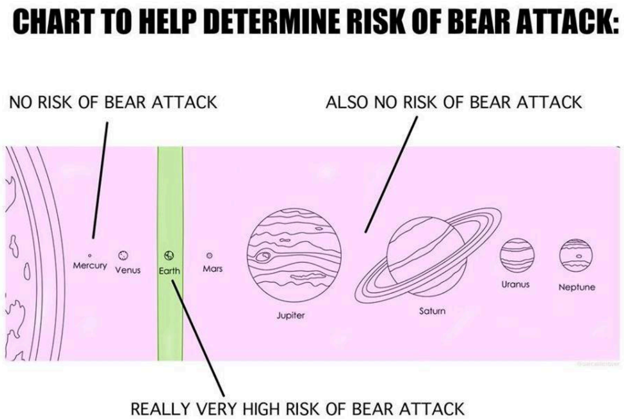
PHYS 275
Planets

Fall 2017

Instructor: Mike Fich



Today's class

1. Overview of course
2. Naked Eye Astronomy
   - The Sky, angles, coordinates
3. Overview of the Solar System
   - The Sun (and other stars)
   - The Planets (but not the smaller bodies)

Course Outline*

1. Introduction to planetary science (2 lectures)
   - Overview of the Solar System, historical development of the science
2. The physics of planetary science (5 lectures)
   - Light, energy, pressure, gravity (dynamics, motions, orbit theory, tides)
3. The structures of planets (6 lectures)
   - Atmospheres
   - Surfaces
   - Interiors and magnetic fields
4. Small objects in the Solar System (4 lectures)
   - Meteorites, minor planets, comets, rings
5. Extrasolar planets (2 lectures)
6. The formation of planets (1 lecture)
7. Life in the Universe (1 lecture)

* Number of lectures on each topic is subject to change, depending on progress through material over the Term

Special Dates

Film Nights
(will fill entire lecture)
Wednesday September 20
Friday October 13

Midterm Exam
Wednesday October 25

No class
Monday Oct 9 (Thanksgiving)
Wednesday Oct 11 (Study Day)

Textbook

1. The textbook is excellent
   - New, up-to-date, detailed
   - BUT at too high a level, we will just go lightly through the more intense parts – so don't be scared when you look through the text
2. The course structure is nearly identical to the order of the text
   - It will be obvious which parts of the text go with the lectures (so there isn't a real need for a separate list of readings or most relevant chapters).

Homework Assignments

1. 5 Homework Assignments
   Tentative Due Dates (subject to change): (all on Wednesday)
   1. Sept 20 (posted on Learn on Sept 7)
   2. Oct 4
   3. Oct 18
   4. Nov 8
   5. Nov 29
2. Primarily mathematical content, problem solving
3. Can be handed in during a class or to box outside room PHYS 211
4. Late assignments accepted, no penalty in grade, **BUT no assignments accepted after solutions posted on-line** (solutions will be posted without advance notice a few days to a week after the due date).
5. You may discuss assignments with other students but you are not permitted to copy ANYTHING from another person's work.

- The Teaching Assistants have been given detailed instructions for looking for cheating on assignments.

Grading Schemes

Two grading schemes – you will receive the best grade from the two schemes

1. Homework 30%, Midterm Exam 30%, Final Exam 40%
2. Homework 15%, Midterm Exam 15%, Final Exam 70%

Consistency matters: very rare to have someone fail who did all of the assignments and exams.

How to do well in this course

1. Do the Assignments!!! **Yourself!!!!** If you need help see TA or Professor in Office Hours
2. Take notes: the Lecture Slides will be available on Learn, usually a day in advance, BUT THESE DO NOT REPLACE YOUR OWN NOTES. The Lecture Slides are just a visual placeholder… usually many words are used in the Lecture to describe each slide and these words are not on the slide!
3. Avoid sitting near people with laptops. It has been found that people using laptops in classes cause a drop in grades for everyone who can see the laptop screen.
   http://news.yorku.ca/2013/03/13/multitasking-on-laptop-impedes-classroom-learning-york-u-study-shows

If you will use a laptop for tasks other than making notes about this class please sit in back of classroom !!!

Math – review if you are unfamiliar with any of this!

How to use your calculator to calculate sin, cos, arctan, inverse functions, etc.

Exponential notation and significant digits: 2.71E4 = 27,100 , $1.5\times10^{-2} = 0.15$

The SI system and prefixes (km, mm, Mm, µm, GW)

Geometry: basic trig, sine and cosine laws, Pythagorean theorem

Calculus: basic derivatives and integrals (what is $\int r^{-2}\,dr$?)

Simple differential equations: what is f(t) if $d\,f(t)/dt = a\,t$?

