The Moon Mess

Olowin Physics & Astronomy Lecture, February 2019
Javier Barbuzano

The Moon Mess

A planet-scale smash created Earth's satellite. But how did it manage to make a moon so like Earth?

"There is *orange soil*! It's all over! Orange!" Harrison Schmitt's excitement crackled over Apollo 17's radio.

His companion, surrounded by the gray lunar landscape, wondered if Schmitt had been on the Moon too long. He came to take a look. "Hey, he's not going out of his wits," Eugene Cernan chimed in, seeing the material Schmitt's footsteps had uncovered and catching his excitement. "It really is."

Schmitt, a geologist and the first scientist-astronaut to set foot on our planet's natural satellite, knew he was seeing something important. The two astronauts hurried to dig a trench, snap images, and collect samples. Further analysis on Earth later revealed that the orange soil was 3.7 billion years old and had formed during a volcanic eruption.

The orange soil wasn't the only thing worth bringing back home. When the Apollo 17 command module finally splashed down in the Pacific Ocean on December 19, 1972, it carried some 110 kilograms (243 pounds) of lunar rocks and dust in its guts. In total, the Apollo teams brought back to Earth 382 kg of samples. Among them were green, yellow, and orange volcanic beads; black basalts from the dark *maria* regions; twisted breccias cemented together by meteorite impacts; and a light-toned rock called anorthosite.

Although furthering lunar science was just one of the many objectives of the Apollo program, conceived during the Cold War for political and technological reasons, it produced an unprecedented amount of knowledge about the Moon. Virtually everything we know about our natural satellite was discovered or confirmed thanks to Apollo's scientific windfall.

But one of the most basic questions remains open: How did the Moon form? For a long time scientists thought they had found the answer in the Apollo lunar samples, but more recent analyses of the very same rocks, combined with powerful computer models, have shown there is still much we don't know about the birth of Earth's companion.

Probable but Unpredictable

Before Apollo, scientists had imagined three possible scenarios for the formation of the Moon: *co-accretion, fission,* and *capture*. Co-accretion means that Earth and the Moon coalesced together as a pair from a primeval cloud of gas and dust. In the capture scenario, the Moon formed elsewhere and was yanked into an Earth-circling orbit when the two bodies came too close. In the fission model, the still-molten Earth started rotating faster and faster until it split itself in two.

However, once scientists could study actual lunar samples, those three ideas became obsolete. Chemically, the Moon looks like what you'd expect after vaporizing Earth material and letting it condense in the vacuum of space. It lacks most of the easily vaporized elements regularly found in meteorites and terrestrial rocks, including water and hydrogen, and has little iron. The oldest rocks on the Moon, the low-density anorthosites, are almost completely devoid of heavy metals and must have formed after a global event melted the entire Moon, allowing these buoyant rocks to float to the top of a magma ocean and solidify on its surface as the Moon's original, frothy crust. None of the three scenarios would produce these characteristics.

Instead, by 1974, two pairs of scientists working independently (William Hartmann and Donald Davis, Alastair Cameron and William Ward) realized that the Moon could have been created

Moon Samples

0.3 kg: Weight of all Soviet Luna mission samples

110.4 kg: Weight of Apollo 17 samples

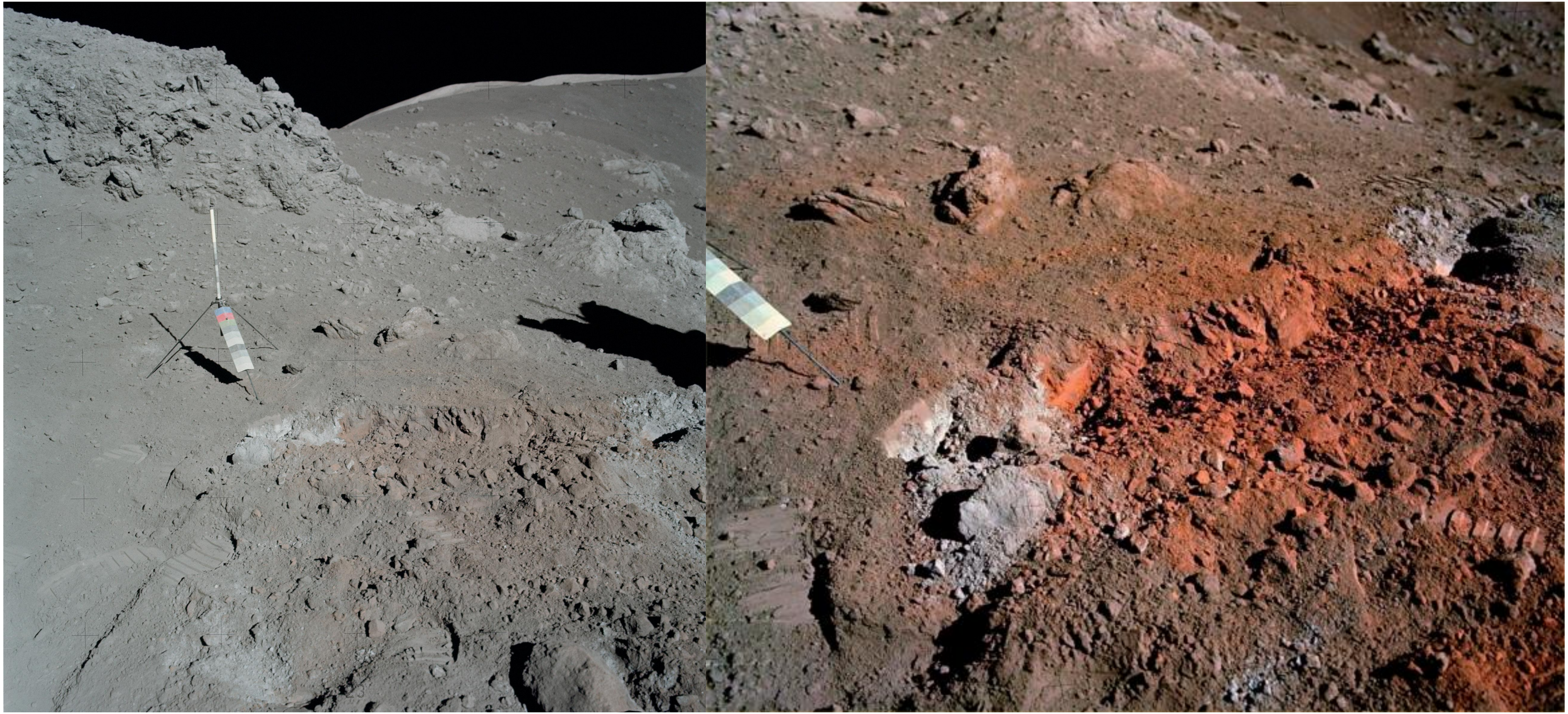
382 kg: Weight of all Apollo samples (about 5 adult men)

