

The Origin of Our Moon

A Cosmic
“Who-Dun-It”



Our Moon Is Exceptional!

- It is unexpectedly large
- It has some surprising differences from (and similarities to) Earth
- It has no significant magnetic field
- It has few “volatiles”
- It has important effects on some of Earth’s “Goldilocks” characteristics

Selected Moons of the Solar System, with Earth for Scale



Mercury and Venus have no moons at all, and Mars' moons are too small to show up on this scale

Scale: 1 pixel = 25 km



For the Nitpickers in the Audience...

- Earth has a few other space stations gravitationally associated
- They are a motley crew



For the Nitpickers in the Audience...

- Earth has a few other space objects gravitationally associated with it, but...
- They are a motley crew
- Most of these associations seem not to be permanent
- It's a major stretch of the definition to call them "moons"
- So, we will ignore them from here on out

The “Goldilocks” Factor

- **The large mass of the Moon (relative to Earth) helps to stabilize the motions of both bodies**
- **Earth’s stable and modest axial tilt offers:**
 - reliable, favorable sunlight
 - moderate seasonal changes
 - temperatures that permit water in liquid form
- **We might not even be here without this Moon!**

So here's the puzzle...

- Our Moon looks like it shouldn't belong to one of the “terrestrial” planets
- Rather, it looks like the moons of the “gas giant” planets
- But there it is in our sky - How could this happen?
- There are some interesting theories....

Theories of the Moon's Origin

- **Fission Theory**
- **Capture Theory**
- **Co-accretion Theory**
- **Giant Impactor Theory**

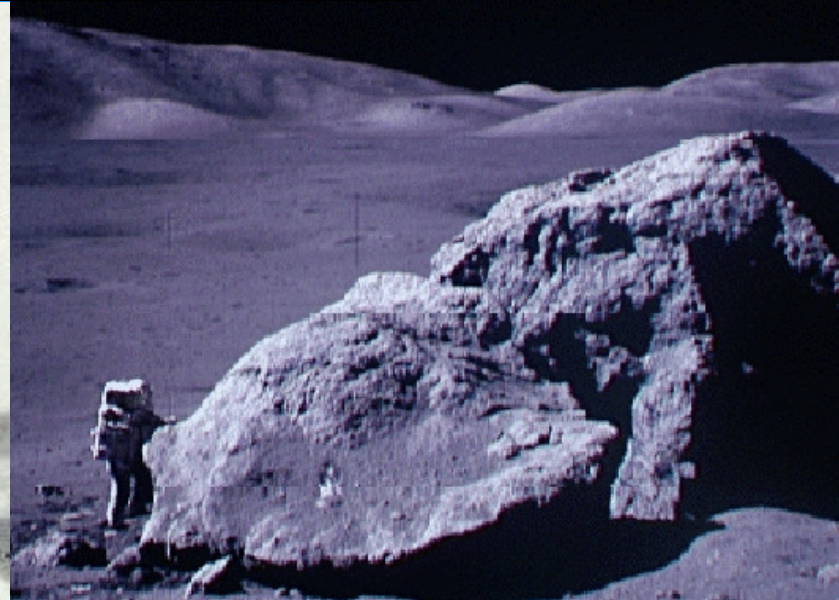
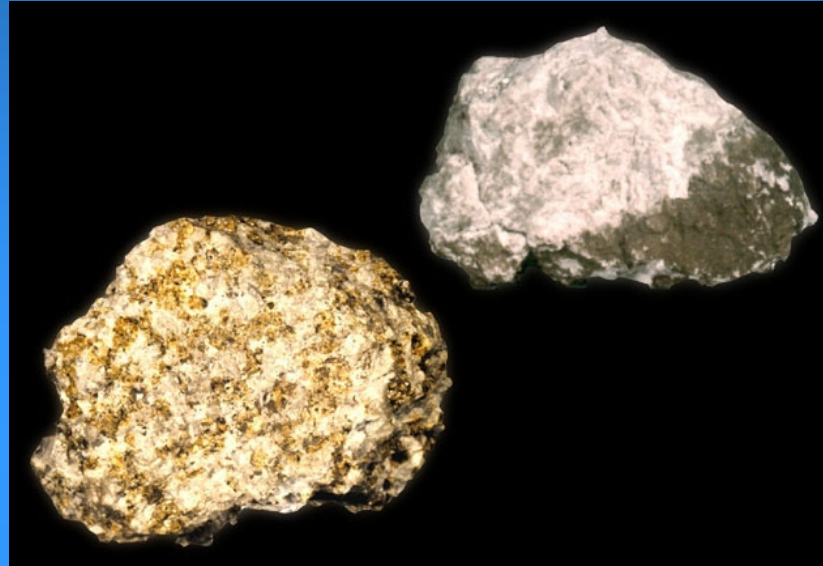
Any theory should explain...