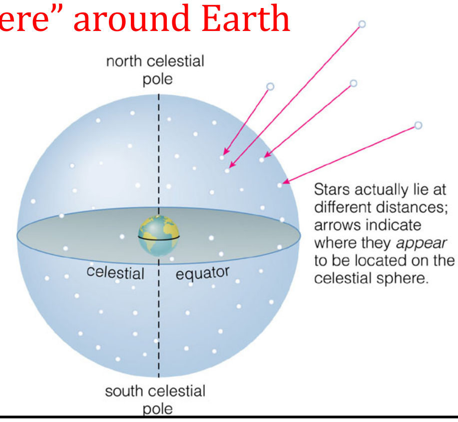
Where are the planets located in the Sky? "Naked-eye" astronomy

1. Most of the planets are visible to your eye
   - "naked eye" planets M,V, E, M, J, S but Uranus and Neptune are always too faint to see without a telescope
2. However "apparent" motions (i.e. relative to our viewing positon on the Earth) are complex
   - The actual motions of the planets are fairly simple
   - But we are on an Earth that rotates and is in orbit around the Sun and has a day-side from which we can not see planets
3. The result was that it took many centuries of observing the sky to work out the planets' motions (more next lecture)

Naked-eye Motions in the Sky

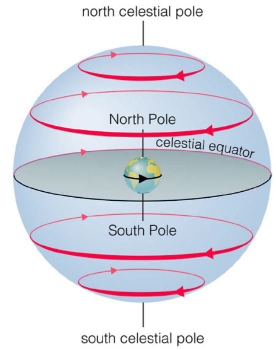
1. daily rotation of sky (of Earth, really!)
2. motion of Moon from one day to next, and change in "phase" (~ 360 degrees/30 days = ~ 12 degrees/day)
3. Motion of the Earth around the Sun
   - motion of Sun from one day to the next: hard to notice, because when the Sun is up you can't see the stars; but the Sun is in a (slightly) different part of the sky (with respect to the stars) every night…
   - a (slightly) different part of the Sky (the stars) is visible every night
4. motion of planets

Stars appear to lie on a great "celestial sphere" around Earth



Stars move "around the sky"

Earth's rotation makes the celestial sphere appear to rotate about us (from E-W)



Sky rotation at the Equator

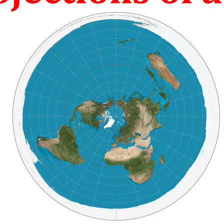
Sept. 14 2007, Montlaux, France. Stars near the celestial equator make almost straight lines.

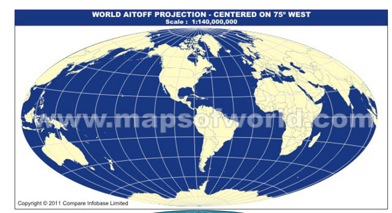
Note Venus rising on the left, a satellite leaving the frame at the top left.

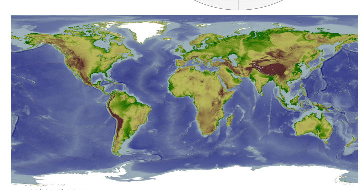
477 consecutive 30 second exposures over 4.3 hours

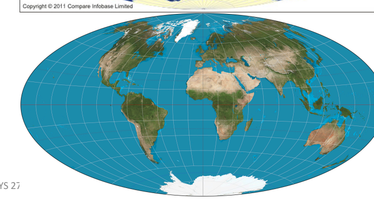
Projections of a sphere onto a plane

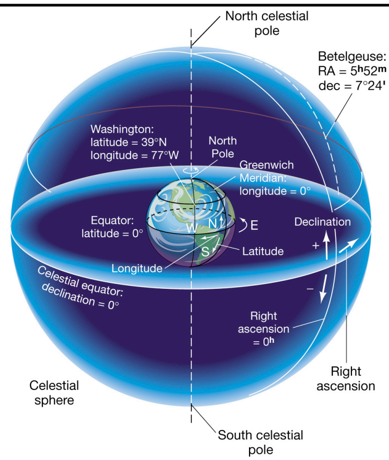
Positions are all angles (longitude and latitude for the Earth)









