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Asteroid Impacts Could Have Warmed Ancient Mars

Mars is a frigid world today, and all of its surface water is frozen solid. However, there's ample evidence that liquid water once coursed over the Red Planet. That paradox has sparked an ongoing debate: What warmed up Mars's climate billions of years ago? A team has now proposed that giant asteroid impacts—the kind that carve out basins exceeding 1,200 kilometers (about 750 miles) in diameter—might have played an important role. The team reported its results in *Geophysical Research Letters* (bit .ly/Mars-climate).

The gullies, streambeds, channels, and lake beds that pepper the Martian landscape are dead ringers, morphologically speaking, for water-sculpted terrain on Earth. The presence of hydrated minerals such as phyllosilicates and sulfates, which have been spotted spectroscopically by Mars-orbiting satellites, has provided more evidence that the Red Planet was once warmer and wetter. By dating geological features and water-altered minerals, scientists have determined that Mars must have been relatively balmy roughly 4 billion years ago.

Don't Look at the Sun

The ancient warm spells that Mars appears to have experienced can't be pinned on a seemingly obvious culprit such as the Sun. That's because our nearest star wasn't any more luminous in the past.

"The Sun was much fainter," said Lu Pan, a planetary scientist at the University of Science and Technology of China in Hefei. She explained that the Sun's power output several billion years ago was probably about 30% lower than it is today, a fact that has been troubling the scientific community for decades. "Climate modelers have been trying to figure out ways to warm up the planet," she said.

Pan and her colleagues recently proposed one possibility, and it hinges on truly catastrophic events. Building on previous research, the team suggested that giant asteroid impacts—far larger than the one that killed off nonavian dinosaurs 66 million years ago on Earth—triggered chemical reactions in Mars's crust and mantle.

In a process known as oxidation, iron-bearing minerals reacted with water present in Mars's subsurface to produce iron oxides and hydrogen gas. That hydrogen collided with the carbon dioxide already present in Mars's atmosphere.

All of that bumping together of molecules changes their electronic structure and allows them to absorb radiation at a wider range of wavelengths, an experimentally verified phenomenon known as collision-induced absorption. "These molecules become even better greenhouse gases," said Ramses Ramirez, a planetary scientist at the University of Central Florida in Orlando who was not involved in the research.

Recent research has suggested that an atmosphere composed of both carbon dioxide and hydrogen can reach temperatures above freezing (bit.ly/early-Mars). On the other hand, a carbon dioxide-dominated atmosphere void of hydrogen or other greenhouse gases can attain a top temperature of only about -40°C. "That's over 40° too cold," Ramirez said.

Go Big or Go Home

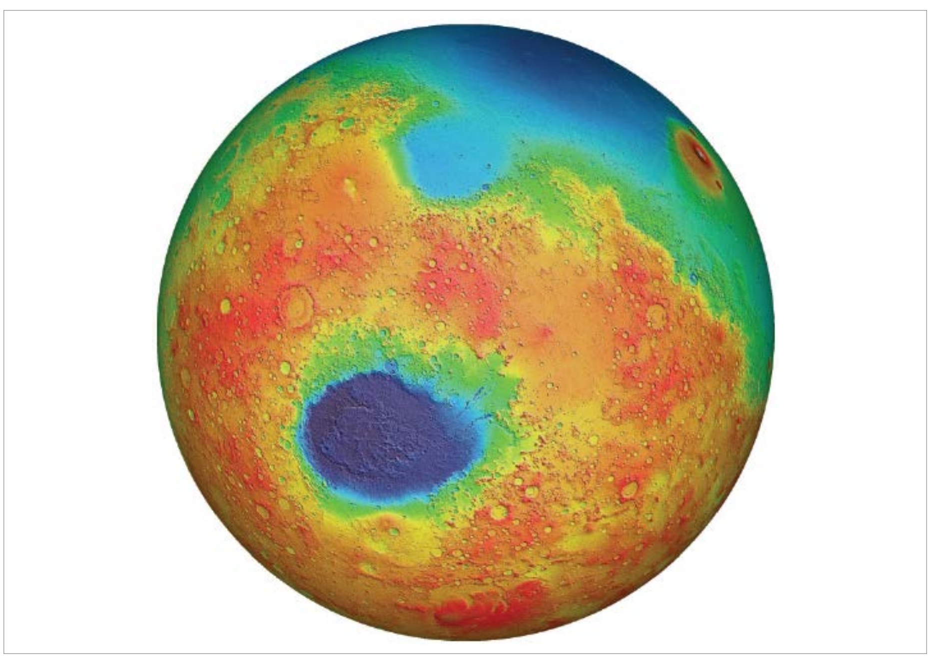
Asteroids larger than 100 kilometers (60 miles) in diameter—more than 10 times the size of Earth's dinosaur-killing impactor—excavate enormous basins when they strike a rocky body. Several such depressions persist today on Mars, including Argyre, Hellas, and Isidis. The impacts that formed those basins would have released copious amounts of hydrogen gas, Pan and her colleagues concluded, because both the asteroids themselves and portions of Mars's crust and mantle would have been oxidized.