THE GREAT WALLOP
About 4½ billion years ago, a Mars-size body and the proto-Earth — both with atmospheres and, likely, surface oceans — crashed into each other. Already scarred by earlier, smaller impacts, the two bodies largely vaporized. The Moon and Earth coalesced out of the debris.

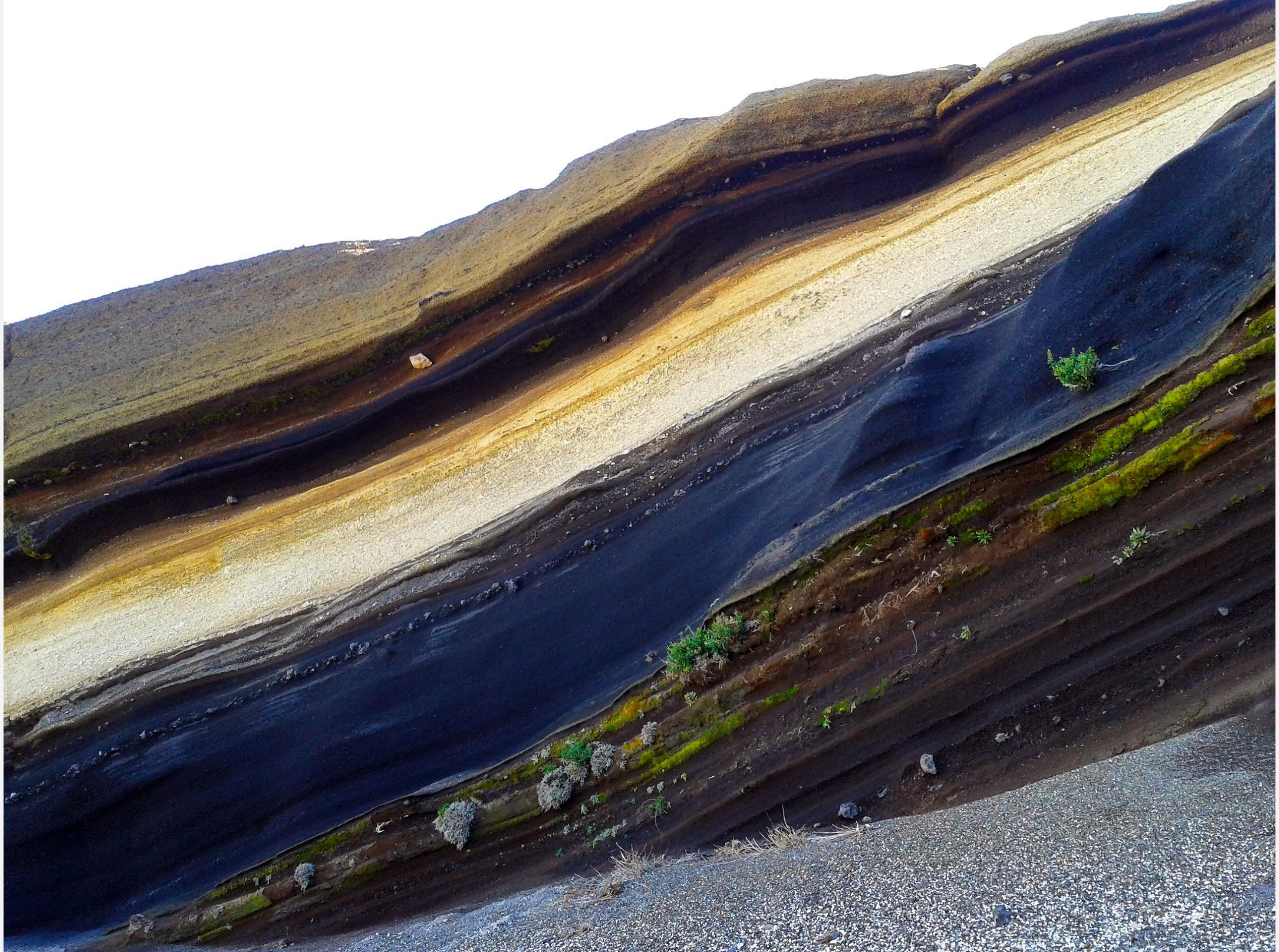
CASEY REED

ORANGE SOIL!

How well do we know the Moon?



