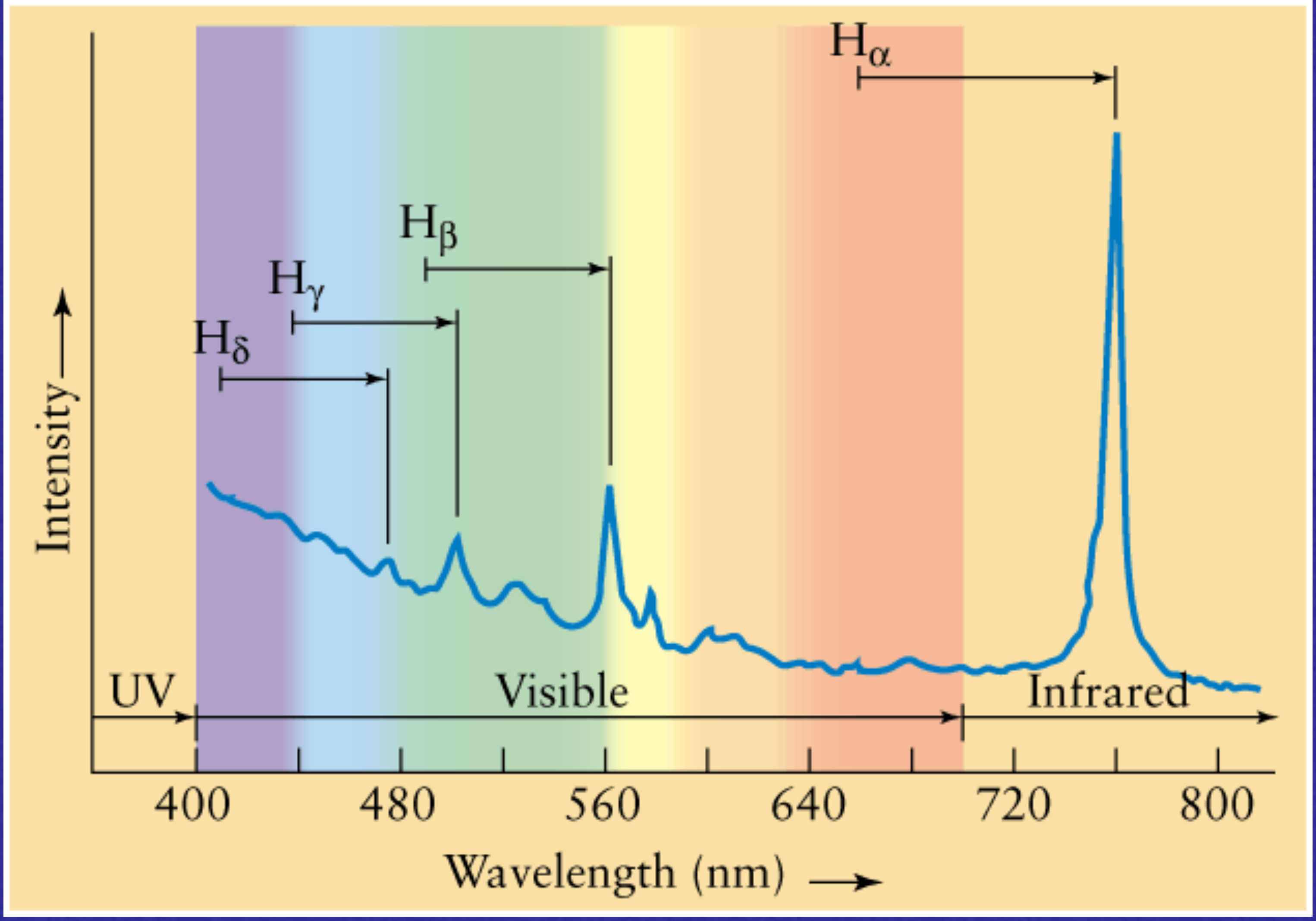


Spectrum of the Sun – what kind of spectrum is this?



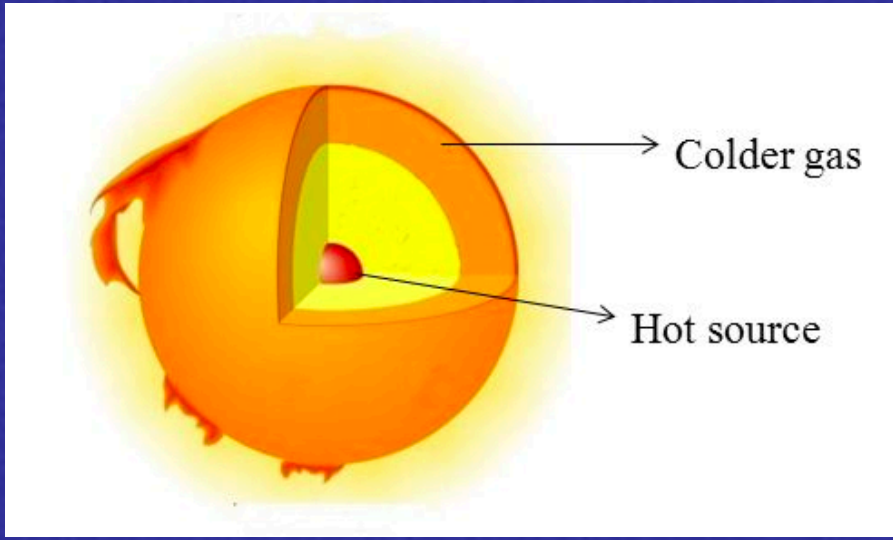

Intensity →
400
500
600
700
Wavelength (nm) →

- Spectrum of a "quasar" – what kind of spectrum is this?



Astrophysical examples:

- Continuous: asteroids, planets, etc.
- Emission line: hot interstellar gas -- HII regions, planetary nebulae, supernova remnants.
- Absorption line: stars (relatively cool atmospheres overlying hot interiors), cool interstellar gas.



Important concepts: temperature and blackbody.