ASTR 1040: Stars & Galaxies

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Lecture 2 *Thur 16 Jan 2020*

zeus.colorado.edu/astr1040-toomre

Reading for today's and Tues class:

- Chap 3, sec 3.3, 3.4 *(Kepler, Nature of Science)*
- Chap 4, read all *(Making Sense of Universe)*
- Read Chap 5, carefully *(Light and Matter)*
- You can get a copy of all our slides after class from course website zeus.colorado.edu/astr1040-toomre
- *Canvas* course site also up and running

Modified Mastering Astronomy (MMA) + homeworks

REMINDER

- Online MMA Assignment (HW # 0) available NOW
  Walks you through how to submit all the assignments and MMA resources available, and some review of concepts (good practice, extra credit)
  Complete by Tues Jan 21, 6pm
- Homework # 1 on "Light & Spectroscopy" now available (green sheet), *involves both MMA portion and written portion, to be turned in by Thur Jan 23 class*
- Get your MMA account set up asap, linking to "ASTR1040TOOMRE2020" -- on Canvas, use MyLab & Mastering tab to get there, and access code from "pink sheet" – your login from 1030 should be helpful

Topics for Today

- Revisit: *Mystery of planetary orbits*: gravity makes you move on ellipses (..Kepler, Newton)
- Light as waves (and as particles)
- Special colors of light associated with each element

REMINDER

FOUR FUNDAMENTAL FORCES (modern view)

At work everywhere, "Universal" – we assume and test

GRAVITY was first to be tackled, in fits and starts

FOUR TYPES OF FORCES IN NATURE

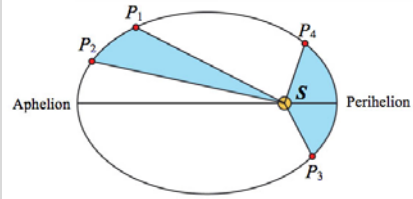
1. GRAVITY
   WEAKEST, BUT DOMINATES UNIVERSE
2. ELECTROMAGNETIC (EM)
3. STRONG NUCLEAR
   100 x EM, BUT ONLY IN NUCLEUS OF ATOM
4. WEAK NUCLEAR
   1/1000 x EM, ONLY IN ATOMIC NUCLEUS

Great puzzle: Earth or Sun Centric?

- Perfect harmony of Sun and planets moving on circles around the Earth had problems: thus epicycles …. *from Greeks onward*
- *Copernicus* (1543) argued that Sun is instead the center around which the planets move
- Good data from *Tycho* allowed *Kepler* (1609, 1619) to devise three "laws" with motion on ellipses (Chap 3)
- *Newton* showed (~1687) that force of gravity could yield elliptic orbits – beginning of a new math and science (Chap 4)

3.3 Copernicus - Tycho - Galileo – Kepler

Kepler and planetary orbits



1571-1630

$p^2 = a^3$

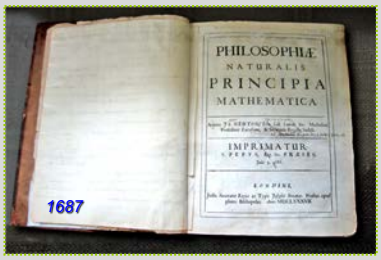
p: planet's orbital period in years

a: average distance from Sun in a.u.

Isaac Newton and Gravitation

(1642-1727)

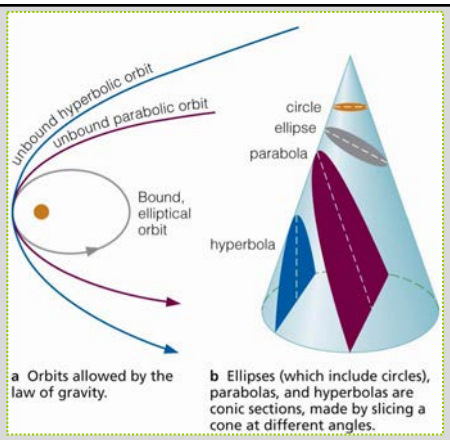
$F_g = G(M_1 M_2)/d^2$



1687

Newton explains Kepler's orbits:

$p^2 = a^3 4\pi^2 / G(M_1 + M_2)$



a Orbits allowed by the law of gravity.