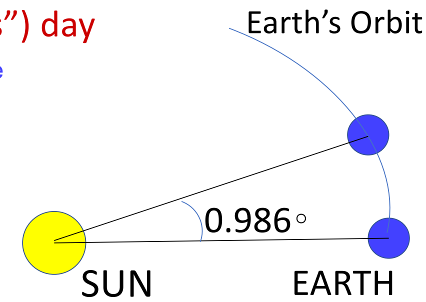


Solar ("Synodic") day compared to Sidereal ("by the stars") day

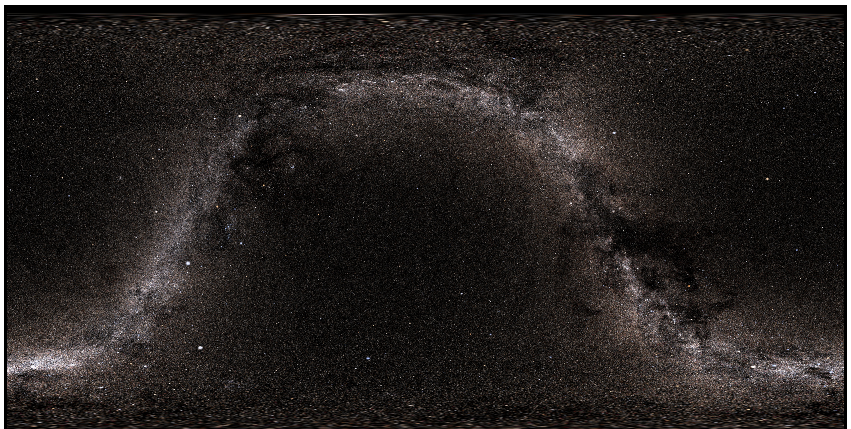
From noon one day to noon the next day the Earth moves a small distance around the Sun

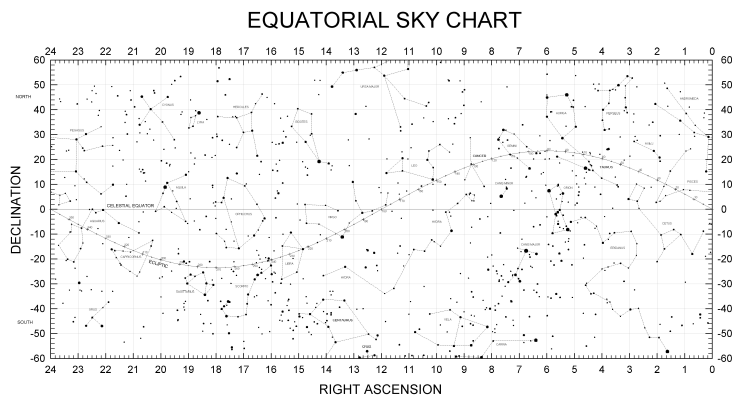
Earth travels 360 degrees around Sun in 365 ¼ days
~1°/day around its orbit
So…one solar day requires ~361° of rotation

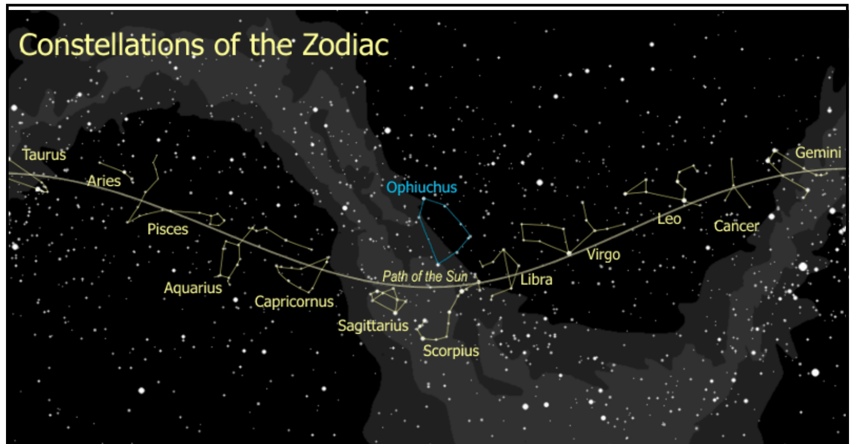
…and a solar day is ~4 min longer than a sidereal day



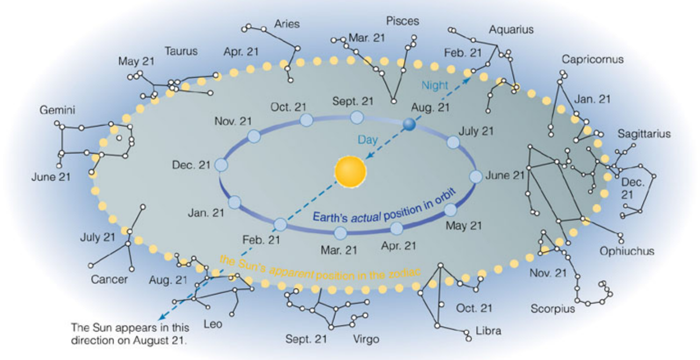
in reference frame: of "the stars"







The Sun's path through the Sky is a "reflection" of the Earth's motion around the Sun



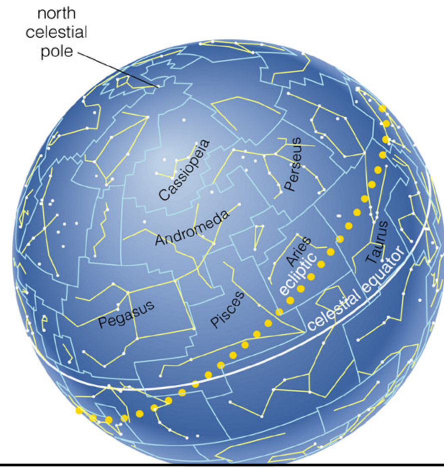
The path of each of the planets across the sky is along a line that is very close to the path followed by the Sun over the course of a year

-> the "**ecliptic**"

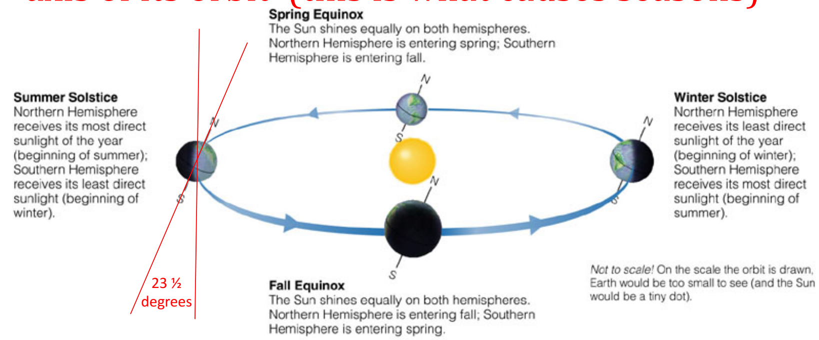
the orbits of all of the planets are in very nearly the same plane in the sky.

L2-Jan 5/17

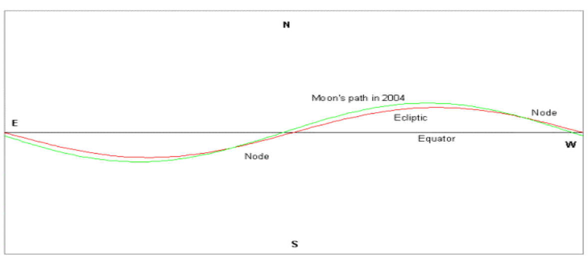
These two planes (ecliptic and equator) are inclined to each other by 23 ½ degrees



The Earth's rotation axis is NOT parallel to the axis of its orbit (this is what causes seasons)

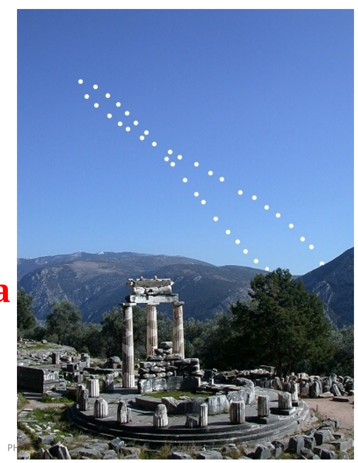


The path of the moon



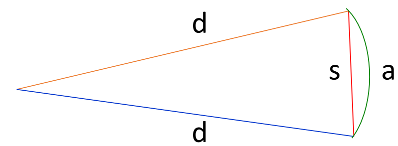
The position of the Sun – over the course of a year…. at 6 am

(approximately once a week [depending on weather!])



Angles and separation in sky

1. angular position… measured in degrees, (arc)minutes, (arc)seconds
   - 1 degree = 60 **arcmin** = 3600 **arcsec** …or… $1° = 60' = 3600''$
2. How far apart are objects in the sky?
   - We measure an angular separation (often a few arcseconds) - to get the true physical or linear separation we need to know how far from us the objects are – their distance from us.
   - Usually the objects are much closer to each other than to us and we can safely assume that they are both at essentially the same distance from us



Definition of angle in radians: $\theta = a/d$

(a = arc-length, d = distance: radius of circular arc)

π radians = 180 degrees

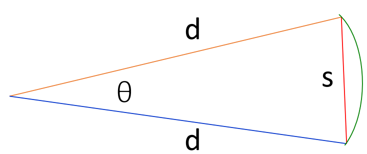
1 radian = $180/\pi$ degrees = 57.29577951… degrees

≈ 57.3 deg

1 radian = $60 \times 60 \times 180/\pi$ arcseconds = 206,264.806…arcsec

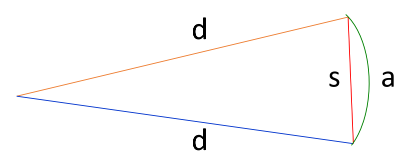
≈ 206265 arcsec

a = d × $\boldsymbol{\theta}$(radians) and $\boldsymbol{\theta}$(radians) = $\boldsymbol{\theta}$(arcsec)/206265



