


**ASTR 1040:
Stars &
Galaxies**



SDO: Eruption on solar surface

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Lecture 2 Thur 19 Jan 2017
zeus.colorado.edu/astr1040-toomre

REMINDER

Reading for today's and Tues class:

- How to Succeed in this course, p. xxiv+
- Chapter 1, all (Our Place in Universe)
- Review Basic Astronomical terms, p. 6
- Chap 3, sec 3.3, 3.4 (Kepler, Nature of Science)
- Chap 4, read all (Making Sense of Universe)
- Begin reading 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
- D2L course site also up and running

Your account on "Mastering Astronomy"

- Some confusion at CU Bookstore on the use of 8th edition of *Cosmic Perspectives*
- It is essential to have **your account established on Mastering Astronomy (MA) tied into our course "ASTR1040TOOMRE2017"**
- We will help replace any incorrect book versions, and get MA access codes corrected
- Be sure to work through MA Homework #0, and start Homework #1, due Thur Jan 26

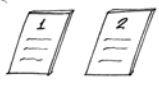
Topics for Today and Tues

- Nature of astronomy as a science
- Scientific method: we observe, hypothesize, test its predictions, maybe fix it and try again
- 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

FUNDAMENTAL ASSUMPTIONS
(always being tested)

INTERPRETATION IN ASTRONOMY (non-relativistic)

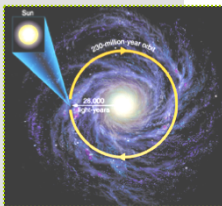
TWO FUNDAMENTAL PRINCIPLES



1. THE COPERNICAN PRINCIPLE
2. UNIVERSALITY OF LAWS OF NATURE

COPERNICAN PRINCIPLE

Copernicus (1473-1543)



THE COPERNICAN PRINCIPLE

Original Form:
EARTH NOT AT CENTER OF SOLAR SYSTEM

More General:
NOTHING SPECIAL ABOUT LOCATION OF ...
... EARTH IN SOLAR SYSTEM (16th-17th c)
... SOLAR SYSTEM IN MILKY WAY GALAXY (SHAPLEY 1915-1919)
... M.W. GALAXY IN UNIVERSE (HUBBLE 1913)

Practical Implications for Astronomy:
ANYTHING OBSERVED ONCE PROBABLY OCCURS ELSEWHERE IN UNIVERSE

Thus, expect to find ...
... OTHER SUNS (STARS)
... OTHER MILKY WAYS (GALAXIES)
... OTHER PLANETARY SYSTEMS (?)
... OTHER LIFE FORMS (?)

UNIVERSALITY OF 'LAWS'

ATOMS BEHAVE THE SAME EVERYWHERE
(we hope, and keep testing !)

GRAVITY ACTS EVERYWHERE

UNIVERSALITY OF LAWS OF NATURE

SOME GENERAL LAWS APPLY EVERYWHERE IN UNIVERSE

EXAMPLES:

- PROTONS AND ELECTRONS ON EARTH SAME AS THOSE ON SUN
- ATOMS OF DIFFERENT ELEMENTS THE SAME EVERYWHERE
- MOON ORBITING EARTH OR " = " STAR ORBITING ANOTHER STAR
- GRAVITY HOLDS TOGETHER STAR ... GALAXY ... CLUSTER OF GALAXIES ... ACCORDING TO ONE LAW