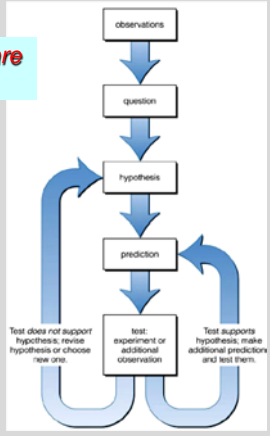
b Ellipses (which include circles), parabolas, and hyperbolas are conic sections, made by slicing a cone at different angles.

Newton's Gravitational Force admits these orbits

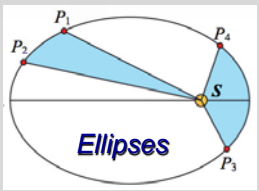
Elliptical is the general "bound orbit"

SCIENTIFIC `LAWS' are constantly being tested

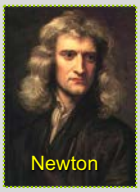
So how did chain of Greeks,…, Copernicus, Brahe, Galileo, Kepler, Newton …. WORK ?



Moral on scientific method: orbits



1619



1687

Force of gravity

$F_g = G(M_1 M_2)/d^2$

Property of elliptic orbits

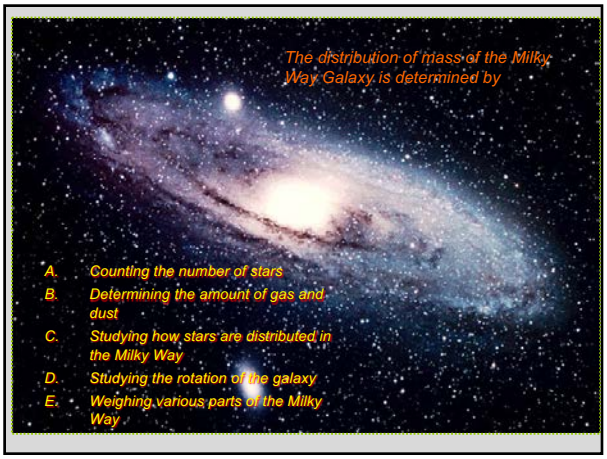
$p^2 = a^3 4\pi^2 / G(M_1 + M_2)$

Reading Clicker Question

The distribution of mass of the Milky Way Galaxy is determined by

A. Counting the number of stars
B. Determining the amount of gas and dust
C. Studying how stars are distributed in the Milky Way
D. Studying the rotation of the galaxy
E. Weighing various parts of the Milky Way

- You must change your clicker channel to AB
- Hold down power until blue light blinks…then press A, then B



Light: The Cosmic Messenger

ELECTRO-MAGNETIC RADIATION

(used for most deductions)

PHOTONS (quanta – particles of light)

ELECTROMAGNETIC RADIATION (EMRAD)

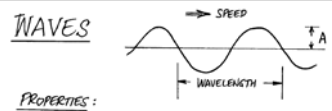
γ-RAYS, X-RAYS, UV, VISIBLE, IR, MICROWAVE, RADIO
← "LIGHT" →

ACT BOTH LIKE
WAVES AND PARTICLES
(PHOTONS)

PHOTONS
SMALLEST PACKETS ("QUANTA") OF LIGHT ENERGY

QUANTUM NATURE OF LIGHT MOST EVIDENT WHEN LIGHT INTERACTS WITH ATOMS
⇒ SPECTRAL LINES

PROPERTIES OF WAVES



PROPERTIES:

WAVELENGTH	λ
FREQUENCY	f (ALSO ν)
AMPLITUDE	A
SPEED	C

WAVELENGTH × FREQUENCY = SPEED

$\lambda \times f = c$

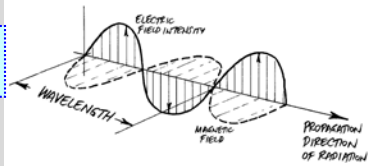
OTHER USEFUL PROPERTIES:

DIFFRACTION	(GRATING)
REFLECTION	(MIRROR)
REFRACTION	(PRISM, LENS)
DOPPLER SHIFT	

E-M (LIGHT) AS WAVES

Speed of light SAME for all wavelengths

ELECTROMAGNETIC RADIATION AS A WAVE



$\lambda \times f = c$

WAVELENGTH × FREQUENCY = SPEED OF "LIGHT"

$\lambda = c/f$, $f = c/\lambda$

PROPAGATION SPEED OF ALL EM WAVES IS THE SAME!

