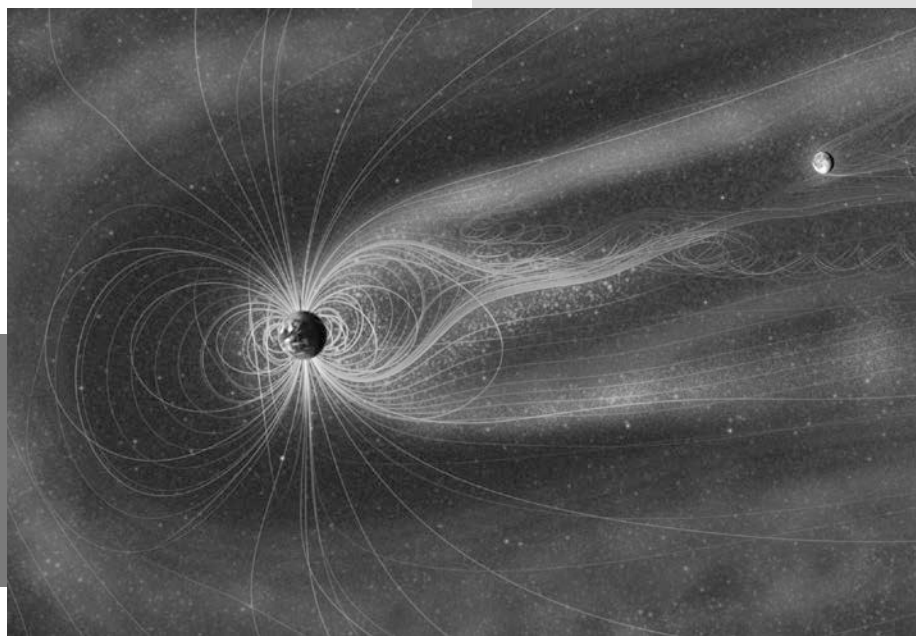


Earth, Wind and Water



Throughout the *Apollo* missions, NASA believed there was no water on the Moon.

In the nearly one thousand pounds of rock and soil samples that these missions brought back, they did find *traces* of water. But they assumed these were contamination from *gathering* and transport.

Then in 2008, the Indian space agency launched a Moon orbiter carrying NASA's Moon Mineralogy Mapper—or M3—which was designed to search for minerals, like water.

The tilt of the Moon's axis prevents sunlight from reaching into some lunar depressions.

M3 used infrared light absorption to discover ice hidden in the dark corners of these craters—especially near the frigid lunar poles.

But the Moon's atmosphere is too thin to keep water from *escaping* into space. As it dissipates, how is it being replaced?

Scientists realized that solar wind bathes the Moon in hydrogen ions for three weeks of its four-week orbit around Earth. The hydrogen reacts with oxygen compounds in Moon rocks to form water.

During the one week of *full* moon, when the Moon is hidden behind Earth, it's also shielded from the solar wind.

At that time, *Earth* wind—the tail of our magnetosphere, which is deformed by solar wind into a teardrop that stretches toward the Moon—*also* bathes it in hydrogen and oxygen.

Without these constant supplies of the building blocks of water, from both Sun and Earth, the Moon would, in fact, be totally dry.

Artist's depiction of the Moon in the magnetosphere, with "Earth wind" made up of flowing oxygen ions (gray) and hydrogen ions (bright blue). These ions can react with the lunar surface to create water. The Moon spends >75% of its orbit in the solar wind (yellow), which is shielded by Earth's magnetosphere when the moon passes behind Earth during the 3 days before and 3 days after the full moon.

Credit: E. Masongsong,
UCLA EPSS, NASA GSFC SVS



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Background: Earth, Wind and Water

Synopsis: Recent unmanned Moon missions have confirmed the existence of ice, as well as rusty iron oxides, near the lunar poles. With its thin atmosphere, water on the Moon's surface should evaporate and be lost to the vacuum of space. Yet evidence of water persists. Scientists believe that most of the time, hydrogen ions needed for lunar water are provided by the solar wind. But for about 25% of the lunar cycle, when Earth shields the Moon from the solar wind around the time of the full moon, it is Earth wind, from Earth's *magnetotail*, that bathes the Moon in ions like hydrogen that react with oxygen in lunar rocks to replenish lunar hydroxyl (-OH) and water (H₂O).

