Astro 301/ Fall 2006

(50405)

Introduction to Astronomy

http://www.as.utexas.edu/~sj/a301-fa06

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Lecture 22: Tu Nov 21

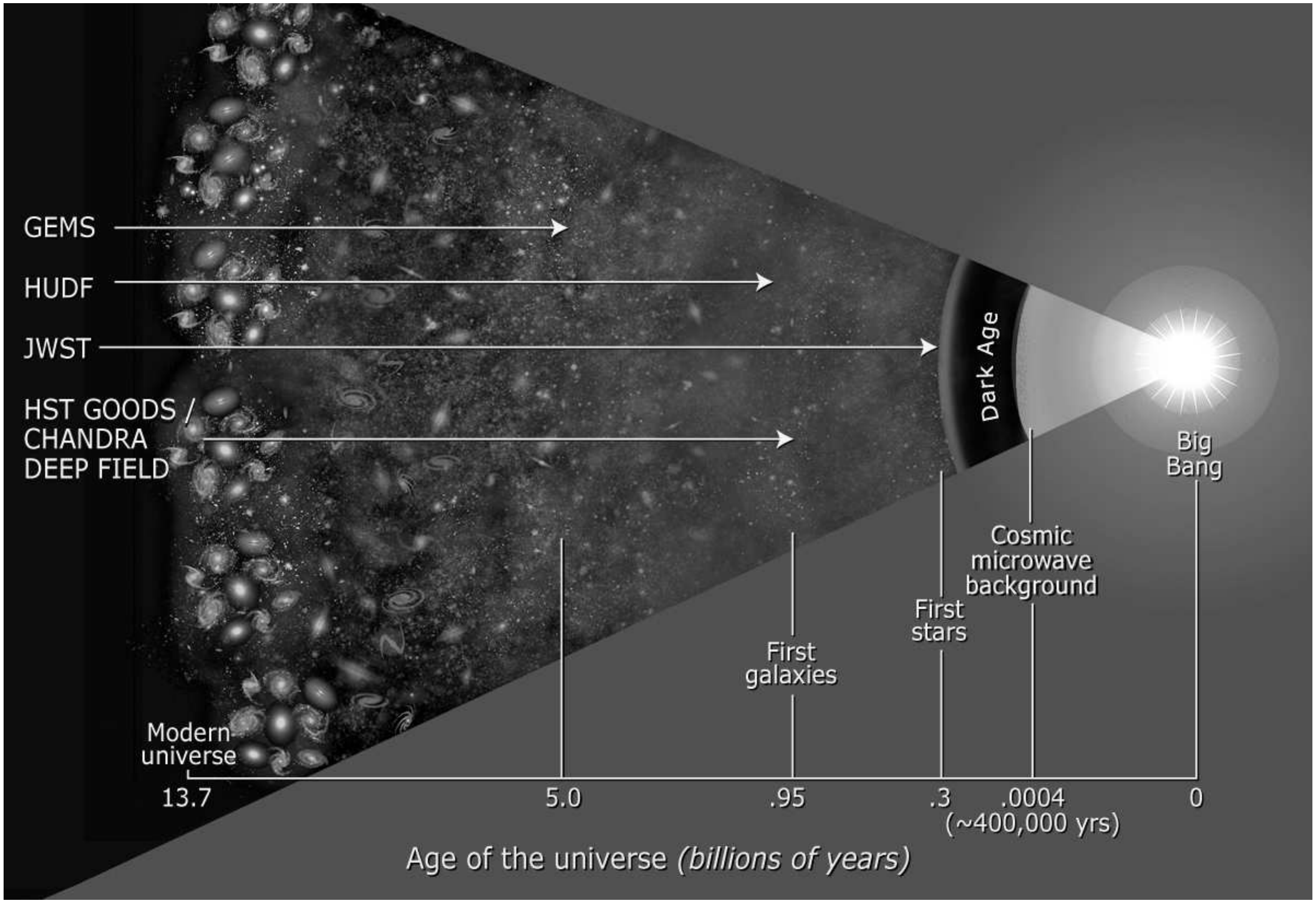
Lecture 22: Announcements

1) Quiz 5 today
2) Pick up homework 4 and related article : due back next Tuesday
3) Exam 3 will be held on Dec 7.
   Details on class website
   There will be absolutely no make up exam under ANY circumstances

   Have a good Thanksgiving break

How do galaxies form and evolve ?

The Universe today is 13.7 Gyr (i.e 13.7 billion years) and host very massive spiral and elliptical galaxies (M = up to a few 10^{12} M_o) , as well as somewhat less massive Irreguar and dwarf galaxies. How did these galaxies form ?



In order to unravel how galaxies evolved, we must first learn about a few key tools and concepts that astronomers use

Recent and Upcoming topics in class

Distances of very nearby galaxies
The Great Shapley-Curtis Debate
Standard candles
Edwin Hubble establishes the existence of external galaxies

Chemical composition and redshifts of galaxies
Particle or photon model of light
How do atoms in galaxies produce emission lines?
Information gathered from emission lines: chemical composition and redshift of a galaxy
Redshift: Doppler redshift and cosmological redshift

Hubble's law demonstrating the expansion of the Universe
Hubble's law : distance-redshift or distance-velocity relationship

Redshifts and lookback time of galaxies
How do astronomers look back in time ?
Using the redshift of a galaxy to figure out its lookback time

Distances of nearby galaxies

“Spiral Nebulae” or “Island Universes”?

1) Mid-1700s telescopes showed spiral-shaped structures in the sky (e.g. M31=And, M101)

à are these spiral gas clouds (spiral nebulae) located within our Milky Way galaxy?

