The Cosmos

# Planets & Life
# PHYS 214

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Please start all class related emails with "214:"

# Today's Lecture

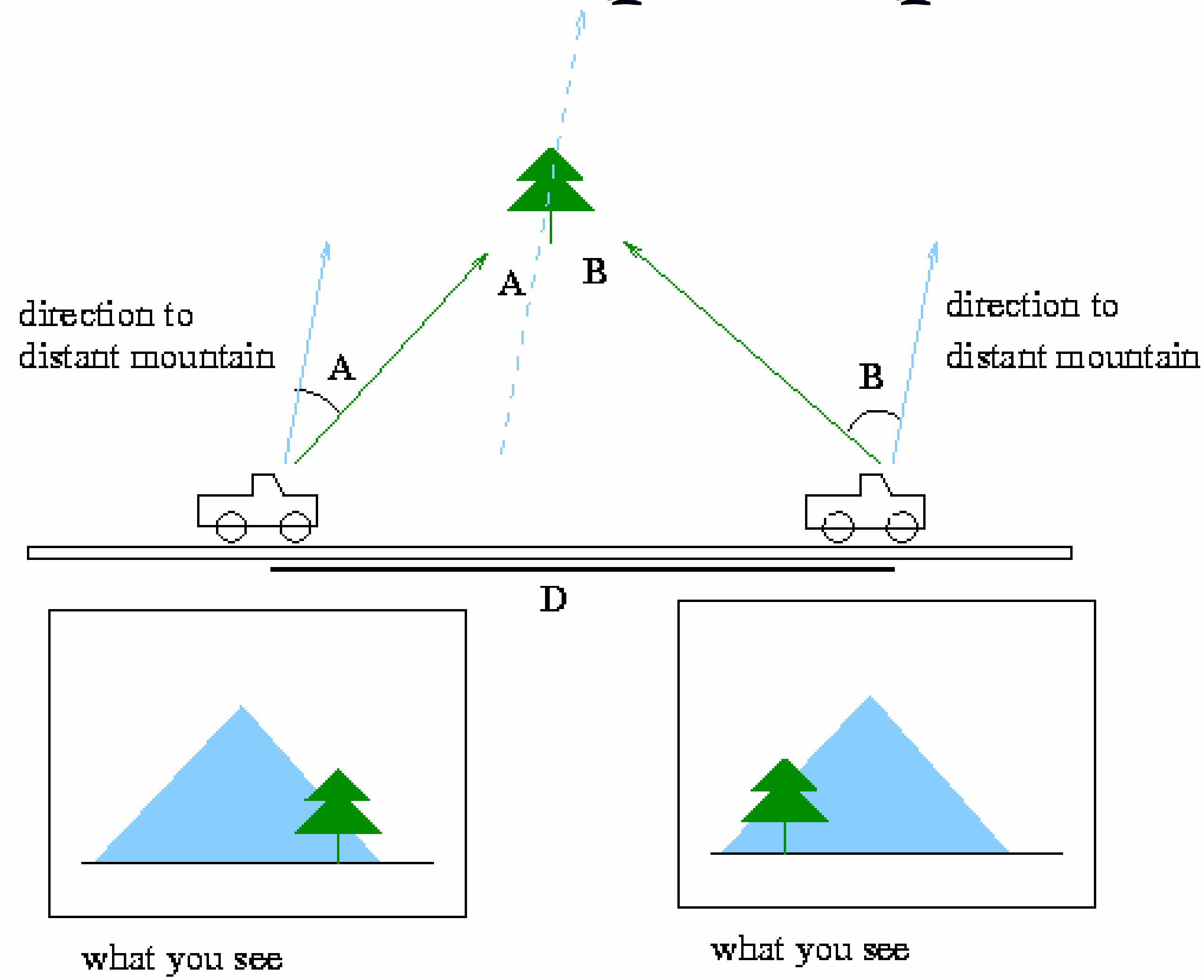
- More astronomical concepts
  - Stellar parallax
  - Luminosity and brightness
  - The magnitude system
  - Electromagnetic spectrum
  - Stellar spectra & atomic absorption/emission

1st Pop Quiz on Monday – 10 questions, 10 minutes
Will cover what we have looked at this week
(multiple choice)

# Parallax – a key method for measuring distance

- Hold your finger out and look at it with right and left eyes separately: it appears to **shift** relative to background.
- **Parallax:** you are looking at your finger from two different vantage points/angles
- Amount of shift depends on how far away your finger is

# Another example of parallax




Foreground appears to "move" faster than the background – distant objects have less parallax.

# Stellar Parallax

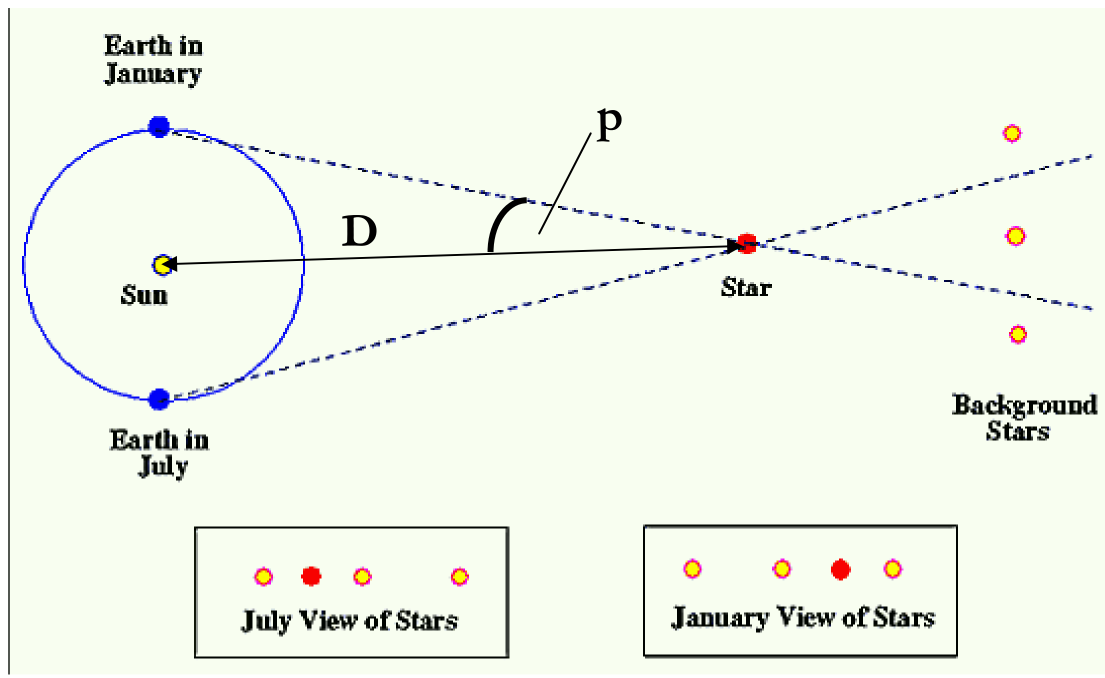
- Baseline is 2 AU for the Earth's orbit around the Sun
- We will get p = 1 arcsec of parallax when the object is 206,265 AU in distance. This defines the **parsec**
- **1 parcsec =** 206,265 AU = 3.08 x 1016 m = 3.26 light years

