ASTR 220
February 24, 2005
Lecture 9

- Homework 3 due Tuesday, March 1, 2005.
- Next Thursday, March 3, 2005: movie day. Don't miss it!

Schedule for Today

- Large Impacts in Solar System
  - Formation of Moon
  - Mercury
  - Venus
  - Mars
  - Uranus
  - Miranda
  - Pluto
- Deep Impact

Last class: impact of Comet Shoemaker-Levy 9 with Jupiter.

Have any other large impacts happened in solar system in past?

Formation of the Moon

Formation of Moon was unsolved mystery for years.

Facts about Moon to be explained:

• Moon has similar, but not identical, composition as rocks in Earth's crust.

• Moon has few **volatiles**.

• Moon has very small core.

• Moon's orbit is tilted 5° from Earth's equator.

Four possible theories for formation of Moon:

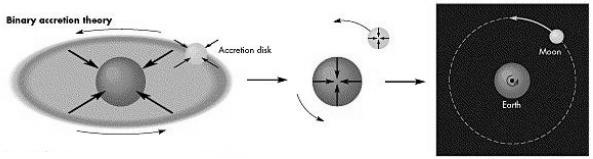
1. Co-accretion Theory
2. Fission Theory
3. Capture Theory
4. Giant Impact Theory

Binary Accretion Theory: Moon formed in orbit around Earth during formation of solar system.

Explains why Moon's composition is similar to Earth's.

Cannot explain: Moon's orbital tilt, lack of volatiles, small core.

Theory fails.

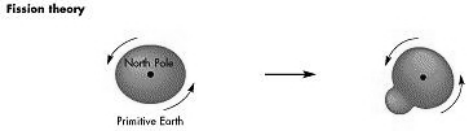


Fission Theory: as Earth was forming, spun so quickly that part of crust was flung off and formed Moon.

Explains: Moon's rocks are similar to Earth's crust and Moon's small core.

Cannot explain: Moon's orbital tilt, lack of volatiles.

Speed of Earth's rotation impossible.



Theory fails.

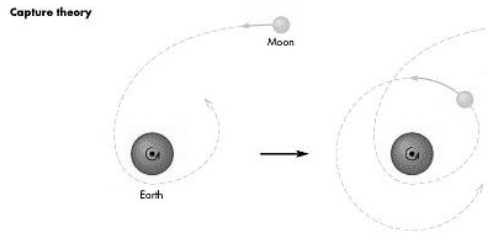
Capture Theory: large planetesimal was captured by Earth's gravity and became Moon.

Explains: Moon's orbital tilt, differences in composition.

If true, likely was asteroid, but Moon's composition not like asteroids.

Extremely unlikely – more likely to collide.

Theory fails.

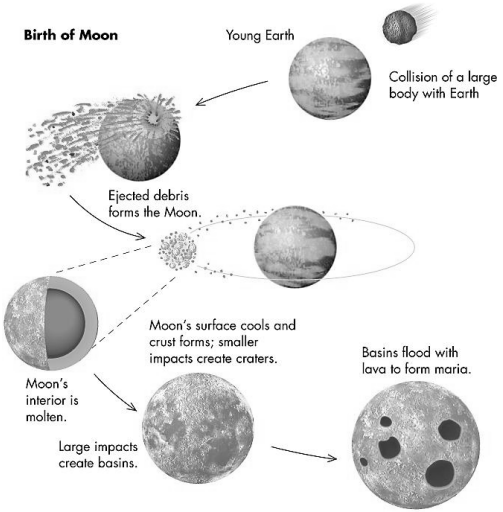


Giant Impact Theory: Mars-sized object collided with Earth, and resulting debris from Earth's crust and object formed Moon.

Impact left Earth's upper layers hot and molten.

Heavy material in impactor's core sank into Earth's core.

Debris from Earth's crust + mantle and impactor's crust + mantle formed Moon.



Explains:
- tilt of Moon's orbit.
- similarities in composition with Earth's crust, but also small differences.
- lack of volatiles.
- small core.

