Astronomy 210

Section 1– MWF 1500-1550

134 Astronomy Building

This Class (Lecture 21):

The Moon

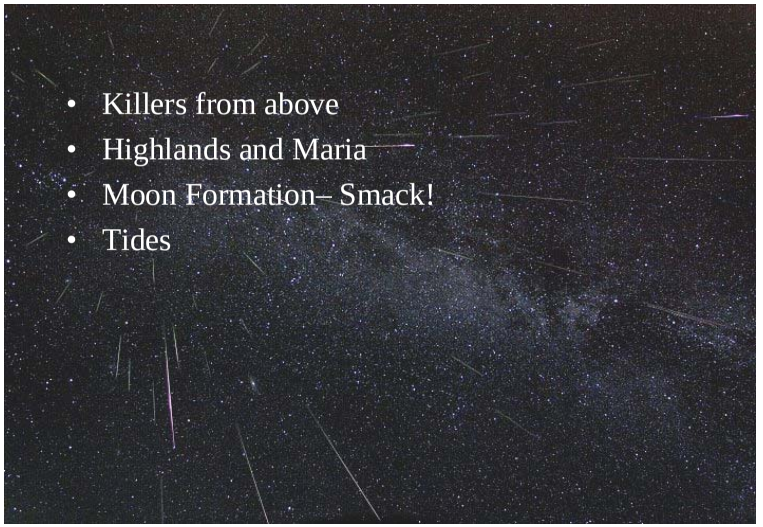
Night Observations!

HW 6 due on Friday!

Next Class:

Terrestrial Planets

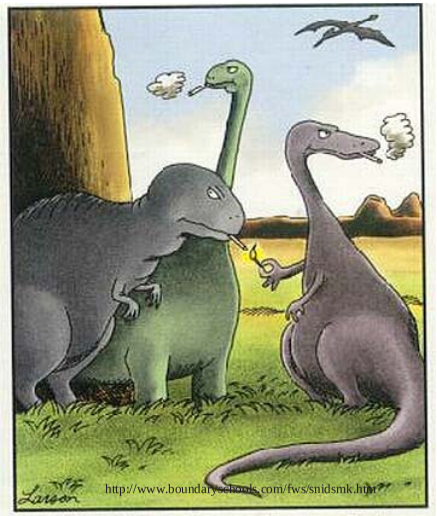
Outline



- Killers from above
- Highlands and Maria
- Moon Formation– Smack!
- Tides

What Killed the Dinosaurs?

- 65 million years ago, 75-95% of all the species on Earth disappeared
- 2nd largest known mass extinction in geological history
- Was a meteoroid collision to blame?



The real reason dinosaurs became extinct

Massive Impacts = Extinctions?

- Scientists have found evidence linking another extinction 250 million years ago to an impact
- Will it happen again?
  - **Yes.** There are many asteroids with Earth-crossing orbits
  - But the chance of being hit by a large asteroid in the next few thousand years is remote

Natural Catastrophes

- Comets and Asteroids
  - Many in Earth-Crossing orbits– NEOs.
  - Again, creates large amounts of dust in the atmosphere leading to global cooling.
  - Small objects can cause a lot of damage because the Earth's orbital velocity is 30 km/s $\Rightarrow$ KE = ½ M V^2
  - That means that a 0.25 km radius rock releases as much energy as 7200 megatons of TNT, as much as a all-out nuclear war!
  - Would make a 10 km crater a few km deep ejecting 10^{12} tons of debris.