à are these external galaxies (island Universes) located well beyond our Milky Way?
(cf. Immanuel Kant 1755)

2) 1920, Washington D.C : The Great Debate on “The Scale of the Universe”
between Harlow Shapley and Heber Curtis

Shapley: spiral nebulae are part of our own galaxy

à One nova seen in M31 has an apparent brightness (flux) similar to novae in our own Galaxy
So M31 must be at a similar distance from Earth as our own Galaxy

[Recall Flux = Luminosity/ $4 \pi D^2$ where D is distance]

Curtis: spiral nebulae are external galaxies, very far away from the Milky Way

à All other novae seen in M31 were much fainter than novae in our own galaxy
So M31 must be much futher away from Earth than our own Galaxy

No one scored convincing victory

Ultimate resolution requires measuring the distance to M31 or M101 directly

Using standard candles to measure distances

1) A standard candle is an object whose luminosity L

- is the same irrespective of where it is in the Universe
- can be determined from some easily observable property.

2) In order to infer the distance D of a g distant galaxy where we see a standard candle

à we measure the apparent brightness or flux F of the standard candle

à we assume a value for the luminosity L of the standard candle

à we infer the distance D from the relation between flux, luminosity and distance

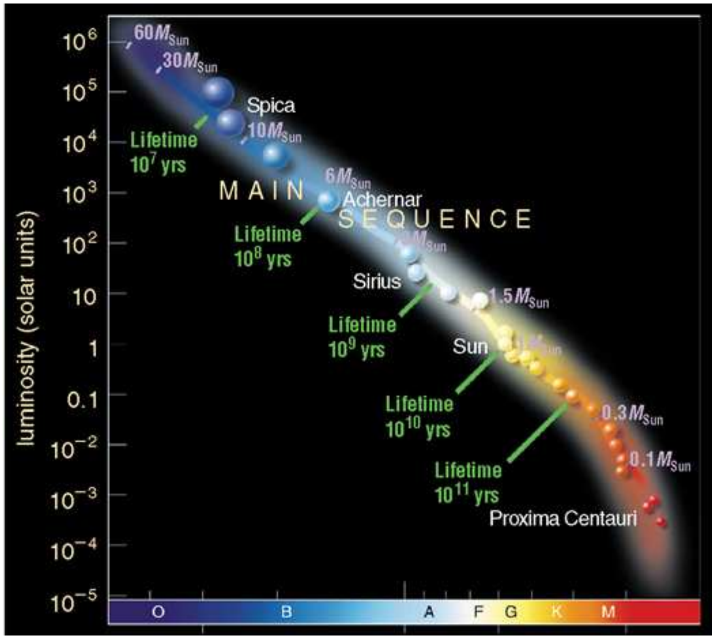
$$F = (L) / (4 \pi \iota D^2)$$

3) How do we know what L of the standard candle is ?

Before we use a standard candle in distant galaxies, we must first calibrate
the luminosity of the standard candle using many NEARBY standard candles

Example of standard candles

1) Main sequence stars in stellar clusters



Main sequence stars in a stellar cluster
obey a color-luminosity relation.
à If you measure the color you can uniquely infer the luminosity

<u>Step 1:</u> Calibrate Color-Luminosity relation of main sequence stars using nearby clusters whose distance we know.
For these stars we measure (color, flux) and convert it into (color, luminosity).

<u>Step 2: Apply calibrated Color-Luminosity relation to stellar clusters in distant galaxies</u>

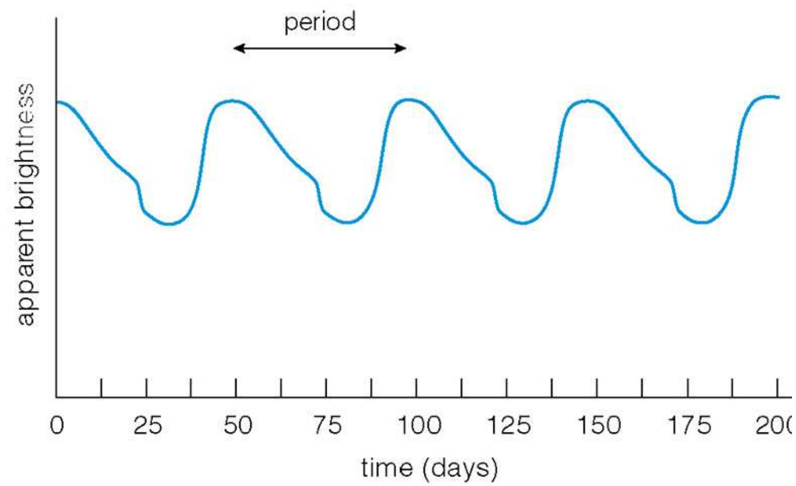
à In a distant galaxy, observe (color, flux) of main sequence stars

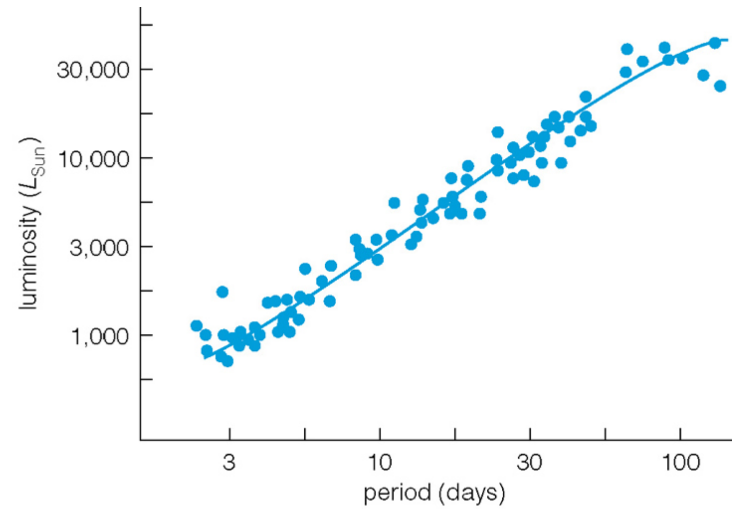
à Use the color and calibrated color-Luminosity relation to infer the luminosity L of the stars

à Since we now know both flux F and luminosity L, we infer the distance D from the relation between flux, luminosity and distance

$$F = (L) / (4 \pi\iota D^2)$$

Example of standard candles: Cepheid Variables





Cepheids are pulsating variable stars.
Their flux fluctuates with a period P that depends directly on their luminosity L
à they obey a Period-Luminosity relation

<u>Step 1:</u> Calibrate Period-Luminosity relation of Cepheids using nearby Cepheids whose distance we know.