- As Earth's moon goes through its monthly phases, it always seems to look the same: oceans of basalt peppered with craters, frozen in time.
 - In a previous *EarthDate* (ED-040 The Man in the Moon), we learned that the Moon is synchronized with Earth, orbitally locked so that we see only its near side.
- On December 19, 1972, astronaut Gene Cernan stepped from the surface of the Moon back into the lunar module for *Apollo 17's* return to Earth. He was the last human to set foot on the Moon.
 - The *Apollo* missions explored the brightly lit equatorial regions on the near side of the Moon, and they never visited during the full moon.
 - Scientists of the *Apollo* era believed the Moon to be bone-dry, reasoning that the limited lunar atmosphere could not prevent water vapor from escaping into space.
- The 842 lb (382 kg) of soil and rock specimens returned to Earth during the *Apollo* program supported that preconceived notion, and any hints of water in the samples were attributed to contamination.
- In the five decades since *Apollo 17's* voyage, unmanned lunar missions have continued to reveal many of the Moon's secrets—including the presence of lunar water.
 - Over the decades, other tools had hinted at the presence of hydrogen on the lunar surface but could not distinguish whether the hydrogen was associated with hydrous minerals or water.
 - In 2008, the Indian Space Research Organization launched the *Chandrayaan-1* orbiter, which was carrying a variety of tools, including NASA's Moon Mineralogy Mapper (M3).
 - The M3 was designed not just to detect minerals like water, but to use infrared light absorption to distinguish among water vapor, liquid water and solid ice.
- The slight tilt of the Moon's rotational axis prevents sunlight from ever touching portions of some lunar depressions. These are called permanently shadowed regions (PSRs).
 - The M3 confirmed that ice is hidden in the eternal darkness of these PSRs, especially those near the lunar poles, where temperatures rarely exceed -250°F (-157°C).
 - Ice is concentrated in craters near the southern pole but is more dispersed around the northern pole.



The full moon from Belgium.

Credit: Luc Viatour, CC BY-SA 3.0, via Wikimedia Commons

References: Earth, Wind and Water

- Water Can Be Created on the Lunar Surface by Earth's Magnetosphere | Phys.org
A New Form of Space Weather: Earth Wind | SpaceWeather
Earth's Magnetic Field Does Strange Things to the Moon | NASA
Water on the Moon: Research Unveils Its Type and Abundance | Phys.org
Bizarre Discovery Reveals the Moon Is Rusting | ScienceAlert

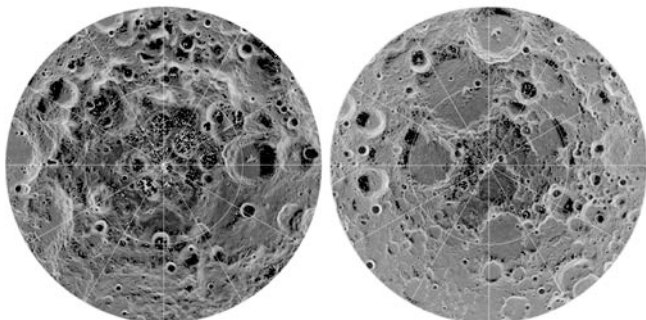
Contributors: Juli Hennings, Harry Lynch



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Fact Sheet:
Episode **ED 231**