- **Size** – largest ratio of moon to its planet
- **Chemistry**
 - same oxygen isotope ratio as Earth
 - absence of volatiles after formation
- **Geology**
 - same composition of mantle layers as Earth
 - difference in relative core sizes
 - oldest Moon rocks older than Earth rocks
- **Physics**
 - how angular momentum was preserved
 - low Lunar density compared to Earth

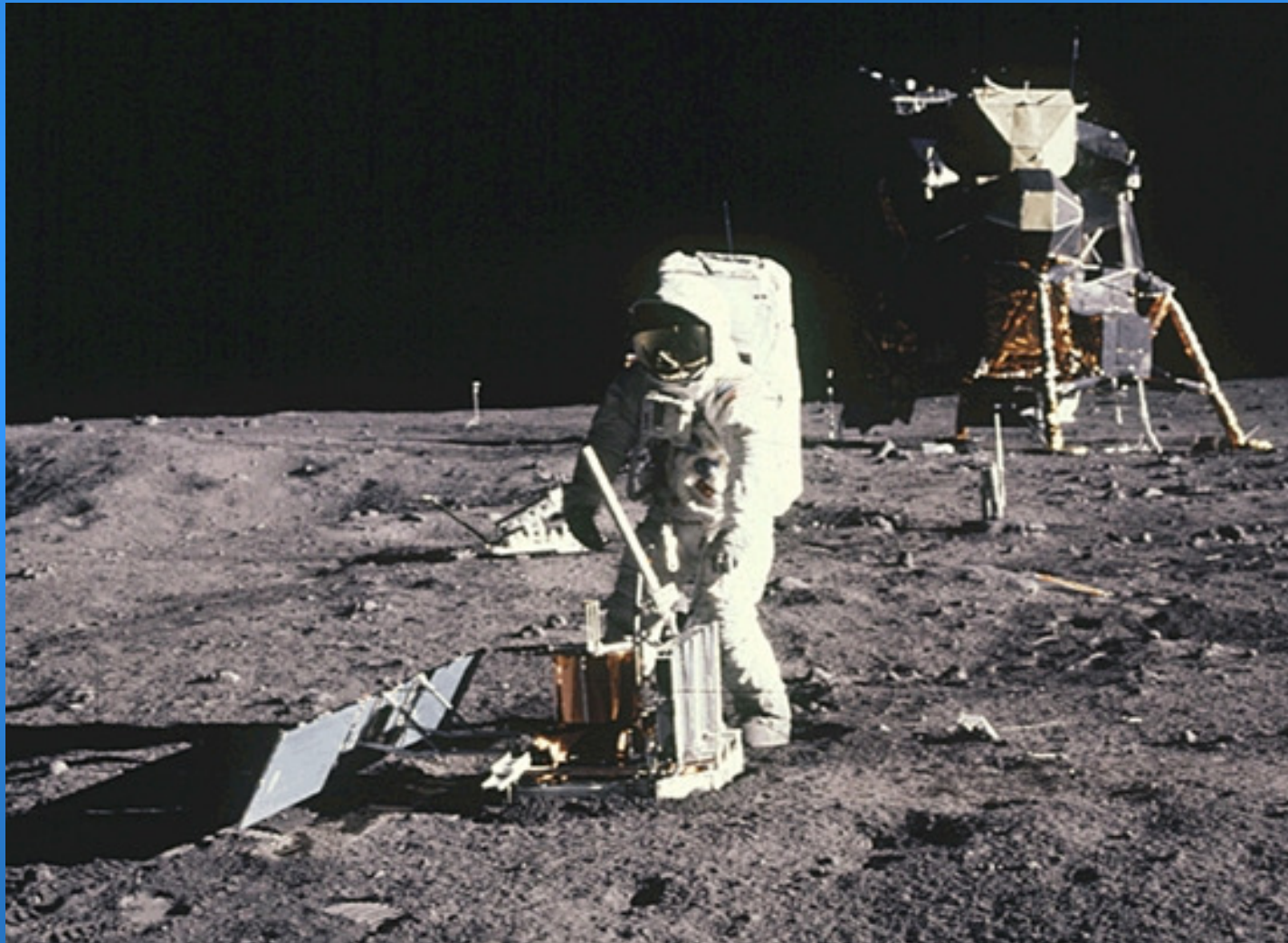
What Do We Know About the Moon That Would Help Us Evaluate These Theories?



