Space exploration goes underground

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Summary by subject area groups, workflow, statistics of panelists (Surveys 1 and 3) and the broader community (Survey 2), and breakdown of the 53 fundamental questions in planetary cave science and engineering by subject area group. Credit: Journal of Geophysical Research: Planets (2022). DOI: 10.1029/2022JE007194

Is there life in Martian caves?

It's a good question, but it's not the right question—yet. An international
A collaboration of scientists led by NAU researcher Jut Wynne has dozens of questions we need asked and answered. Once we figure out how to study caves on the Moon, Mars and other planetary bodies, then we can return to that question.

Wynne, an assistant research professor of cave ecology, is the lead author of two related studies, both published in a special collection of papers on planetary caves by the *Journal of Geophysical Research: Planets*.

The first, "Fundamental Science and Engineering Questions in Planetary Cave Research," was done by an interdisciplinary team of 31 scientists, engineers and astronauts who produced a list of 198 questions that they, working with another 82 space and cave scientists and engineers, narrowed down to the 53 most important.

Harnessing the knowledge of a considerable swath of the space science community, this work is the first study designed to identify the research and engineering priorities to advance the study of planetary caves. The team hopes their work will inform what will ultimately be needed to support robotic and human missions to a planetary cave—namely on the Moon and/or Mars.

The second, "Planetary Caves: A Solar System View of Products and Processes," was born from the first study. Wynne realized there had been no effort to catalog planetary caves across the solar system, which is another important piece of the big-picture puzzle. He assembled another team of planetary scientists to tackle that question.

"With the necessary financial investment and institutional support, the research and technological development required to achieve these necessary advancements over the next decade are attainable," Wynne said. "We now have what I hope will become two foundational papers
that will help propel planetary cave research from an armchair contemplative exercise to robots probing planetary subsurfaces."

**What we know about extraterrestrial caves**

There are a lot of them. Scientists have identified at least 3,545 potential caves on 11 different moons and planets throughout the solar system, including the Moon, Mars and moons of Jupiter and Saturn. Cave formation processes have even been identified on comets and asteroids. If the surrounding environment allows for access into the subsurface, that presents an opportunity for scientific discovery that's never been available before.

The discoveries in these caves could be massive. Caves may one day allow scientists to "peer into the depths" of these rocky and icy bodies, which will provide insights into how they were formed (but also can provide further insights into how Earth was formed). They could also, of course, hold secrets of life.

"Caves on many planetary surfaces represent one of the best environments to search for evidence of extinct or perhaps extant lifeforms," Wynne said. "For example, as Martian caves are sheltered from deadly surface radiation and violent windstorms, they are more likely to exhibit a more constant temperature regime compared to the surface, and some may even contain water ice. This makes caves on Mars one of the most important exploration targets in the search for life."
Planetary bodies for which possible cave entrances have been identified with number of features per body provided in parentheses (at top). Global locations for possible cave entrances for the Moon (center) and Mars (bottom). From Wynne et al. 2022b. Credit: AGU and *Journal of Geophysical Research: Planets*. Top photo: Real-time DNA sequencing in a lab installed in the Corona Lava Tube (Lanzarote, Canary Islands, Spain) in the framework of the ESA PANGAEA-X 2017 Astronaut training program. ESA astronaut Matthias Maurer is inside the lab module with co-author Ana Miller. Credit: ESA.

And it's not just finding life—these same factors make caves good locations for astronaut shelters on Mars and the Moon when crewed
missions are able to explore.

"Radiation shielding will be essential for human exploration of the Moon and Mars," said Leroy Chiao, a retired astronaut, former commander of the International Space Station and co-author of the first paper. "One possible solution is to utilize caves for this purpose. The requirements for astronaut habitats, EVA suits and equipment should take cave exploration and development into consideration, for protection from both solar and galactic cosmic radiation."

What Earth can tell us about other planets

Wynne, whose primary research is in terrestrial caves, said planetary cave research has long been a parallel research question to the earthly variety for nearly two decades. Caves support unique ecosystems that are sometimes quite divorced from the surface ecosystem in the same area. Who's to say a cave on the Moon or Mars would not be similar? So, many questions he's investigated about caves on Earth, he's wondered how it could apply on other planets.

He's not the only one making the connection. Wynne has done multiple research projects with NASA to help advance detection technologies, and his modeling of cave habitats does not much care if a cave is terrestrial or extraterrestrial. There are enough similarities in the cave environment to make reasonable predictions that will factor prominently into the selection of cave targets for exploration.

"Tellurian caves at depth are often characterized by complete darkness, a stable temperature approximating the average annual surface temperature, low to no air flow and a near-water-saturated atmosphere," he said. "The caves of other planetary bodies likely exhibit similar environmental conditions, but these will also be influenced by the surface conditions of the planetary body and the internal structure of the
Keith Cowing, editor of SpaceRef.com and NASAWatch.com, said using the existing infrastructure of a planet's surface and subsurface may help humans get to other planets sooner than if we had to bring everything needed to survive with us.

"Humans have been living in caves for hundreds of thousands of years. Then they built their own when none were available," he said. "As such, it is only natural to assume that caves will offer similar utility as humanity expands to other worlds. While planet-wide terraforming may be an end goal, the use of large, pre-existing structures such as caves and lava tubes may be a more practical way to bootstrap the technology to the maturity needed to tackle the surface of an entire planet."

Where are we now?

While much of this research is forward-looking, there's also a need to consider what resources, research and support currently exist. Numerous robotic platforms and instrumentation suites are being tested, but the roadblock comes where it so often does—the lack of funding. With sufficient support, a robotic exploration mission to a lunar or Martian cave could be possible in the next five to 10 years.

This research builds on past work to form a road map of sorts to move forward; Wynne sees it as a to-do list for that same process. The questions the scientists and engineers answered identify the tasks needed to prepare for that robotic exploration; it also looks even further ahead to the advancements needed in spacesuit technology, habitation modules and hardware that will enable humans to live and work safely underground on the Moon and Mars.

"This is an untapped area of inquiry in planetary science, and its
importance in the search for life should not be overlooked," he said. "In our lifetime, it is quite possible that we will peer into underground Mars to address the age-old question, 'Does life exist beyond Earth?'


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