$$D = 1/p$$

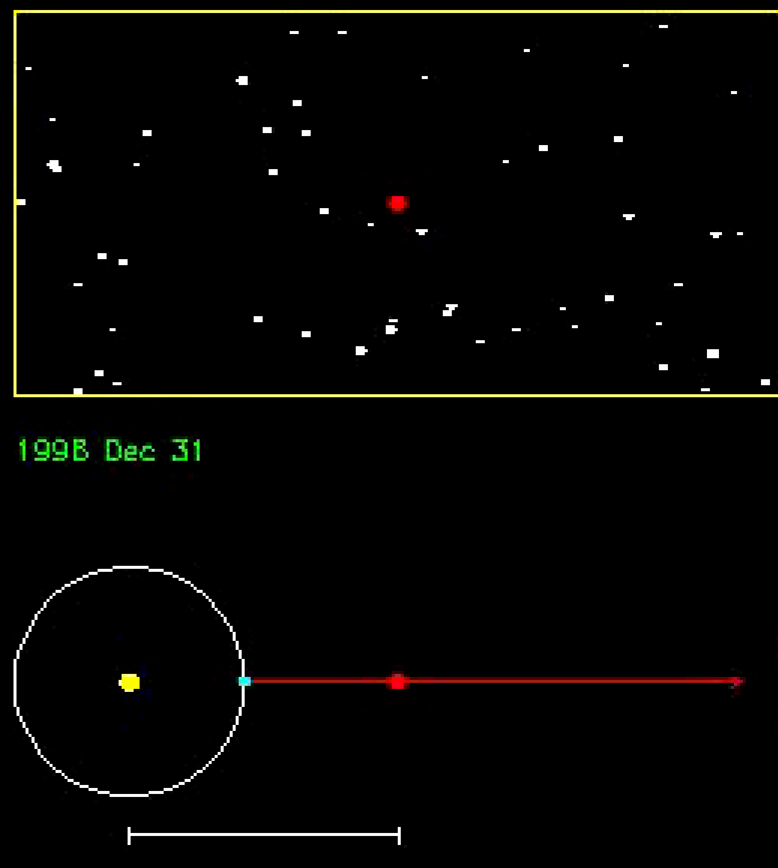
*D* in **parsec**

*p* in **arcsec**

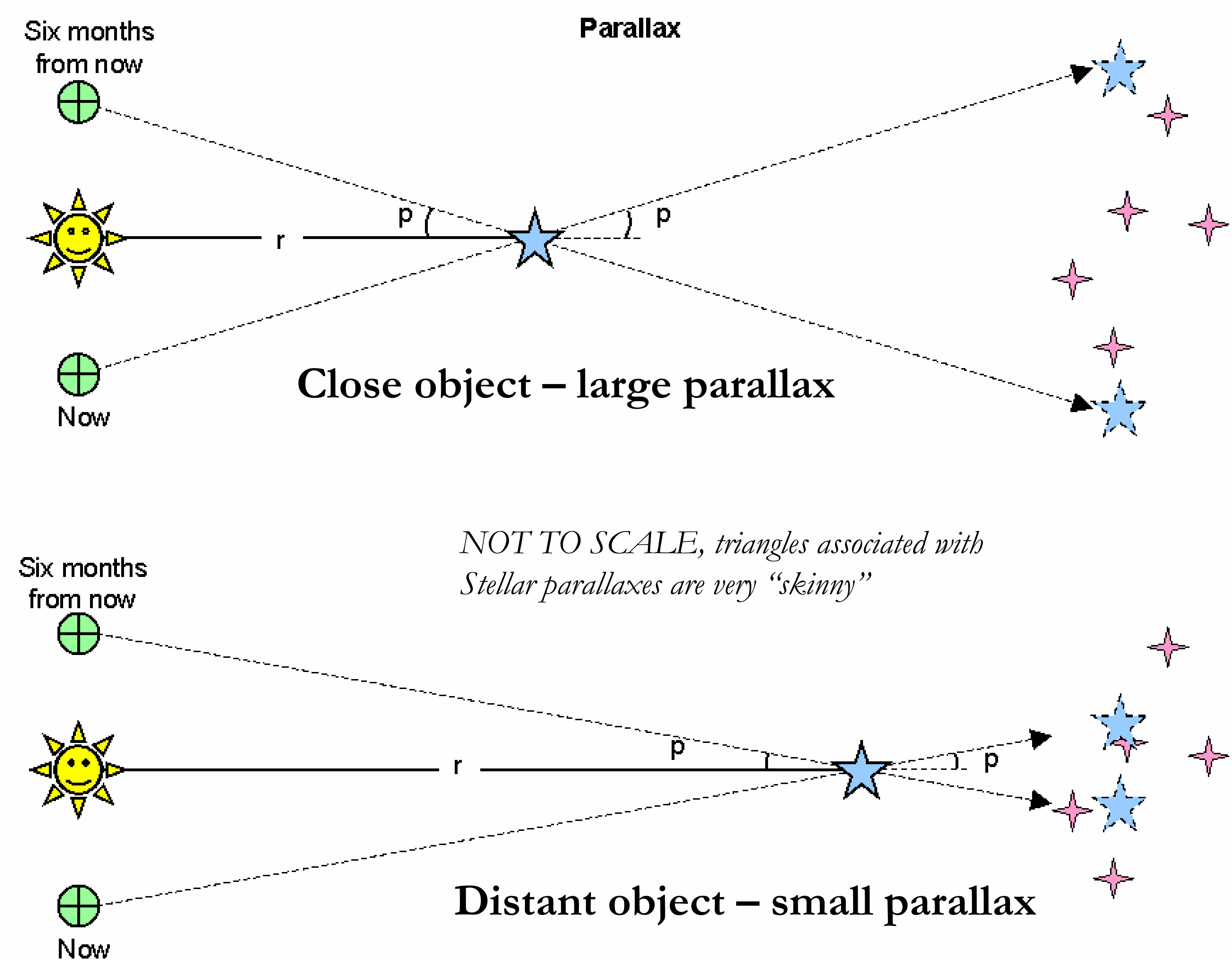
***D*** is the distance to the star
***p*** is *half* the difference in angular position on the sky



# Parallax Movie




Movie by Richard Pogge


Parallax
Six months
from now
p
r
p
Now
Close object – large parallax
NOT TO SCALE, triangles associated with
Stellar parallaxes are very "skinny"
Six months
from now
p
r
p
Now
Distant object – small parallax