Credits: NASA-Apollo 17 Crew - NASA/JPL/NSSDC - Credits for the additional process. and color.: Dr Marco Faccin/Lunar Explorer Italia/IPF

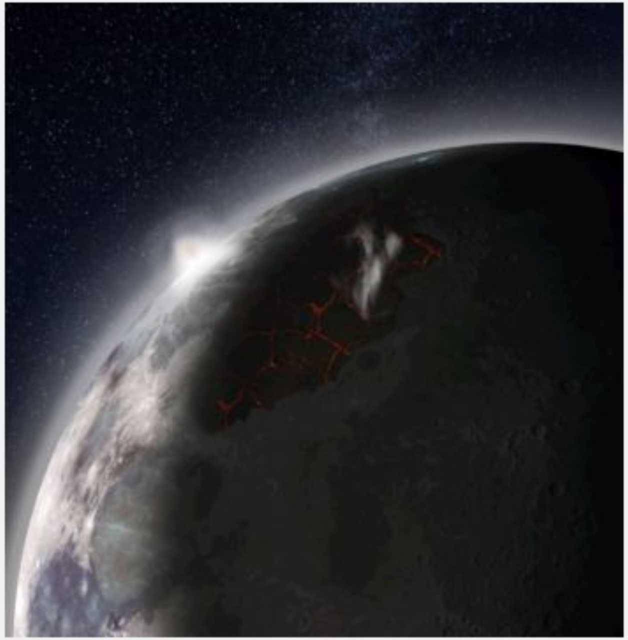


Ancient Moon Had Atmosphere Made of Volcano Smoke

By: **Javier Barbuzano** | October 10, 2017

Roughly 3.5 billion years ago huge volcanoes released enough gas to cover the Moon with a thin atmosphere that was visible from Earth.

We are used to picturing the Moon as a quiet place of "magnificent desolation," its otherworldly peace disturbed only by the occasional meteorite impact or rare terrestrial spacecraft landing. But 3 or 4 billion years ago, it might have looked very different.



This illustration shows the the Moon, looking over the Imbrium Basin, as volcanoes spew lava and gases, producing a visible atmosphere.
Credit: NASA MSFC

After forming around 4.5 billion years ago, the ancient Moon was still cooling and geologically active. Large-scale volcanic eruptions spewed lava, filling huge basins to form *maria* (Latin for seas), the darker regions we can see with the naked eye.

A new study published in *Earth and Planetary Science Letters* reveals that the Moon's intense volcanism might have released large amounts of gas at fast pace, enough to shroud the satellite with a thin atmosphere that survived millions of years before being lost to space.

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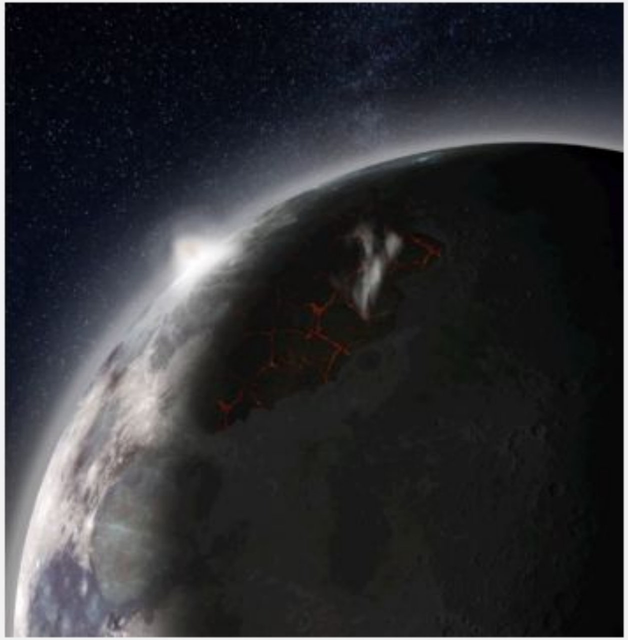

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- The lunar surface was covered in gas-spewing volcanoes and lava - it looked like Mordor- for at good chunk of its history
- Volcanism was so intense that it created a transient atmosphere
- Sulphur content made it visible from Earth
- Most intriguing: it might have contained **water**

Before Apollo...

The first Apollo astronauts were kept in quarantine for 21 days, just to make sure they didn't carry any deadly lunar microbes

Formation Theories Before Apollo

3 Scenarios

Co-accretion: the Moon formed alongside Earth as a pair

Capture: the Moon became trapped by Earth while passing close by

Fission: it was spit out when Earth spun so rapidly that it became unstable and split in two (originally proposed by George Darwin, Charles's son, in 1879.)

After Apollo

No life, past or present

As old as Earth

Made of rocky material variously melted, erupted, and crushed by meteorite impacts

No planetary magnetic field exists today

Covered by rock fragments and dust, called the lunar regolith

It’s strongly related to Earth

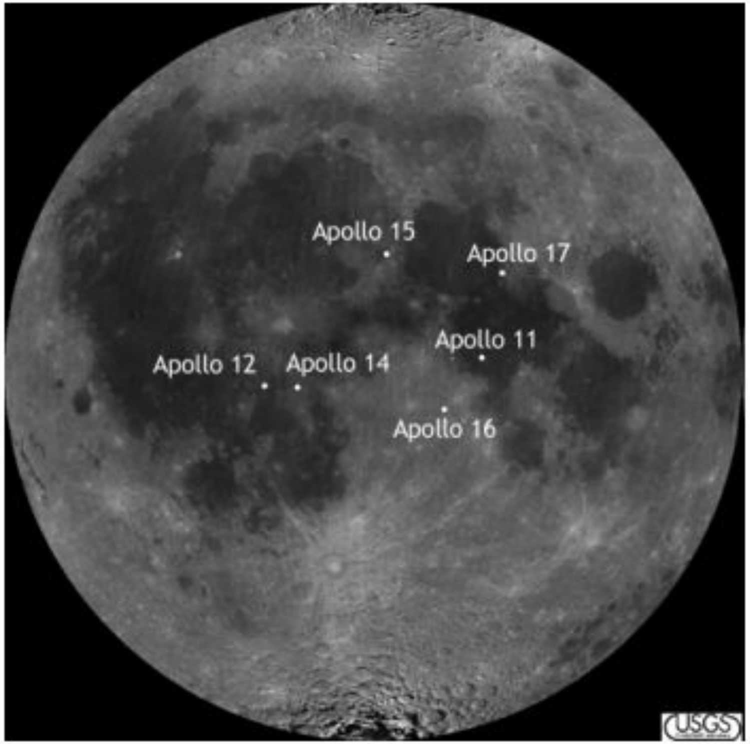
The Moon lacks iron and volatile elements