Background: Earth, Wind and Water

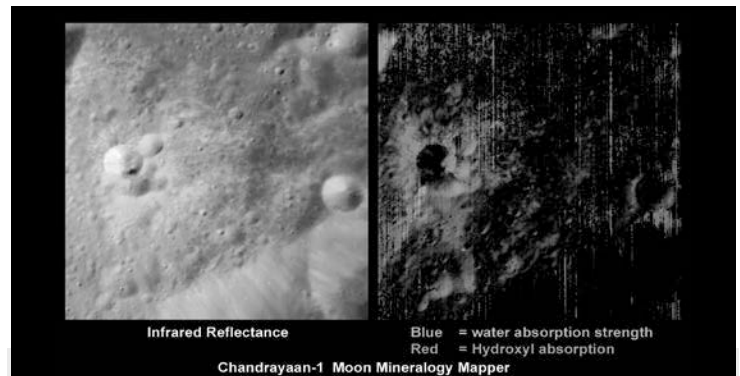
- Since 2009, NASA's *Lunar Reconnaissance Orbiter (LRO)* has mapped PSRs on the lunar surface, creating an extensive atlas.
 - When an impact probe from the *LRO* deliberately crashed into one of the PSRs, the *LRO* analyzed the plume of dust from the impact, which contained an estimated 340 lb (155 kg) of water.
 - In 2018, detailed analysis of the 2009 M3 data revealed that above 70° latitude, lunar water-ice concentrations range from 2% to 30%.
 - Additional water may exist in blocks or sheets below the surface and be contained in hydrous minerals in Moon rocks.
 - Comets and asteroids are known to contain water and have clearly pummeled the Moon, so the ice could be billions of years old.
 - Ice on the Moon could be a resource for future expeditions or Moon bases, including being a source for hydrogen and oxygen for rocket fuel.
- Finding water on the Moon is exciting, but how does that water persist over billions of years on a body with an atmosphere too thin to prevent water vapor from escaping into space? How is it replenished?



Distribution of surface ice at the Moon's south pole (left) and north pole (right), detected by NASA's Moon Mineralogy Mapper instrument. Blue represents the ice locations, plotted over an image of the lunar surface, where the gray scale corresponds to surface temperature (darker representing colder areas and lighter shades indicating warmer zones). Unfortunately, the orbiter stopped sending radio signals after 312 days, prematurely ending the mission.

Credit: NASA

- Like solar plasma, solar wind contains about 90% ionized hydrogen, 8% helium, and trace amounts of other solar fusion materials.
 - The Moon's dayside surface is bombarded by solar wind for three weeks every month. During this period, positively charged hydrogen ions spontaneously react with materials on the lunar surface, producing hydroxyl (-OH) and molecular water (H₂O).
 - Scientists determined that without a supply of hydrogen ions from the solar wind for the last week of the lunar month, evaporation should cause half of the lunar water ice at high latitudes to disappear, drying out the surface. But that does not happen.
- Solar wind blasts out of the Sun continually at >1 million mph (>1.6 million kph), blowing Earth's magnetosphere into an extended teardrop shape with a long magnetotail pointing downwind, away from the Sun.



These images show a lunar crater on the side of the Moon that faces away from Earth, as viewed by NASA's Moon Mineralogy Mapper on the Indian Space Research Organization's *Chandrayaan-1* spacecraft. On the left is an image showing infrared brightness. On the right, the abundance of water (light blue) and hydroxyl (red) is shown around a small crater. Hydroxyl-rich materials are seen as two rays emanating from the crater at the one o'clock and seven o'clock positions. Water-rich materials encircle the crater. Ray patterns such as those containing the hydroxyl usually indicate that materials have been excavated from below the surface. If so, it is possible that there are deposits of water- and hydroxyl-rich materials just below the surface of the Moon.

Credit: ISRO/NASA/JPL-Caltech/USGS/Brown Univ.