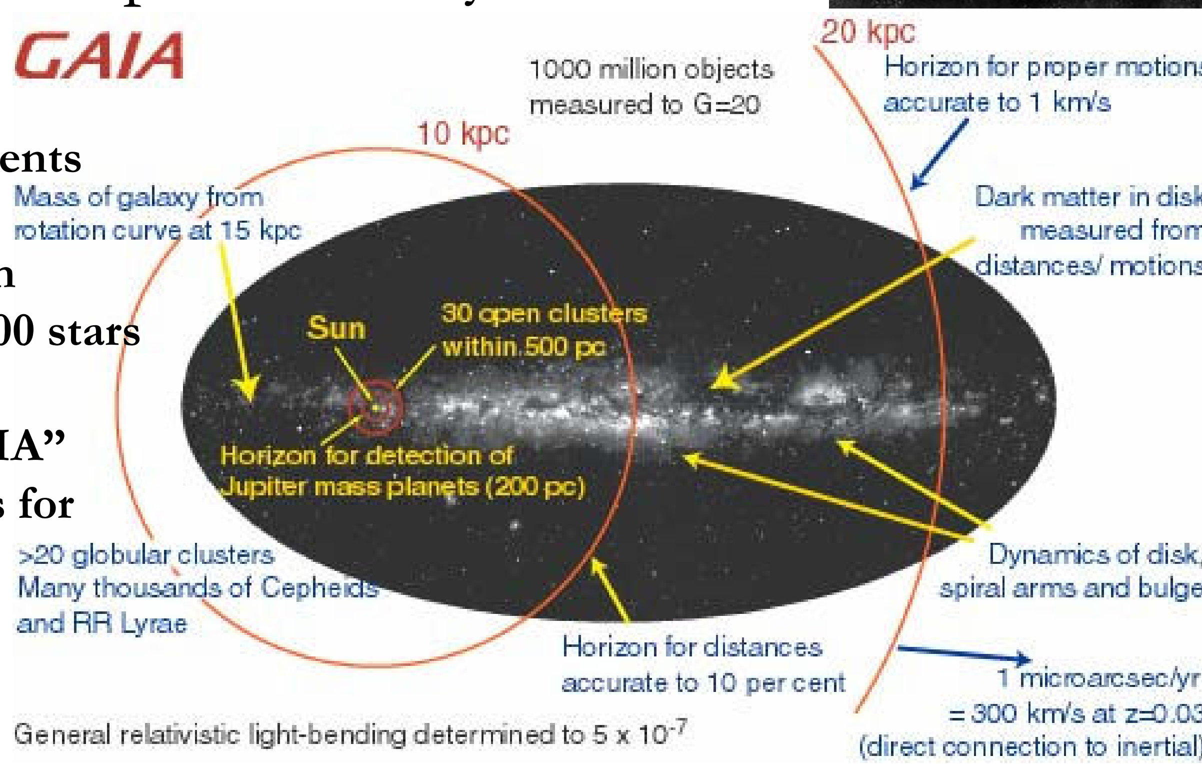
# Interesting facts

- First stellar parallax: Friedrich Bessel (1938) measured the parallax of 61 Cygni ~ 0.3 arcsecs, so 61 Cygni is about 3 parsecs away

**Still used today – we now use satellites to do the measurements**

**HIPPARCOS – precision measurements for 120,000 stars**

**Upcoming mission "GAIA" will make measurements for 1 billion(!) stars**



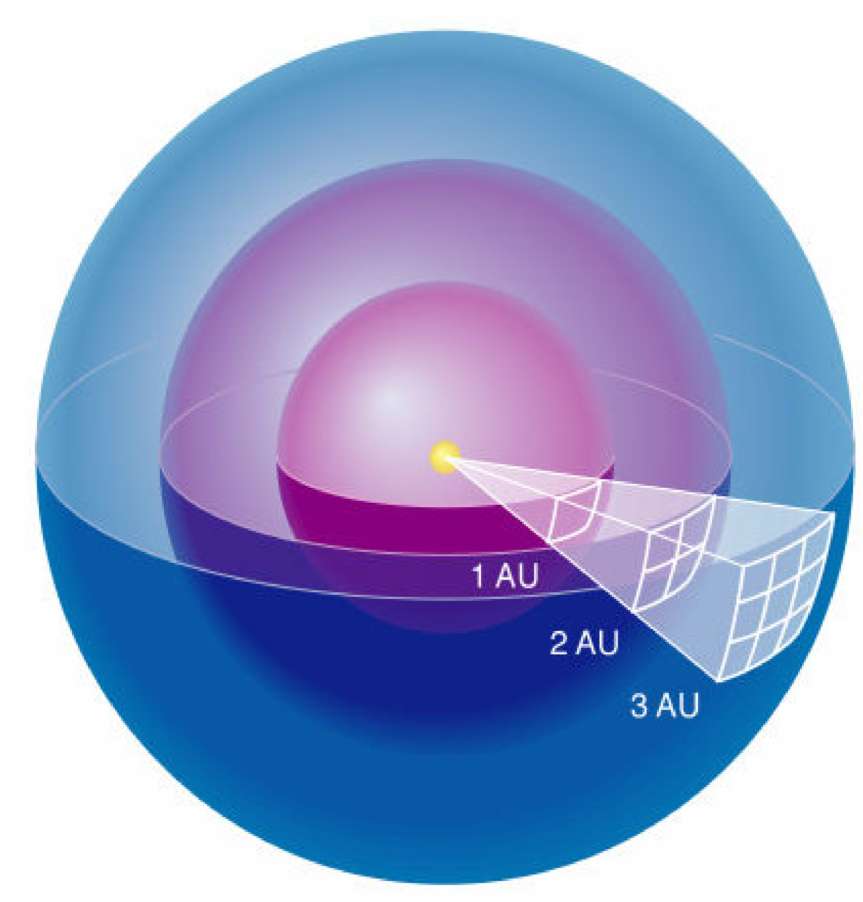
# Luminosity and Apparent Brightness

- ***Luminosity L:  Power*** radiated by an object: Joules/sec = Watts

- At distance R, radiation spread over sphere of radius R: energy falling on each unit area of that sphere is ***Flux*** or ***Apparent Brightness,*** units of $W/m^2$ :

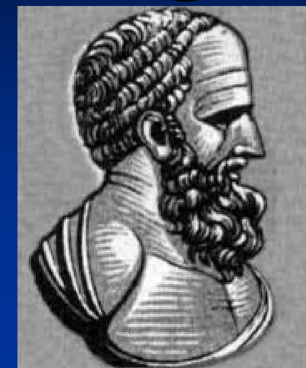
$$\mathbf{F = L/4\pi R^2}$$

- Flux decreases as $1/R^2$




We measure the apparent brightness of stars using the Magnitude system

# Magnitudes: Historical Origin



- The Greek astronomer Hipparchus created the first star well-known star catalogue
  - Brightest stars were "first magnitude", the faintest "$6^{th}$ magnitude", with different levels in between
  - Hipparchus did all this by eye!
- But there is a clear problem
  - *Brighter* stars (higher apparent brightness) are represented by *lower magnitudes*
- The resulting calculation of magnitudes from apparent brightness thus has to take this fact into account

# Magnitudes: Definition

- Magnitude system uses apparent brightness in a *logarithmic* way. ***Apparent magnitude, m,*** defined:

  $$m = -2.5\log(F) + \text{constant}$$
  $$= -2.5\log(L/4\pi R^2) + \text{constant}$$

  (note the "–" sign to account for magnitude system)