Lacks water

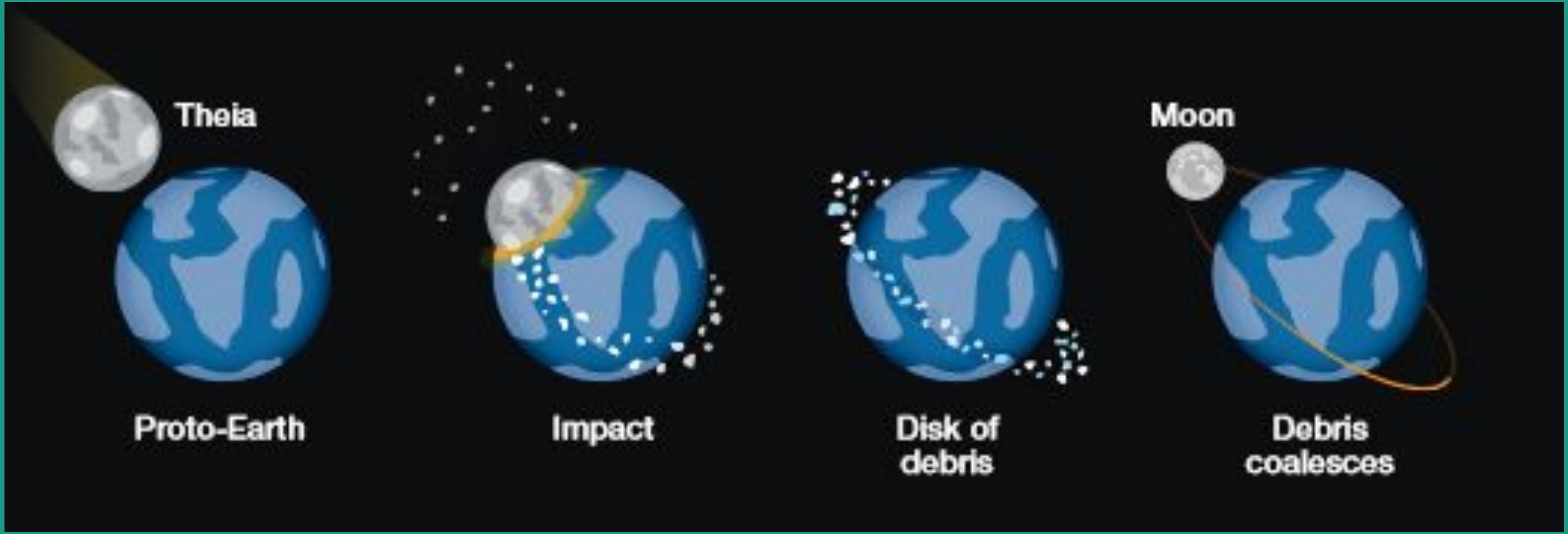
Had a catastrophic past that melted most of it and covered it in a magma ocean

A new Theory was needed

Chemically, the Moon looks like what you'd expect after **vaporizing Earth material and letting it condense in the vacuum of space**. It lacks most of the easily vaporized elements **regularly found in meteorites and terrestrial rocks**, including water and hydrogen, and has little iron



The Giant Impact Theory



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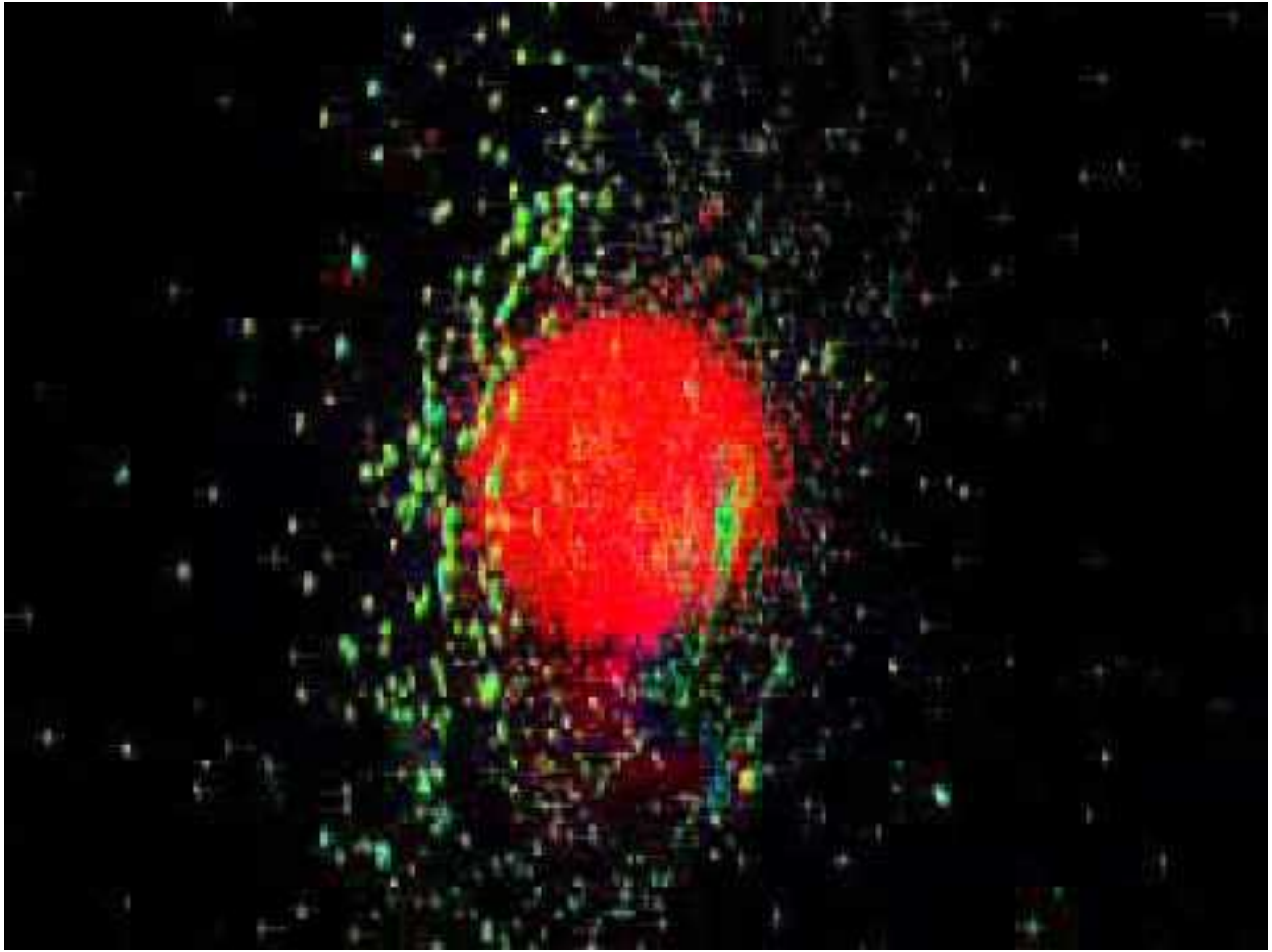
Proposed by William Hartmann and Donald Davis, Alastair Cameron and William Ward