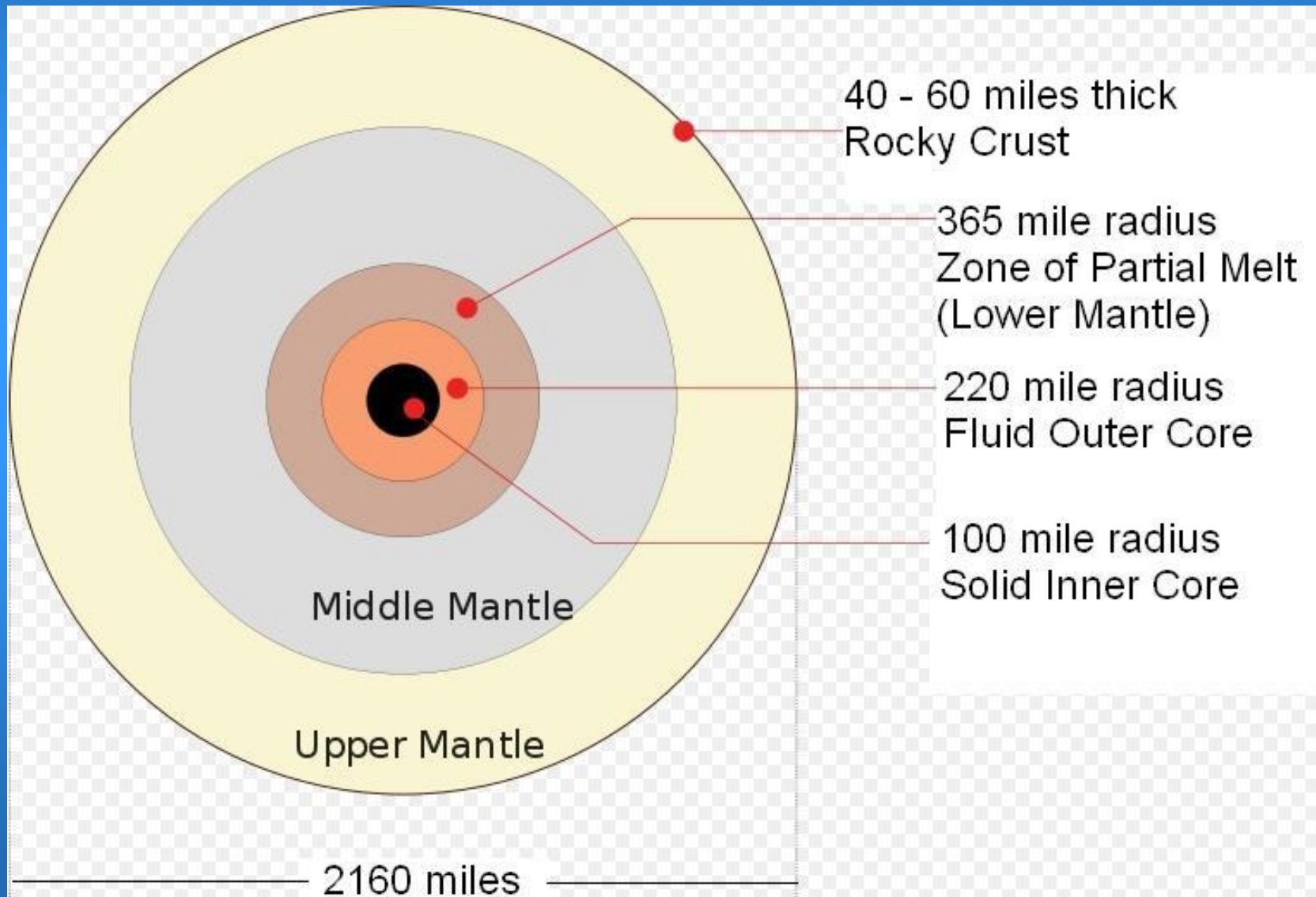
We've Got Moon Rocks....



... and Seismometer Reports on “Moon-quakes”



Interior Geology of Our Moon

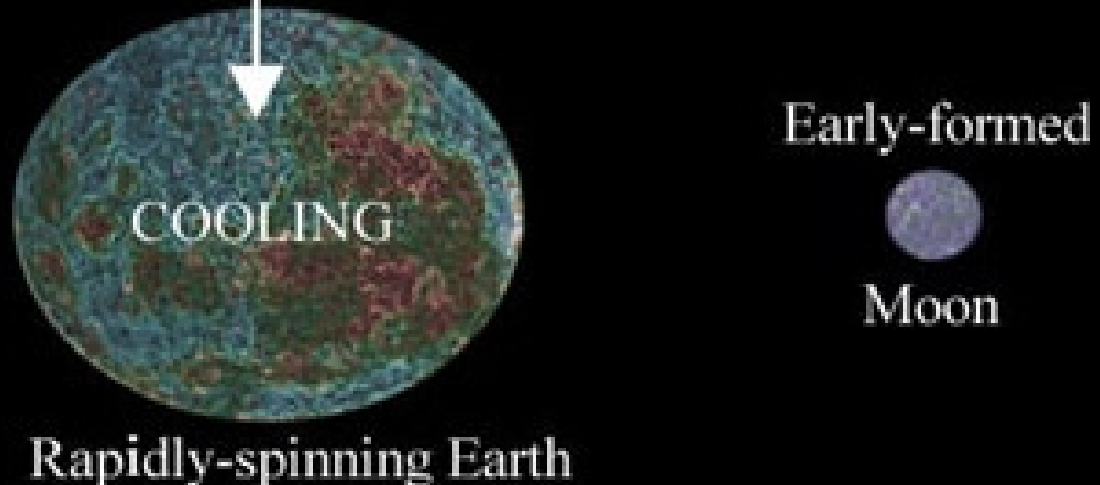
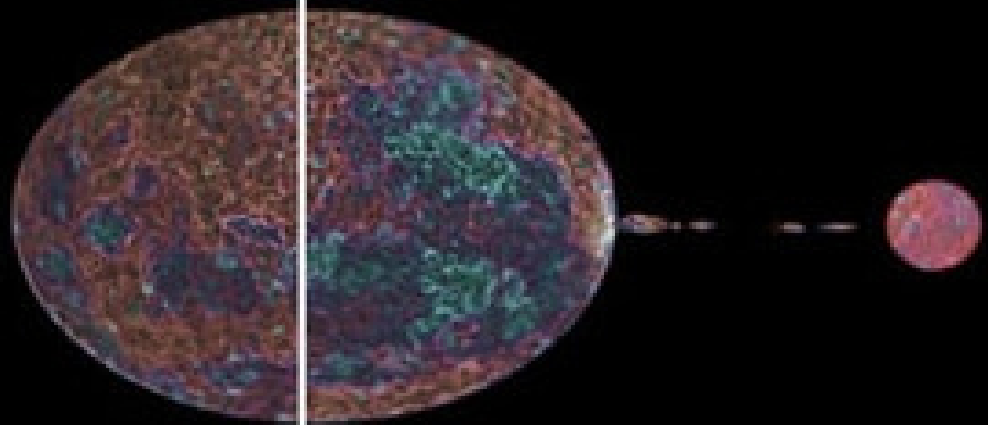
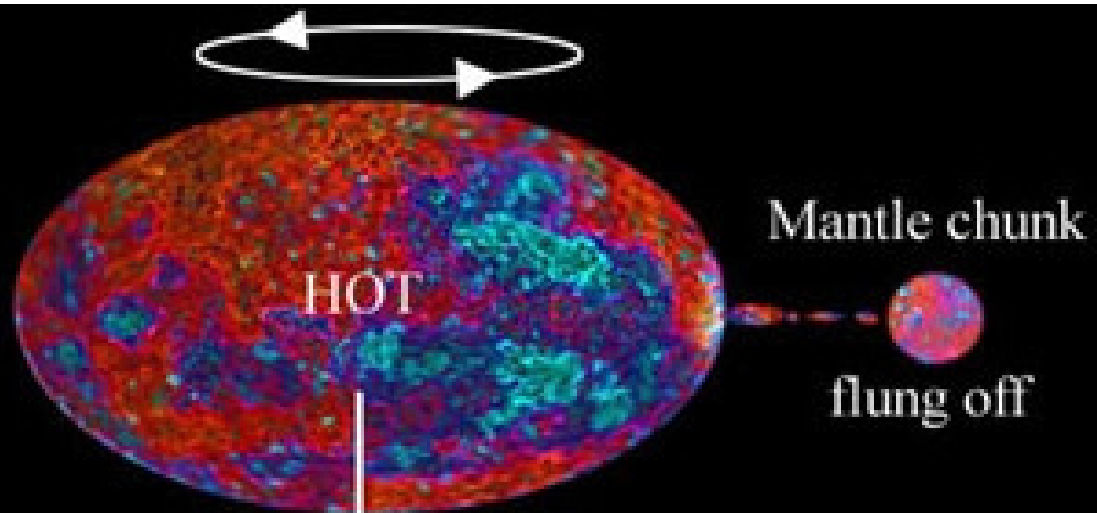