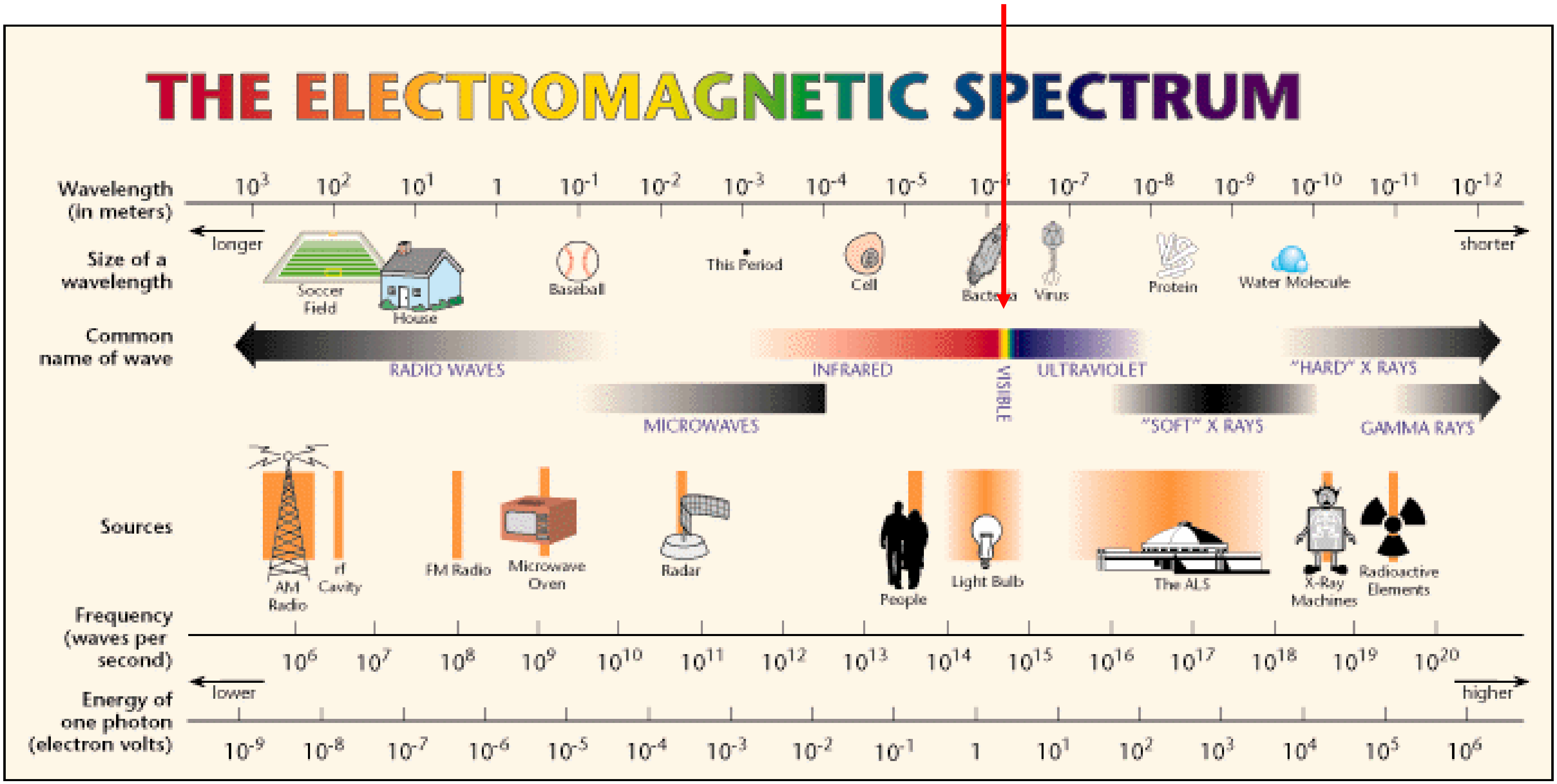
- **so:** change of 1 mag = factor of 2.51 in apparent brightness
  change of 5 mags is a factor of 100 in apparent brightness
  fainter objects have **larger** magnitudes! (what we want)

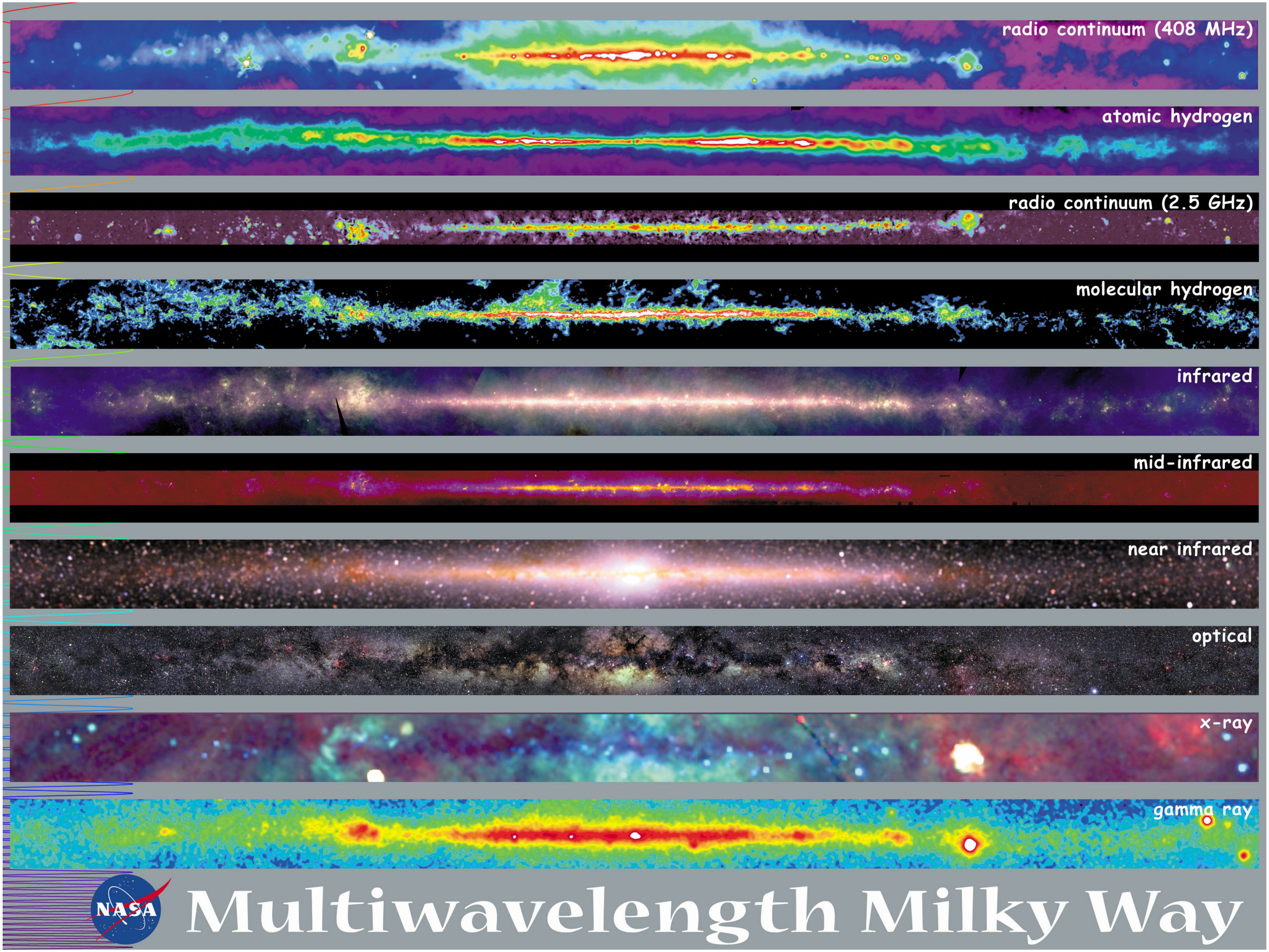
- ***Absolute Magnitude (M)*** is defined as **Apparent Magnitude (m)** at D = 10 pc. Can show that ***distance modulus (m-M)*** is:

  $$\mathbf{(m - M) = 5\log(D) - 5}$$ where D is in pc

# Electromagnetic Spectrum

- Light is just one part of the electromagnetic spectrum, corresponding to a narrow wavelength (or frequency) range