<u>Step 2: Apply calibrated Period-Luminosity relation to distant Cepheids</u>

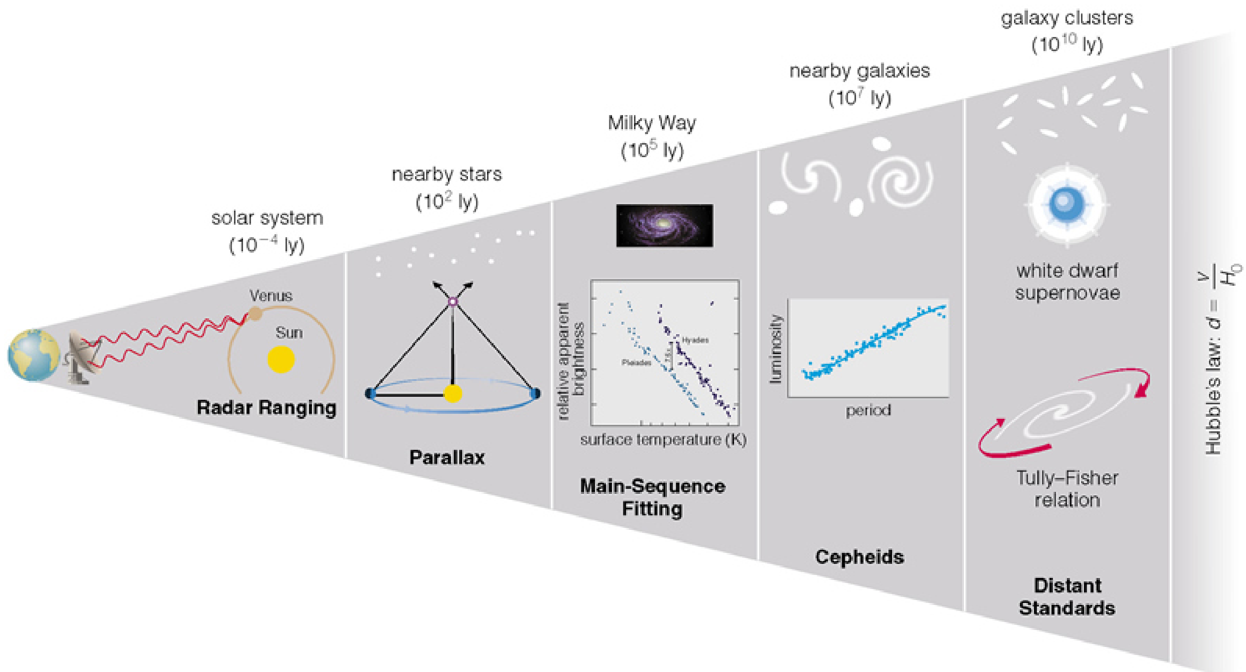
à In a distant galaxy, observe (period, flux) of Cepheids

à Use the period and calibrated Period-Luminosity relation to infer the luminosity L of Cepheids

à Since we now know both flux F and luminosity L, we infer the distance D from the relation between flux, luminosity and distance

$$F = (L) / (4 \pi \iota D^2)$$

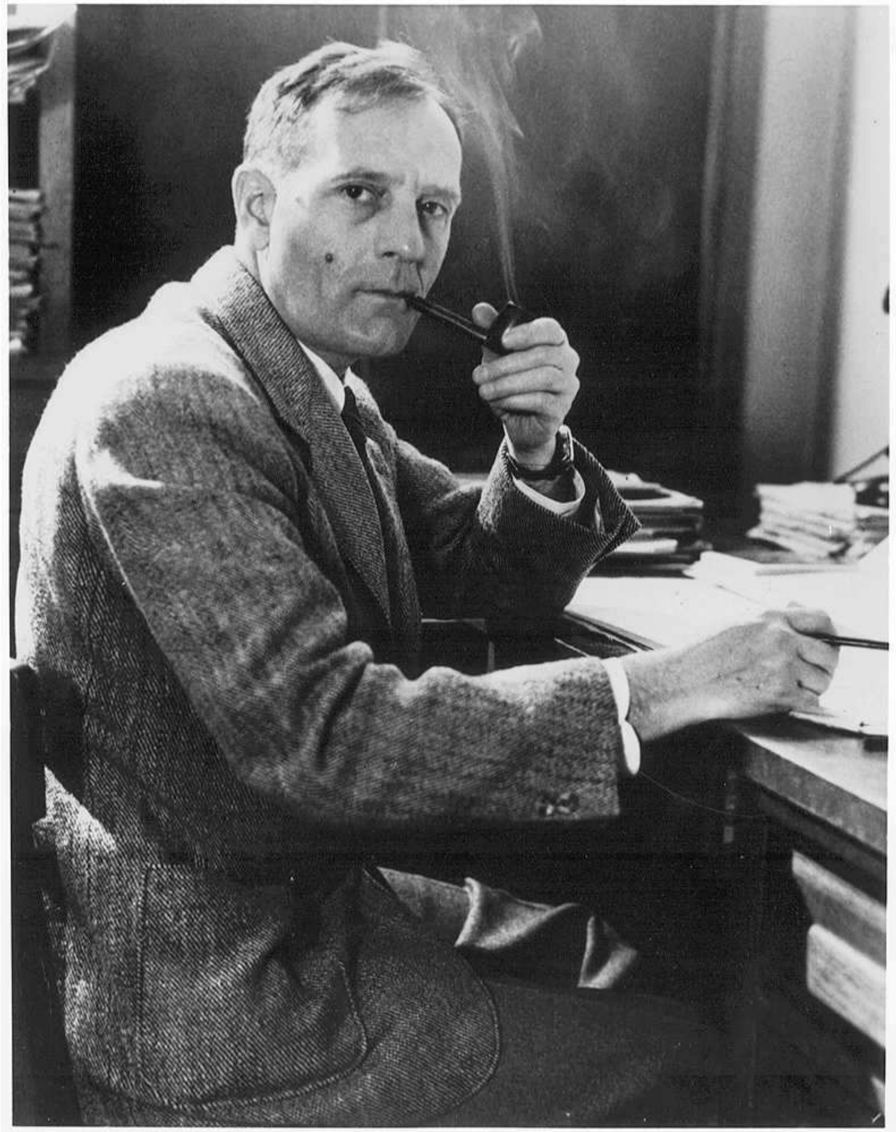
The distance ladder for stars and galaxies



As we move to larger distances we need brighter standard candles.