Theories of the Moon's Origin

#1

- **Fission Theory** –
 - Long ago Earth and Moon were one body – and then they broke apart

F I S S I O N
T H E O R Y



Needs:

- Fast spin
- Plastic body

Analysis of the Fission Theory

- Supposed source of material = Pacific Ocean Basin
- Implies Earth was in a plastic state, rapidly spinning
- Implies centrifugal force caused separation
- Computation of the mechanics of such a fission, and study of geology of the Pacific Ocean floor both showed falsity of the theory

Theories of the Moon's Origin

#2

- **Capture Theory** –
 - Moon formed separately and later was gravitationally captured by the Earth

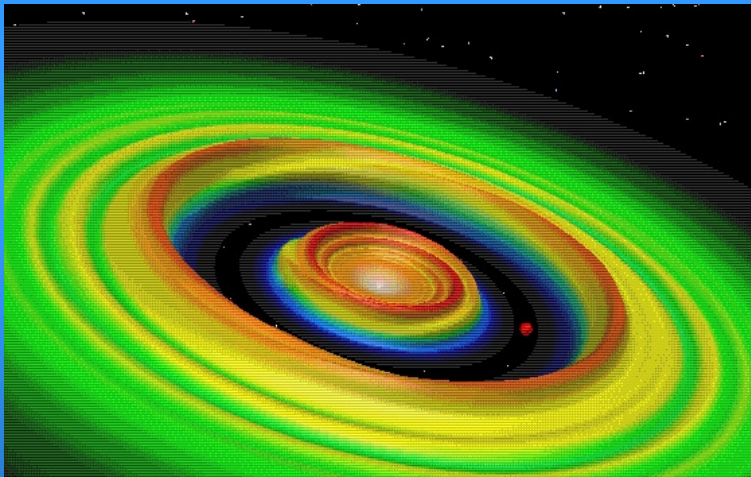
Capture Theory Needs:

- A Moon-sized object



BTW, What's a "Protoplanetary Disk" ?

A rotating disk of dense gas around a newly-formed star, from which planets may form