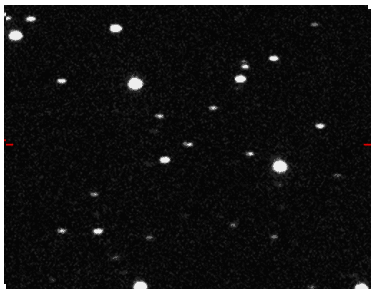
Lifetime Chances

Cause of Death	Chances
Motor vehicle accident	1 in 100
Murder	1 in 300
Fire	1 in 800
Firearms accident	1 in 2,500
Asteroid/comet impact (lower limit)	1 in 3,000
Electrocution	1 in 5,000
Asteroid/comet impact	1 in 20,000
Passenger aircraft crash	1 in 20,000
Flood	1 in 30,000
Tornado	1 in 60,000
Venomous bite or sting	1 in 100,000
Asteroid/comet impact (upper limit)	1 in 250,000
Fireworks accident	1 in 1 million
Food poisoning by botulism	1 in 3 million
Drinking water with EPA limit of TCE*	1 in 10 million

http://www.planetary.org/html/neo/ABCsOfNEOs/FrndorFoe.html

Killer Asteroids

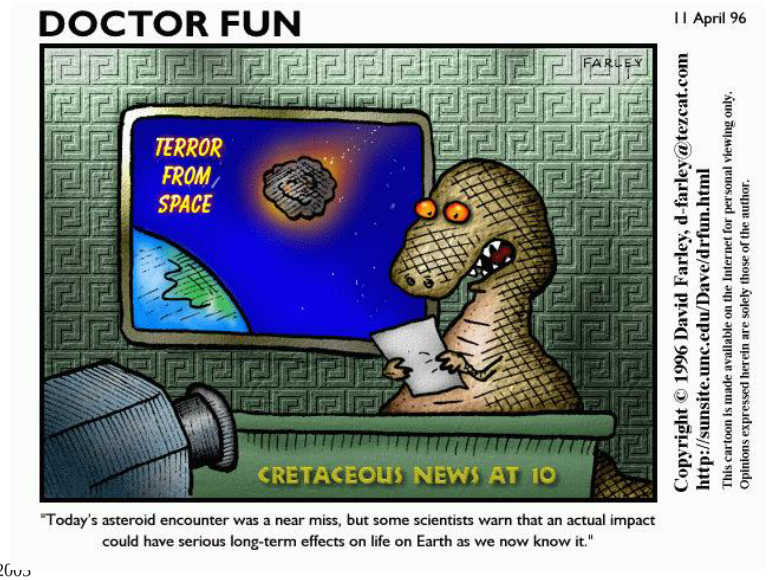
- Small asteroids are often hitting the Earth's atmosphere.
- Commonly giving off around 10 kilotons of energy.
- But how often are Killer Asteroids (~ 0.5 km in diameter) expected?
- In 1992 congress asked NASA to find near Earth objects.
- So far over 400,000 objects.
- The most dangerous known is 1950 DA (~1km), will get close in March 2880 (0.33% chance of collision).
- We can not predict orbits more than 20 years in advance, but 1950 DA would have 100,000 Megatons of energy.



Asteroid 2004 FH. 30 meters in diameter. About 1 Megaton of TNT energy in an Earth impact! Passed within 7 Earth radii of Earth. Hiroshima was 15 kilotons.

http://antwrp.gsfc.nasa.gov/apod/ap040322.html

Be Aware



Killer Asteroids

- The Dino Killer was about 10 km in diameter.
- And, there are many asteroids out there that we still do not know about.
- Estimation of killer asteroids impact is about every million years or so.
- What can we do if there is an immediate threat? There may be little time.

http://www2.ifa.hawaii.edu/newsletters/article.cfm?a=88&n=10

http://neat.jpl.nasa.gov/

http://www.ll.mit.edu/LINEAR/

Killer Asteroids

- Diversion or destruction of object.
- With sufficient warning it doesn't take too much to miss the Earth.
- One example is to change reflectivity of surface.
- Nuclear explosions may result in many small asteroids.
- Expensive and difficult, but advanced civilizations should be able to do it.

http://neat.jpl.nasa.gov/

http://www.ll.mit.edu/LINEAR/

Back to the Moon: The Lunar Surface

- Rocks are all **old**
  - Mostly 3.1-4.5 billion years old
- Divided into darker regions (maria) and lighter regions (highlands)

