

## ASTR 1040: Stars & Galaxies



SDO: Eruption on solar surface

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Lecture 2 Thur 16 Jan 2020

[zeus.colorado.edu/astr1040-toomre](http://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](http://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

**Copernicus**  
1473-1543  
De Revolutionibus by Copernicus 1543

**Johannes Kepler** 1571-1630

**Tycho Brahe**  
1546-1601

**Galileo**  
1564-1642

Other events on timeline:  
 Tycho Brahe 1546-1601  
 William Shakespeare 1564-1616  
 Defeat of Spanish Armada 1588  
 Discovery of Australia by William Janszoon 1606  
 Jamestown established 1607  
 Telescope invented by Johann Lippershey 1608  
 King James Version of The Holy Bible 1611  
 Thirty Years War 1618-1648  
 Pilgrims landed at Plymouth 1620  
 Dutch bought Manhattan for \$24.00 1626  
 Taj Mahal built 1632-1645  
 Harvard College founded 1636  
 Isaac Newton 1642-1727  
 Reign of Louis XIV 1643-1715

### Kepler and planetary orbits

**Kepler's Third Law:**  
 $p^2 = a^3$   
 p: planet's orbital period in years  
 a: average distance from Sun in a.u.

**Kepler** 1571-1630

### Isaac Newton and Gravitation

**Newton explains Kepler's orbits:**

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

**Newton** (1642-1727)

**1687**

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

**Newton's Gravitational Force admits these orbits**

**Elliptical is the general "bound orbit"**

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.

### SCIENTIFIC 'LAWS' are constantly being tested

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

Test does not support hypothesis; revise hypothesis or choose new one.  
 Test supports hypothesis; make additional prediction and test them.

### Moral on scientific method: orbits

**Kepler** 1619

**Force of gravity**  
 $F_g = G(M_1 M_2) / d^2$

**Property of elliptic orbits**  
 $p^2 = a^3 4\pi^2 / G(M_1 + M_2)$

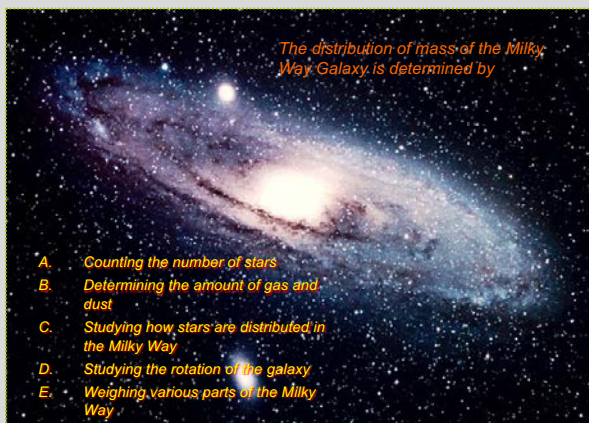
**Newton** 1687

**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*



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**ELECTROMAGNETIC RADIATION** (EMRAD)

γ-RAYS, X-RAYS, UV, VISIBLE, IR, MICROWAVE, RADIO

← "LIGHT" →

ACT BOTH LIKE WAVES AND PARTICLES (PHOTONS)

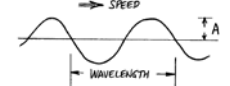
**PHOTONS** (quanta - particles of light)

SMALLEST PACKETS ("QUANTA") OF LIGHT ENERGY

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

**PROPERTIES OF WAVES**

**WAVES**



**PROPERTIES:**

WAVELENGTH	λ
FREQUENCY	f (also ν)
AMPLITUDE	A
SPEED	c

WAVELENGTH x FREQUENCY = SPEED

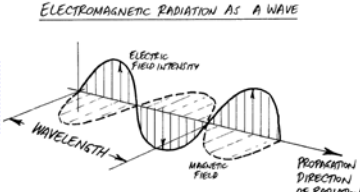
$$\lambda \times f = c$$

**OTHER USEFUL PROPERTIES:**

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

**E-M (LIGHT) AS WAVES**

**ELECTROMAGNETIC RADIATION AS A WAVE**



$\lambda \times f = c$

WAVELENGTH x FREQUENCY = SPEED OF "LIGHT"

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

PROPAGATION SPEED OF ALL EM WAVES IS THE SAME!

