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cities, they were not strongly affected by heat stress.

"I don't have a clear answer for why Maryland behaves a little bit differently than New York and Boston," Reinmann said.

"It reminds me of some research on people's experiences of heat stress," said quantitative ecologist Ailene Ettinger of The Nature Conservancy. "People in northern latitude cities also tend to be much more sensitive to high heat events because we're not as well acclimated."

"It reminds me of some research on people's experiences of heat stress."

It's possible that each city contains genetically distinct subspecies of maples and oaks that have adapted to different weather patterns, Reinmann said. Given that hypothesis, Babst said it could make sense to compare the growth of trees derived from all three cities side by side under a range of climate conditions—a "common garden experiment," as it's called in the field. "That would be a really, really cool project," he added.

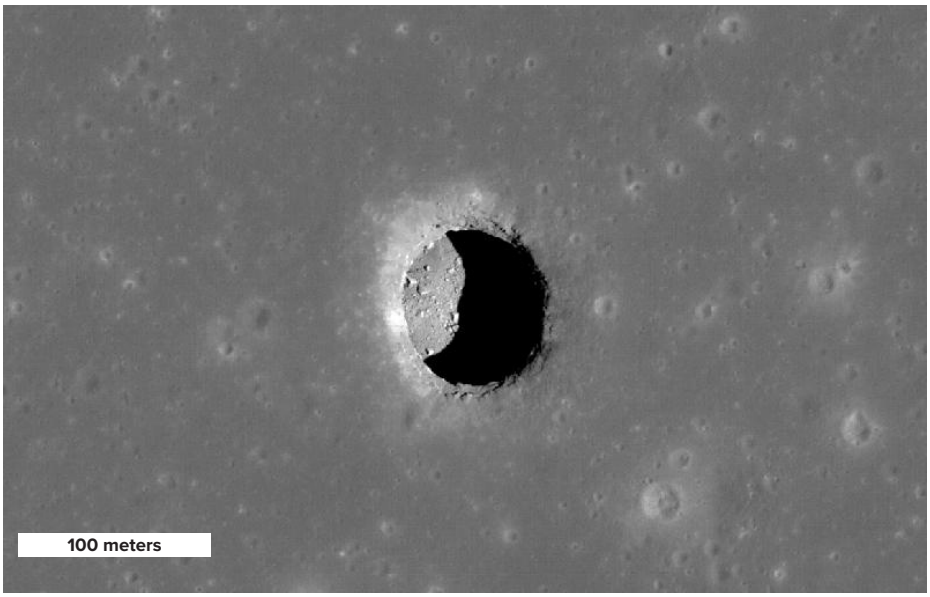
The study is a nice start, but scientists have a way to go before they fully understand how urban trees are responding to climate. "Sample size in this research is relatively small," said forest ecologist and postdoc Jiejie Wang of Université Laval. Analyzing more trees will help researchers draw robust conclusions. Babst suggested analyzing longer time series.

Measuring water stress also can be tricky because it can be difficult to say how much of the water in the environment is actually available to trees. Wang said she thinks analyzing soil moisture would be the most appropriate way to determine this. Instead, the researchers used a combined measure of heat and water. "I would have liked to see a water-only metric, like simply precipitation, for example," Babst said.

The sooner follow-up work can happen, the better, Ettinger said. "Urban trees are critical for bolstering our climate change resilience."

By **Saima May Sidik** (@saimamaysidik), Science Writer

Lunar Lava Tube Revealed Beneath Collapsed Pit



The Lunar Reconnaissance Orbiter took this high-Sun image of the Mare Tranquillitatis pit in 2010. Credit: NASA/GSFC/Arizona State University

The Moon's surface is pockmarked with more than 200 known pits where rocks and regolith collapsed into depths unknown. New research has found that one of those pits, in Mare Tranquillitatis, leads into a lava tube, making an underground cave conduit accessible from the lunar surface.

"We found a sort of front door to enter the subsurface," said Leonardo Carrer, a planetary scientist at the Università di Trento in Italy and first author of the research. Its access to the otherwise shielded lunar subsurface makes this pit a tantalizing site for future human and robotic exploration and could provide new insight into lunar volcanism.