Lunar Surface – Highlands

- Covers about 83% of surface
- Craters on top of craters
- Very old rocks
  - Fused from smaller smashed particles
  - 3.8 to 4.0 billion years old

Lunar Surface – Maria

- Covers about 17% of surface
- Lava filled impact basins
- Mostly on the near side of the Moon
- Relatively few craters
- Age of rocks
  - 3.1 to 3.8 billion years old

Regolith

- The surface of the Moon is covered with pulverized soil
- Called *regolith*
- Made by billions of years of micrometeorite impacts
- Powdery, glassy grit
- A few to tens of meters deep

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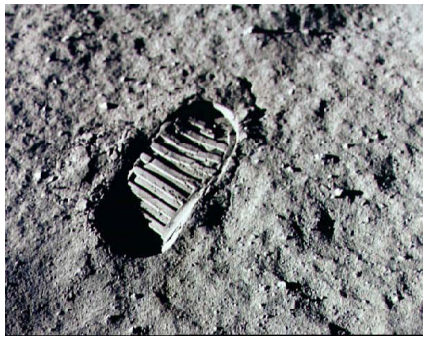
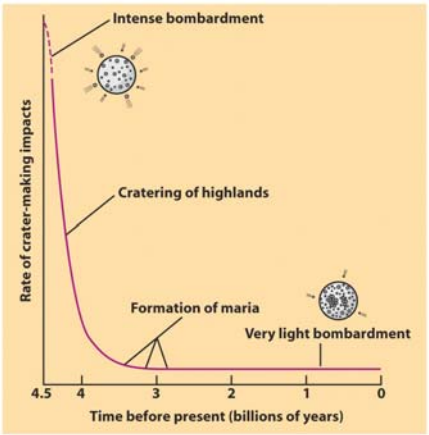


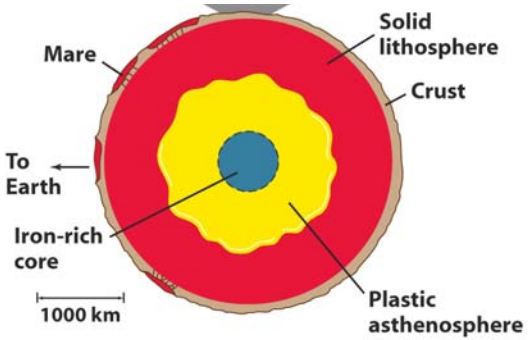
Heavy Bombardment

- Meteoroid activity slowed about 4 billion years ago
- Before then: a period of *heavy bombardment*
- Today, meteoroid bombardment is very light



Lunar Interior

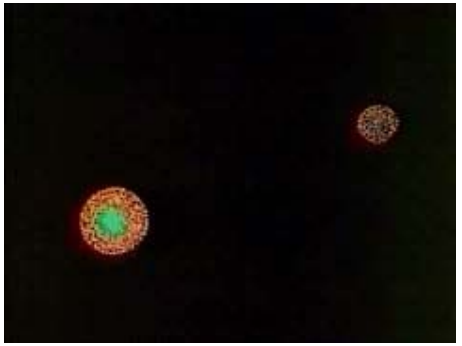
- The Moon has no volcanoes, no plate tectonics, no magnetic field
- This indicates a cold, solid interior



- Moon was too small to retain its heat
  - Cooled off and solidified

Formation of the Moon: Smack

- Collision of Earth with a Mars-sized body early in the solar system's history
- Iron-rich core of the impactor sank within Earth
- Earth's rotation sped up



- Remaining ejecta thrown into orbit, coalesced into the Moon

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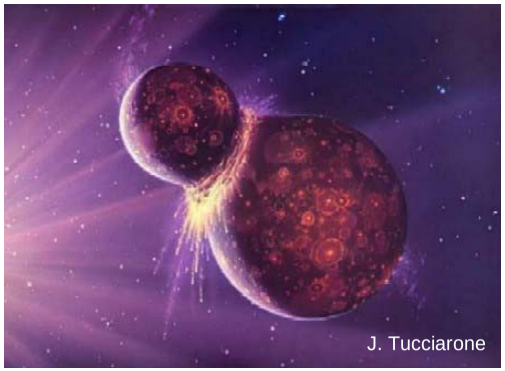

- Remaining ejecta thrown into orbit, coalesced into the Moon

Why is this a good hypothesis?