θ	**a**	**s [= 2sin(θ/2)]**	**% diff**
60 degrees	1.047 × d	1.000 × d	4.5%
10 degrees	0.1745 × d	0.1743 × d	0.11%
1 degree	0.01745 × d	0.01745 × d	0.0013%

for small angles a = s



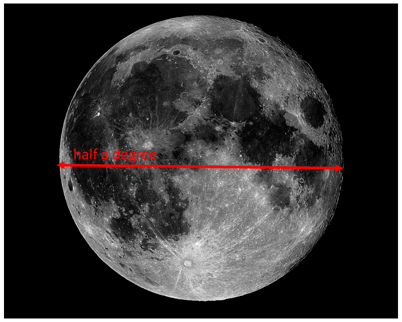
There are lots of "sort-of" wrong ways to determine s (if given distance d and angle θ):

- tan (d tan θ ➔ assumes θ small, right angles for two other angles.)
- cosine law ($s^2=d^2+d^2-2d^2\cos\theta$)
- sin law

These may not be precise enough for small angles. (e.g. 1 arcsecond)

Example: ~how big is a "Maria" (dark "sea") on the Moon?

- Moon is about ½ degree across (30 arcminutes)
- "by eye" largest Maria is ~ 1/3 of Moon's diameter
  = 10 arcmin
  = 10/60 degrees = 0.167 deg
  = 10/60/57.3 radians = 0.0029 rad
- distance to Moon is ~400,000 km
- diameter of Maria
  = 400,000 km × 0.0029
  = ~1,160 km
  1.2×10^3 km
  Note the number of significant figures!



Contents of the Solar System

1. Sun (or "Sol"): A fairly typical star
   - What is a star?
2. Planets
   - Two "types": small "terrestrial" and large "Giant" or "Jovian"
3. Dwarf Planets
4. Smaller bodies
   - In orbit around the Sun
     - Asteroids, comets
   - In orbit around planets
     - Moons
     - Rings

Census of the Solar System

"category"	number	comment
stars	1	
(major) planets	8	
dwarf planets	5 (probably more)	Pluto+
Satellites (moons)	≥ 134	7 with R>1000km
ring systems	4	
asteroids	>150000/10^6?	known/predicted
comets: KBO	10^6?	within 30-50AU?
comets: Oort Cloud	10^{13}?	Oort Cloud not yet directly observed

Recent Solar System Missions

- **Mercury**: Messenger (NASA)
- **Venus**: Venus Express (ESA)
- **Mars**: currently 7 active missions on Mars!
- **Jupiter**: Juno (NASA)
- **Saturn**: Cassini (NASA/ESA) MISSION ENDS SEPT 15, 2017 !
- **Pluto**: New Horizons (NASA)
- **Ceres:** (and Vesta): Dawn (NASA)
- **Comet**: Deep Impact (NASA), Stardust (NASA), Rosetta (ESA)

Our Star
the Sun
or "Sol"

The Sun

Gross Properties:

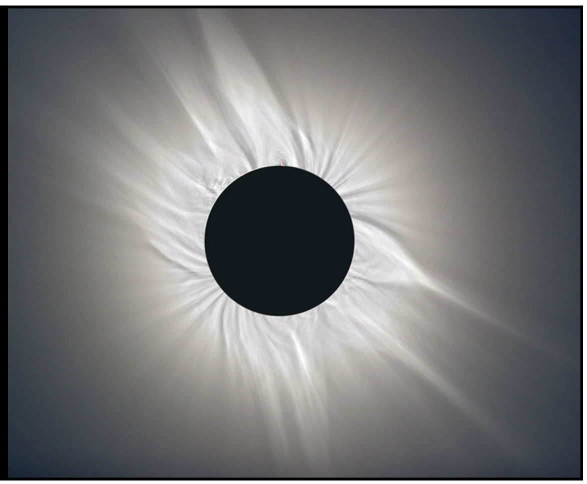
- mass = 1.99×10^{30} kg = **1 M_{Sun}**
- radius = 6.96×10^{8} m (109 x R_{Earth}) = **1 R_{Sun}**
- density = 1410 kg/m^3 (the density of water is 1000 kg/m^3)
- composition: 74% Hydrogen, 25% Helium (1% other stuff)
- luminosity = 3.90×10^{26} Watts = **1 L_{Sun}**
- surface temperature = **5800°K** (also called the effective Temperature: T_{eff})
- rotation period = 25 days at the equator, but varies with latitude and depth
- has strong magnetic field

