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PRESS RELEASE

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Uncovering a Hidden Electrostatic Environment in Lunar Underground Caves

Supercomputer simulations reveal plasma and electrical conditions inside lunar pits and caves, with implications for future Moon exploration

A research team led by Associate Professor Yohei Miyake of the Graduate School of System Informatics and Assistant Professor Jin Nakazono of the Graduate School of Law, both at Kobe University, has used large-scale plasma simulations to characterize the distinctive plasma and electrostatic environment inside lunar pits and the underground caves connected to them.

As lunar exploration intensifies, driven in part by NASA's Artemis program, understanding the Moon's harsh space environment and identifying potential risks to exploration activities are becoming increasingly important. Lunar pits and caves have attracted attention as potential sites for scientific exploration and future human habitation, but their internal plasma and electrostatic environments remain largely unexplored.

The study shows that solar wind electrons and ions behave differently as they pass through a lunar pit. This leads to potential differences of up to approximately 100 V across the cave floor and electric fields reaching tens of volts per meter. The simulations also reveal that secondary electrons generated at the walls and scattered ions can enter even the deeper parts of the cave, where direct access by the solar wind is limited. These findings are expected to provide valuable baseline knowledge for the design and safe operation of future lunar exploration equipment.

The findings have been published in Geophysical Research Letters, a journal of the American Geophysical Union (AGU), on November 6, 2026.

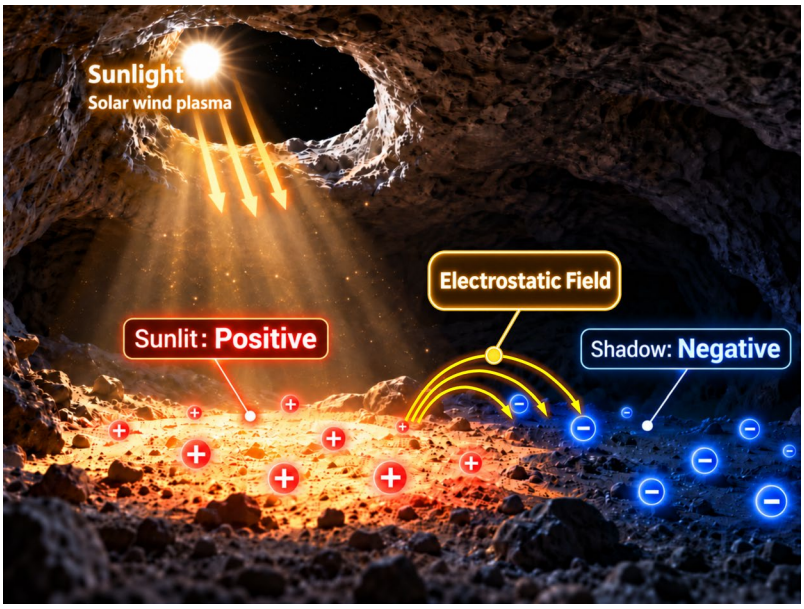


Figure 1. Conceptual illustration of the electrostatic environment inside a lunar pit and connected cave. Sunlit surfaces become positively charged, while shadowed surfaces become negatively charged; arrows illustrate the electric field. © Yohei Miyake, CC BY.

Key Points

- Large-scale three-dimensional particle simulations provide a pioneering characterization of the plasma and electrostatic environment within lunar pits and underground caves.
- Sunlit and shadowed areas of the cave floor become positively and negatively charged, respectively, generating potential differences of up to about 100 V and electric fields of tens of V/m.
- Secondary electrons and scattered ions penetrate deep into the cave, revealing additional environmental factors relevant to future lunar missions.

Background

Unlike Earth, the Moon has virtually no atmosphere or global magnetic field. The solar wind—a stream of electrons and ions flowing outward from the Sun—therefore reaches its surface directly. The arrival of these charged particles, together with the emission of electrons from the lunar surface under sunlight, causes the surface to acquire electric charge (see Note 1). These processes are important environmental risks for lunar exploration because they are associated with electrostatic problems in instruments and the adhesion and transport of fine lunar regolith particles.