Explains the Moon very well

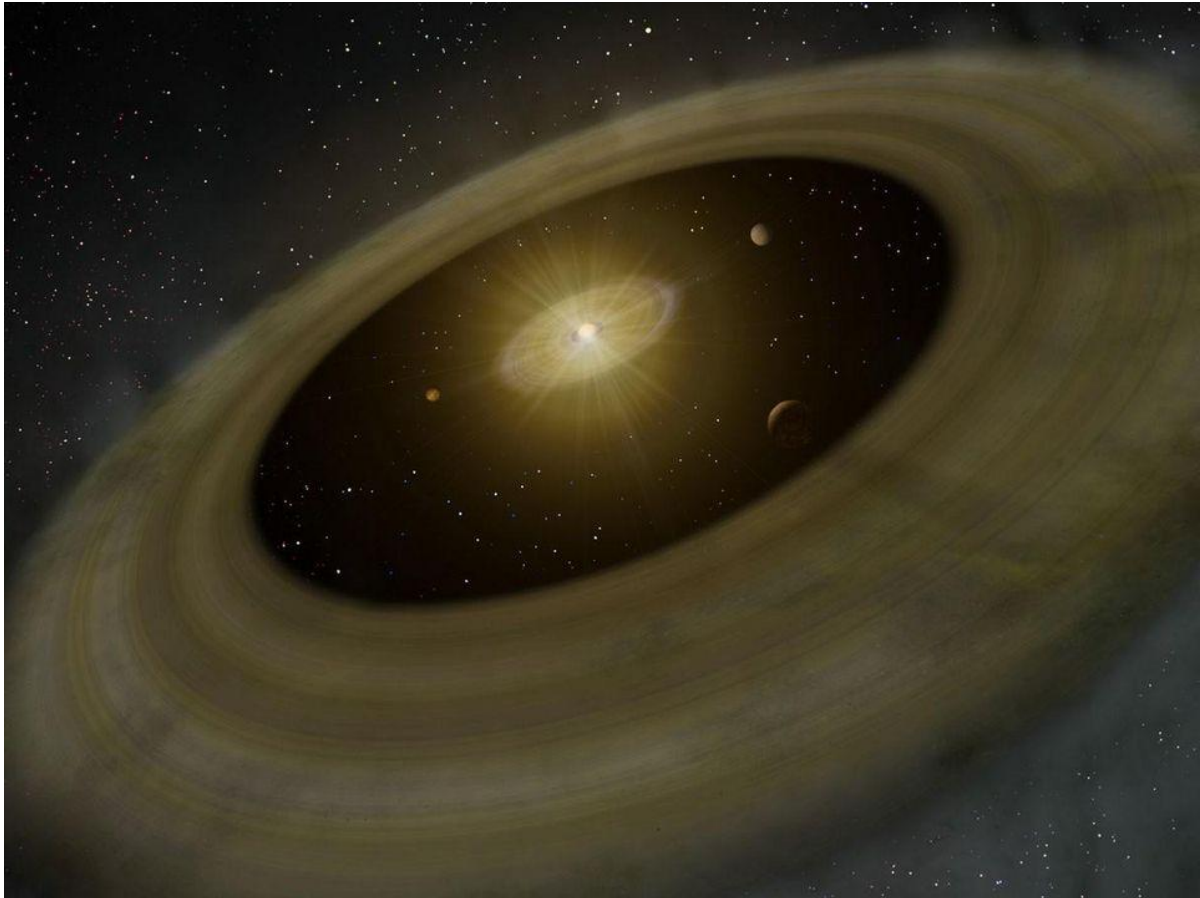
- Volatile elements can scape
- Lack of metallic core
- Large mass ratio compared to its host planet — more than 50 times those of the giant planets
- High angular momentum. If all the angular momentum could somehow be transferred to the Earth alone, our planet would spin around in only 5 hours
- Late formation relative to other solar system objects

Plays well with planet-formation models

- Doesn't gain much traction at first, because it seems that such an impact is considered very unlikely
- New planet-formation models show that such collisions might be common: Giant impacts mark the beginning of the end of a long process in which bits of rocky material gradually clump together, growing in size to form boulders, then planetesimals, and then planets
- Giant Impact Theory Becomes dominant