Solar corona

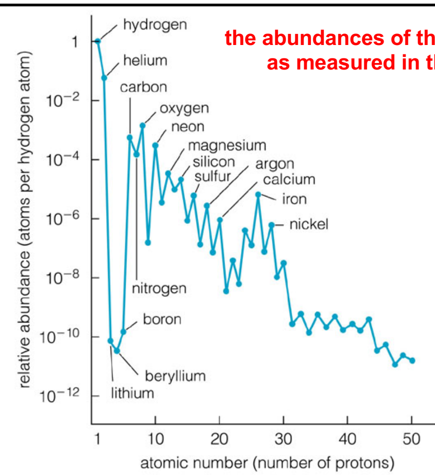
The outermost part of the Sun's atmosphere

the Solar corona seen here during an eclipse in 2006 near solar maximum

the outer parts of the corona escape the Sun as the "**Solar Wind**"

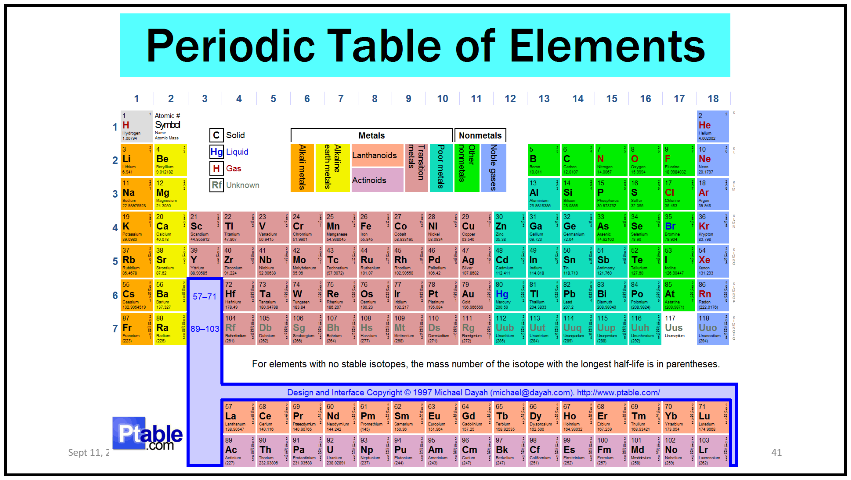


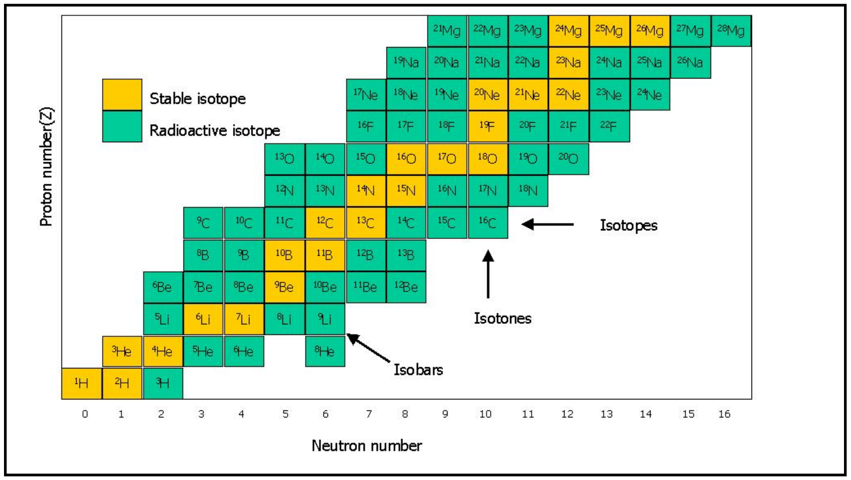
the abundances of the elements as measured in the Sun

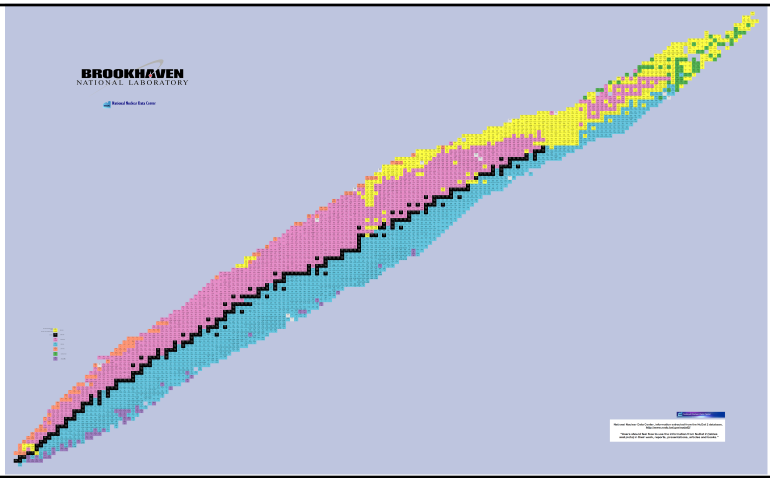


For every 1,000,000 hydrogen atoms there are:

85,114 helium
331 carbon
91 nitrogen
661 oxygen
83 neon
26 magnesium
33 silicon
16 sulphur
40 iron
(<10 of anything else)



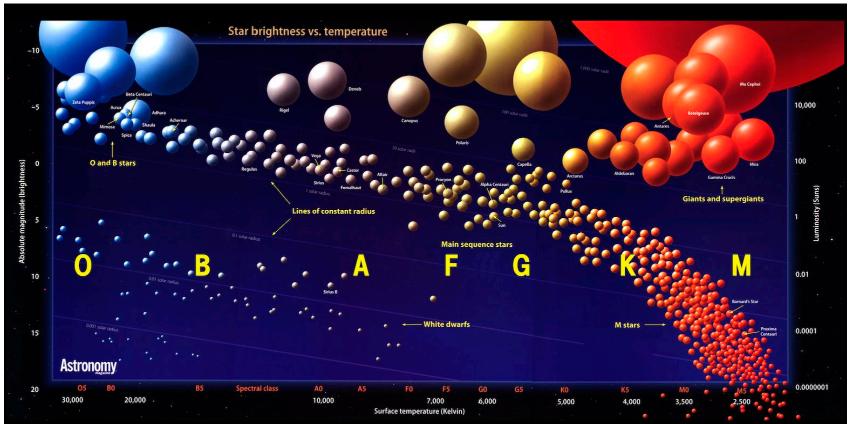




Stars

1. The Sun as a typical star
   - The Sun is mid-way in the range of all stars, by mass
     - Stars are found with masses in the range of 0.01 M_{SUN} to 100 M_{SUN}
     - BUT most stars are less massive than the Sun
2. The Luminosity (energy output) of stars is proportional, very roughly, to the Mass cubed: M^3 .
   - Thus the 50 M_{SUN} stars produce as much light as one billion 0.05 M_{SUN} stars !
3. More massive stars are also bluer (hotter) and have much shorter lifetimes than the less massive stars.

