Course

• Course Website:
  – http://blogs.umass.edu/astron101-tburbine/

• Textbook:
  – *Pathways to Astronomy (2nd Edition)* by Stephen Schneider and Thomas Arny.

• You also will need a calculator.
Office Hours

• Mine
• Tuesday, Thursday - 1:15-2:15pm
• Lederle Graduate Research Tower C 632

• Neil
• Tuesday, Thursday - 11 am-noon
• Lederle Graduate Research Tower B 619-O
Homework

• We will use Spark
• [https://spark.oit.umass.edu/webct/logonDisplay.do](https://spark.oit.umass.edu/webct/logonDisplay.do)
• Homework will be due approximately twice a week
Astronomy Information

• Astronomy Help Desk
• Mon-Thurs 7-9pm
• Hasbrouck 205

• The Observatory should be open on clear Thursdays
• Students should check the observatory website at: http://www.astro.umass.edu/~orchardhill for updated information
• There's a map to the observatory on the website.
Final

• Monday - 12/14
• 4:00 pm
• Hasbrouck 20
HW #7

• Due today
HW #8

• Due today
HW #9

• Due October 27
Exam #2

• Next Thursday
• Bring a calculator and a pencil
• No cell phones, Blackberries, iPhones
• Covers material from September 22 through October 8 (Units 14-31)
Formulas you need to know

- $F = \frac{GMm}{r^2}$
- $F = ma$
- $a = \frac{GM}{r^2}$
- Escape velocity = $\sqrt{\frac{2GM}{r}}$
- $T (K) = T (°C) + 273.15$
- $c = f*\lambda$
- $E = h*f$
- $KE = \frac{1}{2}mv^2$
- $E = mc^2$
More Formulas

• Power emitted per unit surface area = \( \sigma T^4 \)
• \( \lambda_{\text{max}} \) (nm) = \( \frac{(2,900,000 \text{ nm}\cdot\text{K})}{T} \)
• Apparent brightness = \text{Luminosity} \\
\[ 4\pi \times (\text{distance})^2 \]
LCROSS Impact

- http://www.youtube.com/watch?v=VYYKjR1sJY4
Solar System

- Sun
- Eight Planets
- Their moons
- Dwarf Planets
- Asteroids
- Comets
Sun
Sun

- 74% H
- 25% He
- Traces of everything else
Mercury
Venus
Earth
Earth’s crust

- 46.6% O
- 27.7% Si
- 8.1% Al
- 5.0% Fe
- 3.6% Ca
- 2.8% Na
- 2.6% K
- 2.1% Mg
Moon
Comet
Composition of the terrestrial planets

- Mercury
- Venus
- Earth (with silicate mantle and Fe,Ni core)
- Mars
- Moon
Asteroid
Estimated Frequency of Impacts on Earth

Approximate Frequency of Impacts
- Monthly
- Every Year
- Every Decade
- Once a Century
- Once a Millennium
- Every Ten Thousand Yrs.
- Every Hundred Thousand Yrs.
- Every Million Yrs.
- Every 10 Million Yrs.
- Every 100 Million Yrs.

MegaTons TNT Equivalent Energy

- "Annual Event" ~20 kilotons
- Tunguska
- Meteor Crater
- Global Catastrophe Threshold
- K-T impact

http://spaceguard.esa.int
Meteorites

chondrite

Pallasite – mixtures of olivine and metal

Iron
Jupiter
Jupiter

• 90% H
• 10% He
• Traces of everything else
Europa
Saturn
Saturn

- 75% H
- 25% He
- Traces of everything else
Neptune
Pluto
How do we determine what astronomical bodies are made of?
How do we determine what astronomical bodies are made of?

• Measure how they emit or reflect light
  – Tells you about their surfaces

• Measure their physical properties
  – Tells you about their interiors
### TABLE 4.1 Properties of Some Solar System Objects