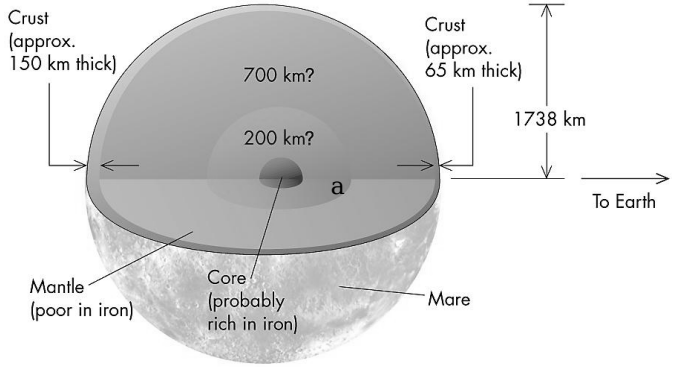
Best theory so far.

Difficult to test theory. Impact melted Earth's crust, erasing any signs.

Impact happened during heavy bombardment, so more impacts happened afterward, hiding evidence further.

Moon was bombarded even more after formation.

Core is off-center and crust is thinner on Earth side.



Mercury

Mercury's core very large for size of planet.

Mercury's rotation very slow: once every 59 d.

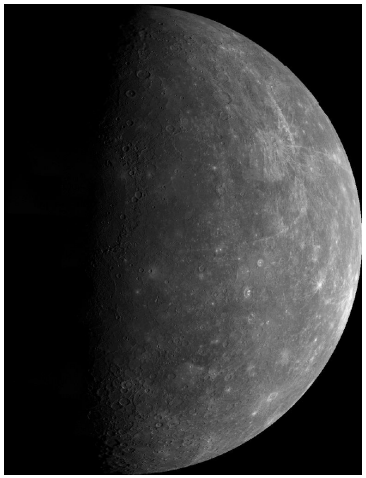
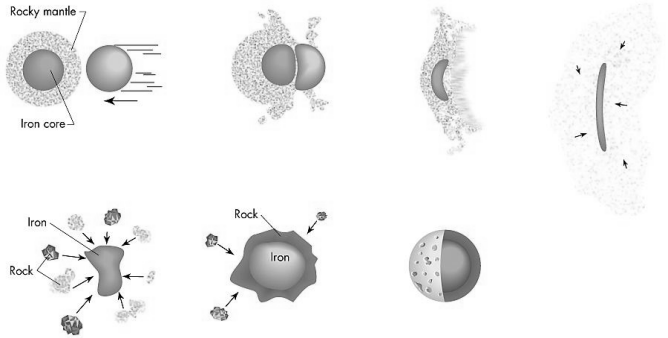


Image from Mariner 10, Northwestern University

Large object may have hit nearly head-on. Crust ejected into space, leaving only heavier core material.

Impact also may have slowed Mercury's spin.



Venus

Venus rotates backwards very slowly: once every 243 days.

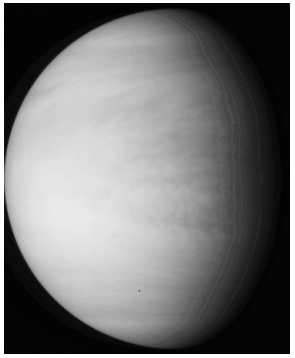
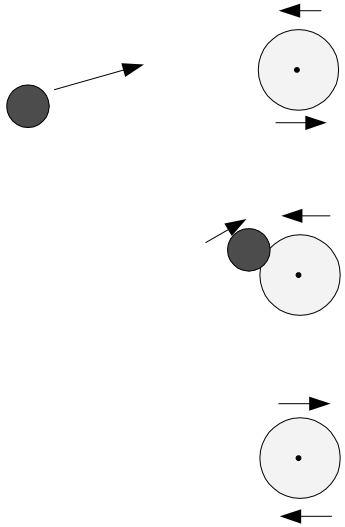


Image by Galileo, JPL, NASA, copyright Calvin J. Hamilton



During formation, large object may have hit at just the right angle.

Impact stopped normal rotation and made Venus rotate backwards very slowly.

Again, no proof!

Mars

Mars has most extreme geological features in solar system.

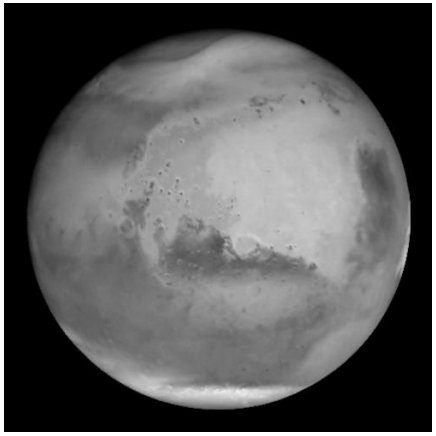


Image by HST, STScI

Mars has extremely tall volcanoes and very low basins.

