



- Homework #3 was due today!
- Last Homework before Exam (HW#4) is due next Friday at 11:50am.
- Nighttime observing has 8 more nights. Check the webpage.
- 1st exam is October 10th – 2 weeks away!

Outline



- Moon Facts
- Surface of the Moon
 - Craters
 - Maria
 - Highlands
 - Regolith
- Origin of the Moon– Smack!
- Tides

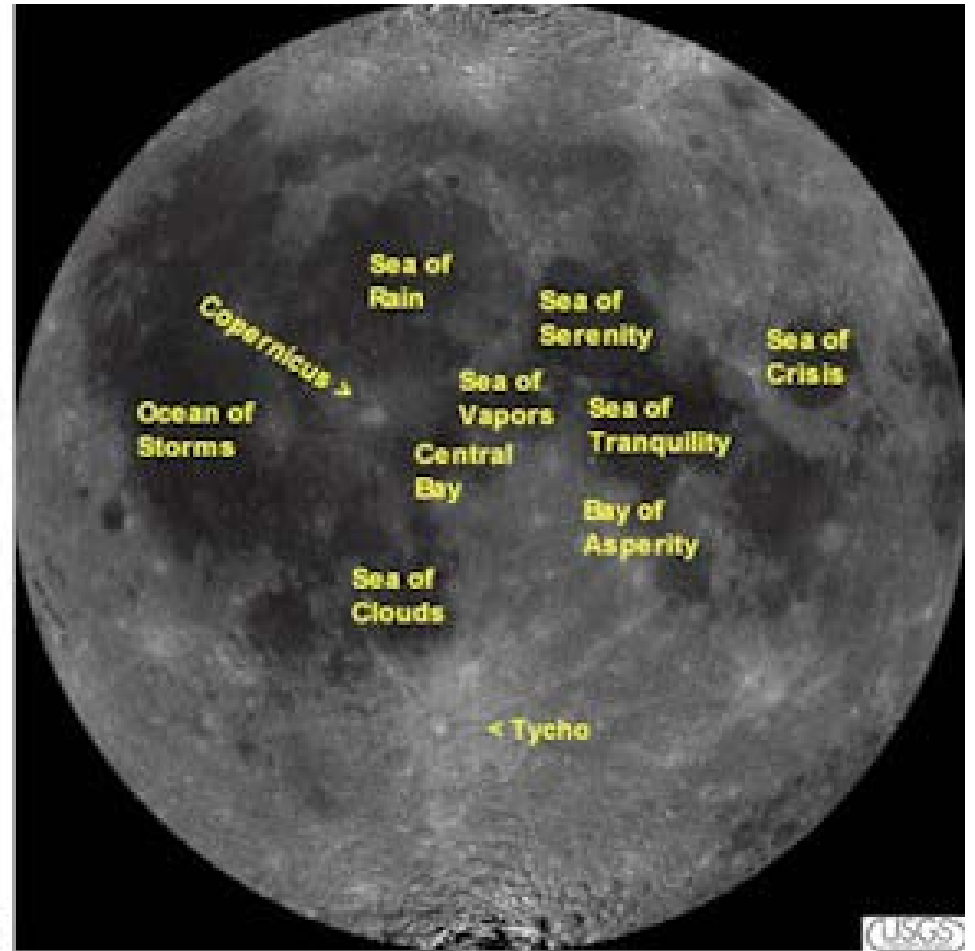


Moon Facts

- Very different than Earth's surface
 - No surface water
 - No atmosphere (not enough mass to retain)
- Unlike the Earth, the Moon is not active. No plate tectonics, no mountains from crust movement, and no active volcanoes.
- Even by naked eye, lunar surface can be divided into dark regions (Maria) and light regions (Highlands).
- In the daytime it reaches +110 degrees C and at night –180 degrees C!



Maria



<http://www.christa.org/wilma.htm>

Woman in the Moon

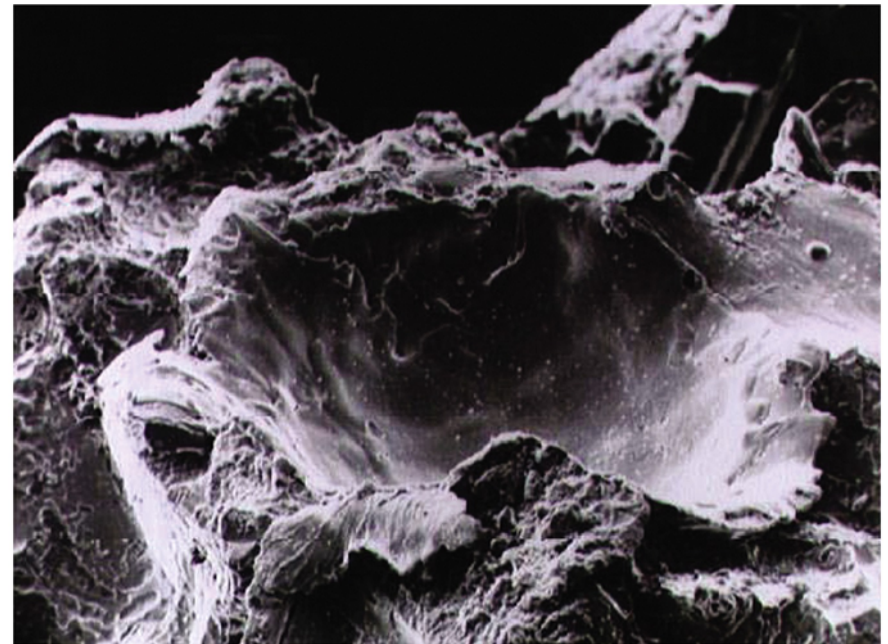
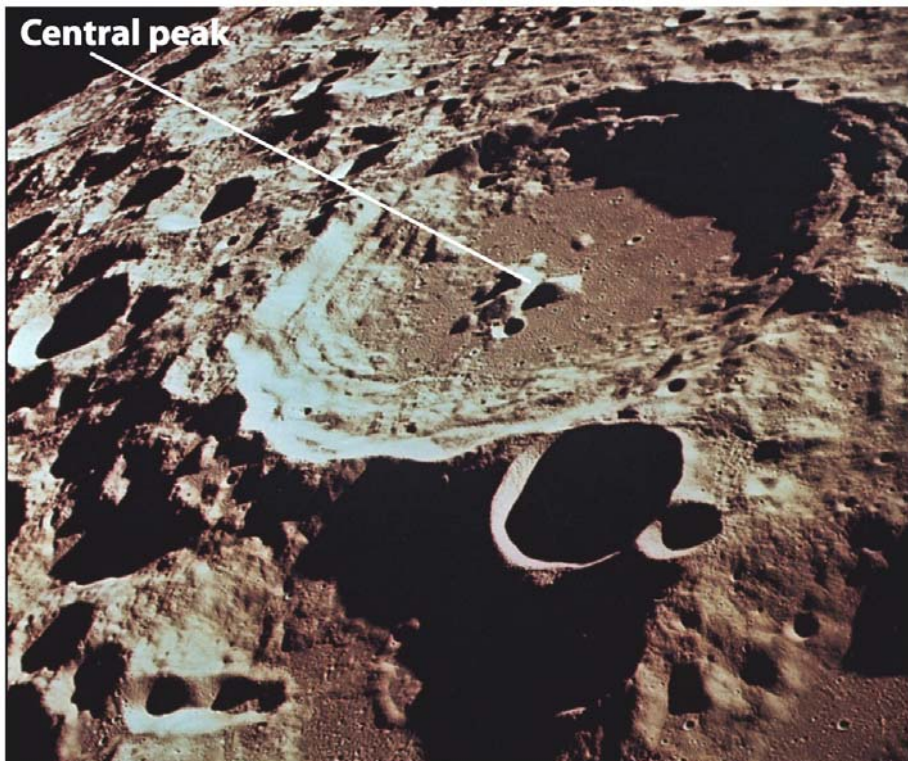


<http://www.christa.org/wilma.htm>

The Surface of the Moon



What is the most distinguishing feature of the Moon?



Crater Copernicus



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<http://antwrp.gsfc.nasa.gov/apod/ap980909.html>

Craters



- Largest are a few hundred km in size, smallest are microscopic
- Many, many more small craters than large craters.
- Craters are fairly circular, often have central peaks.
- Origin of craters:
Volcanic or **Impact**?



<http://images.jsc.nasa.gov/iams/images/pao/AS11/10075255.jpg>



How did the craters form?

Volcanic origin

- **Pros:** most craters on the Earth are volcanic. Why not on the Moon, too?
- **Cons:** no lava seen in lunar craters, lunar craters generally below ground, too many craters.

Impact origin

- **Pros:** appearance like craters on Earth. No weathering, so impact scars can survive.
- **Cons:** impact rate would have to be much higher than current rate. But that fits.

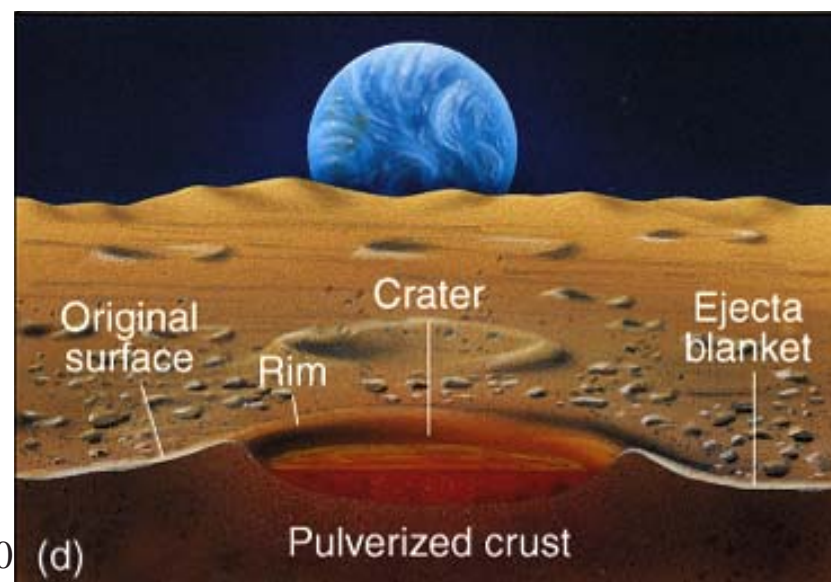
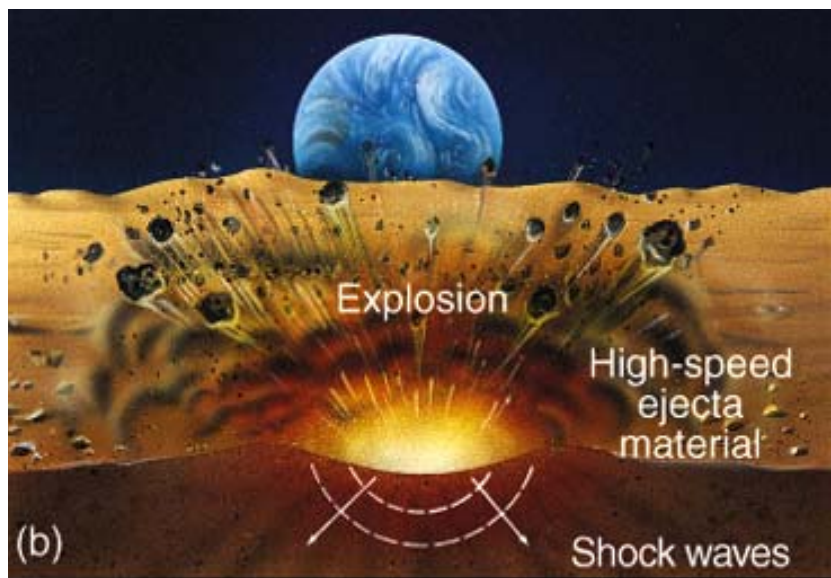
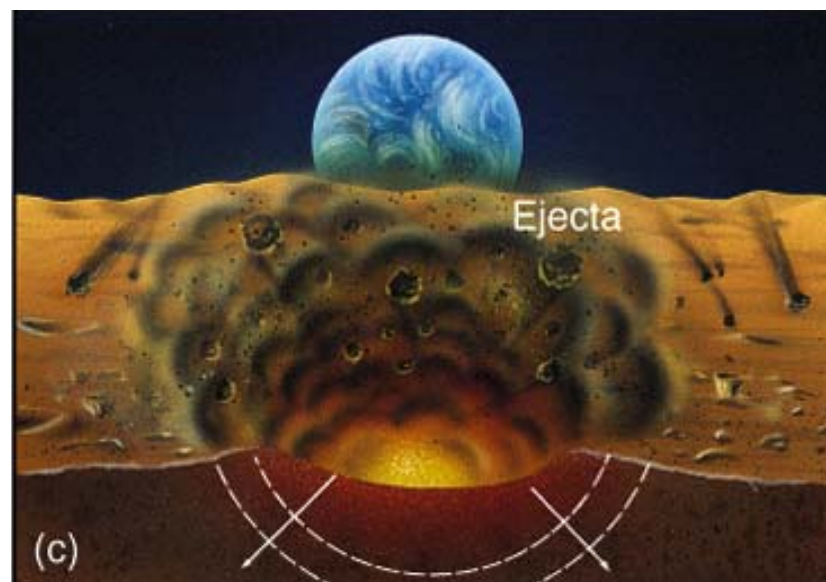
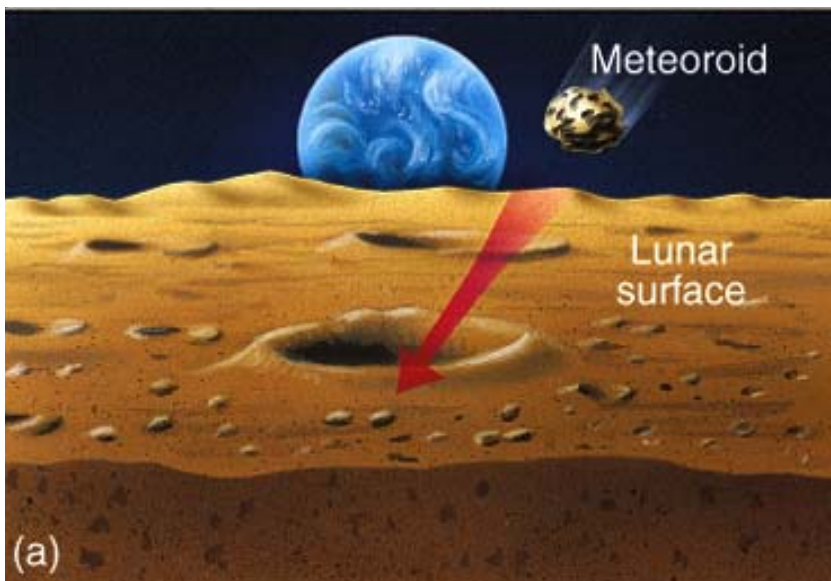
Lunar Craters



- Not Volcanic
- Made by impacts of meteorites
- Solar system debris moves fast
- A 10m meteor with mass of 10^7 kg moving at 10 m/s is energy equivalent to a small nuclear bomb



Impact Craters





Craters

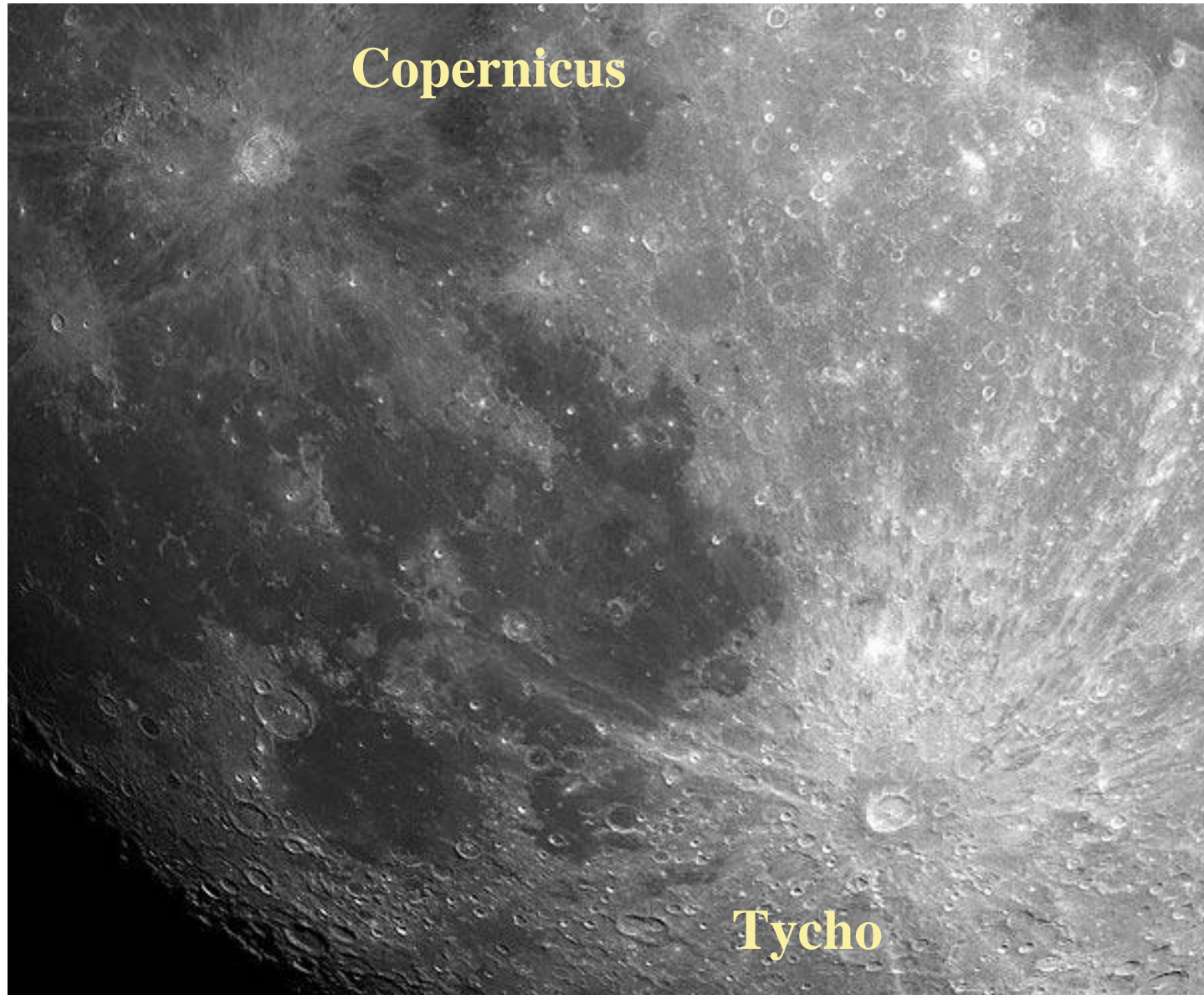
- Impact energy compresses the rock
- Afterwards, a decompression (or rebound) expels ejecta out– the hole is 10 times the width of impact body
- Some ejecta material piles up at edge to create circular crater wall and some surrounds crater in ejecta blanket
- Some ejecta falls back into the crater



Big Craters

- If the force of the impact is large enough, the floor rebounds to produce a central mountain peak
- Ejecta can be large pieces that make secondary craters
- Streamers of ejecta can create white rays (shows the surface under the ground up surface)

Tycho and Copernicus Craters



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Apollo 11 Orbital Images



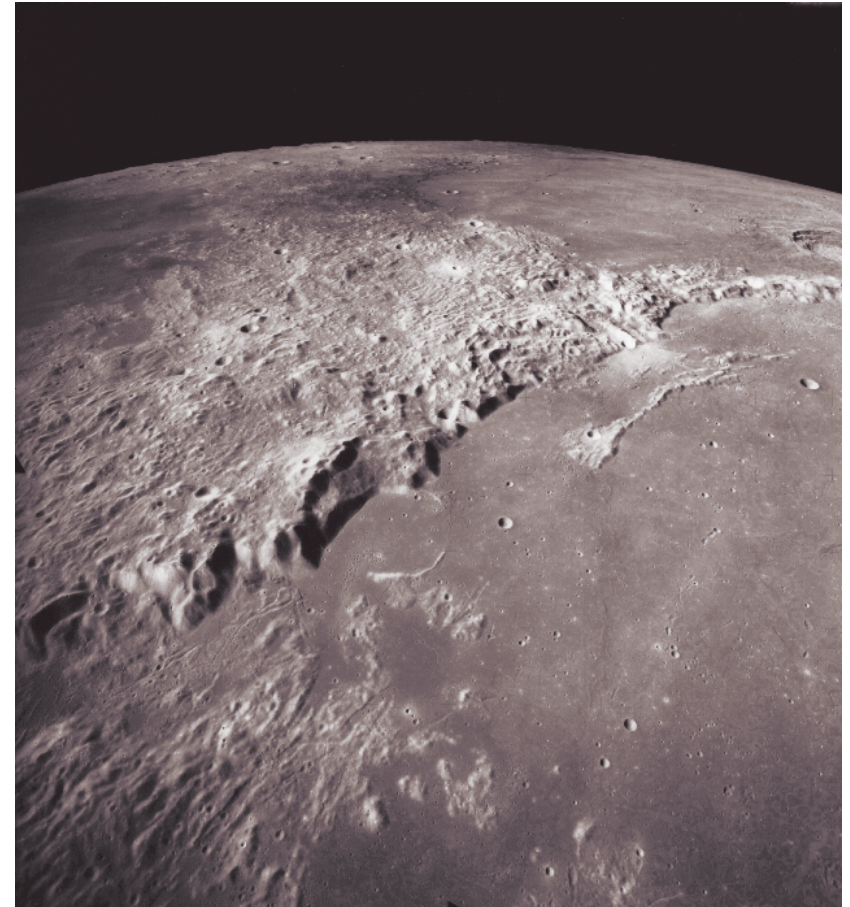
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Surface– Maria



- Perhaps next most obvious feature is the dark areas on the Moon.
- Covers about 17% of surface
- Singular is Mare (Sea in Latin)– originally thought to be bodies of water.
- Rocks are similar to those found in Hawaii– Basalts
- Relatively few craters.
- Circular outlines– contained by large impact basins



<http://www.lpi.usra.edu/expmoon/Apollo17/A17metric2432.gif>

Highlands



- Craters on top of craters
– must have taken a large amount of time
- Some are obviously younger than others
- Covers about 83% of surface
- Lighter colored
- Mountainous region
- Rocks are Anorthosite, a kind of igneous rock that forms when lava cools slowly



Age?

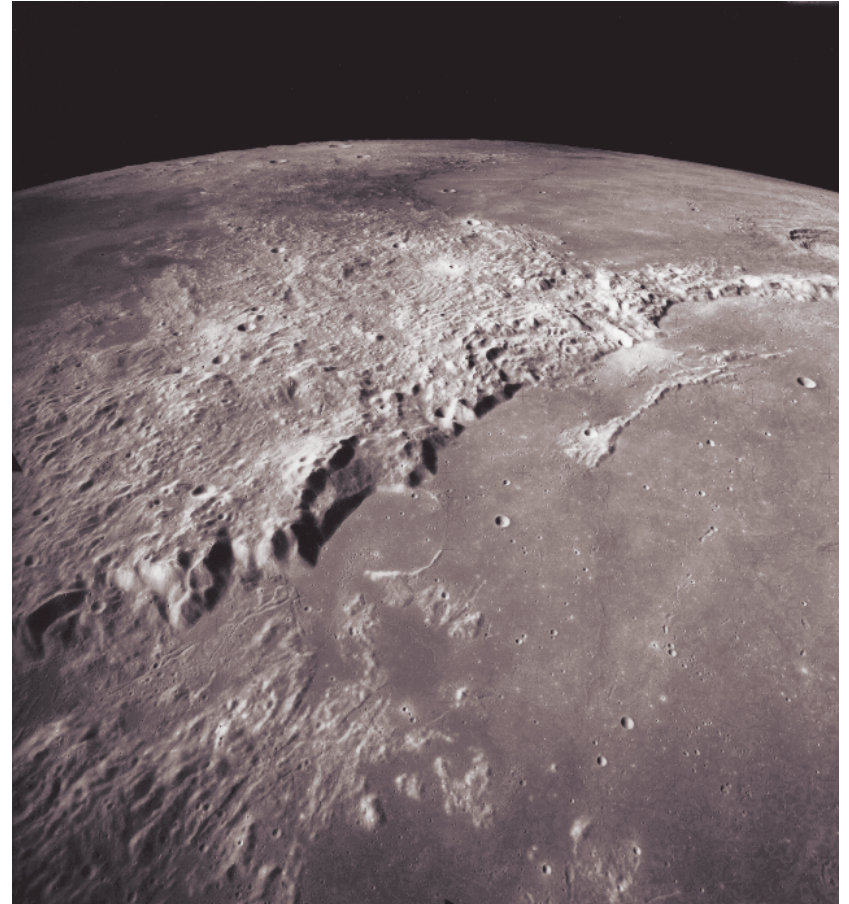


- How do the ages of the Maria and Highlands compare?
 1. The Maria are darker, so older.
 2. The Maria are younger.
 3. The Highlands and Maria are roughly the same age.

Cratering



Which surface has more craters? The lower number of craters indicates a younger age for the Maria.