> **"Climate modelers have been trying to figure out ways to warm up the planet."**

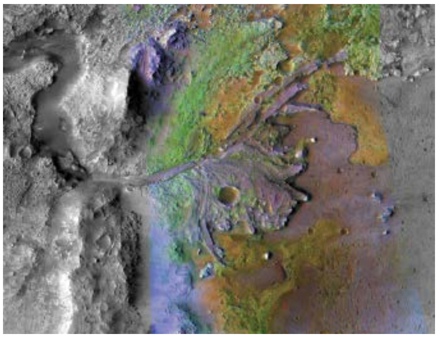
The researchers calculated that impacts that produced basins larger than about 1,200 kilometers (750 miles) in diameter would have created enough hydrogen to heat Mars's atmosphere to above freezing.

But those relatively balmy conditions wouldn't have persisted indefinitely. That's because hydrogen, being so light, tends not to stick around. "Even if you put a lot of hydrogen into the atmosphere instantaneously, it [would] escape very fast," Pan said.

On the basis of assumptions about the physical structure of Mars's atmosphere, the



The Hellas impact basin—the dark blue circular region in this false-color image from the Mars Orbiter Laser Altimeter (MOLA)—is one of the largest known impact craters in the solar system, with a diameter of roughly 2,300 kilometers (1,400 miles). Credit: MOLA Science Team



Mars's Jezero crater contains channels and other water-sculpted features like deltas. Credit: NASA/JPL-Caltech/MSSS/JHU-APL

researchers determined that on the order of a trillion molecules of hydrogen per second would have streamed out of every square centimeter of Mars's atmosphere. Taking that exodus into account, Pan and her colleagues calculated that temperatures on ancient Mars would have remained above freezing for anywhere from about 20,000 to 1,000,000 years after the largest basin-forming impacts.

Twenty basin-forming impacts occurred early on in Mars's history, according to previous research (bit.ly/Mars-impacts), and Pan and her team determined that 14 of those events could have boosted temperatures to above freezing.