à use the main sequence turn off of stellar clusters out to 10^5 lyr in our Milky Way
à use brights Cepheids in external galaxies out to 10^7 lyr
à use Type Ia supernovae further out
à Use Hubble's law even futher out

Edwin Powell Hubble (1889-1953)



Used Cepheids in Andromeda (M31) as standard candles to infer the distance of M31

à Measured period of Cepheids in M31

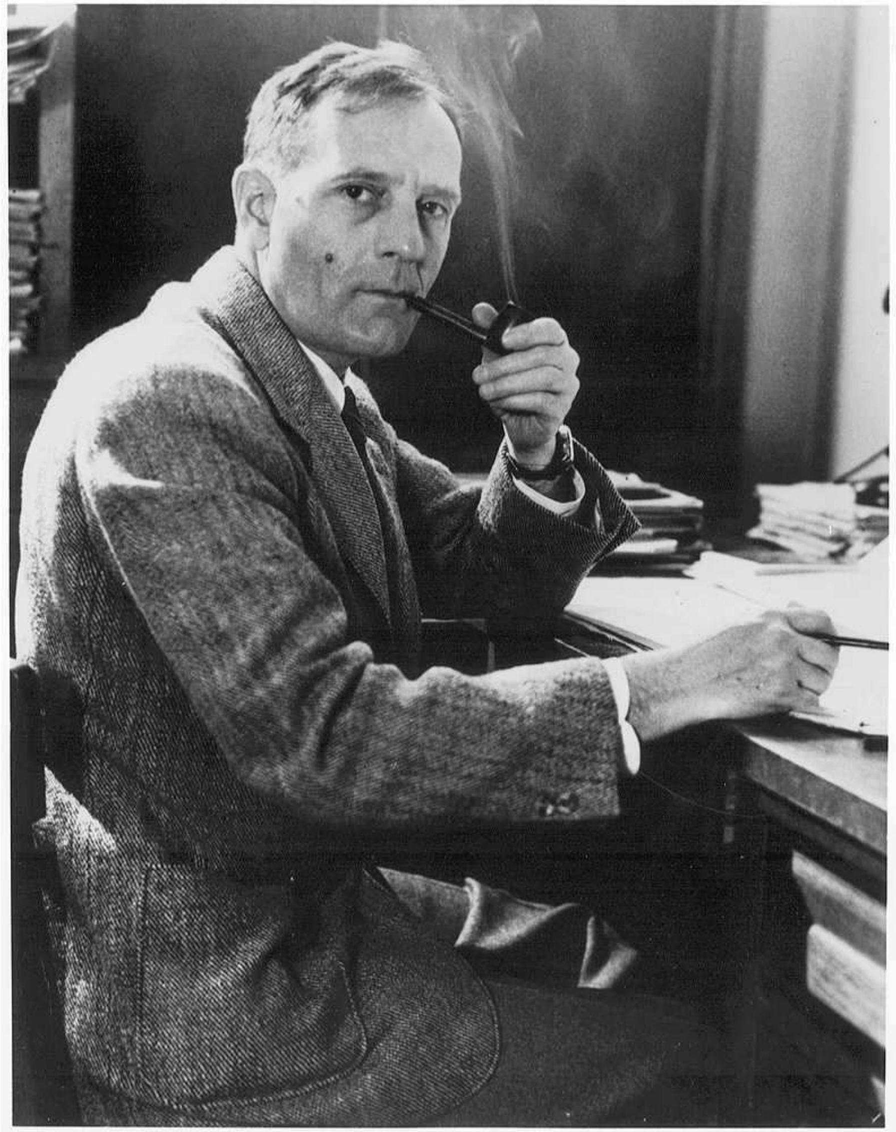
à Applied calibrated Period-Luminosity relation to infer Luminosity of Cepheids

à Since he knows both flux F and luminosity L, he infers the distance D from the relation between flux, luminosity and distance

$$F = (L) / (4 \pi D2)$$

Demonstated conclusively that M31 is an external galaxy

Edwin Powell Hubble (1889-1953)



Revolutionized our view of the Universe. Considered as the father of observational cosmology:

à showed other galaxies exist beyond the Milky Way using 100 inch telescope at Mt Wilson

à developed classification system for galaxies

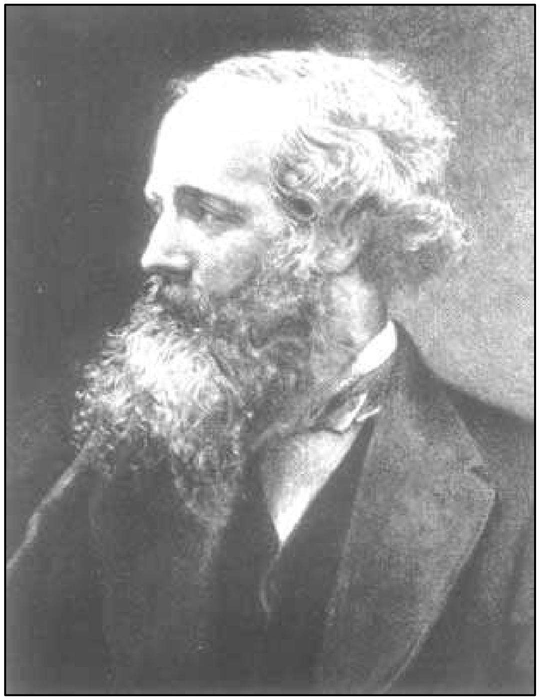
à showed that the Universe is not static but expanding (cf Einstein's blunder)

à Initiated construction of 5 m (200 in) at Palomar

à Hubble Space Telescope named after him

Chemical composition and redshifts of galaxies

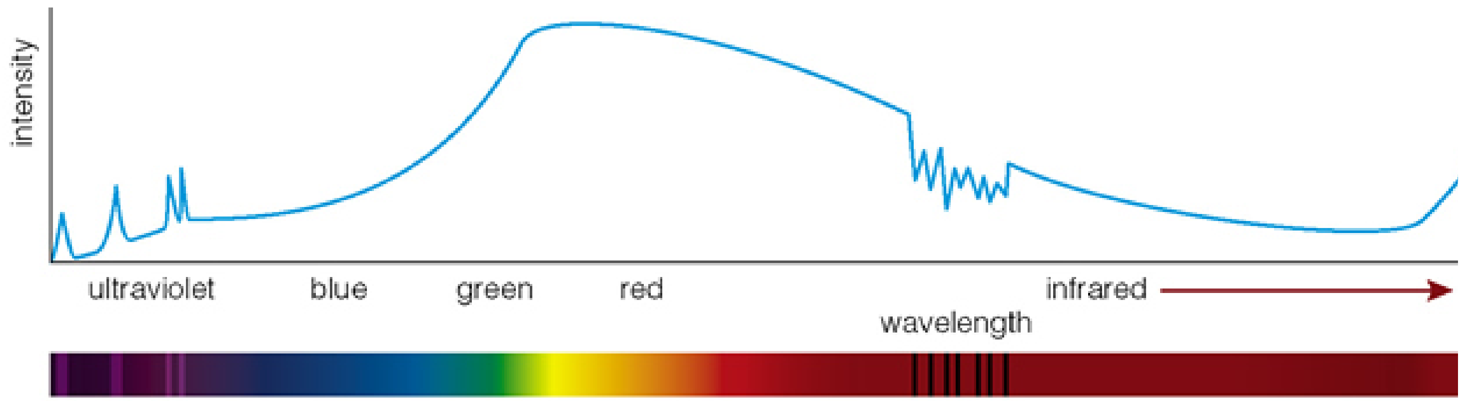
The wave model of of light



According to Maxwell (1831 – 1879):

Light is made of waves of electric and magnetic fields – electromagnetic radiation!

Continuum emission, Emission lines and Absorption lines

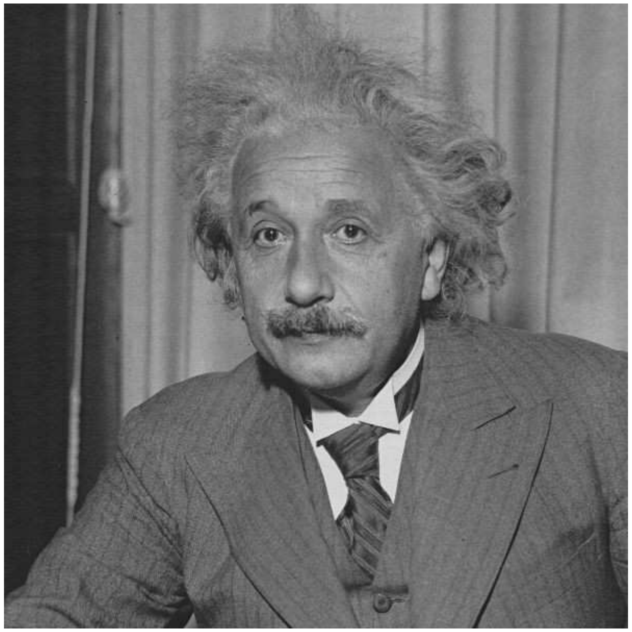


1) Recall: a spectrum is a plot of the intensity of light at each wavelength.

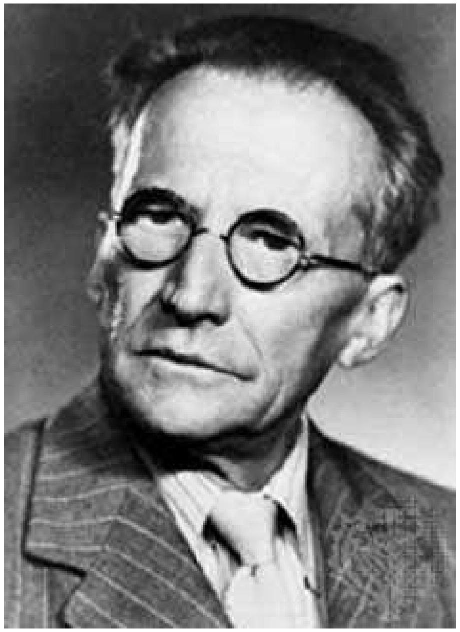
2) In general a spectrum can have 3 types of features:
   - continuum emission : emission over a continuous range of wavelengths
   - emission lines : emission above the continuum at specific wavelengths
   - absorption lines: lack of emission (dip below the continuum) at specific wavelengths

3) Using the wave model of light (along with Kirchoff's law, Wien's law) we have explained the properties of the continuum emission in the spectrum
   But to explain emission and absorption lines … need the photon model of light

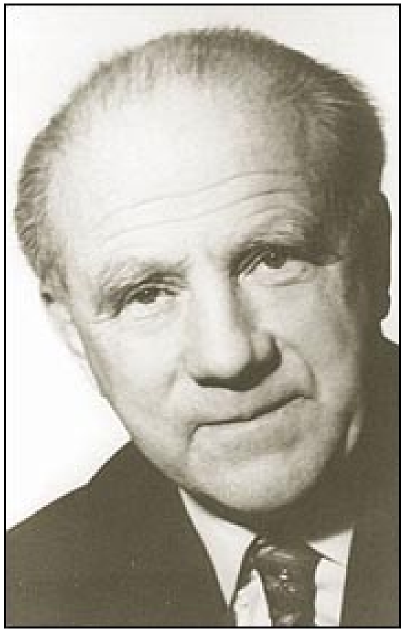
The dual wave-particle nature of light



Einstein
(1879 – 1955)



Schrodinger
(1887 – 1961)



Heisenberg
(1901 – 1976)

Light has a dual nature: It is made up of photons which are packets (quanta) of energy that have both particle and wave properties

The wave nature of particles

Louis de Broglie

Recherches sur la théorie des quanta

He extended work of Einstein and Planck to show that every particle has an associated wave.