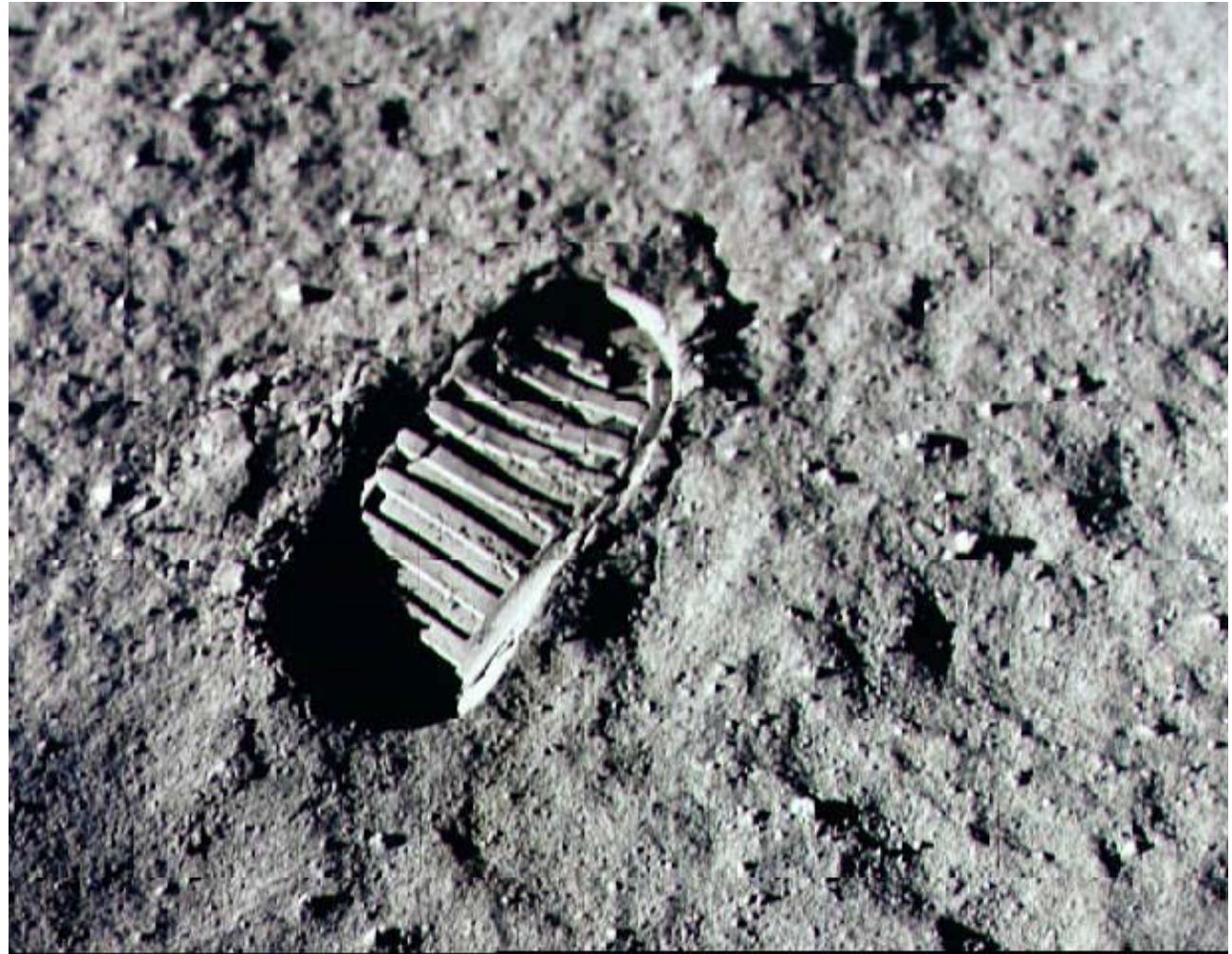


<http://www.lpi.usra.edu/expmoon/Apollo17/A17metric2432.gif>

Regolith



http://www.hq.nasa.gov/office/pao/History/alsj/a11/a11v_1092338.mpg





Regolith

109:25:08 Armstrong: “Yes, the surface is fine and powdery. I can kick it up loosely with my toe. It does adhere in fine layers, like powdered charcoal, to the sole and sides of my boots. I only go in a small fraction of an inch, maybe an eighth of an inch, but I can see the footprints of my boots and the treads in the fine, sandy particles.”



<http://www.hq.nasa.gov/office/pao/History/alsj/a11/a11.step.html>



Maria

- Color and reflectivity indicate that it is solidified lava that somewhat filled in the basins
- Not from volcanoes
- Huge impacts (the lunar mountain ranges are the basin walls)
- Age of 3.1 to 3.8 billion years
- Re-enforces the age of the heavy bombardment
- After the maria were formed, bombardment reduced

Highlands



- Most of rocks fused from smaller smashed particles
- Rocks are all old – 3.8 and 4.0 billion years
- Age estimate from radioactive dating
- This implies that the heavy bombardment of the moon occurred from the solar system formation (around 4.6 billion yrs ago) to the age of the rocks (roughly 3.8 billion yrs ago)!



Timescales

- Moon formed – 4.6 billion years ago
- Soft surface – molten surface
- Crust is formed (Highlands) – 4.2 billion years ago
- Heavy bombardment – 4.0 billion years ago
- Basins fill with lava flows (Maria) – 3.8 billion years ago
- Heavy bombardment ceases and a slow steady bombardment continues until now

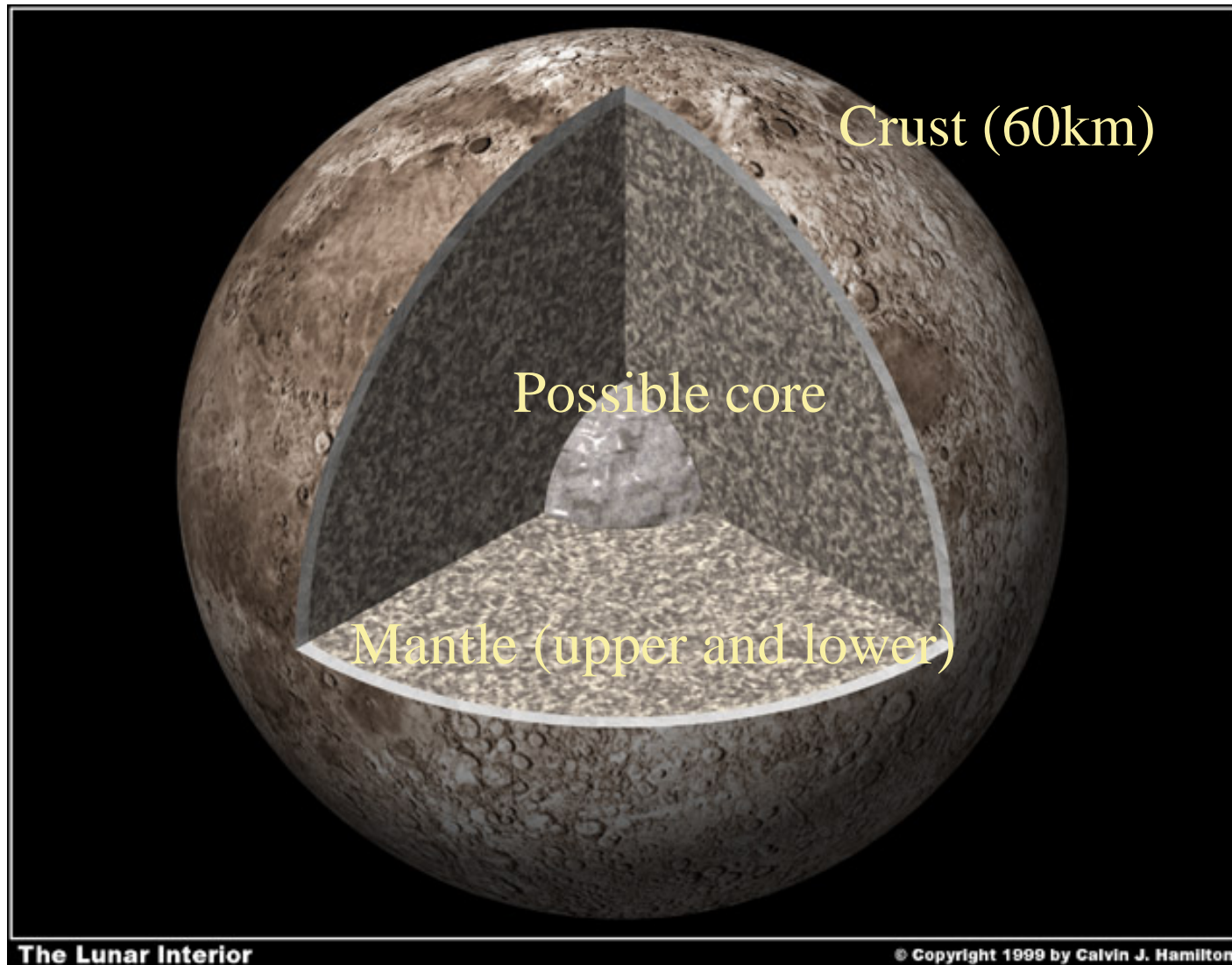


Moon Interior

Before Apollo we knew very little, but they left seismometers on the lunar surface that have allowed us to deduce the interior by studying the seismic waves generated by "moonquakes" (caused by tidal forces) and occasional meteor impacts



Moon Interior



Moon Formation– Collision



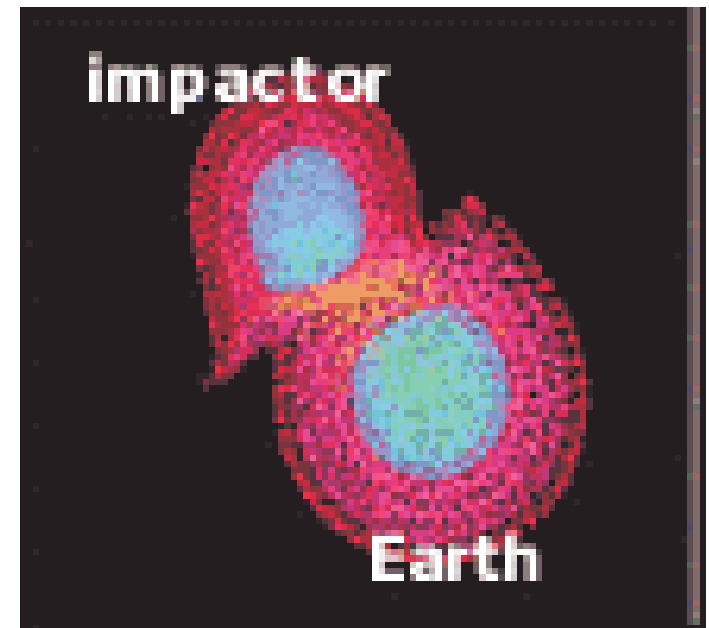
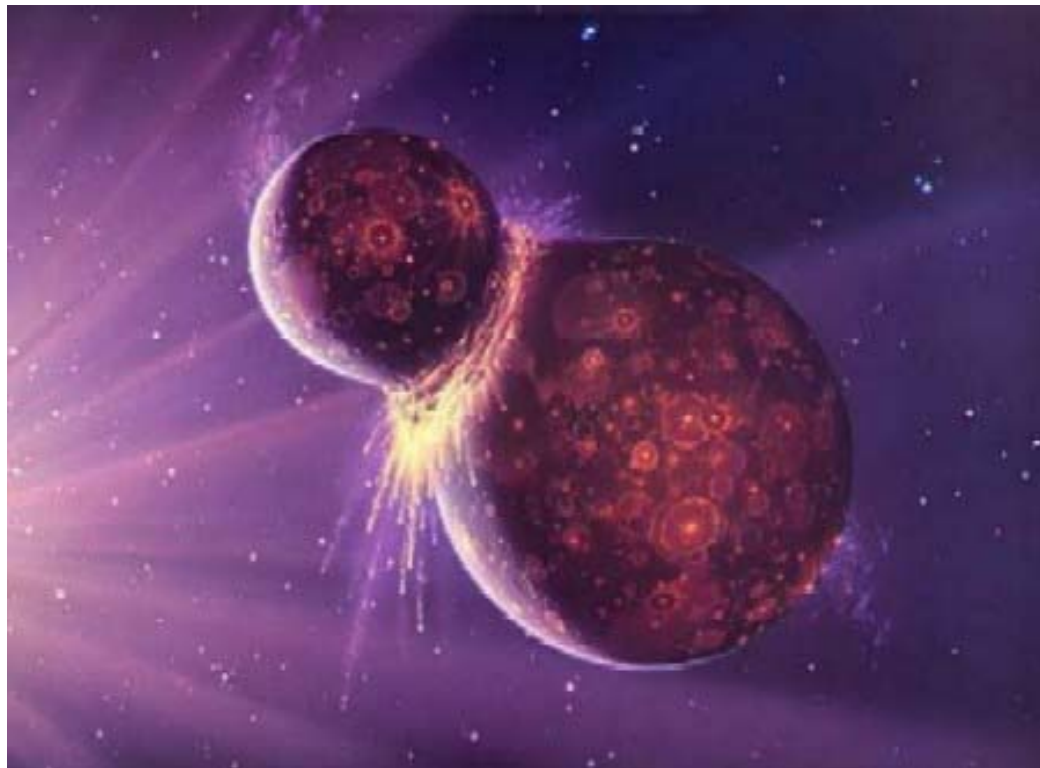
The idea in a nutshell:

At the time Earth formed (4.5 billion years ago) another forming body the size of Mars slammed into the proto-earth, blowing out rocky debris. A fraction of that debris went into orbit around the Earth and aggregated into the moon.

Smack!



- ▶ Collision of Earth with Mars-size planetesimal early in history
- ▶ Core of planetesimal sank within Earth
- ▶ Earth rotation sped up
- ▶ Remaining ejecta thrown into orbit sufficient to coalesce into Moon



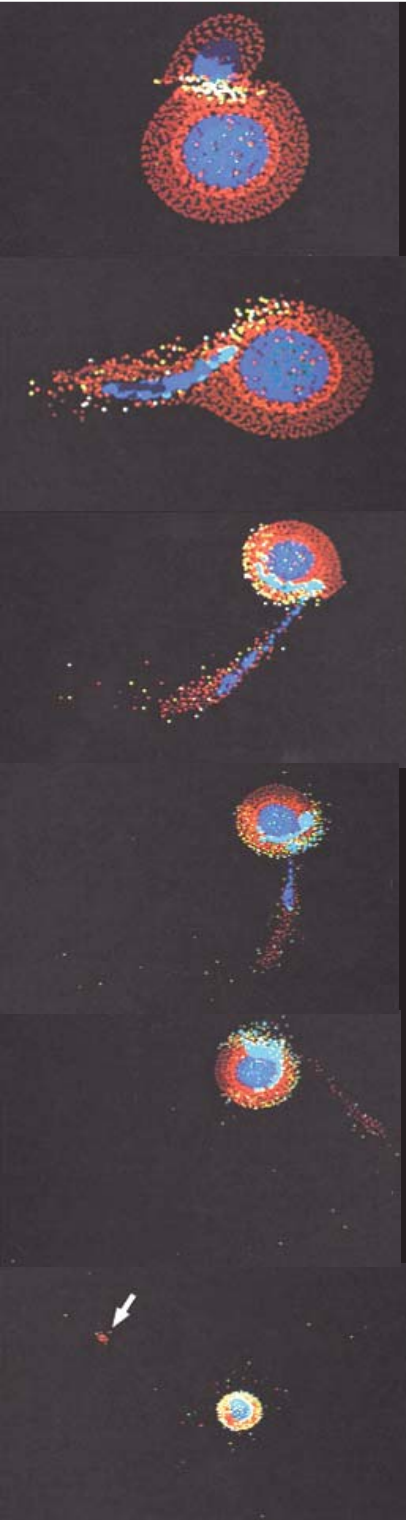
A.G.W. Cameron
Computer simulation

J. Tucciarone

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Large-Impact Hypothesis



Why is this a good hypothesis?

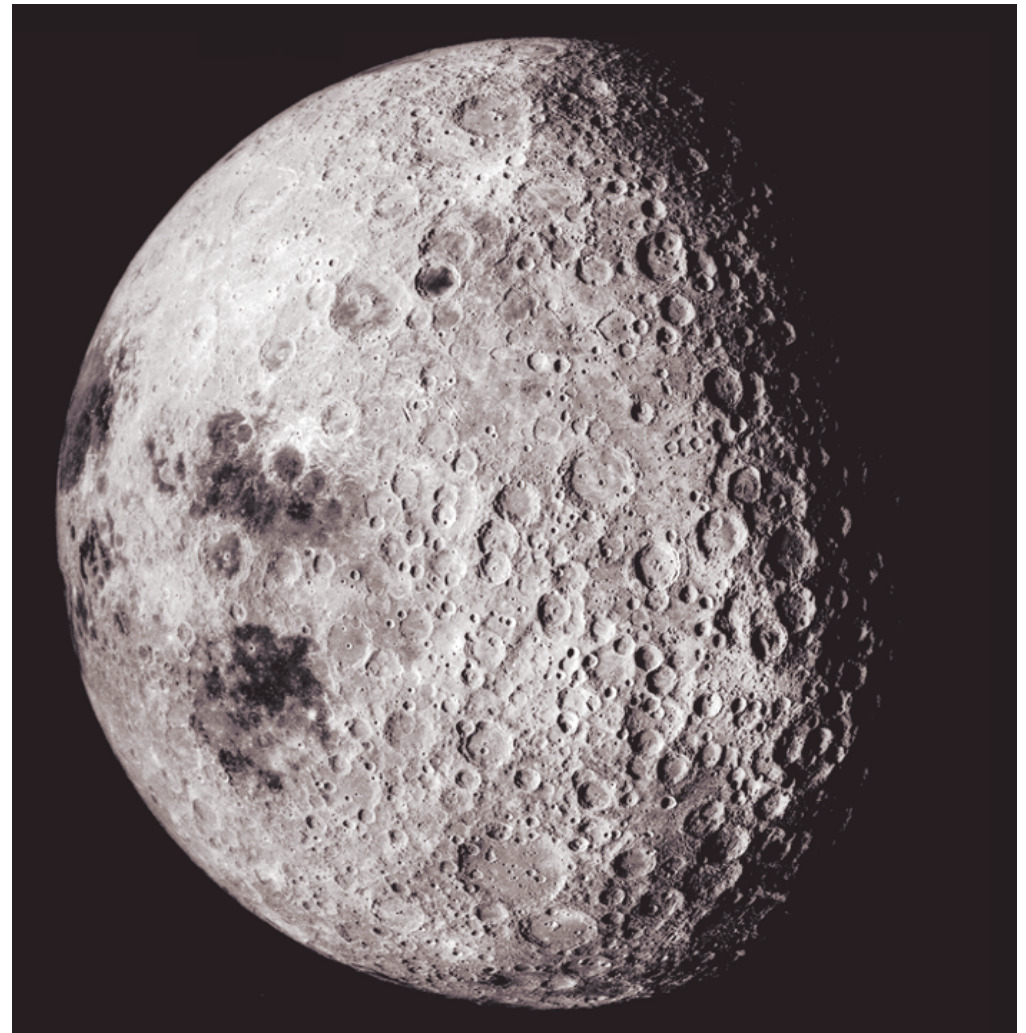


- The Earth has a large iron core (differentiation), but the moon does not.
 - the debris blown out of collision came from the iron-depleted, rocky mantles. The iron core of the impactor melted on impact and merged with the iron core of Earth, according to computer models.
- Compare density of 5.5 g/cm^3 to 3.3 g/cm^3 -- the moon lacks iron.



Far Side of the Moon

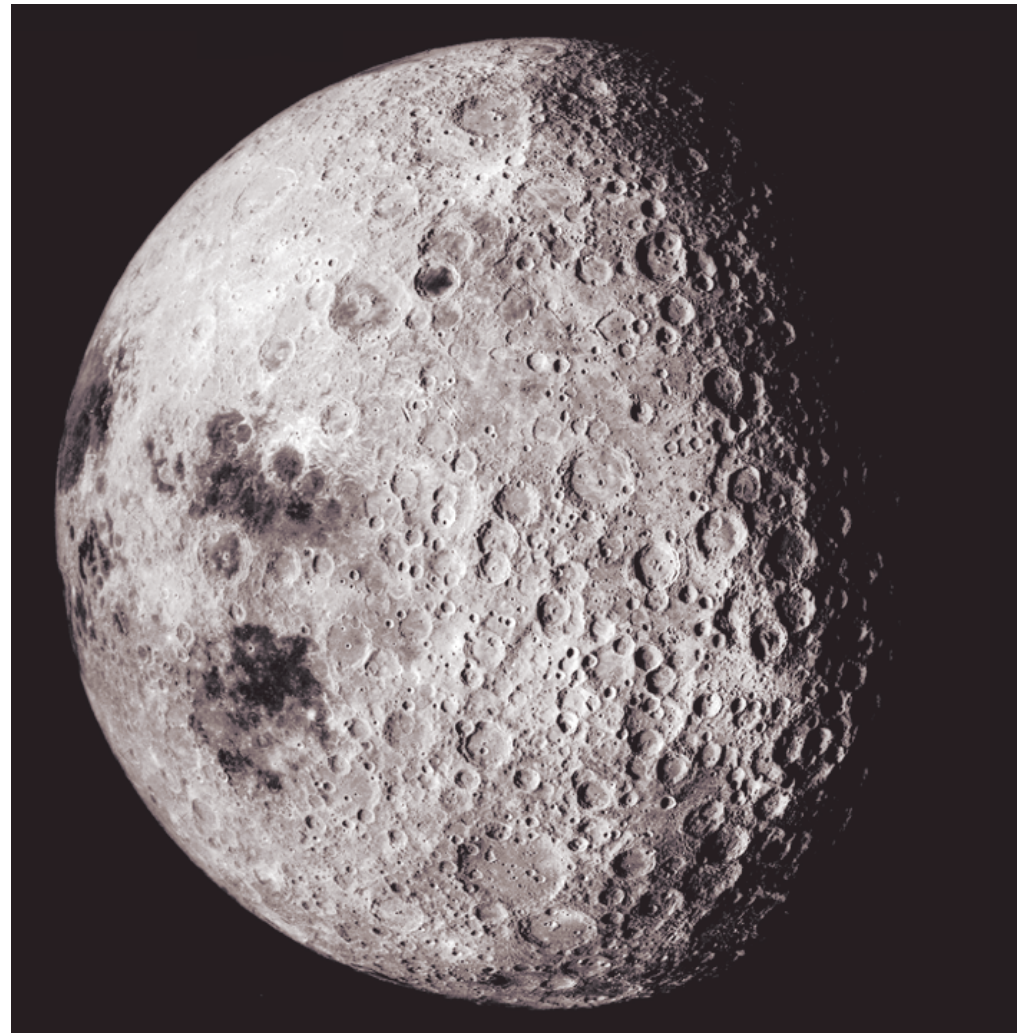
It may seem quite a coincidence that the Moon's rotation and revolution have the same period, so that the same side of the Moon is always facing us. But in fact most moons in the solar system have a similar *synchronous* orbit, caused by the tidal forces exerted on the moon by the planet.



Far Side of the Moon



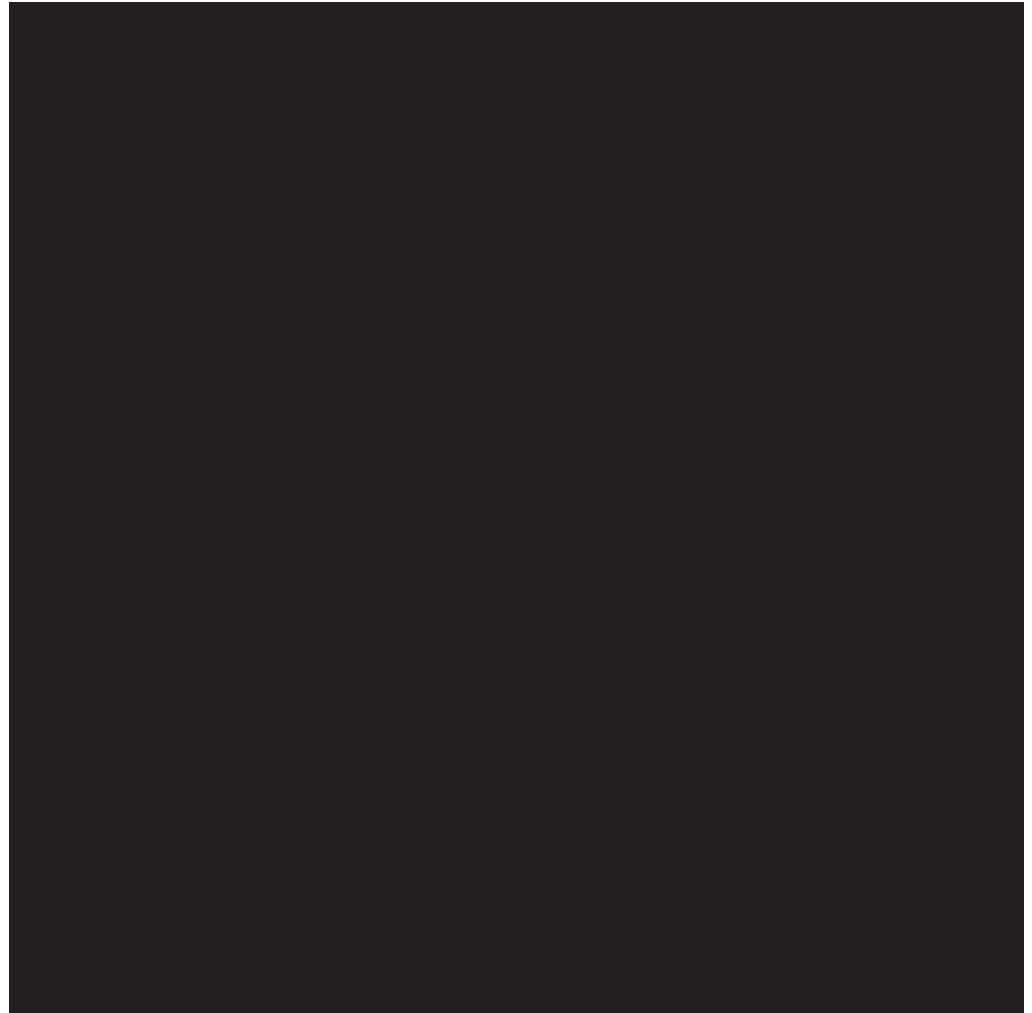
Note that the Far Side looks very different. Less Maria. And the Maria that are there are at a higher altitude. Still not sure why.



Lunation



A small libration occurs over one lunar cycle. This is from the fact that the moon is on an elliptical orbit, so in very aspects of the orbit different features are seen and a slight wobble is evident.

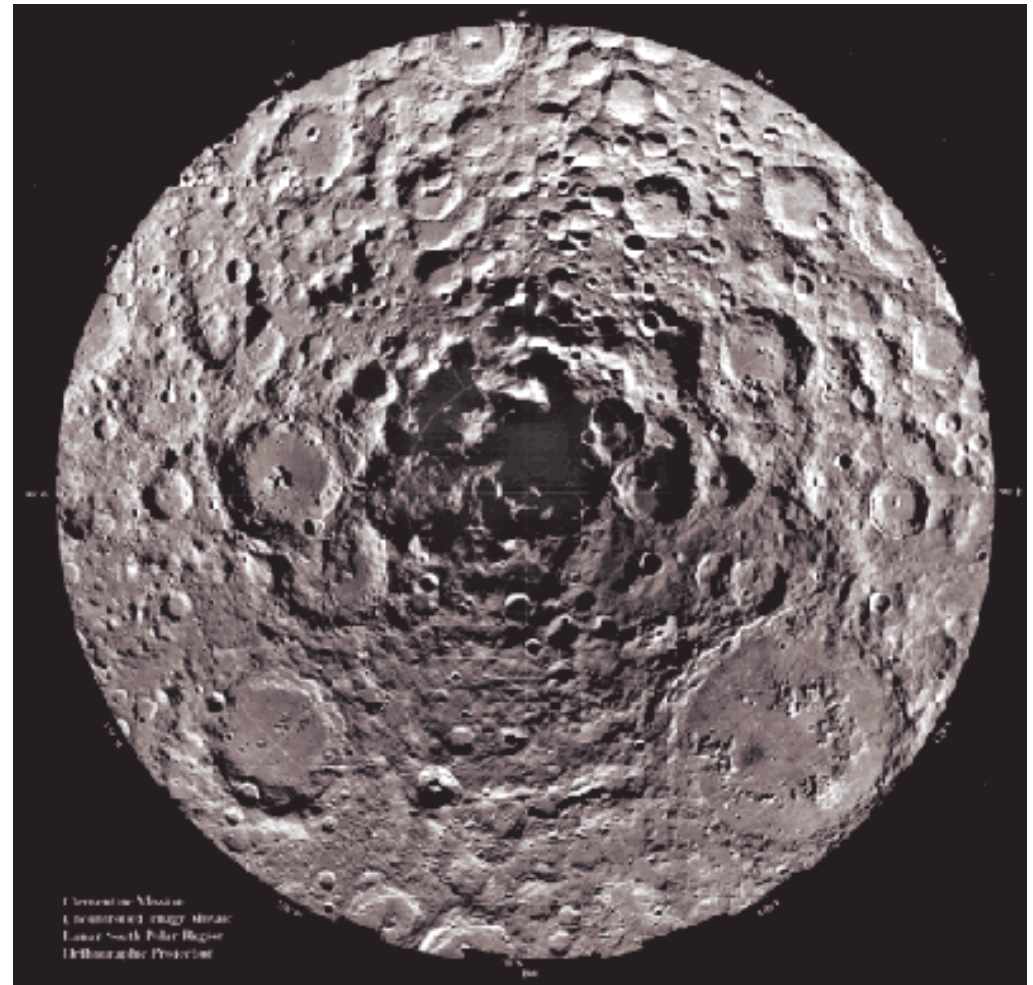


<http://antwrp.gsfc.nasa.gov/apod/ap991108.html>



Ice on the Moon?