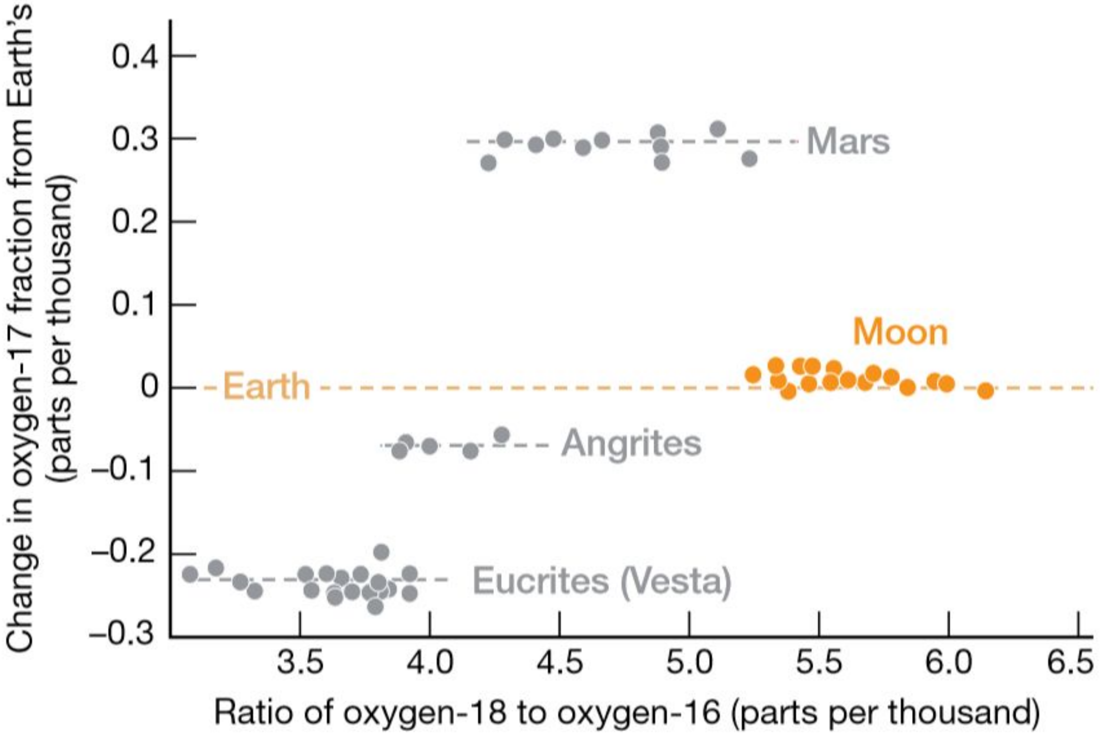
The Giant Impact Theory Runs into Trouble