- The Earth has a large iron core, but the moon does not
  - The debris blown out of collision came from the rocky mantles
  - The iron core of the impactor merged with the iron core of Earth
  - Compare density of 5.5 g/cm^3 to 3.3 g/cm^3 -- the moon lacks iron and other heavy stuff

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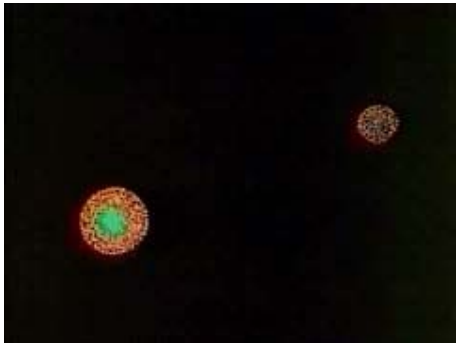
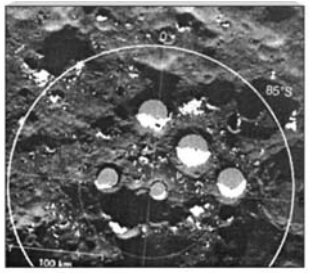
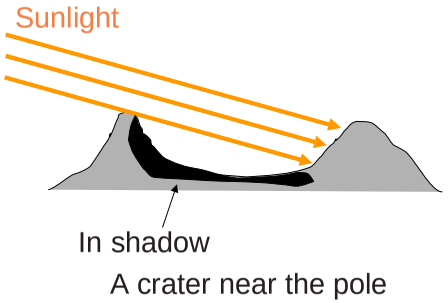


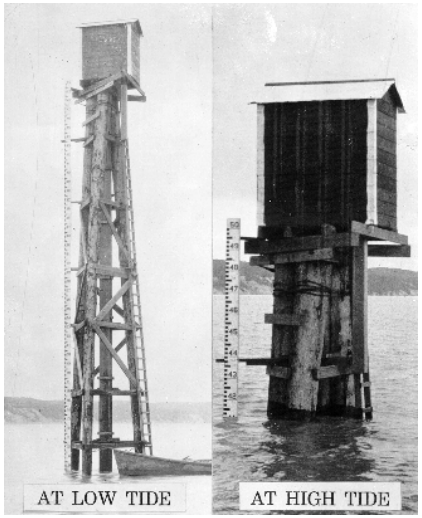
Ice on the Moon?

- Possibility indicated by Clementine (1994)
- Confirmed by Lunar Prospector (1998)





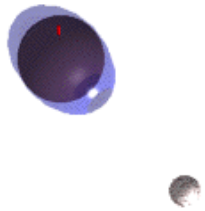
Tides



- Everywhere along the seacoast, the oceans periodically rise and fall
- Called *tides*
- 12 1/2 hours between successive high tides
- http://tidesonline.nos.noaa.gov/

What Causes Tides?