- **Clementine** Spacecraft found the suggestion of Ice at the Moon's South Pole in craters.
- NASA crashed the explorer **Lunar Prospector** into the craters (1999), but no water was detected.
- Still a question.



<http://antwrp.gsfc.nasa.gov/apod/ap961204.html>

How does the Moon Effect the Earth



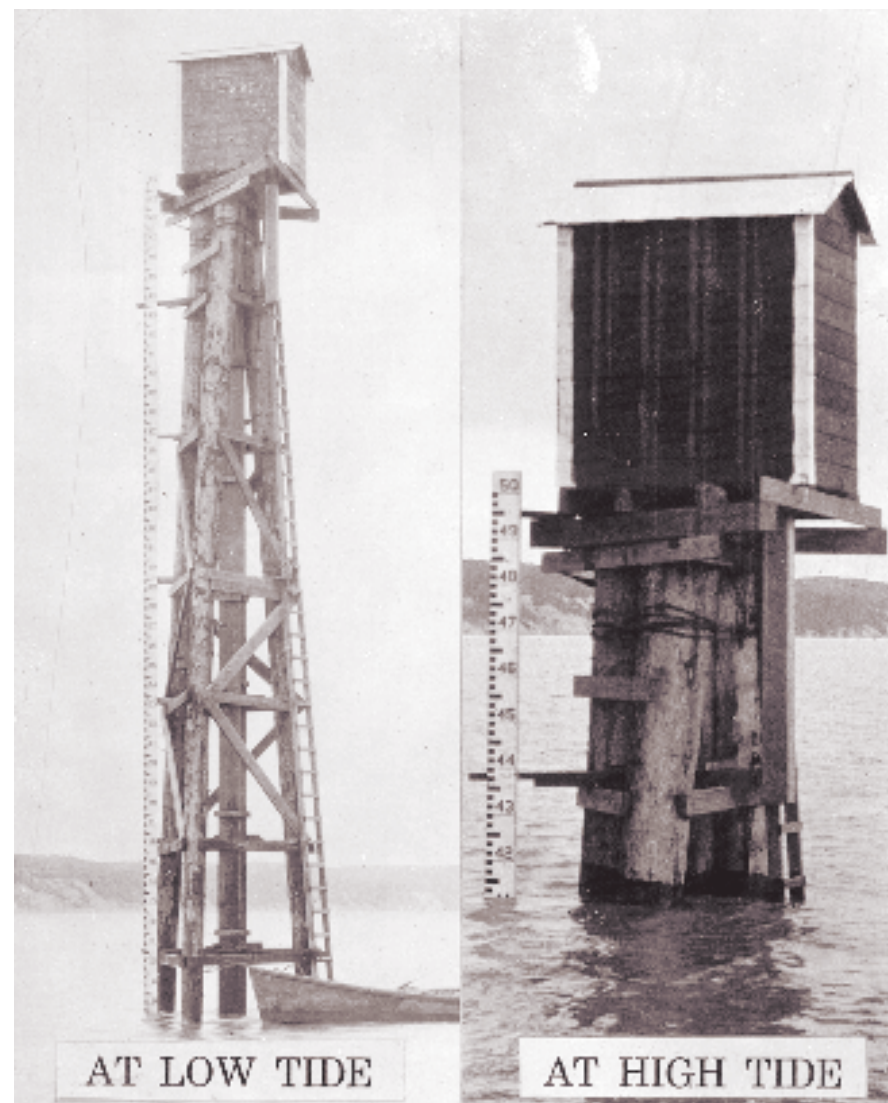
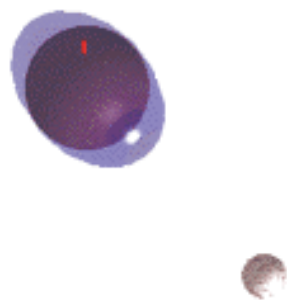
By Newton's 3rd law, we know that the Moon is exerting a force on the Earth that is equal to the force that the Earth exerts on the Moon.

The Tides are probably the biggest influence.

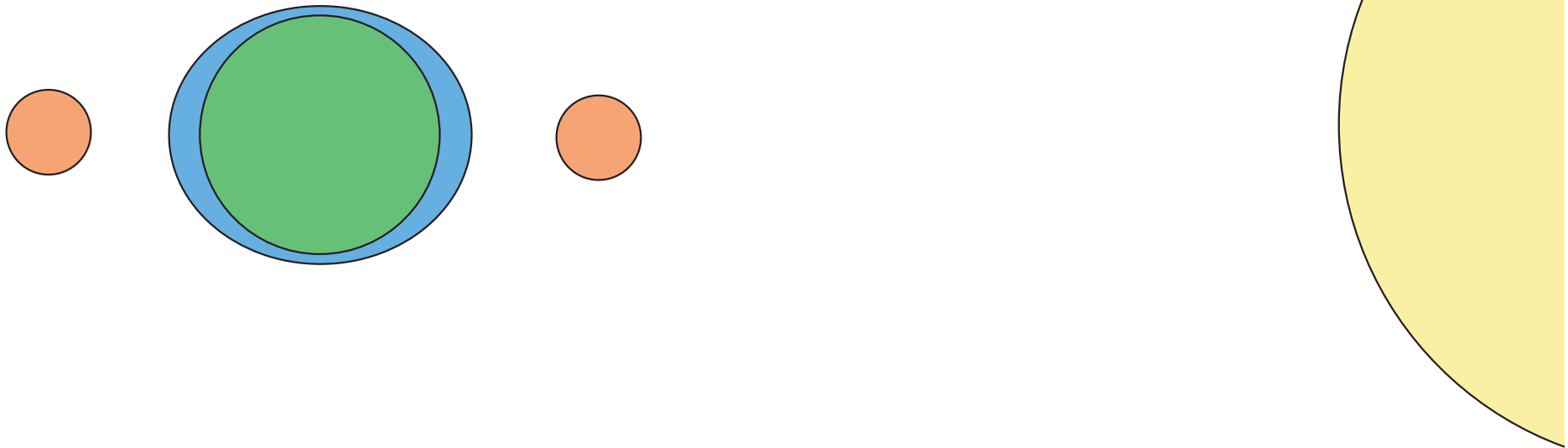


The Tides

<http://tidesonline.nos.noaa.gov/geographic.html>



Spring Tides



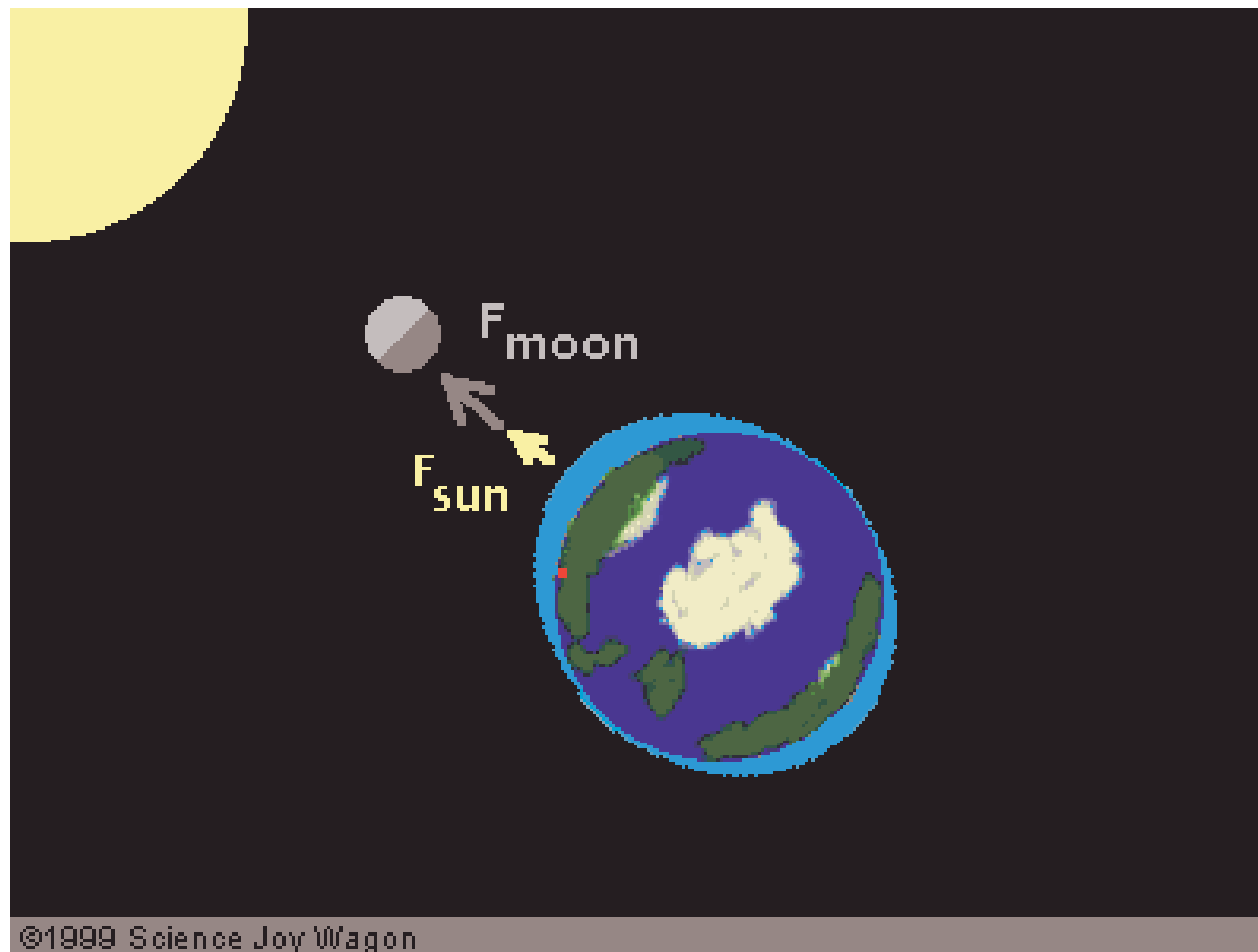
Not for the Season Spring, but the German word Springen— to spring up.