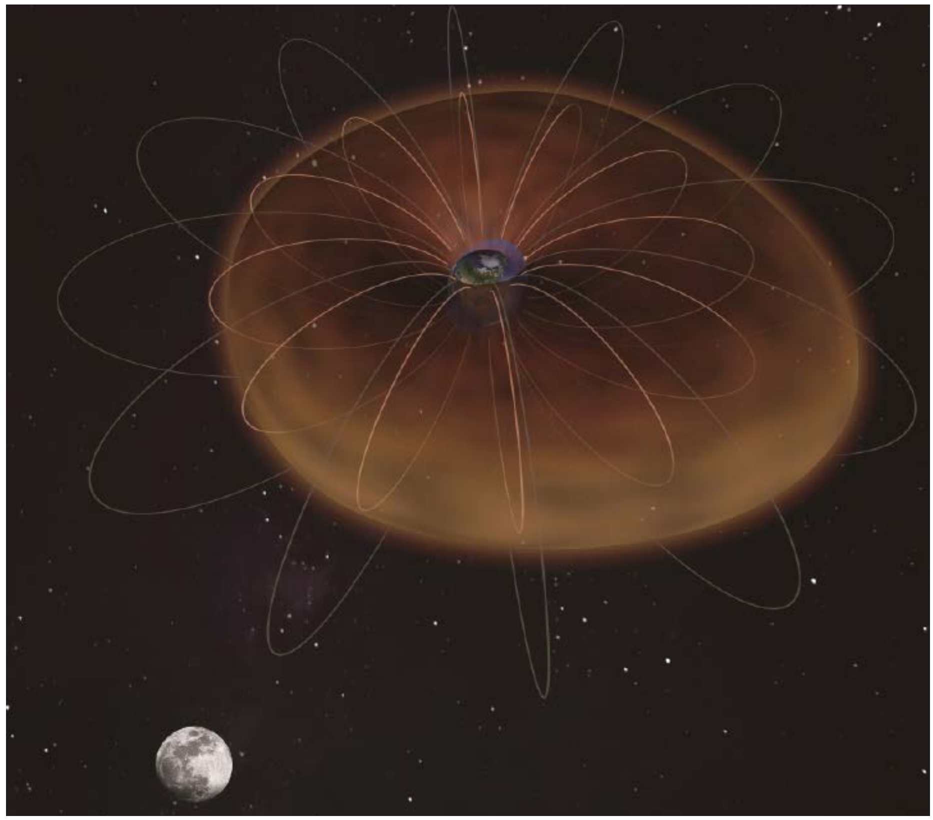
Those results make sense, said Robin Wordsworth, a planetary scientist at Harvard University who was not involved in the research. But it's important to consider the relative timing of asteroid strikes and the emplacement of Mars's water-sculpted terrain, he said.

If one is a cause and one is an effect, the two should sync up in time. But that's not always the case, Wordsworth said, because the largest impacts predate features shaped by flowing water. "The big ones happen before we see valley networks," he said. "That's one of the big challenges of the impact-driven hypothesis."

Pan and her colleagues acknowledged that discrepancy and suggested that Mars's fluvial features, in some cases, might be older than they appear. It's possible that erosion or other geological activity could have removed earlier signatures of water-carved features, Pan said. "We just don't have an exact timing of those early processes."

By **Katherine Kornei** (@KatherineKornei), Science Writer

Tides Ripple Across Earth's Plasma "Donut"



The donut-shaped plasmasphere encircles Earth in this artist's concept, with our planet's magnetic field looping through it. Tides caused by the nearby Moon ripple across the surface of the plasmasphere. Credit: Quanqi Shi

Earth is surrounded by an ocean of plasma—the electrically charged fourth state of matter—and researchers have discovered tides rippling across its surface. The shifting field of plasma surrounding the planet may affect Earth's radiation belts, which can damage spacecraft or astronauts in orbit or traveling to or from the Moon. Similar tides could race around planets in other star systems.

The plasmasphere is a donut of cold plasma centered over Earth's magnetic equator within the magnetosphere—the region encompassing our planet's magnetic field. The plasma is supplied by the ionosphere, the electrically charged layer of the upper atmosphere.

The outer boundary of the plasmasphere—known as the plasmapause—is typically found 20,000–38,000 kilometers (12,000–24,000 miles) from Earth's center, although its location can vary with the seasons, solar activity, and other factors, Quanqi Shi and Chao Xiao, physicists at China's Shandong University and the study's lead authors, wrote in an email.

Plasma Tides

"In the past, lunar tides were mainly found to affect the first three states [of matter]: solid Earth tides, liquid ocean [tides], and neutral gas-dominated atmospheric tides," Shi and Xiao wrote. "Whether lunar tides can influence the plasma-dominated regions had not yet been explored."