He created the field of wave mechanics, uniting the physics of light and matter

Was awarded Nobel Prize in Physics in 1929

The dual wave-particle nature of light

Light has a dual nature: It is made up of photons which are packets (quanta) of energy that have both particle and wave properties

The energy E of a photon is directly proportional to its frequency υ and inversely proportional to its wavelength λ

$$E = h\upsilon = hc/\lambda$$

where h = Planck's constant = 6.6×10^{-34} Js

c = speed of light = 3×10^{8} m s^{-1}

Examples

A UV photon has a shorter wavelength and hence higher energy than a yellow photon. UV photons cause more skin damage than optical photons

X-ray photons can penetrate and traverse the human body while optical photons do not.

The dual wave-particle nature of light

Examples

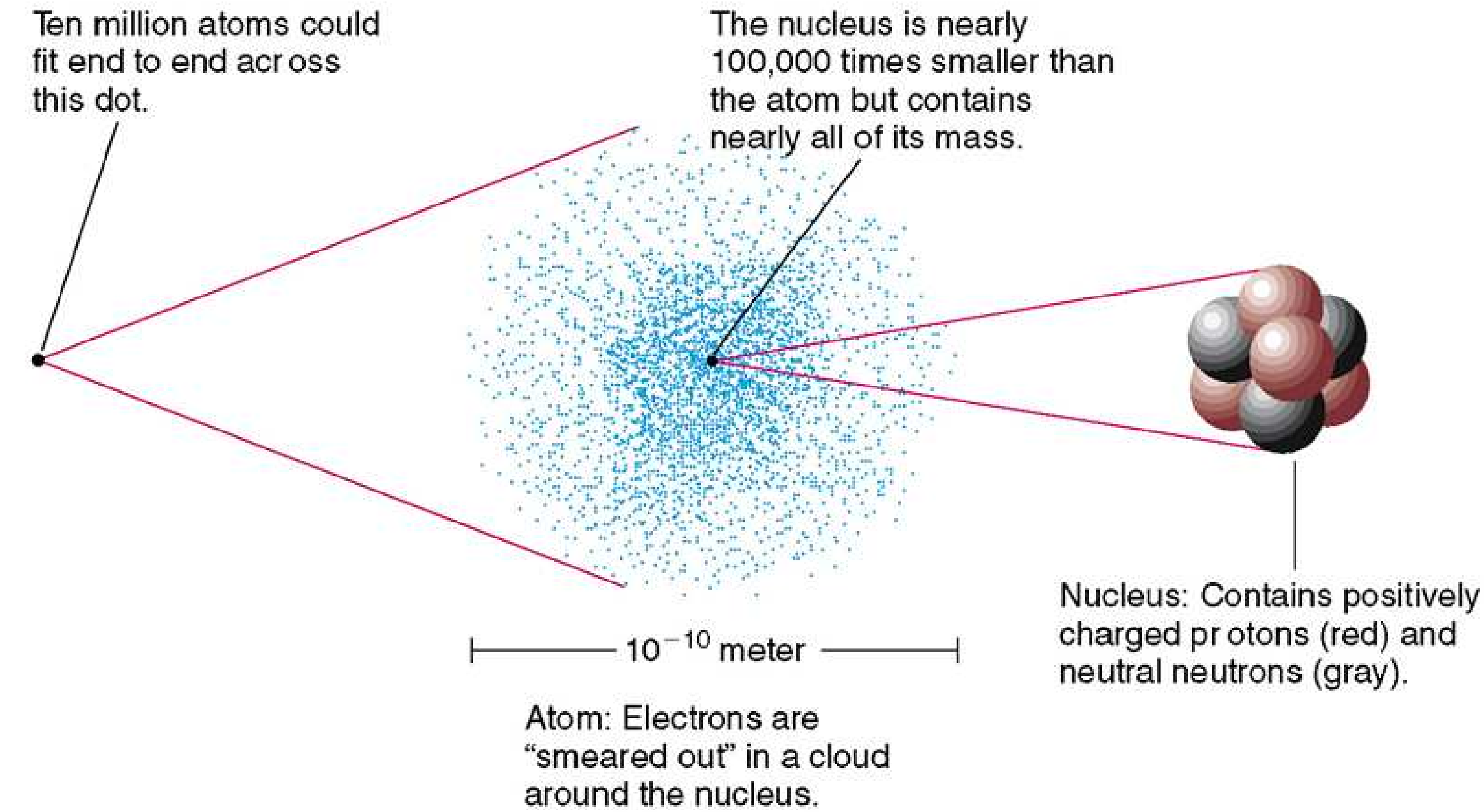
A UV photon has a wavelength of 3×10^{-7} m. What is its energy?

$E = hc/\lambda = 6.6 \times 10^{-34}$ J s 3×10^{8} m s^{-1} /(3×10^{-7} m)