Fly-over animation of Mars.

Animation from Pearson/ Addison Wesley.

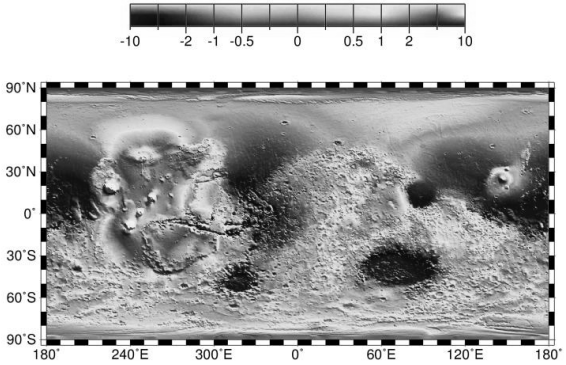


Image from Goddard Space Flight Center.

Volcanoes are located on Tharsis Bulge, which sticks out several km.

Tharsis Bulge almost exactly opposite Hellas Basin, lowest point on Mars.

Large impact may have created Hellas Basin and caused crust on other side to bulge outward.

Stress may have caused Valles Marineris.

Animation of Mars impact.
Animation from Joe Kolecki and NASA Digital Learning Network - Cleveland

Uranus

We didn't know much about Uranus until Voyager 2 visited in 1986.

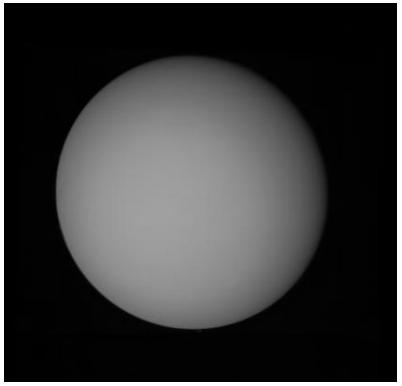
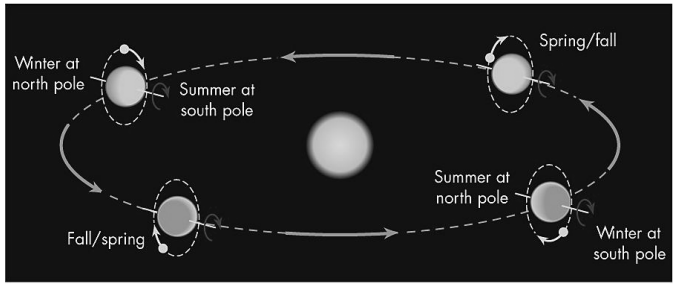


Image by Voyager 2, JPL

Uranus's rotation axis is tipped over 98°.

Seasons are extreme and long.

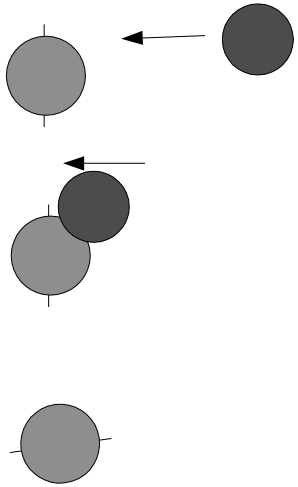
Uranus takes 84 yrs to orbit Sun.



Uranus should not be so tilted.

Possibly knocked over by large impact.

Energy needed to tip over Uranus means that object must have been about as massive as Uranus.



Impact at just the right angle.

Moons orbit Uranus's equator, so happened before moon formation, or moons are debris.

Miranda

Moon of Uranus.

Radius 236 km.

Very unusual features.

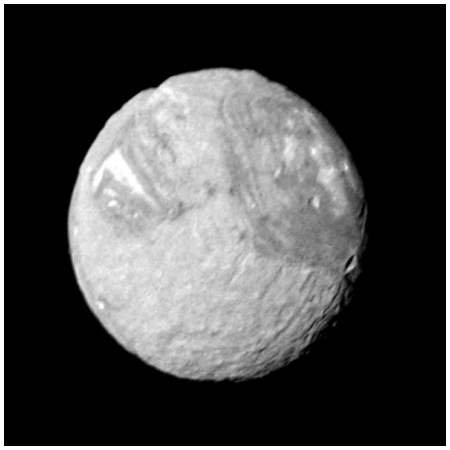
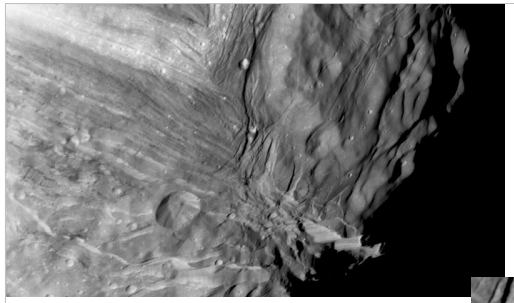
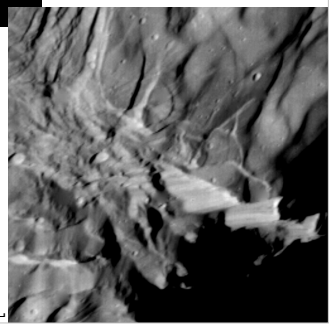