- Tides are caused by the Moon
  - The force of the Moon's gravity is greatest on the near side of the Earth
  - Weaker on the center
  - Weakest on the far side
  - Result, ocean has *tidal bulges* = high tide



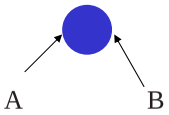
http://co-ops.nos.noaa.gov/about2.html

Totally Tidal

- Gravity forces change with distance.

$$F_A = G\frac{Mm}{r^2} \quad \text{and} \quad F_B = G\frac{Mm}{(r+d)^2}$$

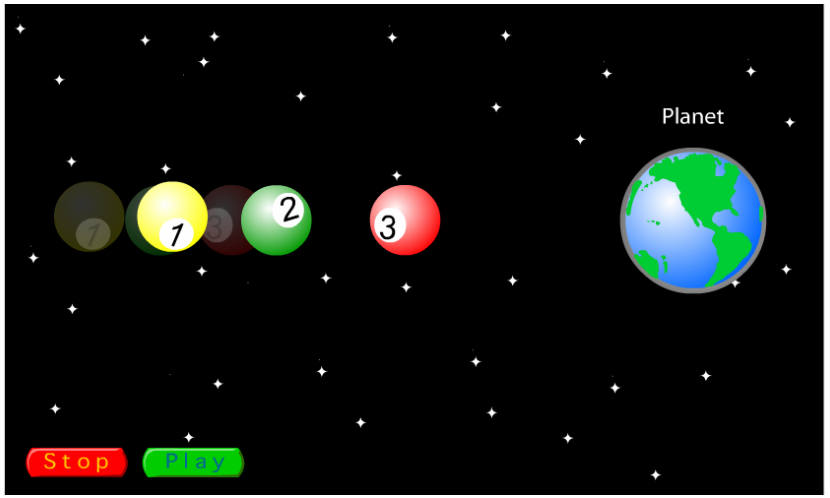
$F_A > F_B$



so gravity tries to pull apart

$\Rightarrow$ Tidal Force

Tidal Forces



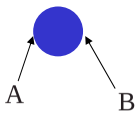
Totally Tidal

$$F_A = G\frac{Mm}{r^2} \quad \text{and} \quad F_B = G\frac{Mm}{(r+d)^2}$$

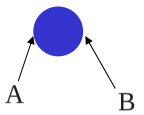
$$F_{tide} = F_A - F_B$$

$$= GMm\left(\frac{1}{r^2} - \frac{1}{(r+d)^2}\right)$$

$$= GMm\left(\frac{(r+d)^2 - r^2}{r^2(r+d)^2}\right)$$



Totally Tidal



$$= 2GMm\left(\frac{d}{r3}\right) \quad \text{if } d << r$$

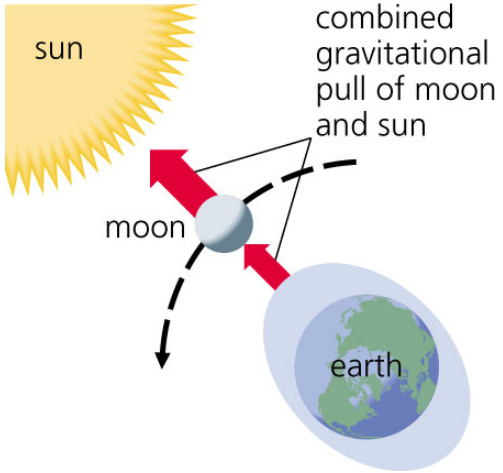
Not All Tides Are Equal

- Over a month, the height of the tides change
- When the high tide is highest, the low tide is lowest
  - Extreme tides, called **spring tides**
  - From German "springen" - to spring up
- When the difference between tides is smallest
  - Called **neap tides**
- Why spring and neap tides?
  - The Sun also creates tides
  - Effect is about half that of the Moon's tides

http://www.normandy-tourism.org/w/ville/MtStMich1.html

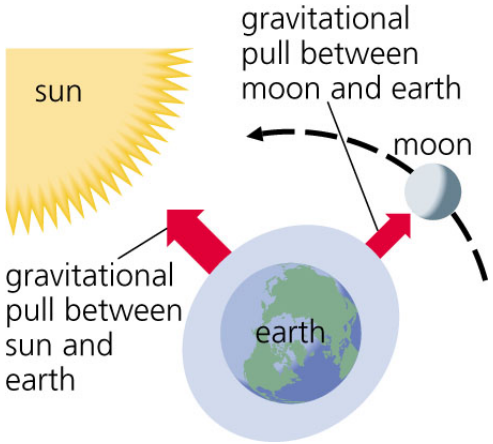
Spring Tides

- Spring tides occur when the Sun and Moon are aligned
- **Both** new moon and full moon!
- Sun's tides and Moon's tides combine to make extreme tides