$= 6.6 \times 10^{-34}$ J s 10^{15} s^{-1}

$= 6.6 \times 10^{-19}$ J

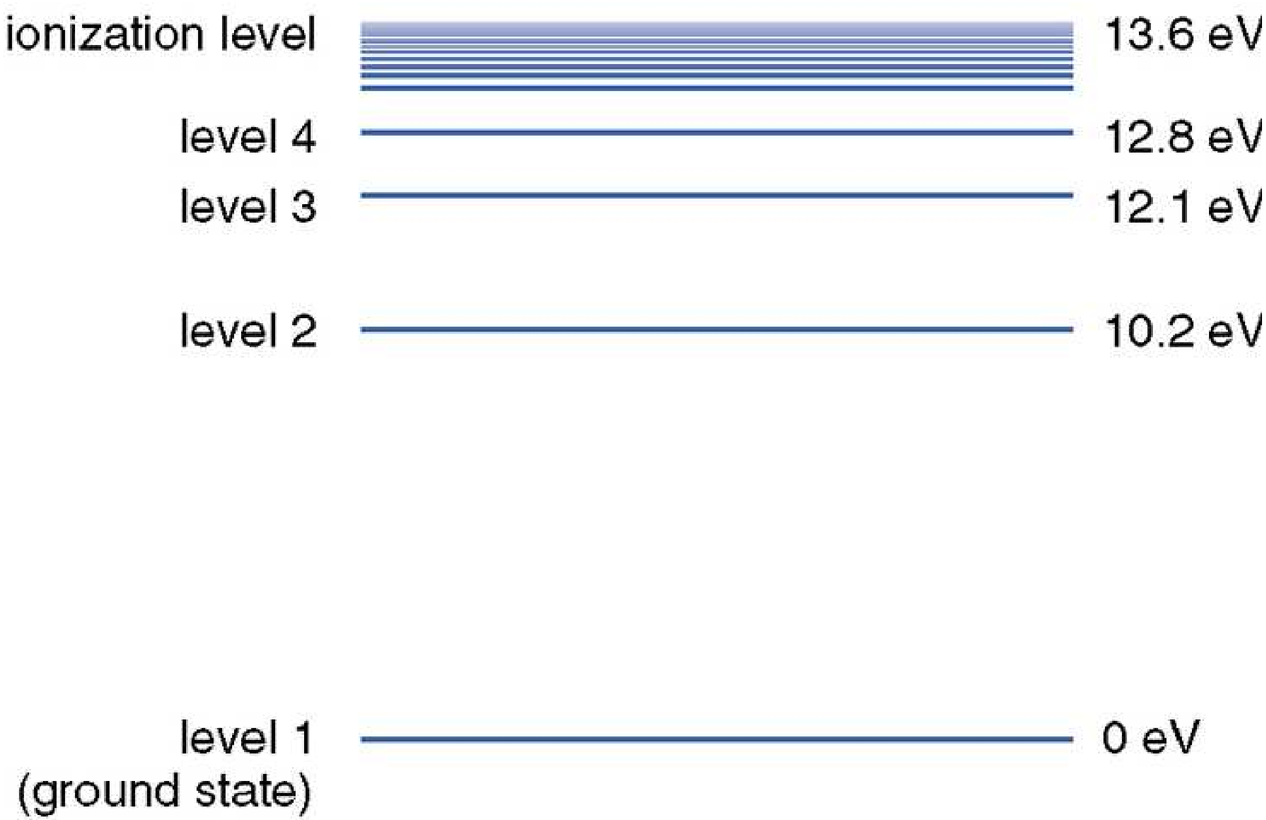
Components of an Atom



Recall : An atom consists of

1) a tiny massive positively charged nucleus
   (made of neutral neutrons and positively charged protons)
2) a large cloud of negatively charged electrons

Electrons only occupy allowed energy levels

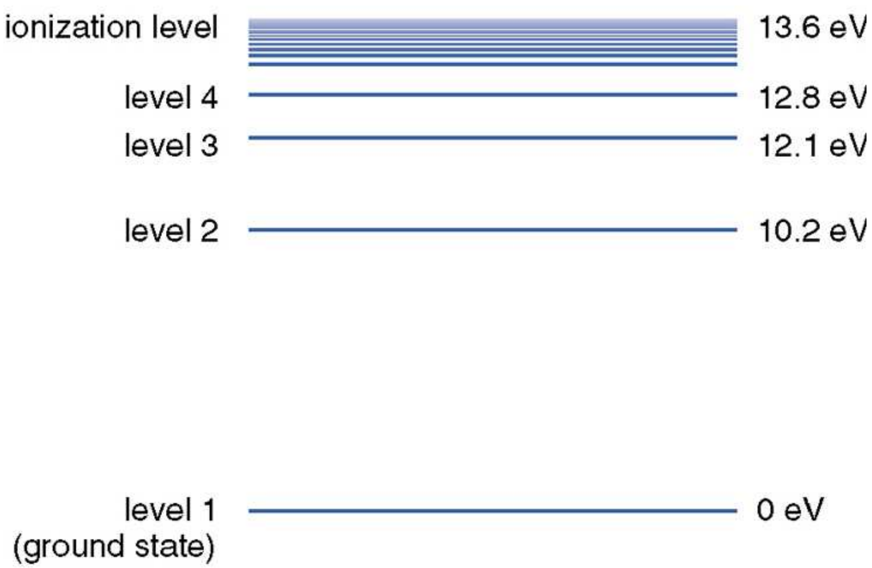


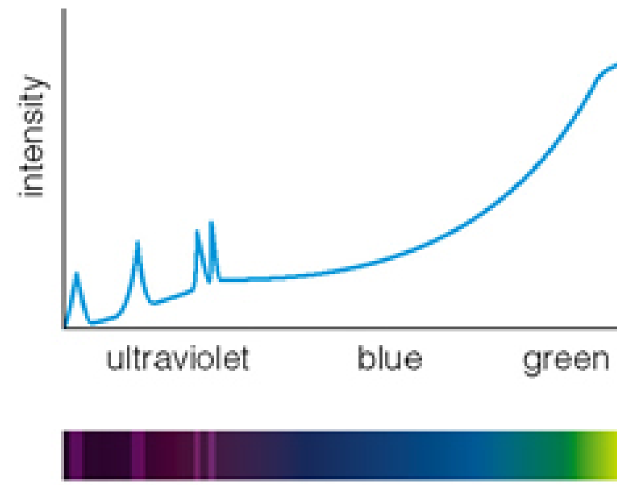
1 eV refers to

1.6×10^{-19} J

An electron in an atom can only exist in certain specific allowed energy levels.
The allowed energy levels for the hydrogen atom is shown above.
The electron cannot exist between allowed energy levels.
(Analogy: think of floors in a building)
An electron with the lowest energy level will be in the ground level with energy=eV

Electron transition from high to low energy level produces emission lines





Consider a hot gas where electrons have a lot of energy and occupy high energy levels

An electron can move from a high energy level E_y to a low energy level E_x by emitting the excess energy ($E = E_y - E_x$) as a photon of energy E.

