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## Lecture #14:

- Origin of the Moon
  - Observations
  - Classical models for the formation of the Moon
  - A relatively new idea: the Giant Impact theory
- Reading:
  - Chapters 8.4, 9.3



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## Moon Hoax?

- Apollo conspiracy theories retain a limited following
- “Conspiracy Theory: Did We Land on the Moon?” (Fox TV, 2001) – NASA faked Moon landings in Nevada desert (Area 51)
  - ➔ Thoroughly discredited at: <http://www.badastronomy.com/bad/tv/foxapollo.html>
- Do *you* think 400,000 people could keep a secret this long?

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## The Main Point

There are four main hypotheses for the origin of the Moon. The most widely accepted among astronomers today is the *giant impact hypothesis*.

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## Observations

- Any successful theory for the origin of the Moon must account for everything we know about the Moon now.
- Facts:
  - The Moon’s mantle composition is in some ways similar to Earth’s (oxygen isotopes), and in other ways different (volatile abundances)
  - The Moon is much less dense than Earth (no large iron core)
  - The Moon orbits in the same direction as the Earth rotates
  - The Moon is slowly drifting away from the Earth
    - The Moon was once much closer to the Earth

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## Some Hypotheses

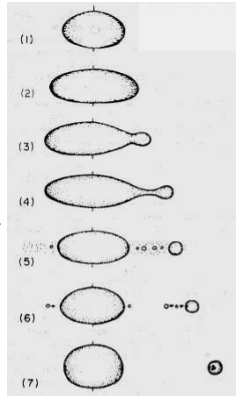
- Many theories have been proposed for the Moon's origin
- Generally, they have fallen into three categories:
  - *Fission*
    - The Moon was once part of the Earth but separated from it early in their history
  - *Co-accretion*
    - The Moon formed together with (but independently of) the Earth – they are planetary “sisters”
  - *Capture*
    - The Moon formed elsewhere in the solar system but was captured by the Earth (in whole, or piecewise)

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## Fission

- The early Earth spun so fast that it spun off the Moon.
- This idea would produce a Moon with a composition similar to Earth's mantle (and no core)



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## Co-accretion

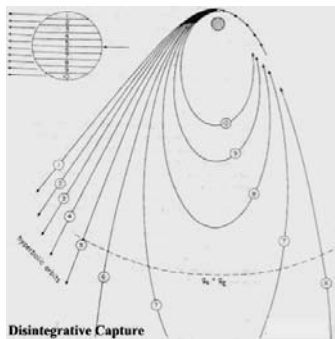
- The Moon is a sister world that formed in orbit around Earth as the Earth formed
- Would explain similar oxygen isotopes

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## Capture

- The Moon formed somewhere else in the solar system where there was little iron, and then was captured into orbit around Earth
- Tidal disintegration provides a way to conserve energy



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## Each of these Models has Problems

- Fission:
  - Does not conserve angular momentum, and mantle compositions should be more similar
- Co-accretion:
  - Does not explain the Moon's low density and inferred lack of an iron core
- Capture:
  - Does not easily explain how Moon rocks could have the same isotopic composition as Earth


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## A Proponent of the Old Models



- Dr. Harrison Schmitt (Apollo 17) discovered “orange soils” on the Moon



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## A New Paradigm

- By the 1960s-1970s, the role of *impacts* as major causes of planetary surface modification was widely accepted
- At the same time, powerful new computers were allowing astronomers to accurately *simulate* impacts and the formation of the solar system
- Consistent finding: The early solar system was a much more violent place than today!
- Could the Moon have been formed by impact?


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## The Giant Impact Hypothesis

- At the time Earth formed 4.5 billion years ago, other smaller planetary bodies were also growing.
- One of these hit Earth late in Earth's growth process, blowing out rocky debris.
- A fraction of that debris went into orbit around the Earth and aggregated into the Moon.

- First proposed by Hartmann and Davis (1975)
- Extremely controversial: many skeptics



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A Mars-sized planetesimal heads for the Earth!

Boom!

Fizz!

Paintings by Bill Hartmann

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Simulations

- Earth ends up spinning with ~5-hour rotation period

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### The Theory Gains Support

- New computer simulations support the scenario, and the prevalence of impacts in the early solar system
- Continuing analyses of Apollo samples continue to point out flaws in older classical theories
- New NASA missions, like Lunar Prospector, provide more detailed evidence that the Moon has a small core (so it was probably once molten)
- Still, many remain skeptical: scenario is *ad hoc*

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### Why Giant Impact is Currently the Best Hypothesis for the Origin of the Moon

- The Earth has a large iron core and a density of  $5.5 \text{ g/cm}^3$ , but the Moon has only a small iron core and a density of only  $3.3 \text{ g/cm}^3$ 
  - Earth's iron had already differentiated into the core by the time the giant impact happened
  - The Mars-sized impactor was also already differentiated
  - Therefore, the debris blown out of both Earth and the impactor came from their iron-depleted, rocky mantles
  - Moon was completely melted, and volatiles were vaporized and lost\*

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## Why Giant Impact is Currently the Best Hypothesis for the Origin of the Moon

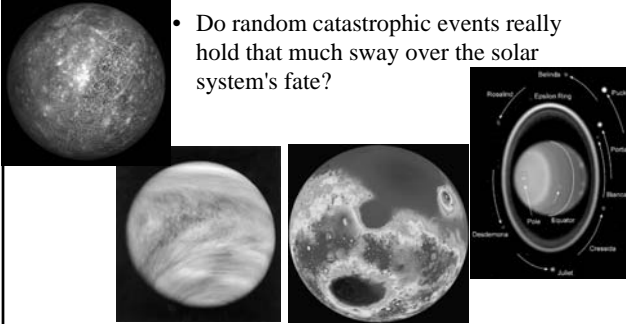
- The Moon has exactly the same oxygen isotope composition as the Earth, whereas Mars rocks and meteorites from other parts of the solar system have different oxygen isotope compositions.
  - This implies that the Moon formed either from the Earth, or from material formed in Earth's neighborhood
- If a theory about lunar origin calls for a common, evolutionary process, it has a hard time explaining why other planets do not have similar moons.
  - Earth's Moon is anomalously large compared to Earth (HW #5, Problem 1)
  - The giant impact hypothesis has the advantage of invoking a stochastic event that might happen only to one or two planets out of 8

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## Other Oddities Due to Giant Impacts?


- Do random catastrophic events really hold that much sway over the solar system's fate?



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## Summary



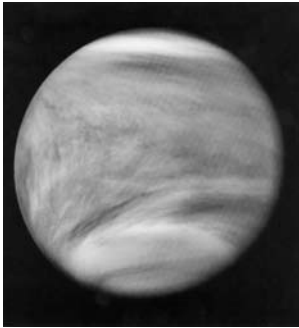
- A successful theory for the origin of the Moon must explain all of the observational facts
- Fission*, *Co-accretion*, and *Capture* have all been considered as possible models
- The *Giant Impact Theory* is currently thought to best explain the available data
- Impacts appear to have substantially affected other planet/moon systems in addition to our own

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## Next Lecture...

- Venus Overview
  - General properties
  - Telescopic observations
  - Space missions
  - Atmospheric characteristics
- Reading:
  - Chapter 7.1 (Venus), 9.5, 10.5



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