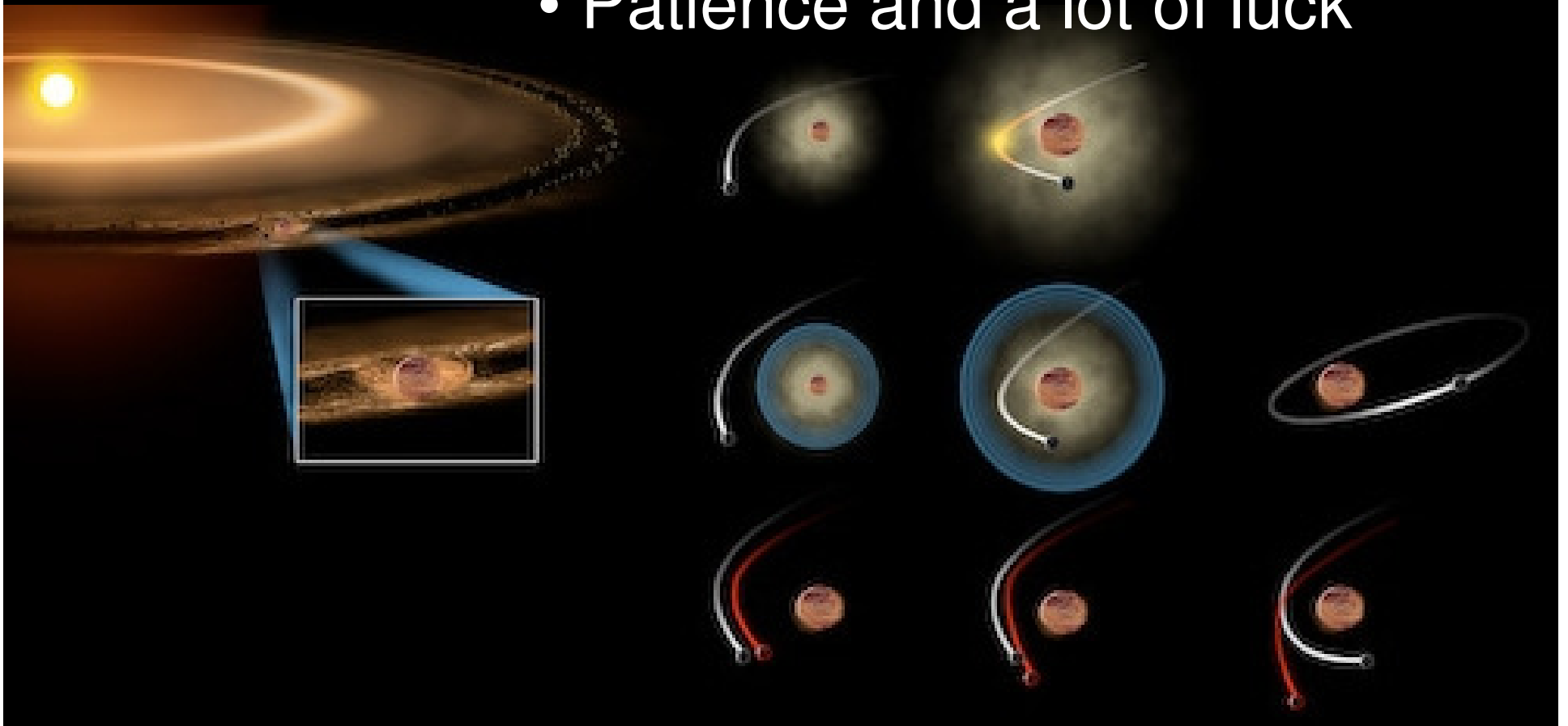
Computer simulation



The real thing

Capture Theory Needs:

- A Moon-sized object
- On a convenient orbit
- Patience and a lot of luck



Analysis of the Capture Theory

Assumes that the Moon formed elsewhere in the early Solar System

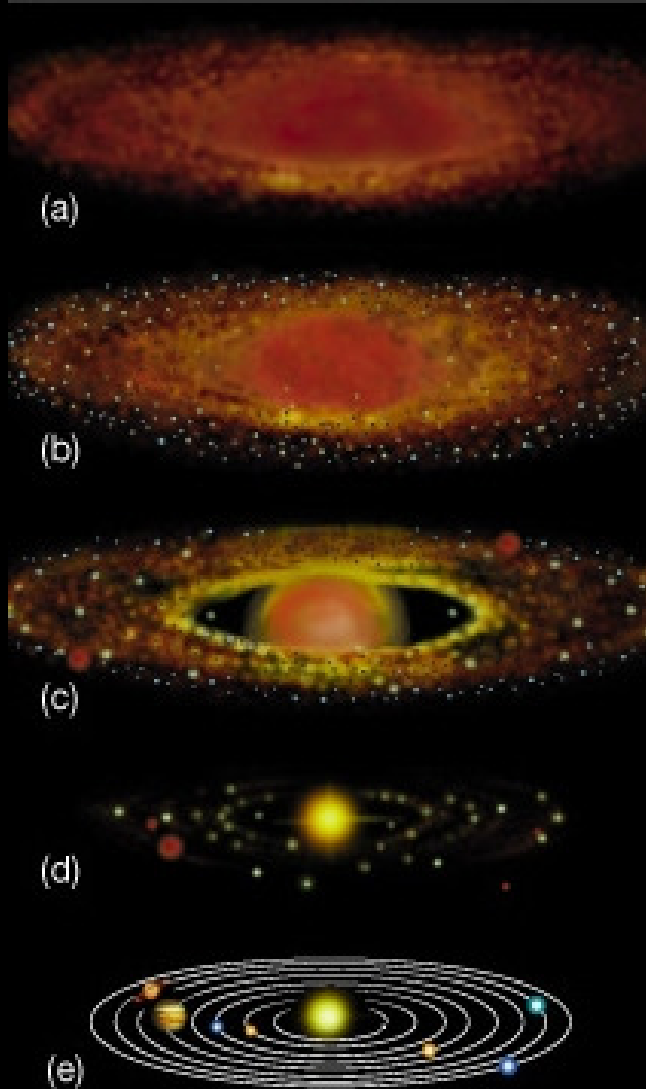
- Moon then found its way to its present gravitational relationship to Earth
- Most experts consider that the process is “highly unlikely”
- Oxygen isotope ratio info was the final blow
- Theory rejected by most astronomers

Theories of the Moon's Origin

#3

- **Co-accretion Theory** –
 - Earth and Moon formed as a binary pair from the same region of the protoplanetary disk

Co-accretion Theory Needs:



- Earth and Moon forming as a binary pair within the protoplanetary disk at about the same radial distance from the Sun

Analysis of the Co-accretion Theory

- **Fails to explain**
 - difference in density – Earth = 5.5 g/cm^3 ,
Moon = 3.3 g/cm^3
 - why other terrestrial planets don't have large satellites
 - the significant tilt of the Moon's orbit away from the plane of the Earth's orbit
- **Rejected by most astronomers when Apollo data became available**

Well, What's Left?