This photon will have a specific wavelength λ that is inversely proportional to its energy E , and lead to an emission line at that specific wavelength λ

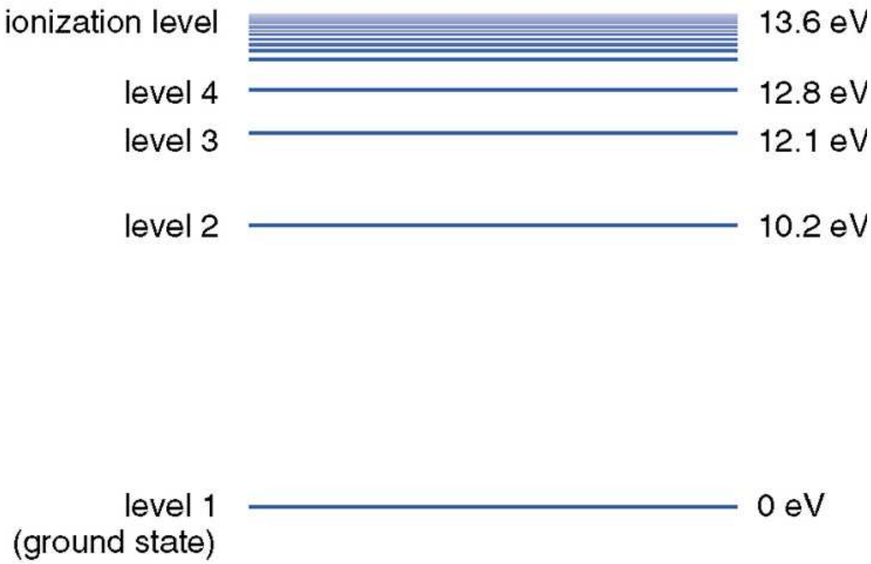
Example: An electron moves from level 2 to level 1 by emitting a photon.
What is the photon's wavelength?

Energy of photon = (10.2 – 0.0) = 10.2 eV = 10.2 x 1.6 x 10^{-19} J = 16.3 x 10^{-19} J

Wavelength of photon = λ = hc/E

= 6.6 x 10^{-34} Js 3 x 10^{8} m s^{-1} /(16.3 x 10^{-19} J) = 1.2 x 10^{-7} m

Electron transition from low to high energy level produces absorption lines



Consider a cold gas where electrons have little energy and occupy the lowest energy levels

An electron can move from a low energy level E_x to a high energy level E_y by absorbing the missing energy difference ($E = E_y - E_x$) as a photon of energy E.

This photon will have a specific wavelength λ that is inversely proportional to its energy E, and lead to an absorption line at that specific wavelength λ

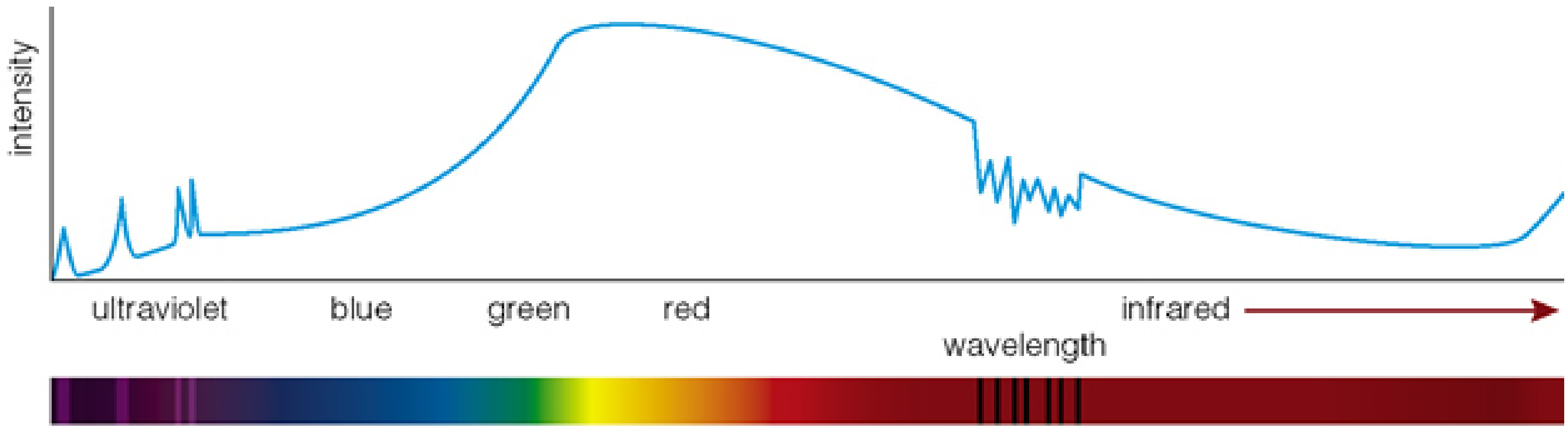
Example: An electron moves from level 1 to level 2 by absorbing a photon.
What is the photon's wavelength?

Energy of photon = (10.2 – 0.0) = 10.2 eV = $10.2 \times 1.6 \times 10^{-19}$ J = 16.3×10^{-19} J

Wavelength of photon = λ = hc/E

= 6.6×10^{-34} Js 3×10^{8} m s^{-1} /(16.3×10^{-19} J) = 1.2×10^{-7} m

Chemical compositon and redshift inferred from emission lines



The spectrum of a galaxy consist of

-continuum emission from stars, hot and warm dust and gas

- emission lines in hot/warm gas caused by electron transitions from high to low energy levels
- absorption lines in cold gas caused by electron transitions from low to high energy levels

From the emission lines of a galaxy, we can infer

- the chemical composition of the galaxy
- the redshift z of the galaxy, which tells us the lookback time of the galaxy