SCIENTIFIC 'LAWS' are constantly being tested

Sec 3.4: Nature of Science

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    graph TD
      A[observations] --> B[question]
      B --> C[hypothesis]
      C --> D[prediction]
      D --> E[test: experiment or additional observation]
      E --> F[Test does not support hypothesis: revise hypothesis or choose new one.]
      E --> G[Test supports hypothesis: make additional predictions and test them.]
      F --> C
      G --> D
  
```

FOUR FUNDAMENTAL FORCES

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

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
- 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

Year	Event
1473-1543	Nicolas Copernicus
1543	De Revolutionibus by Copernicus
1546-1601	Tycho Brahe
1564-1642	Galileo Galilei
1564-1616	William Shakespeare
1571-1630	Johannes Kepler
1588	Defeat of Spanish Armada
1606	Discovery of Australia by William Janszoon
1607	Jamestown established
1608	Telescope invented by Johann Lippershey
1611	King James Version of The Holy Bible
1618-1648	Thirty Years War
1620	Pilgrims landed at Plymouth
1625	Dutch bought Manhattan for \$24.00
1632-1645	Taj Mahal built
1636	Harvard College founded
1642-1727	Isaac Newton
1643-1715	Reign of Louis XIV


Kepler and planetary orbits

$p^2 = a^3$

p: planet's orbital period in years *a*: average distance from Sun in a.u.

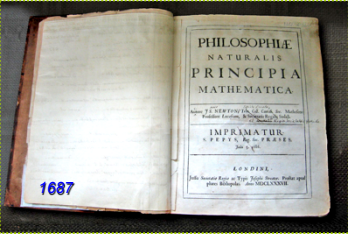
1571-1630

Isaac Newton and Gravitation



(1642-1727)

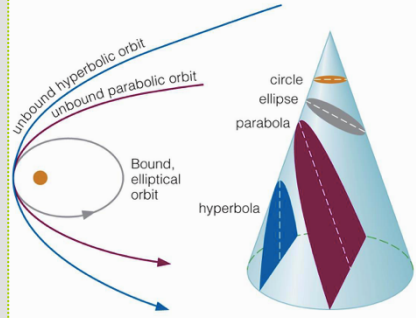
$$F_g = G(M_1 M_2) / d^2$$



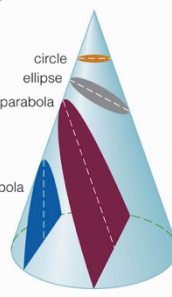
1687

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

Newton explains Kepler's orbits:



a Orbits allowed by the law of gravity.



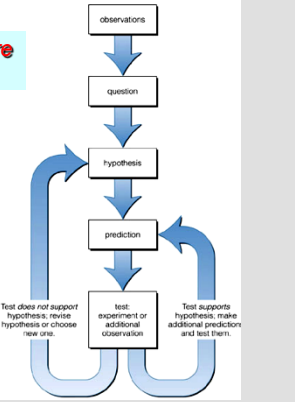
b Ellipses (which include circles), parabolas, and hyperbolas are conic sections, made by slicing a cone at different angles.

Newton's Gravitational Force admits these orbits