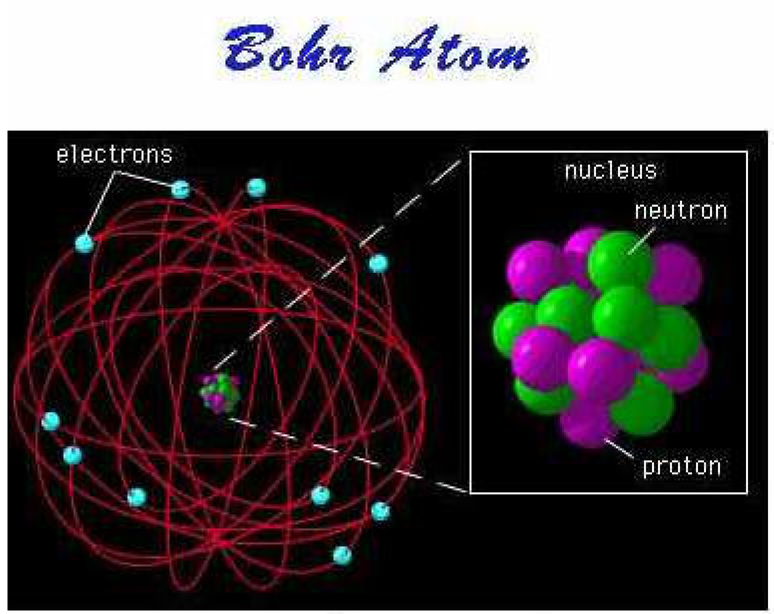

radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
NASA
Multiwavelength Milky Way

# Aside – Why astronomy is a "strange" science

- In biology, chemistry or physics we can set up experiments
  - Test hypotheses
  - Repeat
- In astronomy it is usually impossible for us to do an experiment
  - We only observe systems
  - Can't "make a new planet" or "new universe"
  - Computer experiments are the closest we can come to this!
    - Make new "universes" inside computers!
- It is frankly amazing how much we know about the Universe around us, given that we are largely stuck on the Earth!

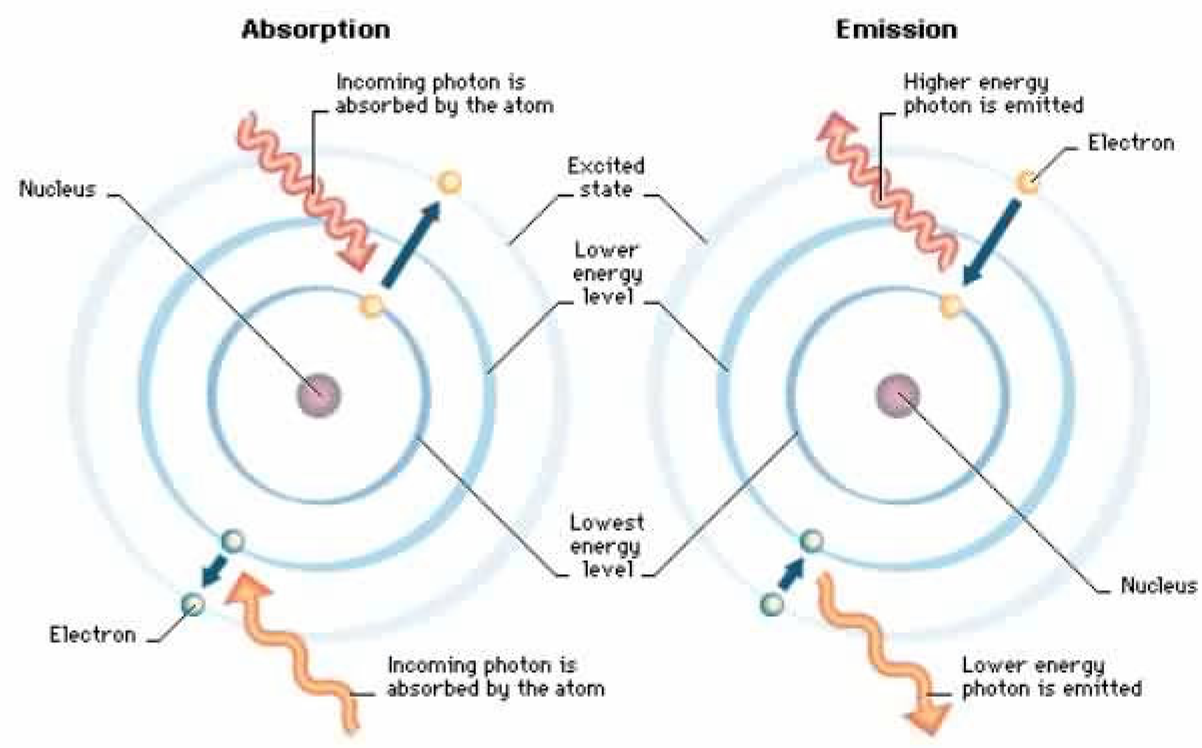
# Atomic structure: the key to understanding distant systems

- **Bohr Atom:** nucleus with **positively-charged protons** and neutral neutrons, surrounded by **negatively-charged electrons**.
  - Electrons **only** have certain **allowed** orbits.  These allowed orbits are **different** for each element, and each orbit has a specific **energy level**.



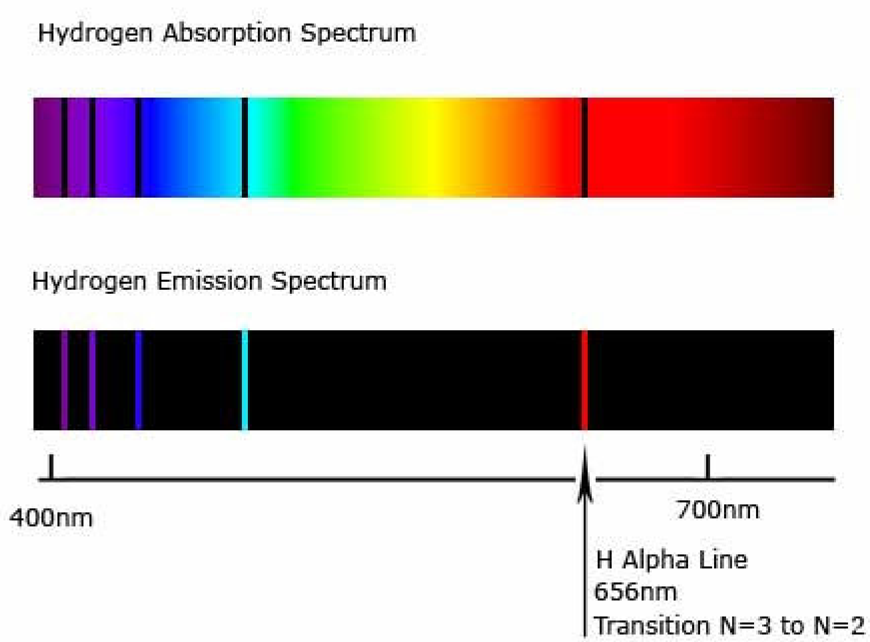
# Absorption & Emission

- Electrons move between energy levels by either *emitting* a photon of the right energy and dropping down to a **lower** orbit, or by *absorbing* a photon of the right energy and being raised to a **higher** orbit.