C IS A CONSTANT $\approx$ 300,000 Km/sec
$= 3 \times 10^{10}$ cm/sec

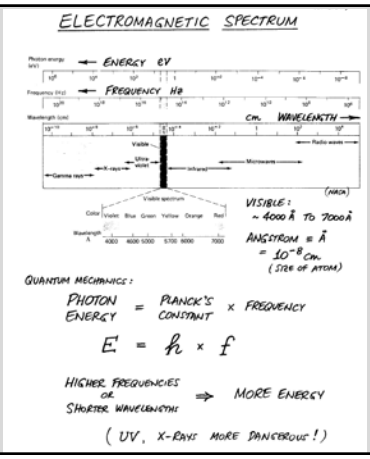
Discuss SI units and "how to get comfortable with the speed of light"

meters, kilograms, seconds

c = 300,000 km/sec

30 cm in 1 nanosecond (10^{-9} sec)

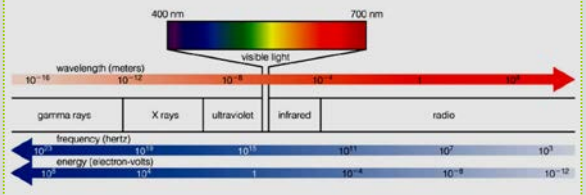
E-M SPECTRUM



Quantum Mechanics

(energy of photons varies)

Electromagnetic Spectrum



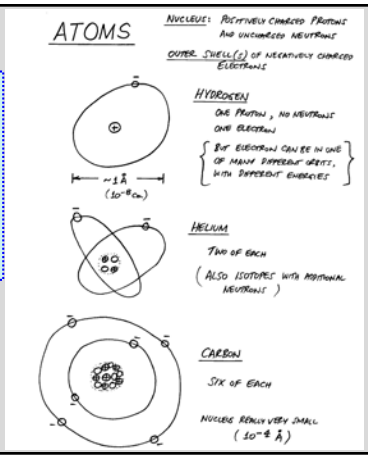
gamma-rays x-rays ultraviolet visible infrared radio

$$c = \lambda \cdot f$$

ATOMS

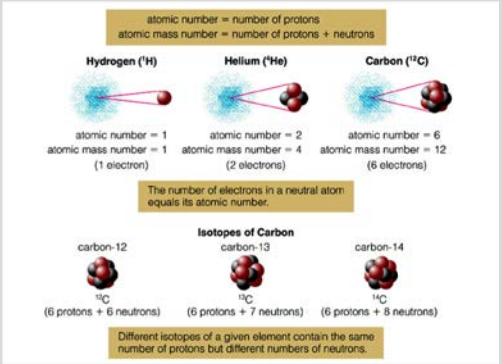
protons, neutrons, electrons

(and quarks ..)

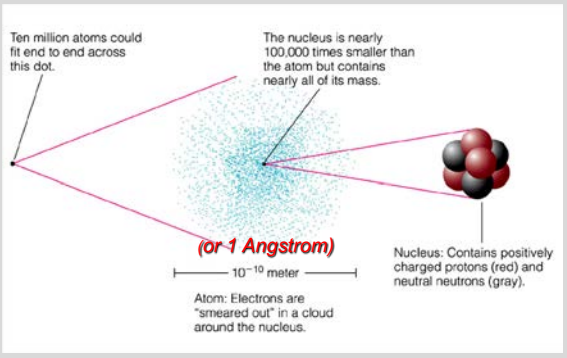


Building blocks for everything

Nucleus and its electron cloud ....