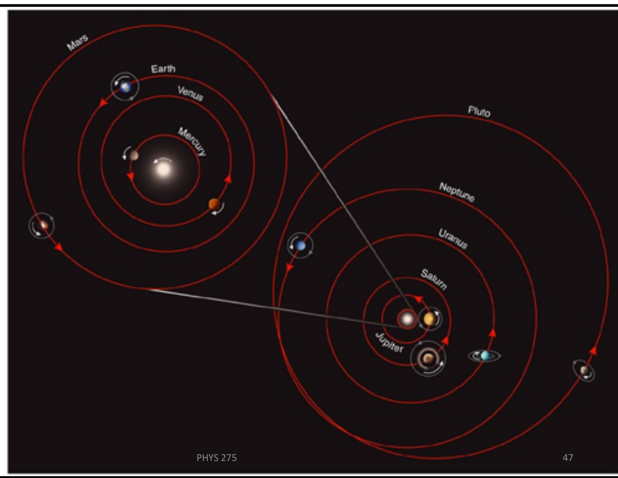
Sept 11, 2017 PHYS 275 44

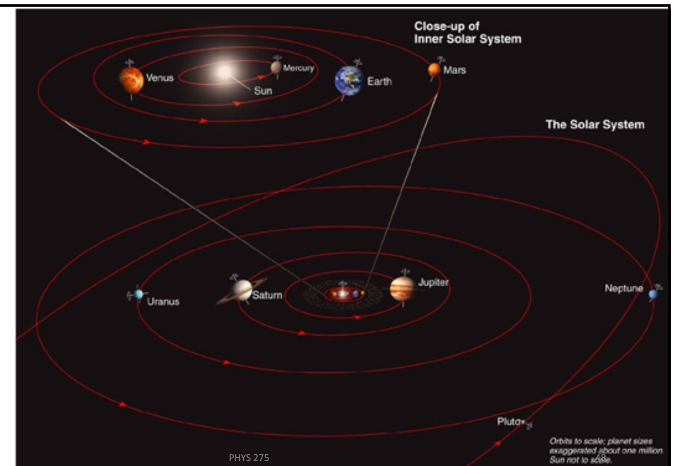


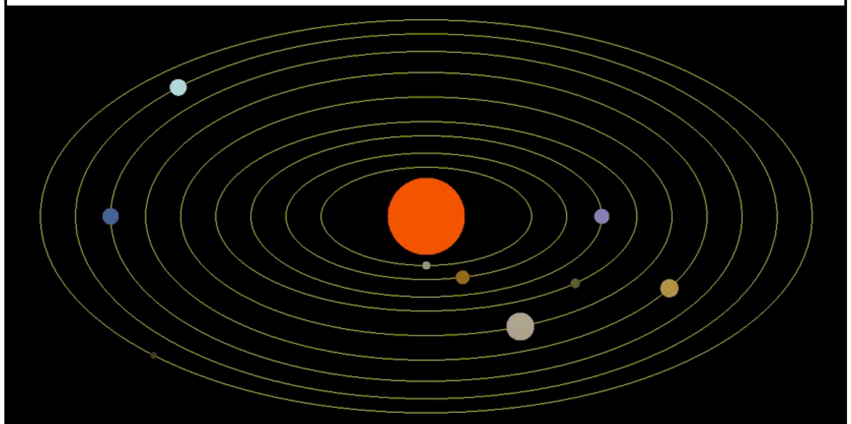
Planets in the Solar System

motions shown by arrows: circular! Red arrows show all orbit the Sun in the same direction [counter-clockwise in this view]. Tiny white arrows show **MOST** planets (but not all) rotate on their axis in the same way

Planet sizes WRONG in this!







Orbital Properties of the Major Planets

Planet	a (AU)	e	period (y)	inclination	v_{orb} (km/s)
Mercury	0.39	0.206	0.24	7.0°	47.87
Venus	0.72	0.007	0.62	3.39	35.02
Earth	1.00	0.017	1.00	0.0	29.79
Mars	1.52	0.093	1.88	1.85	24.13
Jupiter	5.20	0.048	11.86	1.31	13.06
Saturn	9.54	0.054	29.42	2.49	9.65
Uranus	19.19	0.047	83.75	0.77	6.80
Neptune	30.07	0.009	163.7	1.77	5.43

Patterns in planet orbits

- planetary orbits in same plane i.e. coplanar (Mercury)
- planets' orbital plane same as Sun's equatorial plane
- orbital planes of most satellites near equatorial planes of their planets
- rotational axes ~perpendicular to orbital plane (Uranus)
- orbital and rotation directions the same for planets and most satellites (Venus)

Orbital Properties of the Dwarf Planets

Planet	a (AU)	e	period (y)	inclination	v_{orb}(km/s)	Mass/Moon
Ceres	2.77	0.080	4.60	10.59°	17.88	0.013
Pluto	39.48	0.249	248.1	17.14	4.67	0.178
Haumea	43.34	0.189	285.4	28.19	4.484	0.057
Makemake	45.79	0.159	309.9	28.96	4.419	0.05
Eris	67.67	0.44	557	44.2	3.44	0.227

Physical Properties of the Planets

Planet	radius (km)	mass (kg)	density (kg/m^3)	P_{rot} (d)	axis tilt	# moons	rings?
Mercury	2,440	3.30×10^{23}	5,430	58.6	0.0°	0	No
Venus	6,052	4.87×10^{24}	5,240	-243.0	177.4	0	No
Earth	6,378	5.97×10^{24}	5,520	0.9973	23.45	1	No
Mars	3,394	6.42×10^{23}	3,930	1.026	23.98	2	No
Jupiter	71,492	1.90×10^{27}	1,330	0.41	3.08	60	Yes
Saturn	60,268	5.68×10^{26}	690	0.44	26.73	31	Yes
Uranus	25,559	8.68×10^{25}	1,270	-0.72	97.92	21	Yes
Neptune	24,766	1.02×10^{26}	1,640	0.67	29.6	11	Yes

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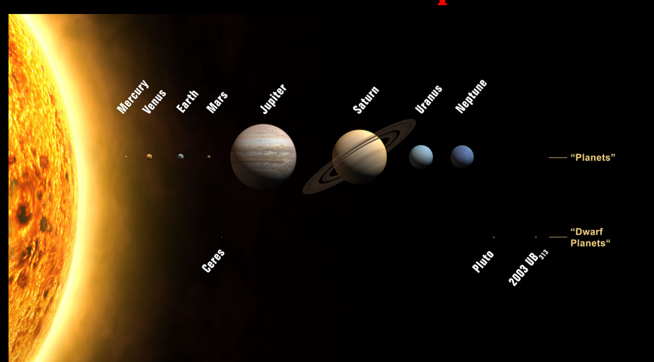
Relative sizes of the planets



Summary: Terrestrial vs. Giant (Jovian) Planets

1. Terrestrial Planets
   - located in inner part of Solar System
   - small
   - rocky (high density), with distinct surfaces
   - few moons
   - no rings
2. Giant Planets
   - in outer part of Solar System
   - large
   - gaseous (low density)
   - many moons
   - rings
   - rapid rotators