<table>
<thead>
<tr>
<th>OBJECT</th>
<th>ORBITAL SEMI-MAJOR AXIS (AU)</th>
<th>ORBITAL PERIOD (EARTH YEARS)</th>
<th>MASS (EARTH MASSES)</th>
<th>RADIUS (EARTH RADII)</th>
<th>NUMBER OF KNOWN MOONS</th>
<th>AVERAGE DENSITY (kg/m³)</th>
<th>(Earth = 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>0.39</td>
<td>0.24</td>
<td>0.055</td>
<td>0.38</td>
<td>0</td>
<td>5400</td>
<td>0.98</td>
</tr>
<tr>
<td>Venus</td>
<td>0.72</td>
<td>0.62</td>
<td>0.82</td>
<td>0.95</td>
<td>0</td>
<td>5200</td>
<td>0.95</td>
</tr>
<tr>
<td>Earth</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1</td>
<td>5500</td>
<td>1.00</td>
</tr>
<tr>
<td>Moon</td>
<td>—</td>
<td>—</td>
<td>0.012</td>
<td>0.27</td>
<td>—</td>
<td>3300</td>
<td>0.60</td>
</tr>
<tr>
<td>Mars</td>
<td>1.5</td>
<td>1.9</td>
<td>0.11</td>
<td>0.53</td>
<td>2</td>
<td>3900</td>
<td>0.71</td>
</tr>
<tr>
<td>Ceres (asteroid)</td>
<td>2.8</td>
<td>4.7</td>
<td>0.00015</td>
<td>0.073</td>
<td>0</td>
<td>2700</td>
<td>0.49</td>
</tr>
<tr>
<td>Jupiter</td>
<td>5.2</td>
<td>11.9</td>
<td>318</td>
<td>11.2</td>
<td>63</td>
<td>1300</td>
<td>0.24</td>
</tr>
<tr>
<td>Saturn</td>
<td>9.5</td>
<td>29.4</td>
<td>95</td>
<td>9.5</td>
<td>50</td>
<td>700</td>
<td>0.13</td>
</tr>
<tr>
<td>Uranus</td>
<td>19.2</td>
<td>84</td>
<td>15</td>
<td>4.0</td>
<td>27</td>
<td>1300</td>
<td>0.24</td>
</tr>
<tr>
<td>Neptune</td>
<td>30.1</td>
<td>164</td>
<td>17</td>
<td>3.9</td>
<td>13</td>
<td>1600</td>
<td>0.29</td>
</tr>
<tr>
<td>Pluto</td>
<td>39.5</td>
<td>249</td>
<td>0.002</td>
<td>0.2</td>
<td>1</td>
<td>2100</td>
<td>0.38</td>
</tr>
<tr>
<td>Comet Hale-Bopp</td>
<td>180</td>
<td>2400</td>
<td>1.0 × 10⁻⁹</td>
<td>0.004</td>
<td>—</td>
<td>100</td>
<td>0.02</td>
</tr>
<tr>
<td>Sun</td>
<td>—</td>
<td>—</td>
<td>332,000</td>
<td>109</td>
<td>—</td>
<td>1400</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Source: NASA
Planetary densities

\[
density = \frac{mass}{volume}
\]

Units are g/cm\(^3\) or kg/m\(^3\)
1 g/cm\(^3\) = 1,000 kg/m\(^3\)

\[
volume = \frac{4}{3} \pi r^3
\]

But how do we determine mass?
Use Newton’s Laws of motion…

\[ M = \frac{4\pi^2 a^3}{Gp^2} \]

Where \( P \) is the period of a planet’s orbit
\( a \) is the distance from the planet to the Sun
\( G \) is Newton’s constant
\( M \) is the mass of the Sun

This assumes that orbits are circles, and that the mass of a planet is tiny compared to the mass of the Sun.

Use this relation with \( P \) and \( a \) for the Earth, and you’ll get the mass of the Sun: \( M_{\text{Sun}} = 1.98892 \times 10^{30} \text{ kg} \)
But we want to know the mass of a planet!

$$F = \frac{GmM}{r^2}$$  and  $$F = ma$$

Where  
F is the gravitational force  
G is the constant of proportionality  
M and m are the two masses exerting forces  
r is the radius of the planet  
a is its acceleration due to gravity
Solve for \( M \), the mass of the Earth, by using
\[
\frac{GM}{r^2} = a
\]
Re-arrange to get
\[
M = \frac{ar^2}{G}
\]
\[
\begin{align*}
a &= 9.8 \text{ m/sec}^2 \\
r &= 6.4 \times 10^6 \text{ m} \\
G &= 6.67 \times 10^{-11} \text{ m}^3/(\text{kg sec}^2) \\
M_{Earth} &= 5.9736 \times 10^{24} \text{ kg} \\
V_{Earth} &= 1.0832 \times 10^{21} \text{ m}^3 \\
D_{Earth} &= 5515 \text{ kg/m}^3 = 5.515 \text{ g/cm}^3
\end{align*}
\]
Volume

- If you assume a planet is a sphere:
- Volume $= \frac{4}{3}\pi r^3$
Density \( \rho = \text{Mass/Volume} \)
\[
\rho_{\text{Earth}} = 5.515 \text{ g/cm}^3
\]

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic iron</td>
<td>7.87</td>
</tr>
<tr>
<td>Basalt</td>
<td>3.3</td>
</tr>
<tr>
<td>Water</td>
<td>1.0</td>
</tr>
<tr>
<td>Water Ice</td>
<td>0.9</td>
</tr>
<tr>
<td>Liquid Hydrogen</td>
<td>0.07</td>
</tr>
</tbody>
</table>
Density of water

- Density of water is 1 g/cm³
- Density of water is 1,000 kg/m³
<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
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</tr>
<tr>
<td>Basalt</td>
<td>3.3</td>
</tr>
<tr>
<td>Water</td>
<td>1.0</td>
</tr>
<tr>
<td>Cold ices</td>
<td>0.07-0.09</td>
</tr>
</tbody>
</table>