Only #4, the.....

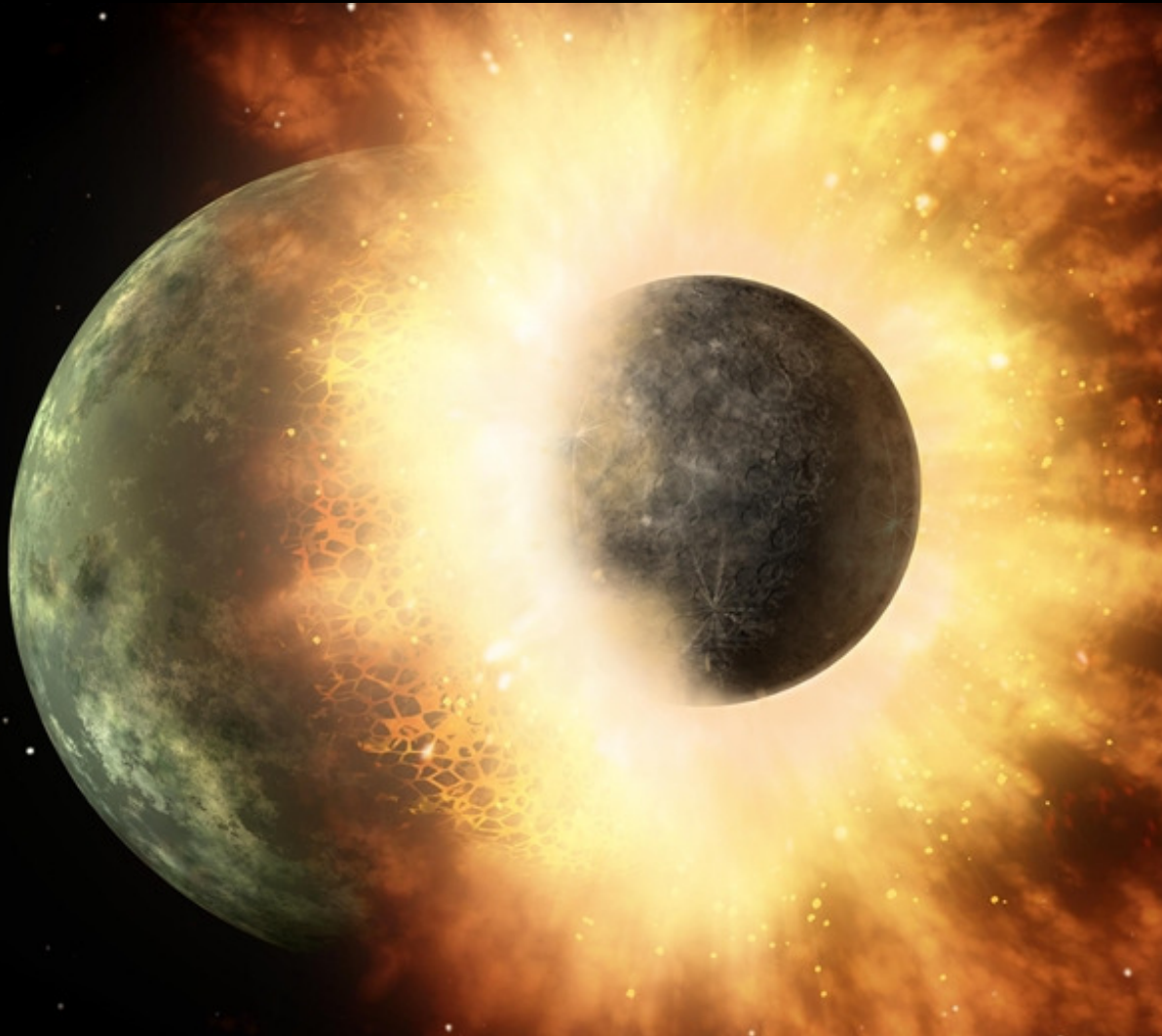
**GIANT IMPACTOR
THEORY!**

Theories of the Moon's Origin

#4

- **Giant Impactor Theory** –
 - A Mars-sized body hit the Earth, exchanged material with it, and then moved on to become the Moon

Giant Impactor Theory Needs:



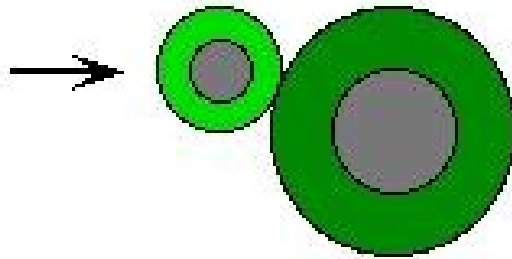
Several
things....