Neap Tides

- Neap tides occur when the Sun and Moon are at a right angle
- 1st and 3rd quarter moon phases
- Sun's tides partially cancel the Moon's tides



Tidally Yours

- Remember the moon's rotation period equals it's orbital period.
- And it is in co-rotation: $\omega_{orbit} = \omega_{spin}$
- Why?
- Tidal interaction and friction.
- Friction will drive a system to a non-friction state.
  - e.g. a ball rolling in a bowl.

Rotation period= Orbit period

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Rotation period=
Orbit period

Tidally Yours

- Friction will drive a system to a non-friction state.
  - e.g. a ball rolling in a bowl.
- The moon is constantly deformed from the Earth's gravitational pull.
- This causes a frictional force that acts against the spin.
- The moon's orbit evolved toward a frictionless state
  $\Rightarrow$ co-rotation $\omega_{orbit} = \omega_{spin}$

Tidally Yours

- $\omega_{orbit} = \omega_{spin}$ can take a long time
- It has happened for the Moon, it will eventually happen to the Earth.
  $\omega^{E}_{orbit} < \omega^{E}_{spin}$

Effects of Tides

- The sloshing water slows down the rotation of the Earth!
- Gravity of the tidal bulge speeds up the orbit of the Moon!

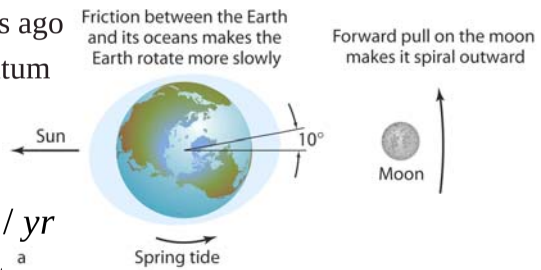
1. Earth's spin decreases (angular momentum is reduced)

$$dP_{spin}/dt \approx 1.6\times10^{-5}\, s/yr = 16\, s/Myr$$

18 hour day 900 Myrs ago

2. Adds angular momentum to Moon, which increases distance.

$$dR/dt \approx 2.3\, cm/yr$$

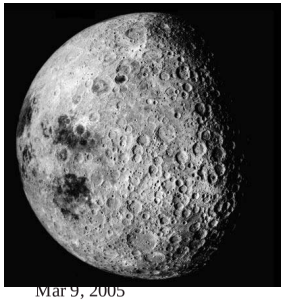


Moon is Moving Away!

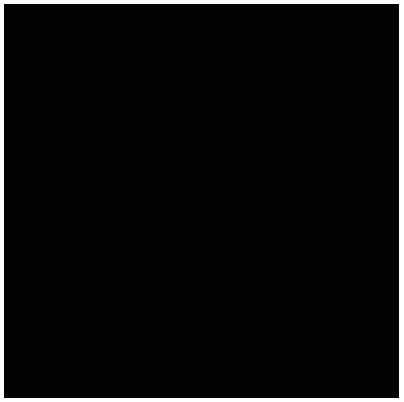
- Astronauts left mirrors on the surface, so we can reflect light back to Earth and measure the changing distance
- Moon was closer in past.
- E.g. about 1.2 Byrs ago it was 18000 km away.
- How far away now?

Lunation

- Image of a complete lunar cycle.
- See more than half the surface (59%)– libration.
- Mostly due to the elliptical orbit.



The far side of the Moon.



http://antwrp.gsfc.nasa.gov/apod/ap991108.html
http://antwrp.gsfc.nasa.gov/apod/ap981008.html