Numerous deep openings known as lunar pits have been identified on the Moon. Some may connect to subterranean cavities such as lava tubes. These underground spaces could serve as natural shelters, protecting spacecraft and astronauts from intense radiation, meteoroid impacts, and extreme temperature variations.

However, the geometry of pits and caves blocks sunlight and solar wind particles, potentially producing complex charging conditions that differ from those on an open, flat lunar surface. Characterizing these environments has therefore been an important outstanding challenge for future missions targeting lunar subsurface spaces.

Research Findings

The team constructed a three-dimensional model of a lunar pit 50 m in diameter and 50 m deep, connected to an underground cave with a height of 20 m. They then investigated the motion of charged solar wind particles and the charging of the lunar surface. Using Kyoto University's Camphor 3 supercomputing facility (Note 2) and the high-performance parallel computing algorithm OhHelp (Note 3), developed over many years, they performed a plasma particle simulation (Note 4) involving approximately 25 billion computational particles.

The simulations revealed a pronounced difference in surface charging between the sunlit section of the cave floor, which receives sunlight through the pit opening, and adjacent regions shielded from sunlight by the pit walls (Figure 2a).

This contrast arises from the different behavior of ions and electrons. Solar wind ions (primarily protons) travel predominantly in one direction and can therefore reach the bottom of the pit relatively easily. Electrons, by contrast, move in many directions because of their thermal motion (Note 5), and many are absorbed by the pit walls before reaching the cave floor (Figure 2b). As a result, the influx of positively charged ions dominates in the sunlit region, causing strong positive surface charging. In the shadowed region, where ions cannot arrive directly, a small population of high-energy electrons produces negative charging (Figure 2a).

These contrasting charging processes generate potential differences of up to approximately 100 V across the cave floor and electric fields of tens of V/m near the boundary between sunlight and shadow. Although these fields are weaker than the intense fields thought to occur within microscopic gaps between regolith grains, they can extend over macroscopic distances of tens of meters. Such large-scale fields may affect the movement of charged lunar dust (Note 6) and the electrostatic environment encountered by exploration instruments.