Giant Impactor Parameters

- **Time** - about 4.5 billion years ago
- **Earth** - about 90% of present size and having retrograde spin
- **Impactor**
 - about the size of Mars
 - on a collision course with Earth
- **Impact point** - offset from head-on
- **Impact velocity** - 2.5 miles/second or less

Impact Process Step-by Step

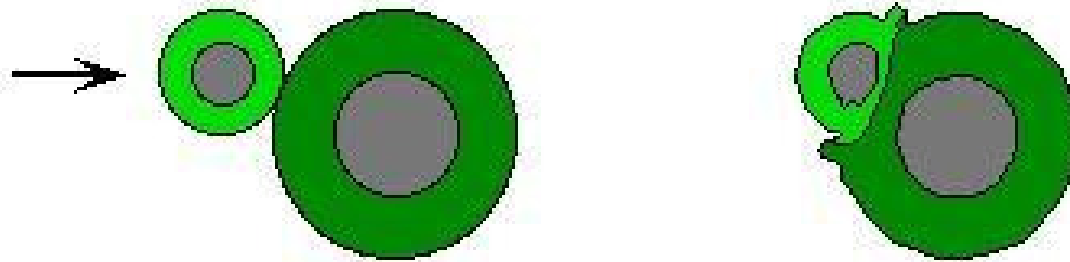
An Oblique Collision between the proto-Earth and a Mars-sized impactor



Minarik 1996, after Kipp and Melosh (86), Tonks and Melosh (93)

Impact Process Step-by Step

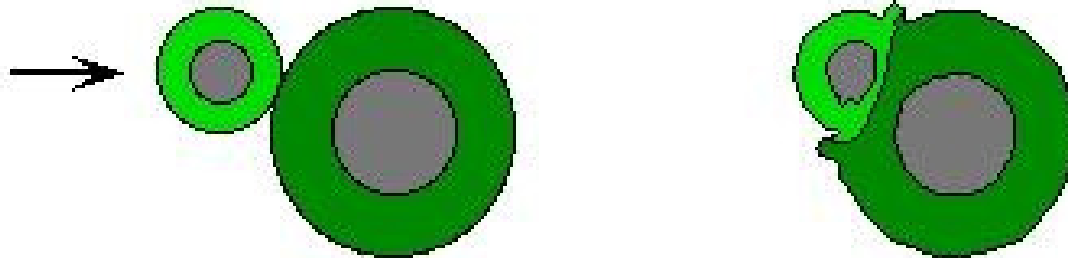
An Oblique Collision between the proto-Earth and a Mars-sized impactor
4.2 minutes



Minarik 1996, after Kipp and Melosh (86), Tonks and Melosh (93)

Impact Process Step-by Step

An Oblique Collision between the proto-Earth and a Mars-sized impactor
4.2 minutes



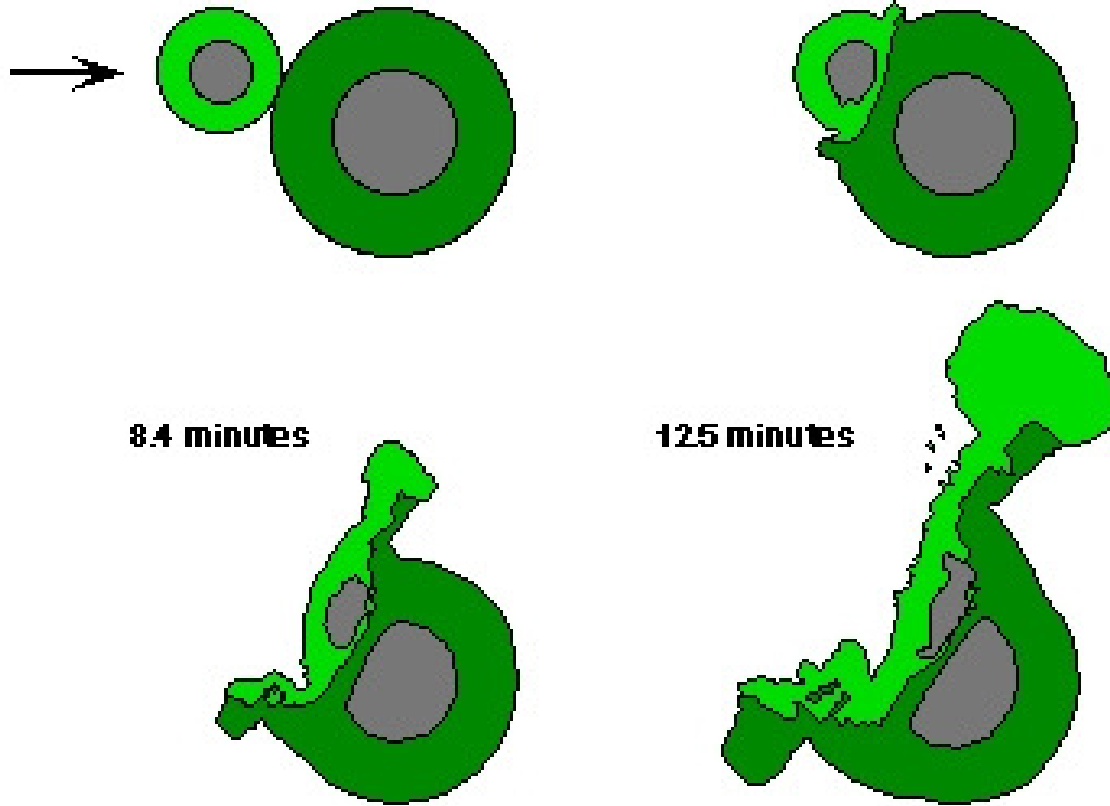
8.4 minutes



Minarik 1996, after Kipp and Melosh (86), Tonks and Melosh (93)

Impact Process Step-by Step

An Oblique Collision between the proto-Earth and a Mars-sized impactor
4.2 minutes



Minarik 1996, after Kipp and Melosh (86), Tonks and Melosh (93)

A Lot of Facts Are Explained by This Theory

- Density differences
- Same oxygen isotope ratios
- Relative core size differences
- Moon's early molten surface
- Believable scenario for the existence of the Impactor
- Believable preservation of angular momentum in the resulting bodies

Conservation of Angular Momentum



Why Do We Care About It?