What do these densities tell us?
<table>
<thead>
<tr>
<th>TERRESTRIAL</th>
<th>JOVIAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>close to the Sun</td>
<td>far from the Sun</td>
</tr>
<tr>
<td>closely spaced orbits</td>
<td>widely spaced orbits</td>
</tr>
<tr>
<td>small masses</td>
<td>large masses</td>
</tr>
<tr>
<td>small radii</td>
<td>large radii</td>
</tr>
<tr>
<td>predominantly rocky</td>
<td>predominantly gaseous</td>
</tr>
<tr>
<td>solid surface</td>
<td>no solid surface</td>
</tr>
<tr>
<td>high density</td>
<td>low density</td>
</tr>
<tr>
<td>slower rotation</td>
<td>faster rotation</td>
</tr>
<tr>
<td>weak magnetic fields</td>
<td>strong magnetic fields</td>
</tr>
<tr>
<td>no rings</td>
<td>many rings</td>
</tr>
<tr>
<td>few moons</td>
<td>many moons</td>
</tr>
</tbody>
</table>
How big is the Solar System?

One boundary

• Some scientists think that the furthest influence of the Solar System extends out to 125,000 astronomical units (2 light years).

• Since the nearest star is 4.22 light-years away, the Solar System size could extend almost half-way to the nearest star.

• Astronomers think that the Sun's gravitational field dominates the gravitational forces of the other stars in the Solar System out to this distance.
What is out there?

- The Oort Cloud (the source of long period comets) extends out to a distance of 50,000 AU, and maybe even out to 100,000 AU.
- The Oort Cloud has never been seen directly.
- Appears to exist because comets with extremely long orbits sometimes pass near the Sun and then head back out again.
- The Oort cloud could have a trillion icy objects.
The Oort Cloud (comprising many billions of comets)
Another possible boundary- Heliopause

- Heliopause is the region of space where the sun's solar wind meets the interstellar medium. Solar wind's strength is no longer great enough to push back against the interstellar medium.
  - Solar wind – charged particles ejected from the Sun
  - Interstellar medium – gas and dust between stars
- Heliosphere is a bubble in space "blown" into the interstellar medium
- It is a fluctuating boundary that is estimated to be ~80-100 AU away
• Termination shock - the point where the solar wind slows down.
• Bow shock - the point where the interstellar medium, travelling in the opposite direction, slows down as it collides with the heliosphere.
To learn how the Solar System formed

• Important to study the bodies that were the building blocks of the planets
  – Asteroids
    • meteorites are almost all samples of asteroids
  – Comets
What’s the difference?

- Asteroids
- Comets
- Meteorites
What’s the difference?

• Asteroids - small, solid objects in the Solar System
• Comets - small bodies in the Solar System that (at least occasionally) exhibit a coma (or atmosphere) and/or a tail
• Meteorites - small extraterrestrial body that reaches the Earth's surface
How do we know the age of the solar system
Radioactive dating
What do we date?
Meteorites
How old is the solar system?

• ~4.6 billion years
• All meteorites tend to have these ages
• Except:
How old is the solar system?

• ~4.6 billion years
• All meteorites tend to have these ages
• Except:
  – Martian meteorites
  – Lunar meteorites
Ages

• Ages
How do you determine this age?
Dating a planetary surface

- Radioactive Dating – Need sample
- Crater counting – Need image of surface
Radioactivity

• The spontaneous emission of radiation (light and/or particles) from the nucleus of an atom
### Radioactivity

<table>
<thead>
<tr>
<th><strong>Unstable parent nucleus</strong></th>
<th><strong>Daughter nucleus</strong></th>
<th><strong>Daughter nucleus</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton + Neutron</td>
<td></td>
<td>Alpha particle emission</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proton + Neutron</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Proton + Electron</td>
</tr>
</tbody>
</table>

http://wps.prenhall.com/wps/media/tmp/labeling/2130796_dyn.jpg
Half-Life

• The time required for half of a given sample of a radioactive isotope (parent) to decay to its daughter isotope.
Radioactive Dating

- You are dating when a rock crystallized
Radioactive Dating

\[ n = n_0 \left(\frac{1}{2}\right)^{t/\text{half-life}} \]

\( n_0 = \) original amount
\( n = \) amount left after decay

Also can write the formula as
\[ n = n_0 e^{-\lambda t} \]
\( \lambda = \) the decay constant

decay constant is the fraction of a number of atoms of a radioactive nuclide that disintegrates in a unit of time

Half life = \( (\ln 2)/\lambda = 0.693/\lambda \)
• where $e = 2.718 \, 281 \, 828 \, 459 \, 045 \, ...$

• Limit $(1 + 1/n)^n = e$

  \[ n \to \infty \]

• For example if you have $n = 1,000$
• The limit would be 2.716924
Exponential decay is where the rate of decay is directly proportional to the amount present.
Any Questions?