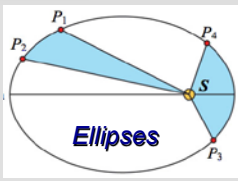
Elliptical is the general "bound orbit"

SCIENTIFIC 'LAWS' are constantly being tested


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



Moral on scientific method: orbits



Ellipses



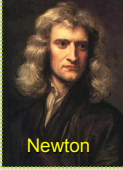
Kepler 1619

Force of gravity

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

Property of elliptic orbits

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



1687
Newton

Reading Clicker Question (real credit starts next week)

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

A. Counting the number of stars

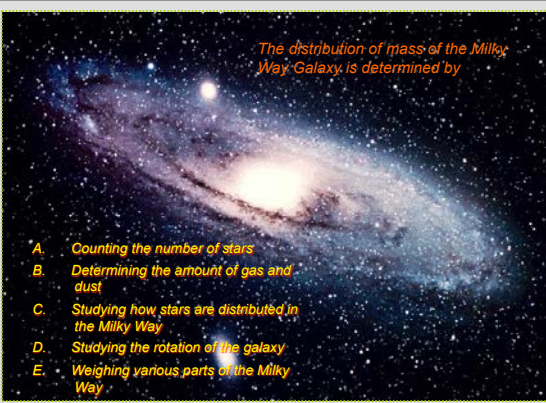
B. Determining the amount of gas and dust

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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ELECTRO-MAGNETIC RADIATION

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 $\approx 300,000$ 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)

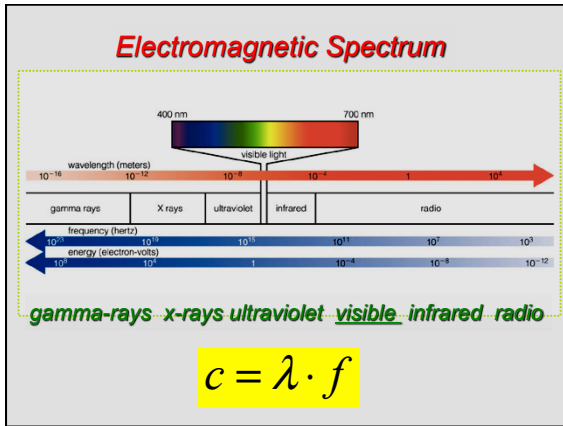
E-M SPECTRUM

ELECTROMAGNETIC SPECTRUM

QUANTUM MECHANICS:

PHOTON ENERGY = PLANCK'S CONSTANT x FREQUENCY
 $E = h \times f$

HIGHER FREQUENCIES or SHORTER WAVELENGTHS ⇒ MORE ENERGY
(UV, X-RAY MORE DANGEROUS!)



ATOMS

NUCLEUS: RELATIVELY CHARGED PROTONS AND UNCHARGED NEUTRONS
OUTER SHELL(S): OF NEGATIVELY CHARGED ELECTRONS

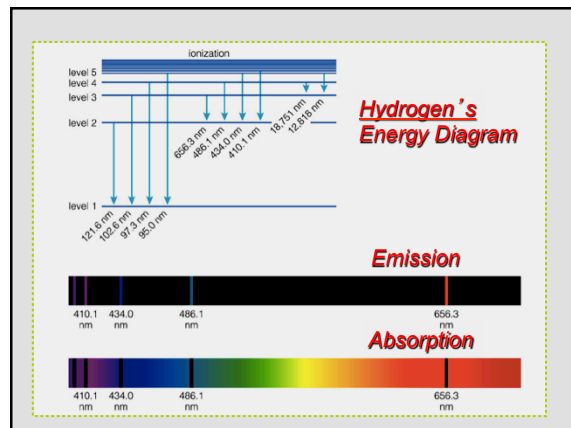
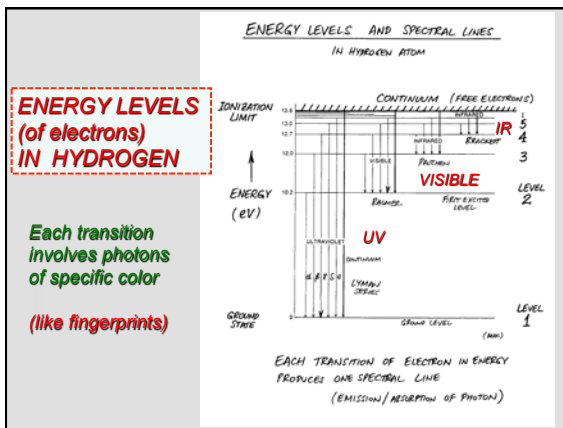
ATOMS
 protons, neutrons, electrons
 (and quarks ..)

Building blocks for everything

HYDROGEN:
 ONE PROTON, NO NEUTRONS
 ONE ELECTRON
 BUT ELECTRONS CAN BE IN ONE OF MANY DIFFERENT SHELLS, WITH DIFFERENT ENERGIES

HELIUM:
 TWO OF EACH
 (ALSO ISOTOPES WITH NEUTRONS, NEUTRAL)

CARBON:
 SIX OF EACH
 NUCLEUS REALLY VERY SMALL (10^{-14} m)



DEMO of Bright Line EMISSION from different hot gases
 Hydrogen (bottom), Helium, Incandescent White, Fluoresc White, Neon, Mercury (top)

You should each have a small plastic diffraction grating