# Emission & absorption spectra

- The emitted or absorbed photons have energy $E=hf$, where h is Planck's constant and f is the frequency
- All the different possible transitions produce *emission/absorption spectra*

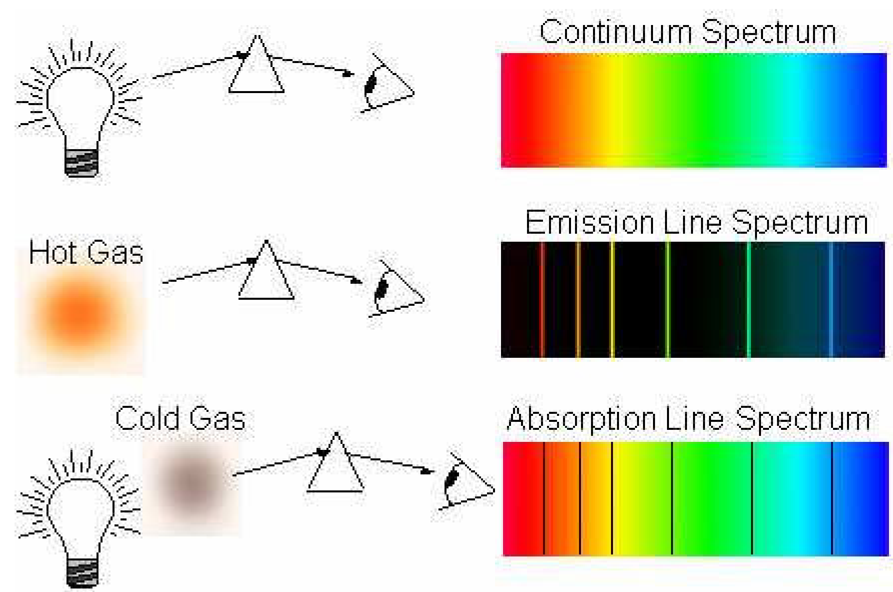



Frequently dubbed "atomic bar-codes"

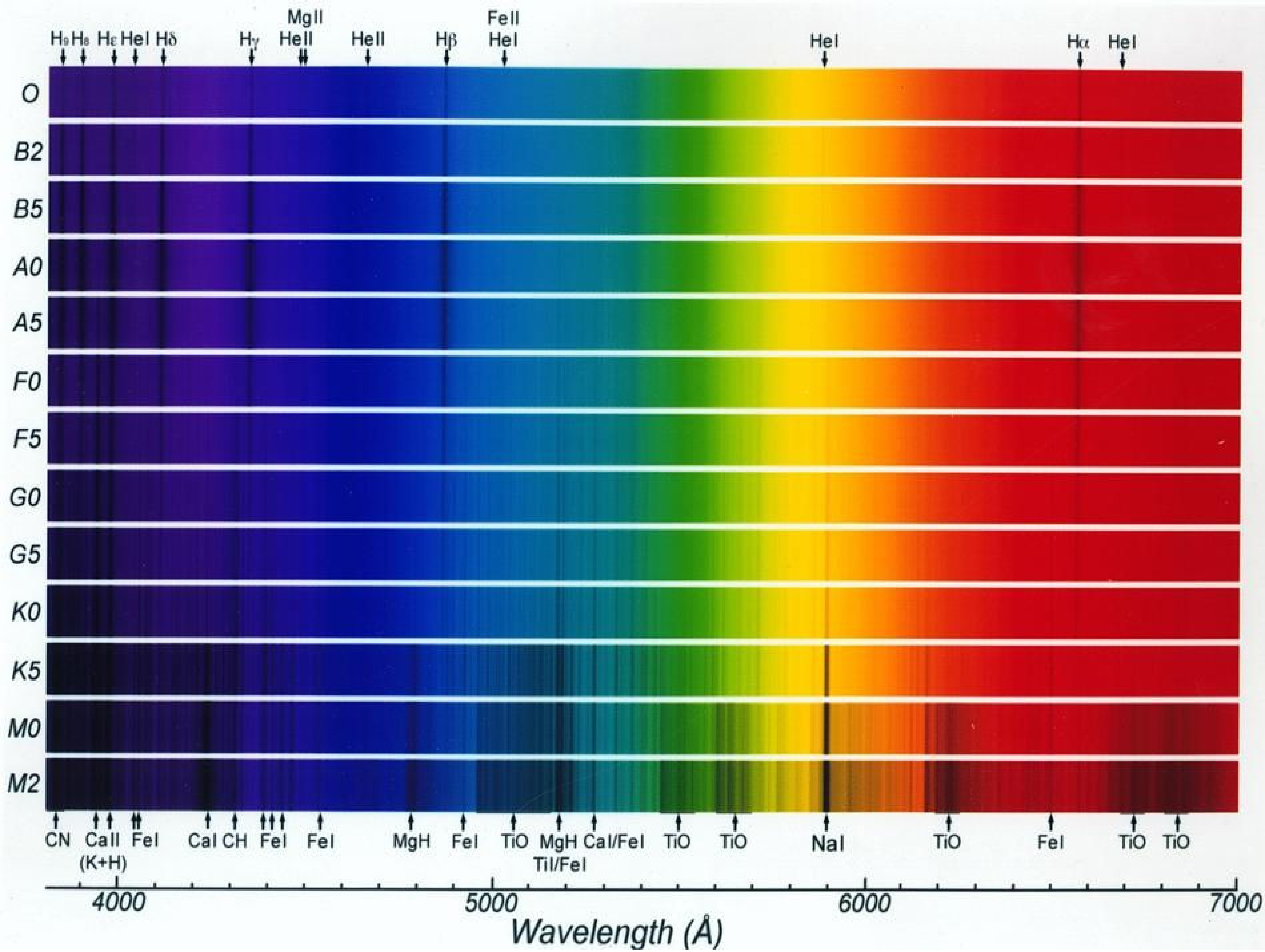
# Kirchoff's Laws of Spectroscopy

- A hot dense body (solid or dense gas) gives off a continuous "black body" spectrum.
  - **e.g. at the center of the Sun and other stars.**
- A hot, low-density (diffuse) gas emits light at only certain wavelengths.
  - **e.g. hot gaseous nebulae. The emission lines tell us the composition of the gas.**
- When light with a continuous spectrum passes through cool gas, dark lines appear in the continuous spectrum.
  - **Such "cool" gas exists in outer layers of stars, absorbing light at certain wavelengths from continuous spectrum coming from below.**