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Spring Tides

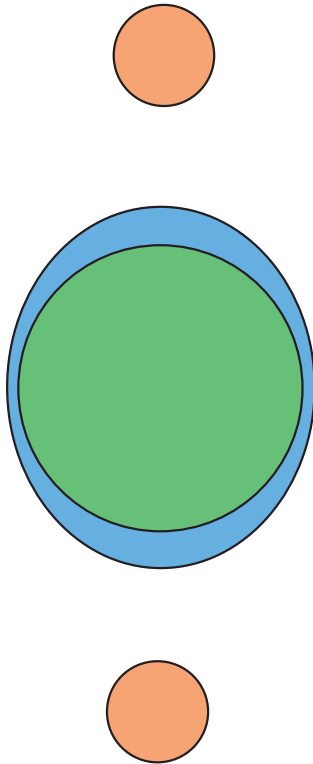


<http://207.10.97.102/earthzone/lessons/09space/tide/tide.htm>

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Neap Tides

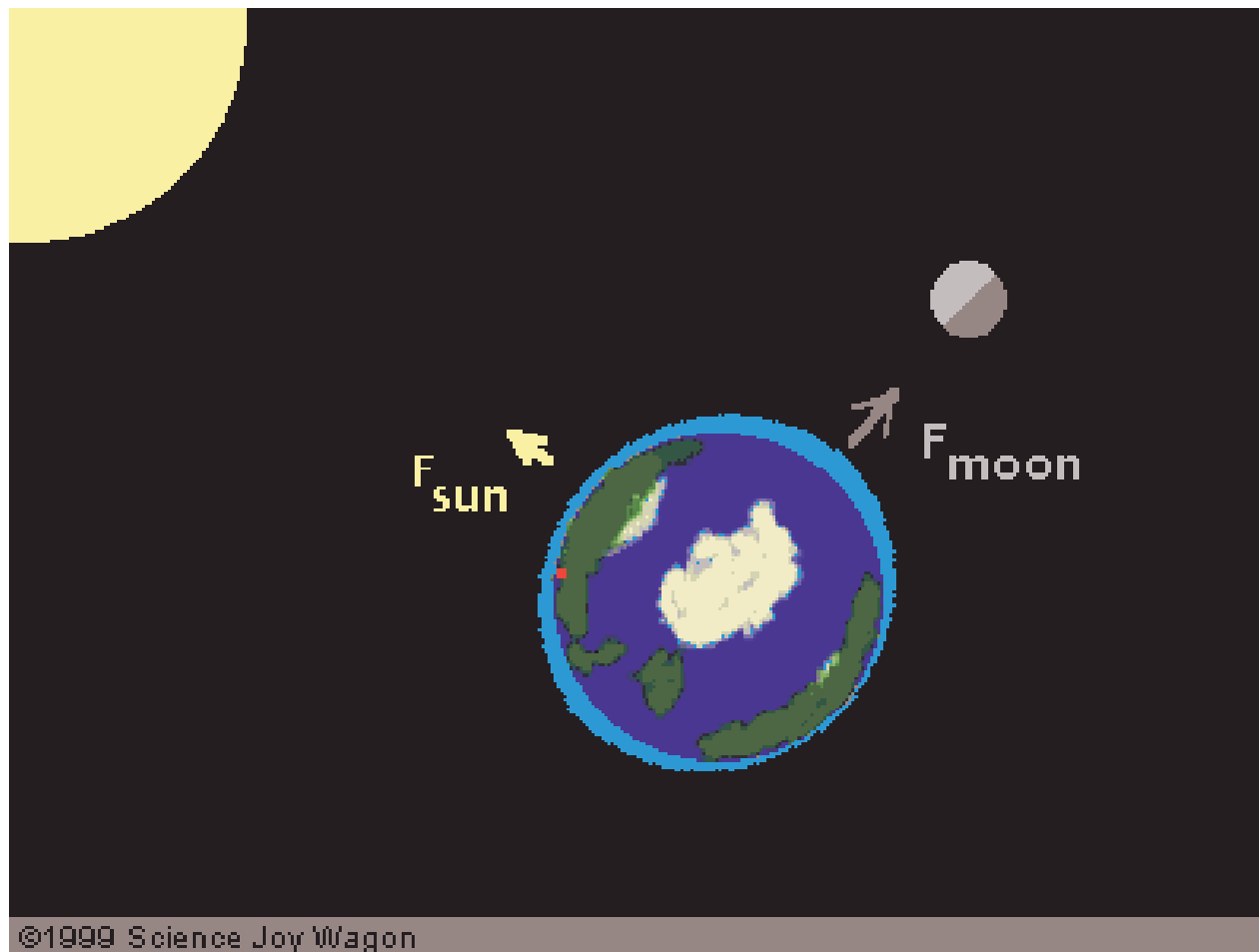


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Neap Tides



<http://207.10.97.102/earthzone/lessons/09space/tide/tide.htm>

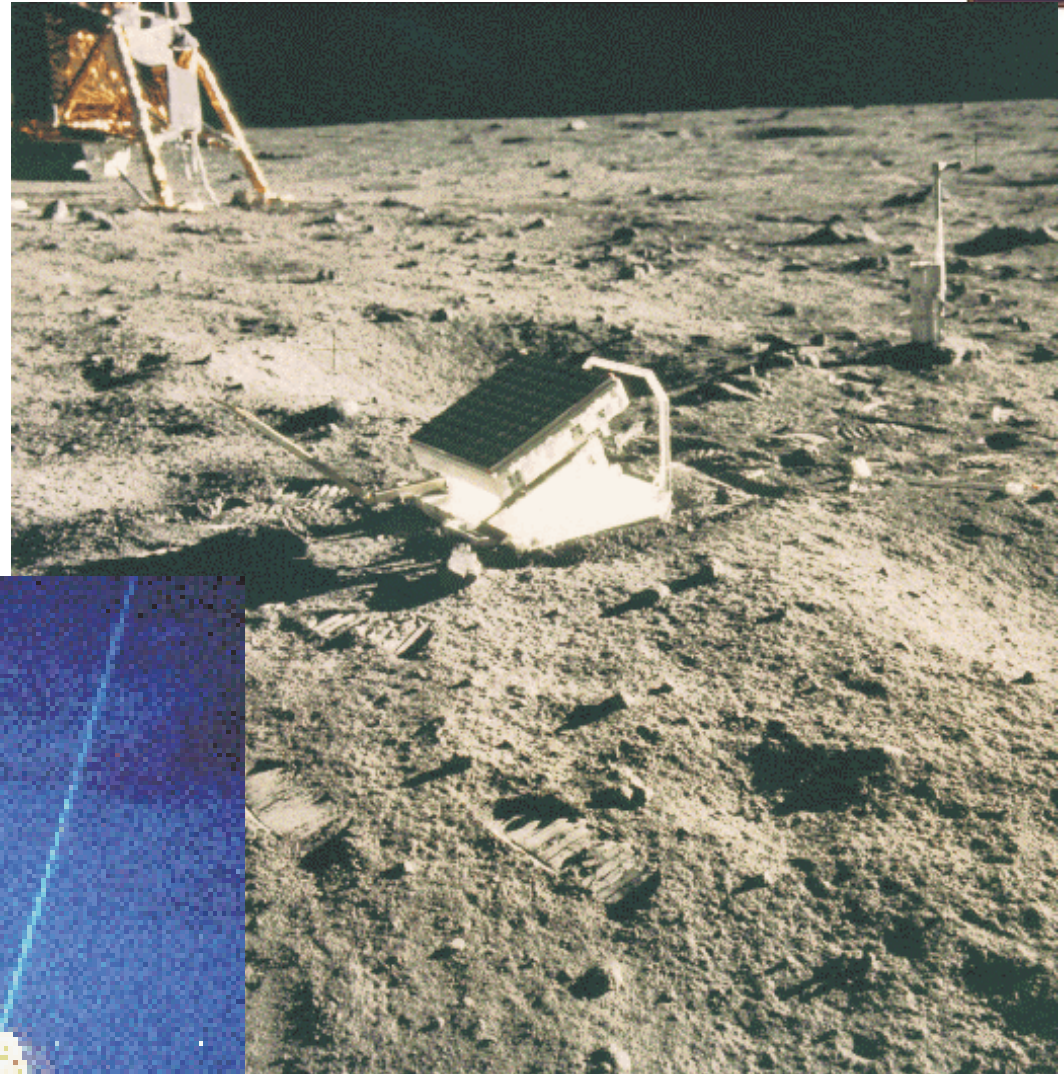
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Moon is Moving Away



- Apollo mission left mirrors on surface, so can reflect light back to Earth and measure the distance.
- About 3.8 cm/year



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http://www.lpi.usra.edu/expmoon/Apollo11/A11_Experiments_LRRR.html