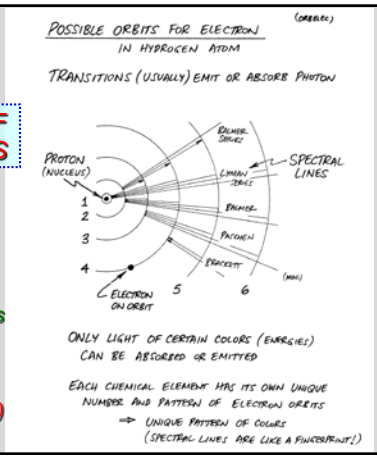
Atoms Involve Big Empty Spaces



"ORBITS" OF ELECTRONS

Popping from one orbit to another involves particular PHOTONS

(like DNA prints)



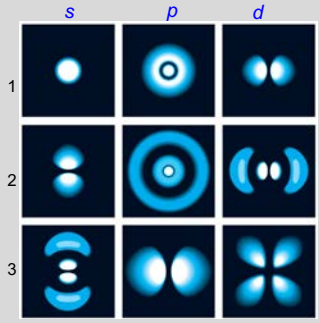
Clicker: *How much time does it take light to travel one Astronomical Unit (1 AU)?*

- A. Speed of light x 1 AU
- B. Speed of light / 1 AU
- C. 1 AU / speed of light
- D. 1 light-year

Revolution of "Quantum Mechanics"

- Discrete spectral lines and electron energy levels go hand in hand, but WHY?
- **Classical physics had no real explanations, even if Bohr's model of electron orbits for H looked good**
- A new mathematics/physics had to be invented in the 1920s, with solutions of the *"Schroedinger wave equation"* giving *probabilities* (orbitals) of where electrons could be located
- **Such "quantum mechanics" also explained why light (photons) act both like waves and particles, and so too electrons!**

Electron in Hydrogen Atom (S4.3)



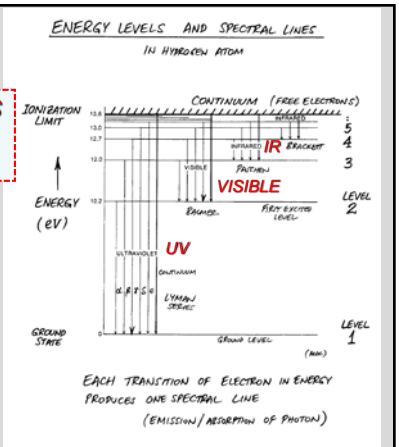
- In ***quantum mechanics***, an electron in an atom does not orbit in the usual sense
- We can know only the *probability* of finding an electron at a particular spot (orbital)

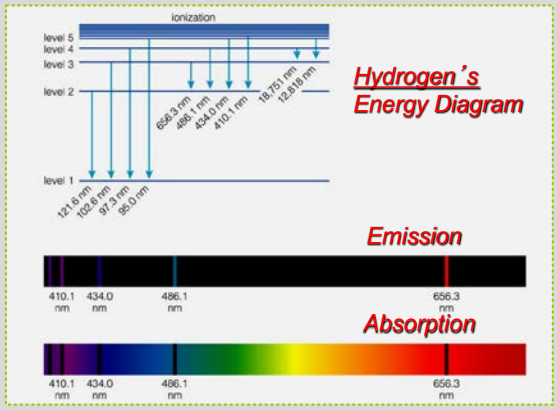
Orbital solutions from Schroedinger wave equation

ENERGY LEVELS (of electrons) IN HYDROGEN

Each transition involves photons of specific color

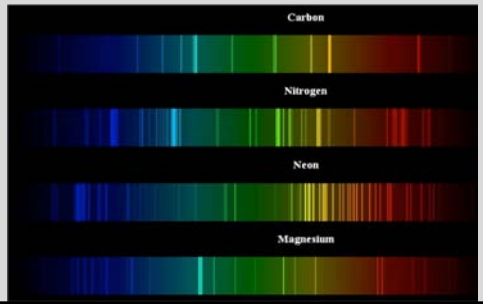
(like fingerprints)





Each atom has a different set of energy levels

- Just like no two people have the same fingerprints, no two elements have the same emission spectrum



DEMO of Bright Line EMISSION from different hot gases

Hydrogen (bottom), Helium, Incandescent White, Fluoresc White, Neon, Argon (top)

You should each have a small plastic diffraction grating