**C IS A CONSTANT** ≈ 300,000 km/sec =  $3 \times 10^{10}$  cm/sec

**Speed of light SAME for all wavelengths**

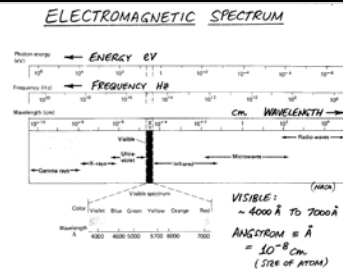
Discuss SI units and "how to get comfortable with the speed of light"

meters, kilograms, seconds

$$c = 300,000 \text{ km/sec}$$

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

**E-M SPECTRUM**

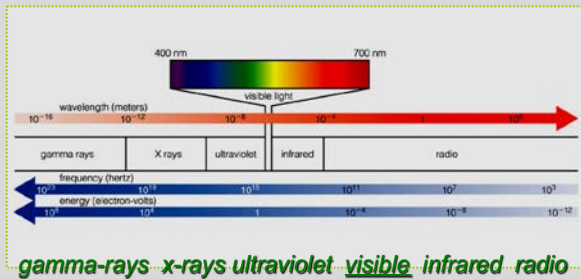


**Quantum Mechanics**

(energy of photons varies)

QUANTUM MECHANICS:  
 PHOTON ENERGY = PLANCK'S CONSTANT  $\times$  FREQUENCY  
 $E = hf$   
 HIGHER FREQUENCIES OR SHORTER WAVELENGTHS  $\Rightarrow$  MORE ENERGY  
 (UV, X-RAYS MORE DANGEROUS!)

**Electromagnetic Spectrum**



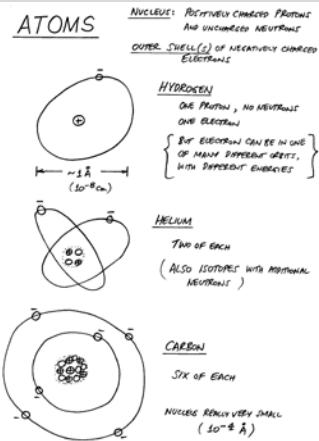
$$c = \lambda \cdot f$$

**ATOMS**

protons, neutrons, electrons

(and quarks ..)

Building blocks for everything



**Nucleus and its electron cloud ....**

atomic number = number of protons  
 atomic mass number = number of protons + neutrons

Hydrogen ( $^1\text{H}$ )	Helium ( $^4\text{He}$ )	Carbon ( $^{12}\text{C}$ )
atomic number = 1 atomic mass number = 1 (1 electron)	atomic number = 2 atomic mass number = 4 (2 electrons)	atomic number = 6 atomic mass number = 12 (6 electrons)

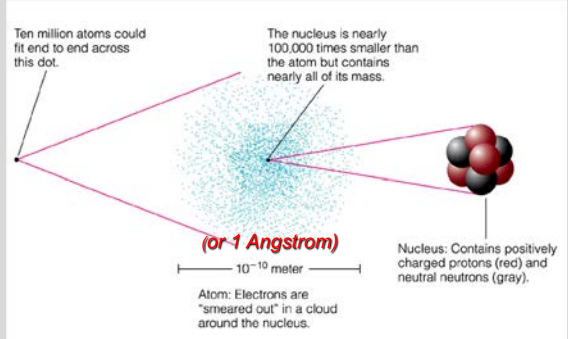
The number of electrons in a neutral atom equals its atomic number.

**Isotopes of Carbon**

carbon-12	carbon-13	carbon-14
$^{12}\text{C}$ (6 protons + 6 neutrons)	$^{13}\text{C}$ (6 protons + 7 neutrons)	$^{14}\text{C}$ (6 protons + 8 neutrons)

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

**Atoms Involve Big Empty Spaces**



**"ORBITS" OF ELECTRONS**

Popping from one orbit to another involves particular PHOTONS (like DNA prints)

*POSSIBLE ORBITS FOR ELECTRON IN HYDROGEN ATOM*  
 TRANSITIONS (USUALLY) EMIT OR ABSORB PHOTON

ONLY LIGHT OF CERTAIN COLORS (ENERGIES) CAN BE ABSORBED OR EMITTED

EACH CHEMICAL ELEMENT HAS ITS OWN UNIQUE NUMBER AND PATTERN OF ELECTRON ORBITS → UNIQUE PATTERN OF COLORS (SPECTRAL LINES ARE LIKE A FINGERPRINT!)

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 "Schrodinger 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 Schrodinger wave equation

**ENERGY LEVELS (of electrons) IN HYDROGEN**

Each transition involves photons of specific color (like fingerprints)

*ENERGY LEVELS AND SPECTRAL LINES IN HYDROGEN ATOM*

EACH TRANSITION OF ELECTRON IN ENERGY PRODUCES ONE SPECTRAL LINE (EMISSION/ABSORPTION OF PHOTON)

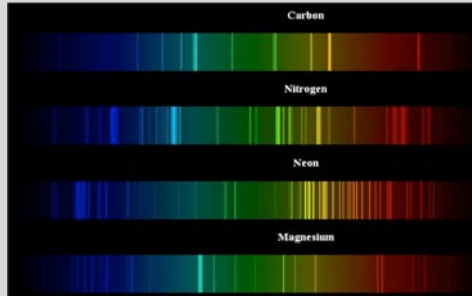
**Hydrogen's Energy Diagram**

Emission

Absorption

**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*