Prism breaks up incoming light into components

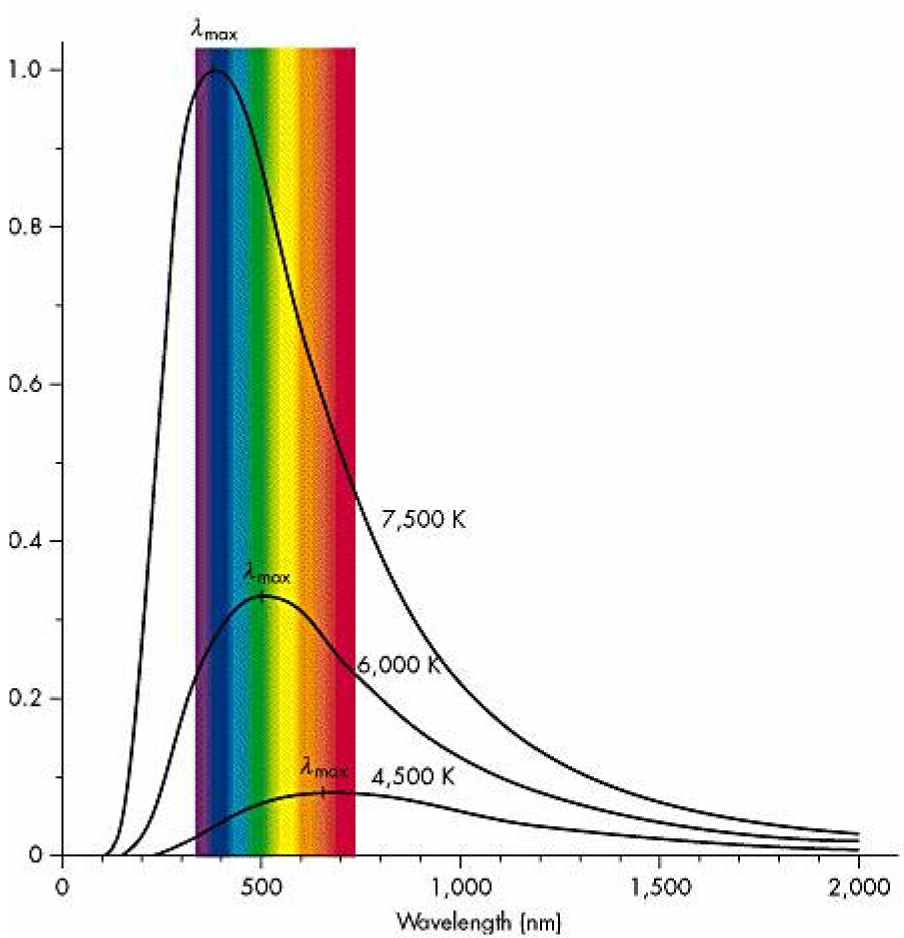



***Stars of a certain type have very specific atomic composition, so we can use the absorption line spectrum to tell us what type of star we are looking at!***



H9 H8 Hε HeI Hδ
Hγ
MgII
HeII
HeII
Hβ
FeII
HeI
HeI
Hα
HeI
O
B2
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M2
CN
CaII
(K+H)
FeI
CaI
CH
FeI
FeI
MgH
FeI
TiO
MgH
TiI/FeI
CaI/FeI
TiO
TiO
NaI
TiO
FeI
TiO
TiO
4000
5000
6000
7000
Wavelength (Å)

# The "Black body" spectrum



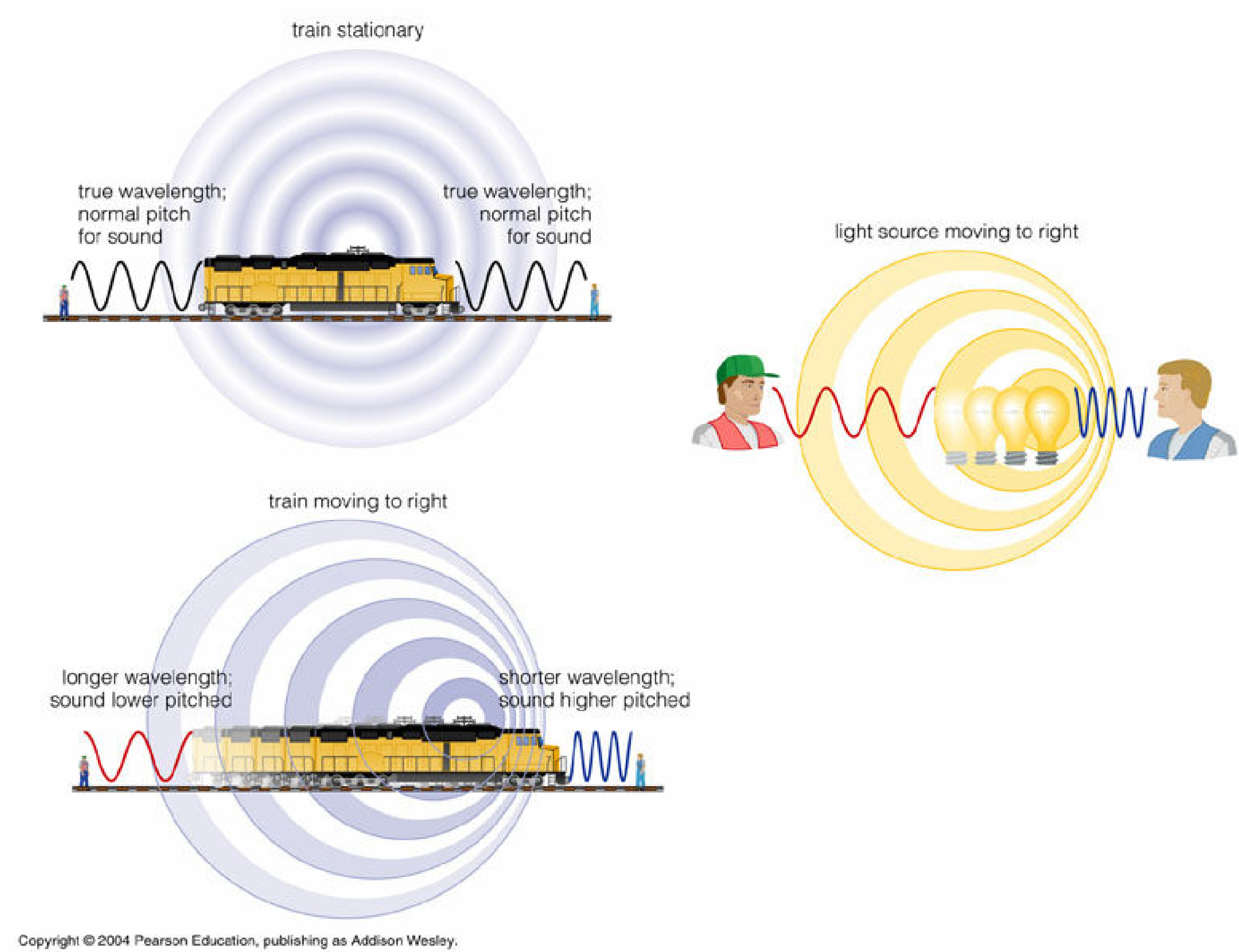

- **Colours** of stars and **total energy** they produce depends on their **temperatures**
- **<u>Stefan-Boltzmann Law</u>:** $\mathbf{E = \sigma T^4}$

  **E =** energy emitted per unit area, **T** is temperature, $\sigma$ = constant
- **<u>Wien's Law</u>:**

  $\boldsymbol{\lambda_{max} T}$ **= constant**

  where $\lambda_{max}$ is wavelength of peak emission, T= temperature (K)

