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# On a New Moon Far, Far Away

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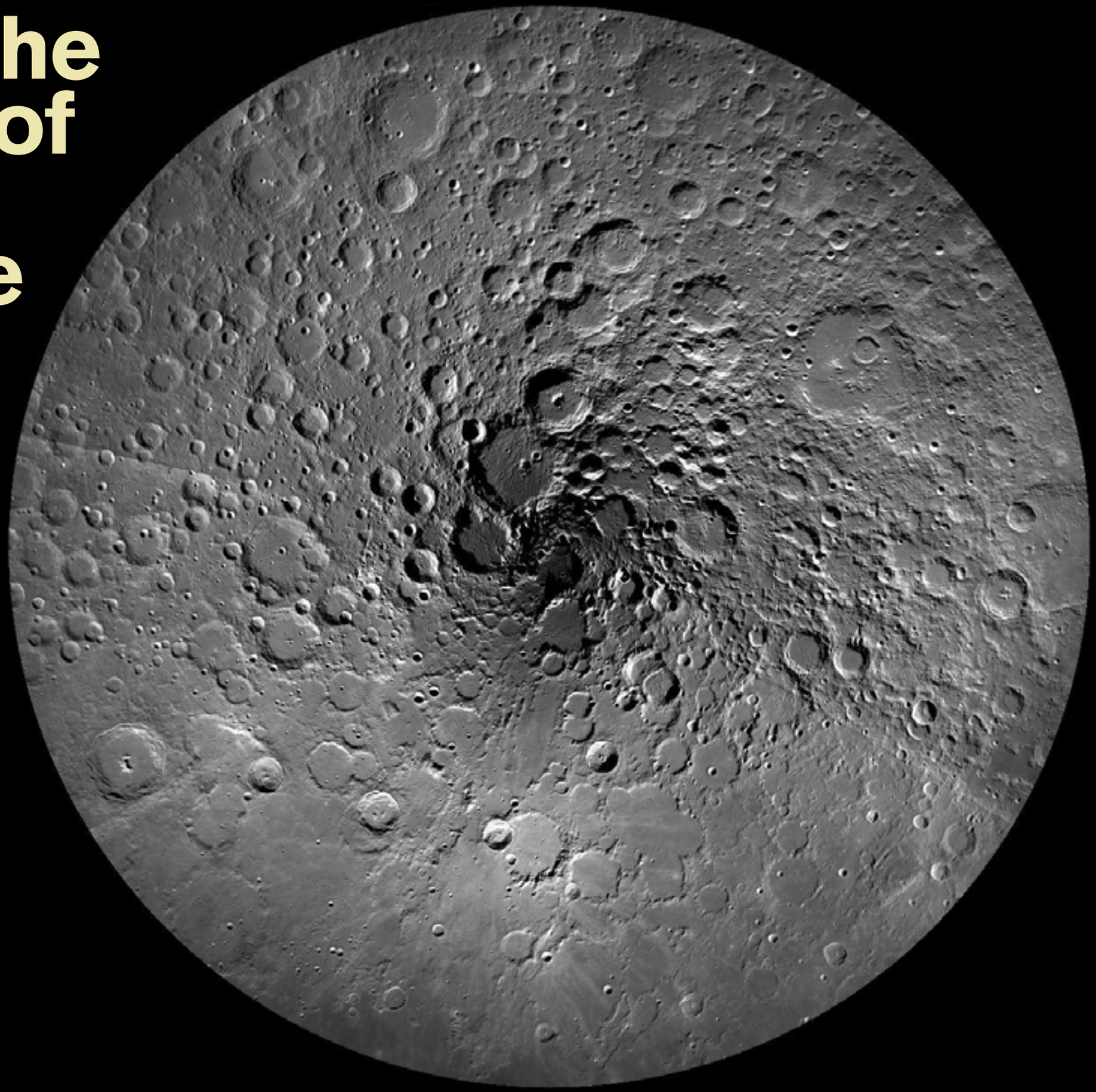
# Beyond the Shadow of a Doubt, Water Ice Exists on the Moon

## Deposited in perpetually dark craters around the poles, the ice could be a boon for future crewed lunar outposts

*By Leonard David*



Mosaic of 983 images of the moon's north polar region. Taken over the course of a month by the Lunar Reconnaissance Orbiter Camera.

NASA, GSFC AND ARIZONA STATE UNIVERSITY

THE VIEW THAT EARTH'S MOON IS A DRIED-OUT, DESOLATE WORLD MAY BE ALL WET.

A new analysis of data from the Indian Space Research Organization's Chandrayaan 1 orbiter, which operated at the moon from 2008 to 2009, has revealed what researchers say is definitive proof of water ice exposed on the lunar surface. Gathered by NASA's Moon Mineralogy Mapper (M3) spectrometer onboard the Indian probe, the data all but confirm extensive but tentative evidence from earlier missions hinting at water ice deposits lurking in permanently shadowed craters at the moon's poles. Such deposits could someday support crewed lunar outposts while also revealing previously hidden chapters of the moon's history. The results appeared in a study published August 20 in *Proceedings of the National Academy of Sciences USA*.