- Any Moon-origin theory must involve moving around spinning masses
- Before, during and after any formation process we have to ensure that we know how the total momentum is distributed and that the combined total hasn't changed
- Giant Impactor theory meets that criterion
- Other theories require some unlikely assumptions

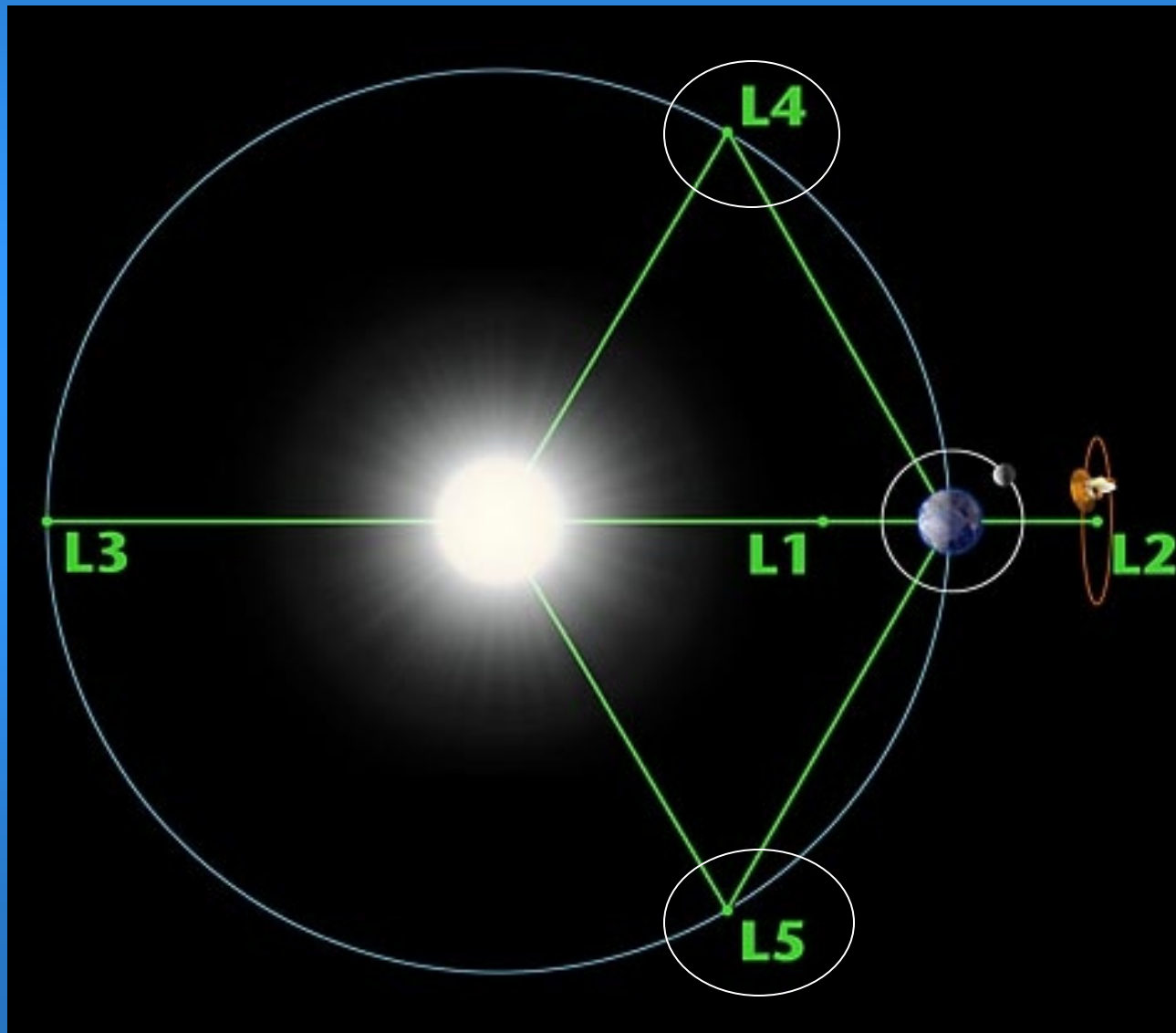
But the Giant Impactor Theory Fails to Explain...

- Theory predicts a magma “ocean” on early Earth – no evidence for this has been found
- Why the Moon does not have higher levels of some metallic elements
- Presence of atypical amounts of lunar rock-encapsulated water at one particular Apollo landing site
- Moon’s 20-mile crust thickness difference

Was There a Second Impact?

- The Moon is lop-sided - the side we see is smooth, “dark” side is more mountainous
- Heavy bombardment of space junk occurred 4.5 to 3.8 billion years ago
- Could a fairly large body have hit the Moon causing the dark-side differences?
- Where could such a body have come from?
- The LaGrange Points?

The LaGrange Points



It's Time For An Astronomical Sing-Along!

To be sung to the tune of
“Home, home on the range”

- Home, home on Lagrange
- Where the space debris always collects
- We possess, so it seems
- Two of Man's greatest dreams
- Solar power and ...
- Zero-gee sex!

So, What Can We Conclude?

- **Giant Impactor Theory**
 - accurate enough to be the leading candidate theory
- **Divergence of facts from theory needs:**
 - further research
 - probably more Moon missions
- **Radical theory change?**
 - Quite unlikely, but might be required by results of future research

Question Time....

?

?

?

?

?

?

?

?

?

?