Isotopic ratios



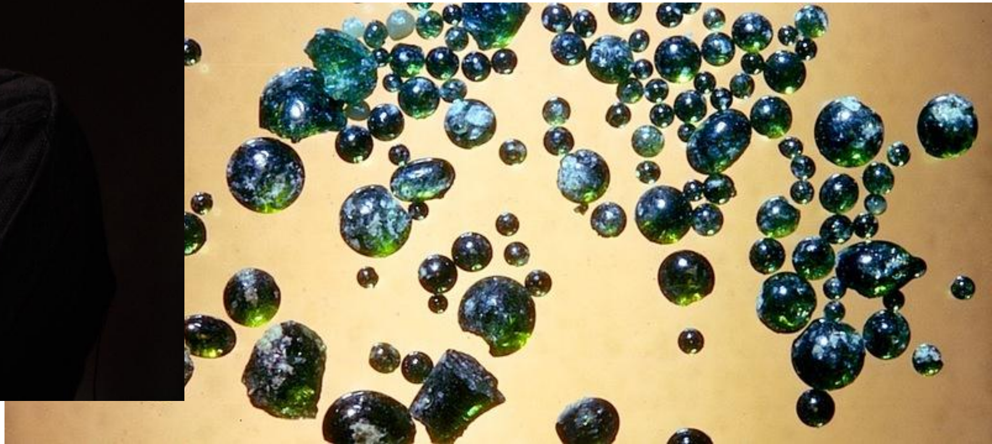
Isotopic ratios

- Oxigen 16, 17, 18
- Tungsten-182



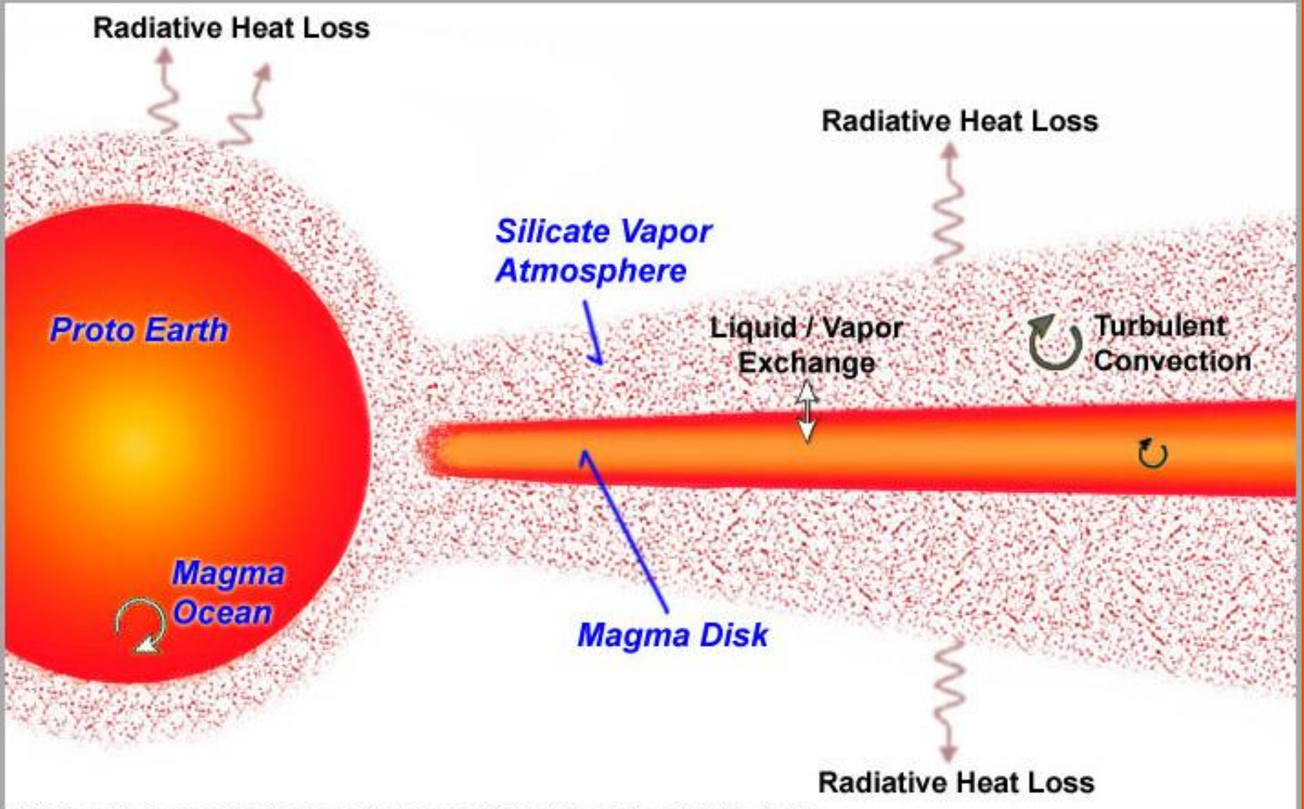
Just add Water

Alberto Saal,
Brown University



Saving the Giant Impact Theory

Mixing things up

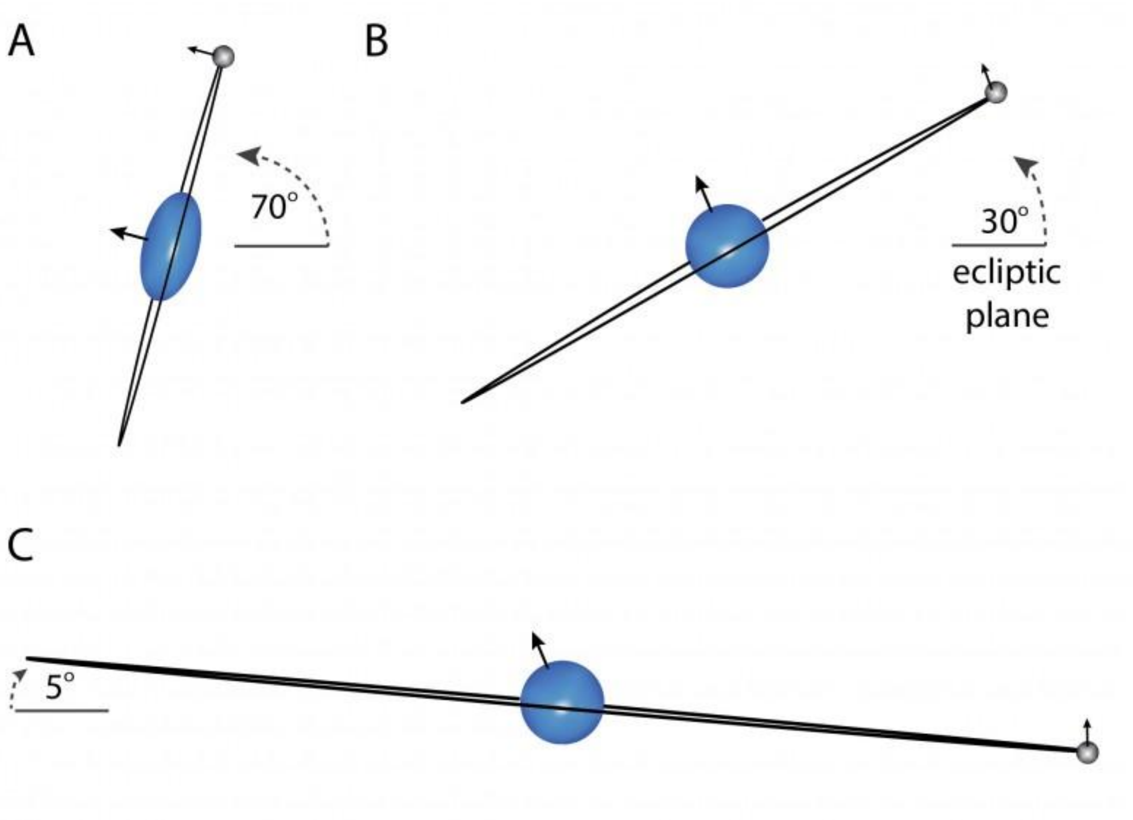


(PSRD graphic based on Pahlevan and Stevenson, 2007, *EPSL*, v. 262, p.438-449, Fig. 3.)