To fill in that gap, Shi, Xiao, and their colleagues combed through a database of more than 50,000 plasmapause crossings recorded from 1977 through 2015 by NASA's twin Van Allen Probes, the five-spacecraft THEMIS (Time History of Events and Macroscale Interactions during Substorms) mission, Europe's four-spacecraft Cluster mission, and others.

Because solar flares and related phenomena can cause substantial changes in the plasmasphere, the researchers eliminated readings taken when the Sun was active, leaving almost 36,000 observations.

Their analysis revealed tides in the plasmapause that ranged from about 0.12 times Earth's radius (300 kilometers) above average at high tide to 0.14 times Earth's radius (350 kilometers) below average at low tide—a difference of just 3% in the "smoothness" of the plasmapause. The researchers published their findings in *Nature Physics* (bit.ly/lunar-tide-effects).

"Whether lunar tides can influence the plasma-dominated regions had not yet been explored."

Surprising Offset

Ocean and land tides are highest and lowest close to the new and full Moon, when the Moon aligns with Earth and the Sun, and lunar and solar gravity pull along the same line. Unlike those tides, however, the plasma tides are offset from the Moon's position in the sky by 90°.

High plasmapause tide occurs when the Moon is at first quarter, and low tide occurs 2 weeks later, at last quarter. The tidal waves in the plasmasphere occur once per day and once per month, versus the twice-per-day and twice-per-month cycles for ocean and other tides.

It is reasonable that the Moon has a small but noticeable effect on the plasmasphere, said Jerry Goldstein, a space physicist at Southwest Research Institute in San Antonio, Texas, who studies the plasmasphere but was not involved in this project. "The most surprising thing is that the largest effect is 90° away from the lunar direction," he said. "Intuitively, one might expect the largest effect to line up with the Moon."

The plasmapause tide itself is caused by the Moon's gravitational pull, according to the researchers, but the 90° offset is more difficult to explain. It doesn't vary with the lunar phase, the Earth-Moon distance, changes in seasons, or any other known factors. That means it's caused not by gravity alone but by gravity and electromagnetic forces working together, the researchers said.

One possibility is that electrically neutral winds in the ionosphere, which vary with the Moon's phase, modify electric currents that thread along magnetic field lines through the ionosphere and into the plasmasphere. The currents might disturb the magnetic field, pulling the plasmasphere out of sync with the motions of the Moon. The researchers noted that this mechanism is poorly understood, however, and "is a subject of ongoing research."

The plasma tides "may indicate a fundamental interaction mechanism in the Earth-Moon system that has not been previously considered," Shi and Xiao wrote in their email. "That is to say, lunar tides may not be ignored in the study of the magnetosphere."

"Understanding this new result is going to require a fun dive into some basic space plasma physics."

Diving into Plasma Physics

The tides in the plasmasphere could have implications for space travel and studies of other planets in our solar system and beyond.

Magnetospheres have been detected at other planets, the study's authors noted, suggesting that plasma tides "may be observed universally throughout the cosmos," opening new avenues of research into planetary systems and other bodies with strong magnetic fields.

Earth's magnetic field plays an important role in spaceflight as well. It deflects cosmic rays and particles of the solar wind, offering some protection to craft within the magnetosphere. However, it funnels other particles toward Earth's surface or traps them in the radiation belts, potentially threatening spacecraft and astronauts, particularly when they travel to the Moon, outside the protection of the magnetic field.

"We suspect that the observed plasma tide may subtly affect the distribution of energetic radiation belt particles, which are a well-known hazard to space-based infrastructure and human activities in space," the authors noted. "It is therefore worthwhile to look for evidence of this effect in future studies."

"Understanding this new result is going to require a fun dive into some basic space plasma physics," Goldstein said.

By **Damond Benningfield,** Science Writer

This artist's rendering depicts NASA's twin Van Allen Probes, which looped through the plasmapause many times, in Earth orbit. Credit: JHU/APL, NASA