Based on M3's measurements of water ice's near-infrared absorption features at and around the lunar poles, the study's authors concluded the ice is only exposed in around 3.5 percent of the craters' shadowed area, and is intermixed with large volumes of lunar dust. Such sparse coverage and heterogeneity suggests this lunar ice has a substantially different history than similar deposits found on other airless rocky worlds, such as Mercury and the dwarf planet Ceres, where water ice in permanently shadowed craters is more abundant and of greater purity.

## A DISCOVERY DECADES IN THE MAKING

"Before our work there is no direct evidence to show there is surface-exposed water ice on the moon," says lead author Shuai Li, a planetary scientist at the University of Hawaii in Mānoa. For decades radar sweeps from Earth of the lunar polar regions and by moon-orbiting craft have delivered ambiguous results. Similarly, instruments carried onboard NASA's still-circling Lunar Reconnaissance Orbiter cannot directly, definitively detect the presence of water ice, he says. In fact, he notes, many past claims of "water" on the moon were really just detections of hydrogen-enriched, bone-dry minerals on the lunar surface.

Likewise, Shuai adds, although NASA's Lunar CRater Observation and Sensing Satellite (LCROSS) mission did uncover signs of lunar water in 2009, when it sent probes crashing into the permanently shadowed region of Cabeus Crater near the moon's south pole, that water was not necessarily from exposed ice at the surface. "LCROSS is a great mission.... However, the conclusion of surface-exposed ice from this mission is based on modeling; it is indirect. And also, there is only one data point in the south polar region," Shuai says. In contrast, he notes, the "very unique" spectral features of water in the M3 data incontrovertibly show the presence of exposed ice on the floors of craters across the moon's polar regions.

"The results seem very convincing to me," says Ian Crawford, a planetary scientist at Birkbeck, University of London, who was not a part of the study.

Now that these deposits have been found exposed on the lunar surface, Shuai and other researchers say, they could be more easily used to fuel future exploration and sustain human outposts. The ice could be melted and distilled to provide potable water, and could also be broken apart into its constituent hydrogen and oxygen to produce breathable air as well as rocket propellant.

## A FROSTY VENEER—OR THE TIP OF AN ICEBERG?

Before any of that water is exploited for exploratory gain, however, most scientists would prefer to know just how much of it there is, and how it got there in the first place.

According to Anthony Colaprete, who served as principal LCROSS investigator at NASA's Ames Research Center, the ice's patchy distribution is key for determining its history. "Assuming [it] isn't a measurement effect, this says to me that these patches of water ice are not in equilibrium with a current, ongoing source of water," Colaprete says. A more uniform distribution—like that seen

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for ice in craters at Mercury's poles—could indicate the ice was being supplied by periodic impacts from water-rich comets or asteroids.

But if the moon's polar ice is not the product of regular, geologically recent impact events, where did it come from? "One possibility is it is from an ancient reservoir," Colaprete says, referring to the early stages of more than 4.5 billion years of lunar history, when outgassing from volcanoes and colossal impacts may have briefly imbued the moon with a warm, wet atmosphere. Any deposits of water ice leftover from that bygone era could later be excavated, mixed and diffused to and around the surface via subsequent impacts and solar irradiation.

In the paper Shuai and his co-authors note the ice's patchiness may be due to a hypothesized phenomenon called "true polar wander," in which the orientation of the moon's axis of spin shifts over long periods of time. In this scenario the distribution of exposed surface ice would hew close to how the moon's polar wandering altered its craters' exposure to sunlight across geologic time.

Because of such uncertainties about its origins as well as the limited nature of the M3 observations, Colaprete says it is currently impossible to say how much bulk water lurks in the moon's polar caters. "At [M3's] wavelengths we are only sampling the top 10 microns or so; thus the water could be a frost or veneer only 100 microns thick—or it could be the tip of the 'iceberg.'"

What is needed, says Crawford, is more high-resolution mapping from low-orbiting satellites, which could use neutron spectrometry to peer beneath the surface—or better yet, on-location robotic landers to obtain samples.

## A COMMUNITY CONVINCED

"When Shuai Li first described what he wanted to investigate using M3 data, I thought he was crazy," says Carle Pieters, a planetary scientist at Brown University and principal investigator for the M3 instrument who was not a part of Shuai's study. Whereas the concept behind Shuai's work is sound, she says, many researchers had given up on searching for water ice within the M3 data, due to its relatively poor quality for most of the moon's shadowy poles. Shuai and his team tackled the problem by developing multiple independent statistical tests to demonstrate the data's indications of water ice were genuine and not coincidental flukes.

"Through the years, I've learned not to tell a bright, energetic young scientist that something really hard is impossible. Often it is, but sometimes—like now—I'm delighted to be surprised," Pieters says. "They have indeed convinced me of the existence of water ice in the polar shadows."

*Additional reporting by Lee Billings.*