References: Earth, Wind and Water

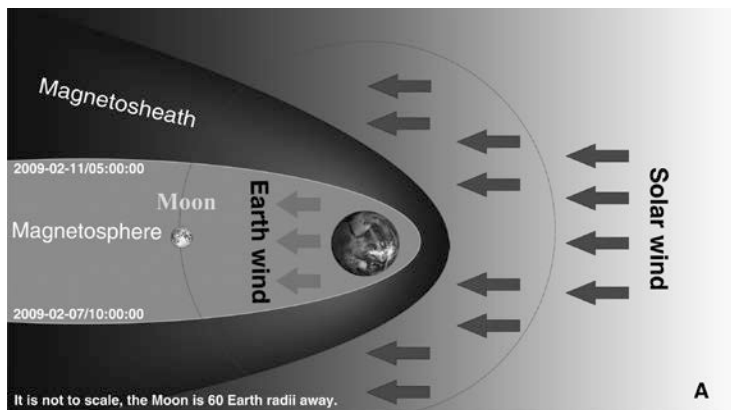
- Water Can Be Created on the Lunar Surface by Earth's Magnetosphere | Phys.org
- A New Form of Space Weather: Earth Wind | SpaceWeather
- Earth's Magnetic Field Does Strange Things to the Moon | NASA
- Water on the Moon: Research Unveils Its Type and Abundance | Phys.org
- Bizarre Discovery Reveals the Moon Is Rusting | ScienceAlert

Contributors: Juli Hennings, Harry Lynch

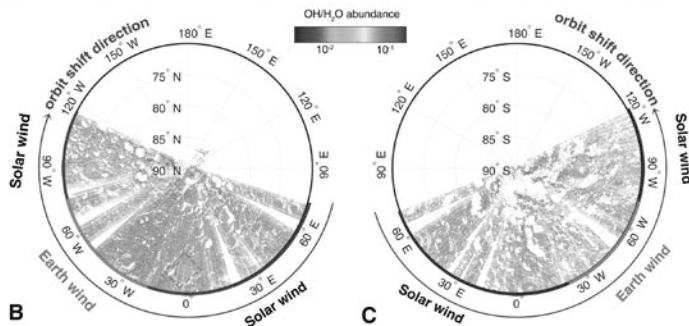


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- Earth's magnetotail whips back and forth, bathing the full moon repeatedly with hydrogen, helium, oxygen and nitrogen ions and compounds.
- Recent analyses have shown that the polar regions of the Moon contain oxidized hematite (Fe_2O_3), commonly known as rust. The oxygen component of Earth wind appears to be rusting iron minerals on the Moon.
- If you can see the full moon, you can be sure it is being shielded and enriched by Earth wind from Earth's invisible magnetic tail—and probably rusted, too.
- Humans have never experienced Earth wind while on the Moon: none of the *Apollo* missions occurred during the full moon. Extreme voltage variation may be a hazard of a manned Moon mission experiencing Earth wind.
- During the new moon phase, Earth is in the path of Moon wind.



(A) Lunar orbit in a *lunation*, indicating that for 3 to 5 days of every lunation, the Moon lies within the Earth's magnetosphere, shielded from the solar wind.

(B) Northern and (C) southern overview of lunar -OH/H₂O abundance in the polar regions derived from the M3 observations from January 26 to February 23, 2009. There is no data in the blank area. Red and black bars mark the duration of the Moon's exposure to Earth wind and solar wind, respectively. The blue arrow indicates the M3 orbital shift direction. The red rectangle indicates the Goldschmidt crater, in which lunar -OH/H₂O abundance is anomalously high due to its material composition.

Credit: Wang and others (2021), *The Astrophysical Journal Letters*



Enhanced map of the hematite (red) at the lunar poles. Higher concentrations occur on the near side, closer to the earthly source of the oxygen.

Credit: Shuai Li, Hawai'i Institute of Geophysics and Planetology (HIGP) in the UH Mānoa School of Ocean and Earth Science and Technology (SOEST)

- During the week of the full moon, Earth is between the Sun and Moon, so Earth's magnetotail points directly toward the Moon, shielding it from the solar wind. But that is not all that it does. The tail produces Earth wind.
- Careful analysis of water surface maps before, during and after the Moon's transit through the magnetotail indicate that Earth wind provides a richer flow of earthy magnetospheric ions than solar wind.

References: Earth, Wind and Water

- Water Can Be Created on the Lunar Surface by Earth's Magnetosphere | *Phys.org*
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 Earth's Magnetic Field Does Strange Things to the Moon | *NASA*
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