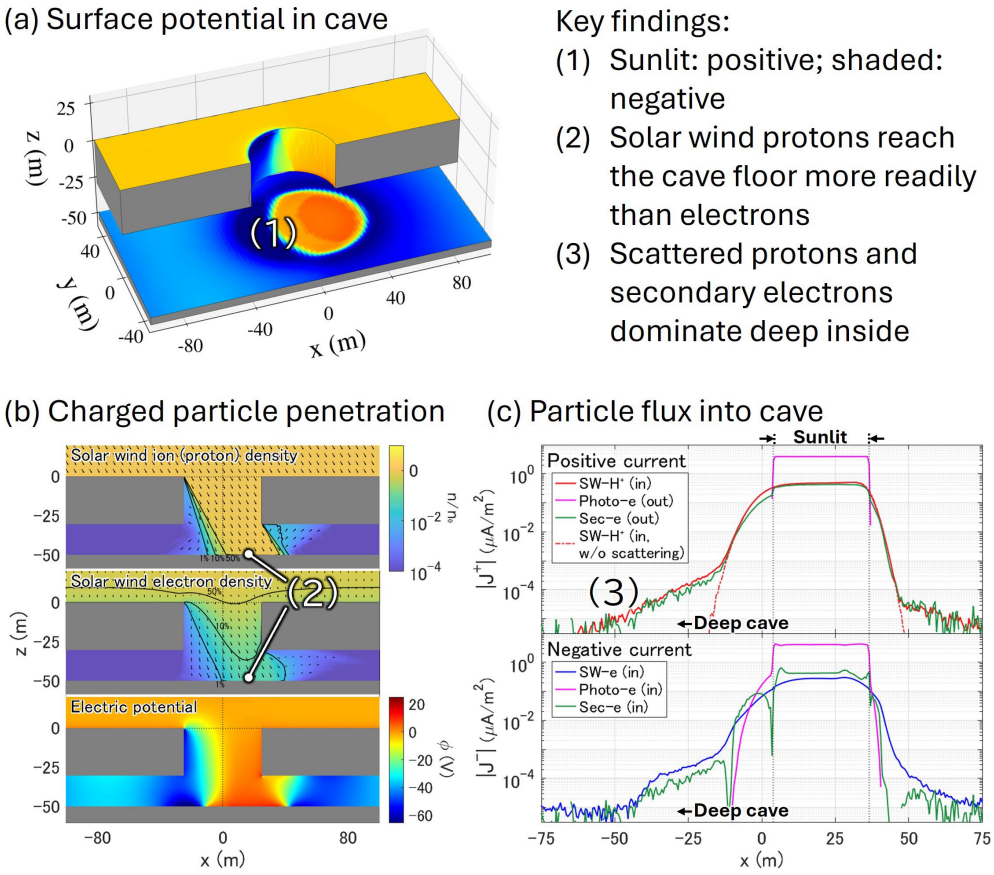


Figure 2. Main numerical results, adapted and translated in part from Figures 1–3 of Miyake and Nakazono, Geophysical Research Letters (2026). (a) Surface potential inside the cave; (b) penetration of solar wind charged particles into the pit; (c) particle fluxes reaching the cave floor, including scattered protons and secondary electrons. © Yohei Miyake, CC BY.

The study further shows that, although solar wind particles have difficulty reaching the deep interior of the cave directly, small numbers of secondary electrons emitted by particle impacts on the walls and ions scattered from surfaces can still penetrate into these regions (Figure 2c). These particle populations play a significant role in determining charging conditions where charged particles are otherwise extremely scarce. Because ambient charged particles may also help dissipate charge generated when exploration equipment contacts or rubs against the lunar surface, this finding has important implications for equipment operation inside underground caves.

Future Prospects

Japan Aerospace Exploration Agency (JAXA) and partners continue to study the UZUME concept, which aims to explore lunar pits. NASA has also announced GIMLI, a science investigation targeting the Marius Hills Pit (Note 7), reflecting growing international interest in the lunar subsurface.

The plasma and electrostatic conditions characterized in this study may inform instrument design and the assessment of charging and dust-related risks for such missions. Future work will examine different solar wind conditions and pit geometries to deepen our understanding of the space environment within lunar underground caves.

Glossary

Note 1. Electrostatic charging

The process by which a material acquires positive or negative electric charge through the arrival or departure of charged particles. Differences in electrical potential around charged surfaces give rise to electric fields.

Note 2. Camphor 3 supercomputer

A computing system installed at Kyoto University's Academic Center for Computing and Media Studies that began shared operation in October 2023.

Note 3. OhHelp

A parallel computing algorithm conceived by Professor Hiroshi Nakashima and colleagues at Kyoto University to accelerate large-scale particle simulations. It redistributes computational work among processors to avoid excessive workloads on particular processors and maintain efficiency even when particles are distributed very unevenly.

Note 4. Plasma particle simulation

A numerical method that calculates the motion of large numbers of electrons and ions and the electric fields they produce. By solving particle equations of motion together with Poisson's equation for the electric potential, it represents the mutual influence between particles and the electric field.

Note 5. Thermal motion

The continuous random motion of particles due to their thermal energy. Electrons and ions in plasmas undergo thermal motion; because electrons are much lighter, they typically move faster than ions at comparable temperatures.

Note 6. Lunar dust

Especially fine particles of lunar regolith. These particles may be lofted by micrometeoroid impacts, electrostatic forces, or exploration activities. Their sharp edges and tendency to adhere to equipment and spacesuits raise concerns about instrument failures and astronaut health.

Note 7. Marius Hills Pit

A lunar pit discovered in 2009 by Japan's lunar orbiter Kaguya (SELENE), located in the Marius Hills region and approximately 50 m in both diameter and depth. It is considered a possible entrance to an underground lava tube and a promising target for future exploration.

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