Pahlevan and Stevenson

- Not efficient
- Requires too much energy

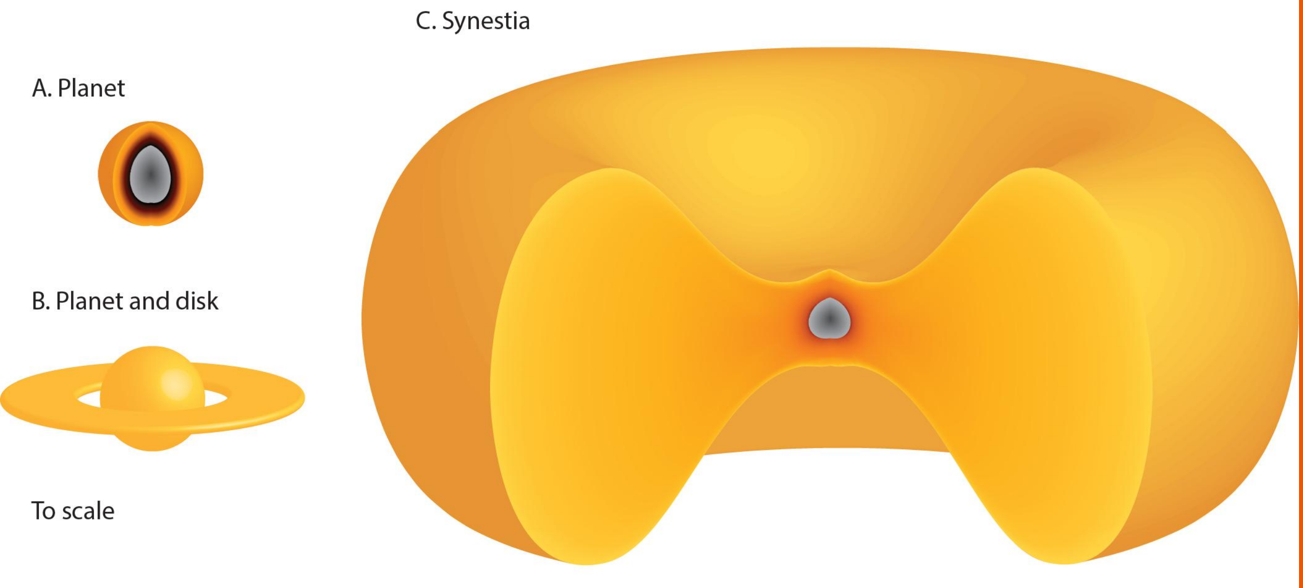
Use Less Theia - Hit Harder



Stewart and Ćuk

- More energetic impacts are possible
- Still not enough mixing

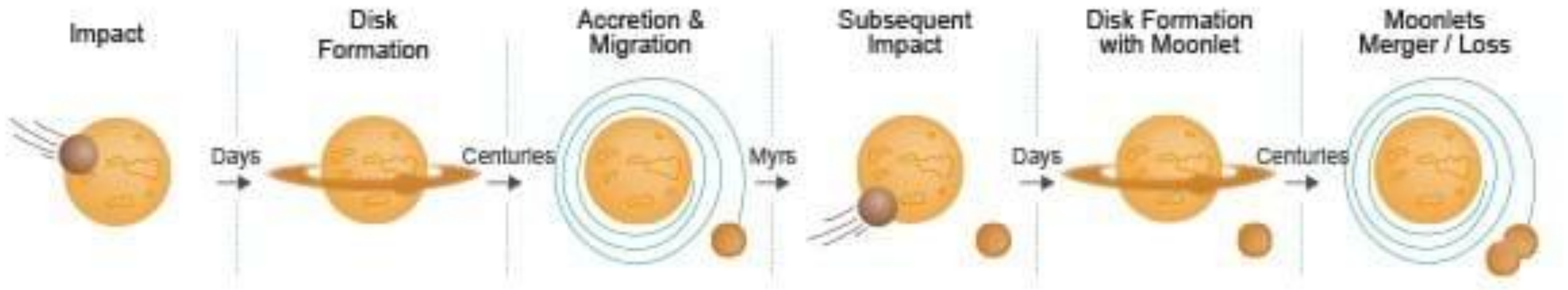
Vaporize Everything



Lock and Stewart

- Ultimate mixer
- Allows for more energetic impacts
- Could explain water

Multiple Impacts



Rufu et al.

- Faster impacts
- Mask Impactors signatures

Fix Theia

Dauphas

- Enstatite Chondrites
- Against Solar System formation models
- Doesn't explain Tungsten-182

1. Pre-Apollo theories didn’t work
2. Giant Impact Theory appears and becomes dominant
3. Computer simulations and isotopic ratios create problems
4. Now scientists are trying to find ways to save the GIT

Will we ever know?

Get more samples

- Venus and Mercury
- Meteorites
- Moon

Look elsewhere

- Exoplanets
- Exomoons
- Signs of synestias

Will we ever know?

A giant impact as the likely origin of different twins in the Kepler-107 exoplanet system

Aldo S. Bonomo ✉, Li Zeng, [...] Chris Watson

Nature Astronomy (2019) | Download Citation

Will we ever know?

Delivery of carbon, nitrogen, and sulfur to the silicate Earth by a giant impact

Damanveer S. Grewal*, Rajdeep Dasgupta*, Chenguang Sun, Ky
+ See all authors and affiliations

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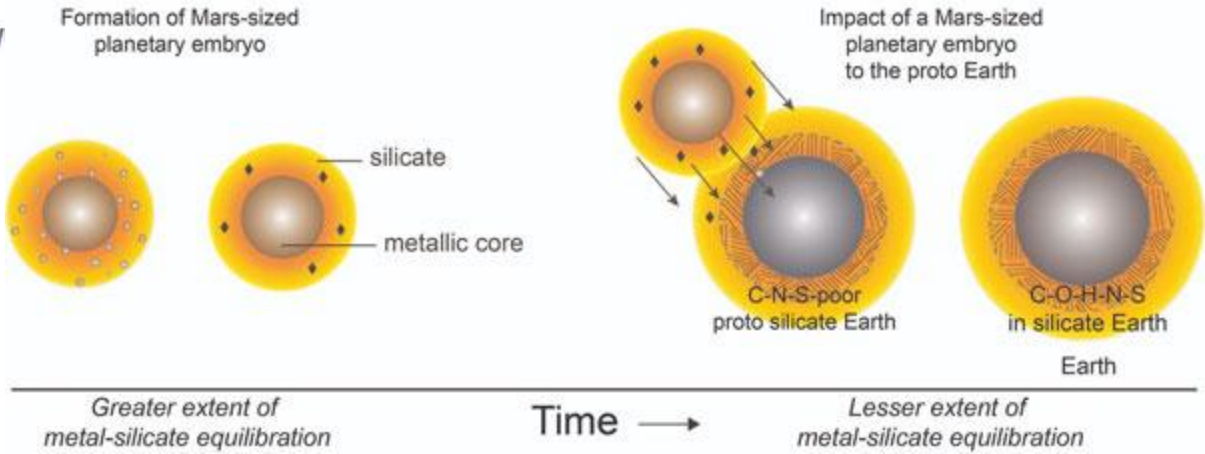

THANKS!