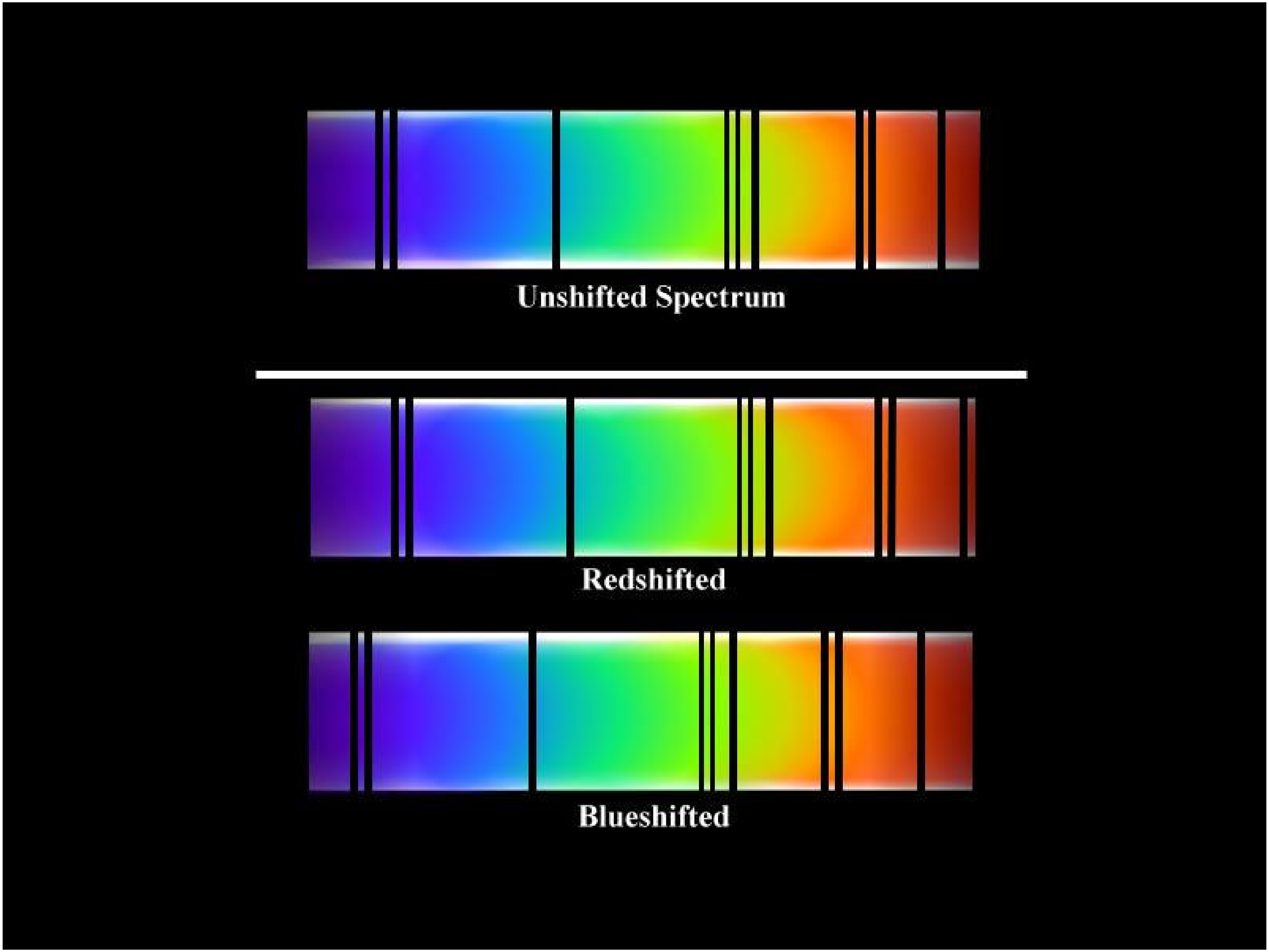
# Doppler shift



# Radial velocity and Doppler shift

- Like sound waves, light (EM) waves show a **Doppler Shift**: if an object is coming towards us, light has shorter than normal wavelengths and will be **blue-shifted**. For a receding object, the wavelengths become longer and the light is **red-shifted**.

- So by comparing the spectrum of an object (star, galaxy) with that produced by similar elements in the lab (zero velocity), we can determine if the object is moving ***towards*** or ***away*** from us, **and** its speed towards/away from us. This really depends on using the **absorption lines.**


Unshifted Spectrum
Redshifted
Blueshifted

# Measuring radial velocities

- So we **match spectral line patterns** to determine the wavelength (Doppler) shift

- For velocities v << c we have:

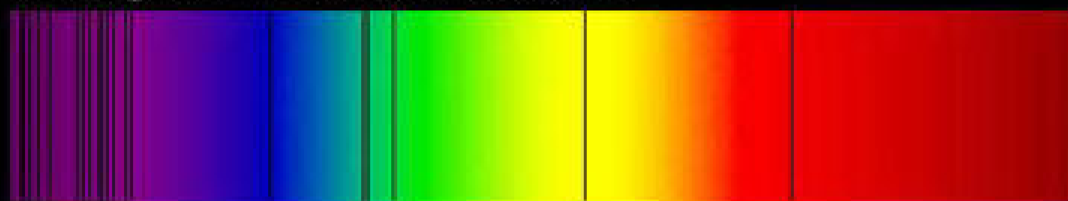
$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

where $\Delta\lambda$= wavelength shift, $\lambda$= wavelength for stationary source, $v$ = velocity of object, and c = speed of light

- Given measured $\Delta\lambda$, and the wavelength of the atomic line were are looking at, $\lambda$, we can then get **velocity *v*** of object using the speed of light c

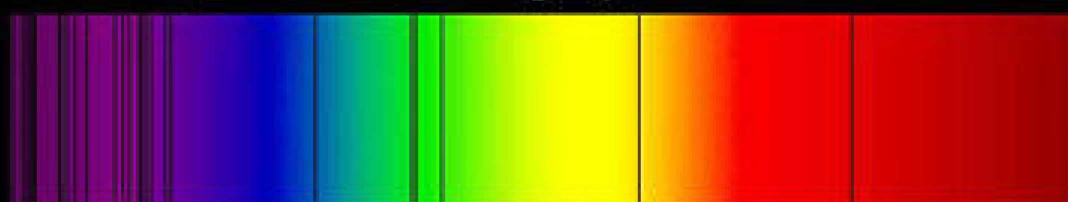
- Used to measure velocities of stars and galaxies, as well as rotation of **Sun** (and other stars), **planets**, and **binary stars**

Absorption Lines from our Sun



Absorption Lines from a supercluster of galaxies, BAS11

$v = 0.07\,c, \quad d = 1$ billion light years



# Summary of lecture 3

- Parallax allows us to calculate the distance to local stars
  - A star 1 parsec distant has a parallax angle of 1 arcsecond
- Brightness of stars is measured in terms of the magnitude system
  - Lower magnitudes are brighter than higher ones
  - The relationship is logarithmic relative to luminosity
- Atomic emission spectra are fundamental to interpretation of astronomical observations
  - Can determine composition and movement of the object from the spectrum

# Next lecture

- Cosmology
  - The “Big Bang” & the evolution (+ “shape”) of the Universe