Image by NASA/JPL



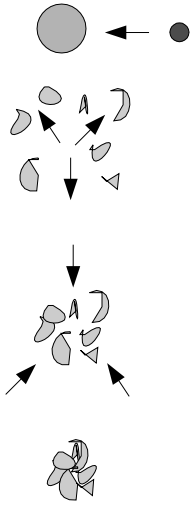
Huge grooves on surface.



Huge faults and cracks.

This one 5 km tall!

Images by NASA/JPL



Miranda may have been shattered by large impact.

Pieces re-assembled because of gravity.

Resulting moon has very chaotic features.

May have been shattered as many as 5 times!

Pluto

Discovery of Pluto's moon Charon let us learn about Pluto's tilt.

Image by R. Albrecht, ESA/ESO Space Telescope European Coordinating Facility, NASA

Assuming Charon orbits Pluto's equator, Pluto is tilted 113°.

Tilt doesn't affect seasons as much as eccentricity.

Possibly knocked over and Charon formed by large impact.

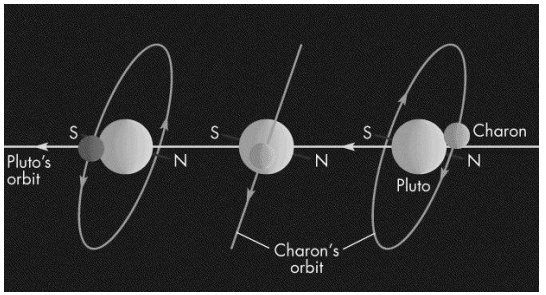


Image copyright The McGraw-Hill Companies, Inc.

Animation of Pluto collision.

Animation copyright Southwest Research Institute

Large Impacts

Large impacts were common in young solar system and possibly occurred on several planets.

Giant Impact Theory for formation of Moon is accepted.

Other large impacts are hard to prove.

How could we confirm large impacts to Mercury, Venus, Mars, Uranus, Miranda, Pluto?

Deep Impact

Spacecraft by UM which will shoot impactor at Comet Tempel 1.

Goals:
- Watch crater form
- Measure depth and diameter
- Measure composition
- See if gasses subliming from comet change after impact

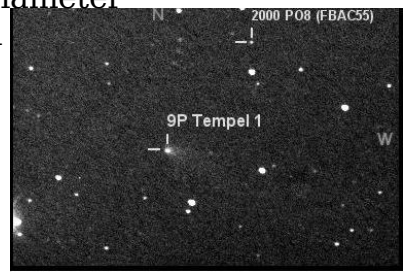
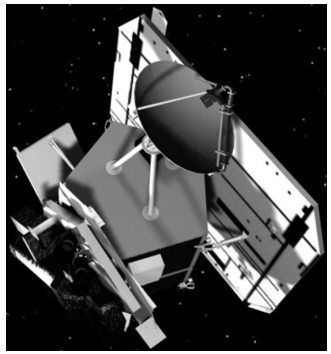


Image by B. Dillon, C. Gustava, K. Rivich, George Observatory

Image by Kennedy Space Center

Deep Impact launched Jan. 12, 2005.

Impact will happen on July 4, 2005.



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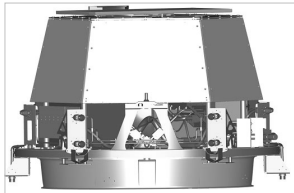

Image copyright Deep Impact

Impactor: 370 kg, 1 m across.

Hit at 10 km/s (23,000 mph).

Crater size: between house and football field.

Depth: 2 – 7 stories.

Animation of impact.

Animation by Deep Impact.

Drawing by Pat Rawlings