Reflections from Below

The Moon was once covered in seas of magma that eventually cooled into the dark basaltic maria visible today. Lunar scientists have long thought that like Earth, the Moon could host other volcanic features such as lava tubes.

Lava tubes form when a lava stream cools and forms a hardened exterior shell. Hot lava continues to flow through it like sludge through a pipe. Eventually, lava flows out of the tube and leaves a hollow conduit that could connect to emptied magma chambers or caves.

"We had a lot of evidence on the surface of the Moon suggesting that lunar lava tubes could have existed," Carrer said. Lunar pits, elliptical craters that formed not from an impact but from the surface collapsing into an underground void, have been some of the most compelling evidence for these tubes. More than 200 of these pits have been imaged on the Moon's surface, and scientists have speculated that they may be skylights into cave conduits, which happen on Earth when the top of a cave collapses and exposes it to the surface.

"It was quite easy to understand the signals seen on the Moon, thanks to the Earth validation."

Carrer and his colleagues, including fellow Università di Trento planetary scientist

Lorenzo Bruzzone, wanted to know whether it was possible to map a hidden cave using orbital synthetic aperture radar (SAR) instruments. They first tested this method at a terrestrial cave system in Lanzarote, Spain, and another at the Well of Barhout in Yemen. Both are planetary analogues. They used the SAR data to create 3D reconstructions of the two terrestrial cave systems near their entrances.

"We verified that the cave characteristics we were measuring from space matched what the speleologists measured on the ground," Carrer said. That gave them the confidence to try out the technique on the Moon.

The researchers focused their attention on the Mare Tranquillitatis pit, a nearly circular sinkhole about 100 meters across and 105 meters deep. The radar data were taken in 2010 by the Lunar Reconnaissance Orbiter, which sent a signal into the pit at an angle and received a radar reflection from the bottom.

"We could detect from this pit…a reflection that clearly proved an opening on the bottom and the entrance of a cave, which probably is a part of a lava tube," Bruzzone said. "It was quite easy to understand the signals seen on the Moon, thanks to the Earth validation."

They fed those radar measurements into their computer model to create a 3D visualization of the lava tube with estimates of its dimensions. The model suggested that the entrance is at least 45 meters (148 feet) wide. Depending on how sharply the conduit slopes downward, it extends 30–80 meters (100–260 feet) from the entrance and reaches 135–175 meters (443–574 feet) below the lunar surface. This research was published in *Nature Astronomy* (bit.ly/lunar-conduits).

"Studying the rocks there, since they are pristine rocks not altered by the harsh surface, could give a lot of insight about lunar volcanism and the history of volcanism on the Moon."

Pristine, Unweathered Lunar History

"[This] analysis certainly indicates that there's a passage that goes deeper than we've been able to see with visible-wavelength images," said Robert Wagner, a planetary scientist at Arizona State University in Tempe who was not involved with this research. The passage might not connect with a larger cave, he cautioned, "but this new study is consistent with present-day access to a lava tube. The next step is really to send a mission to this pit to go in and directly investigate what's down there."

With international focus on lunar exploration and even permanent habitation, lunar caves are of interest for their potential to shield astronauts from radiation. But Bruzzone and Carrer are more excited by the geologic history that may be preserved inside this lava tube within rocks shielded from weathering and alteration by the solar wind and cosmic rays.

"Studying the rocks there, since they are pristine rocks not altered by the harsh surface, could give a lot of insight about lunar volcanism and the history of volcanism on the Moon," Carrer said.

What's more, if there is one intact lunar lava tube, there may be many, Wagner added. The prevalence of subsurface lava tubes could shed light on how lunar magma moved, cooled, and settled.

"Finding one that is completely intact, apart from one comparatively tiny hole in the roof, indicates that there may be quite a lot of deeply buried conduits waiting for us to get down on the surface with seismometers, gravimeters, or radar in order to find them," Wagner said.

However, exploring whether other pits connect with lava tubes will have to wait for better radar coverage of the Moon. "This cannot be seen with an optical camera," Bruzzone said, and currently available lunar radar data either are not of high enough resolution to study smaller pits or do not cover the maria regions where pits have been found.

"With the data that we have," he added, "it is not possible to clearly identify reflections that prove the accessibility from a pit and then into a cave."

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer