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Eyes in the Sky

The Artemis moon missions are a game changer for astronomy

BY JOSEPH HOWLETT

AS THE U.S. GOVERNMENT SLASHES its spending on basic science, one thing seems certain: there's still plenty of money for going back to the moon.

NASA's Artemis II mission is only the tip of the space agency's lunar-exploration spear; planning for crewed and robotic follow-ups is well underway. And all of these other trips could involve equipment for groundbreaking research, too.

There's a lot to learn on the moon. Most of it is about the moon itself—its murky origins, its expansive history and even the vital resources it might hold. But some astronomers, faced with increasingly austere government funding for their ground- and space-based projects, are beginning to see the moon as a more stable stage for some of their most ambitious cosmic studies.

ANŽE SLOSAR, A PHYSICIST at Brookhaven National Laboratory in New York State, had once hoped to put a radio telescope on the farside of the moon but abandoned his dream years ago. The mission just seemed too expensive, and there wasn't enough interest in it. "After the Apollo landings, the thinking was, 'We've done it,' and that was that," he recalls. Sentiments changed during the first Trump administration. One day Slosar got an e-mail from a Department of Energy program director asking him whether he still thought building a farside radio telescope was possible and whether he was interested in leading the DOE's involvement with such a project. It was the easiest choice of his professional career. "I said, 'Of course!' " he recalls. "It changed my life forever."

The reason for Slosar's enthusiasm is that a radio telescope on the moon could do things none on Earth can. Radio telescopes on the ground can collect signals from only a limited range of wavelengths. That's because as air molecules in the upper atmosphere soak up the sun's ultraviolet rays, they get so excited that they shed their electrons, becoming ionized. For most radio waves, the resulting ion-filled layer—the ionosphere—is like a giant mirror, blocking many inbound cosmic messengers.

The solution isn't as simple as launching a radio telescope into space. To be of much use to radio astronomers, any spaceborne observatory would need to be exquisitely sensitive—so sensitive that its observations would be swamped by telecommunications emanating from Earth. To tune in to distant galaxies and other faraway objects, astronomers would need an antenna in a place with no atmosphere that also would be somehow protected from all our terrestrial chatter.

Such a place exists, of course, and it's only a proverbial stone's throw from the third rock from the sun. Earth is locked in a synchronous dance with the moon, so the same lunar hemisphere always faces away from us. On that farside surface, the moon itself acts as a shield from Earth's cacophony of radio signals. This obstruction is exactly why Houston Ground Control lost contact with the Artemis II crew for about 40 minutes during the April 6 lunar flyby, when the mission's Orion spacecraft was masked by the moon. "Behind the moon, at the right time, you can avoid interference from both the sun and Earth," Slosar says. "It becomes one of the quietest places in our solar system for observing these radio frequencies."

That span of wavelengths happens to be a window into the most mysterious epoch of the universe's history.

Our oldest snapshot of the universe comes from some 380,000 years after the big bang. It is known as the cosmic microwave background, or CMB, and is made up of the light that was released when the hot, dense plasma that suffused the early universe cooled enough to form hydrogen atoms. Much like the radio-blocking swarms of electrons in Earth's ionosphere, unbonded electrons in that ancient, ionized plasma blocked light, too—so when they all settled down into

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NASA

The farside of the moon as viewed by the crew of the Artemis II mission. The moon blocks all radio waves from Earth, so it's an ideal place to gather them from the cosmos.

atomic hydrogen, light that had spent millennia hidden by the primordial fog was liberated to stream freely across the universe. Today we see this “last scattering surface” as a diffuse all-sky radio glow.

But we have essentially no data at all about the cosmos for hundreds of millions of years after that singular moment in time. That’s because the universe was full of relatively cool, light-smothering hydrogen, which emitted scarcely any light of its own. Only when stars and galaxies started forming from all that hydrogen was there enough light and heat to reionize some of the hydrogen atoms, making those growing cosmic structures visible to our telescopes.

There was a bit of light in the so-called cosmic dark ages, though: a faint trickle of 21-centimeter-wavelength radio emissions emanating from the hydrogen atoms. Astronomers have managed to detect some 21-centimeter cosmic signals through heroic efforts using ground-based instruments, but the noisy, patchy view painted by these detections is woefully incomplete. To map the dark ages in all their hidden majesty—to discover how, exactly, cool matter coalesced into luminous cosmic structures—the best option, by far, is to search from the farside of the moon.

That is where Slosar comes in. He now directs the DOE’s contributions to its partnership with NASA on a project called the Lunar Surface Electromagnetics Experiment–Night (LuSEE-Night), which aims to launch to the lunar farside in December 2026. It will fly onboard a Blue Ghost lander from Firefly Aerospace as part of NASA’s Commercial Lunar Payload Services (CLPS) initiative, which relies on landers built and operated by private industry to deliver spacecraft, experiments, and other payloads to the moon’s surface.

Once LuSEE-Night reaches its destination, its greatest challenge will be getting through the cryogenically cold lunar night, which lasts for the equivalent of about 14 Earth days. Pink Floyd might have misled you: the moon’s farside isn’t always dark. When it is, though, it’s an inhospitable place—few experiments have survived the night. Ultimately the mission is meant to be a pathfinder, proof that even larger and grander radio telescopes can be built and operated on the moon’s farside.

A FREE TRIP TO THE MOON would be a dream for the newest additions to the ranks of astronomers: those who study the universe by investigating gravitational waves.

The moon may be a more stable stage for astronomers’ most ambitious cosmic studies.

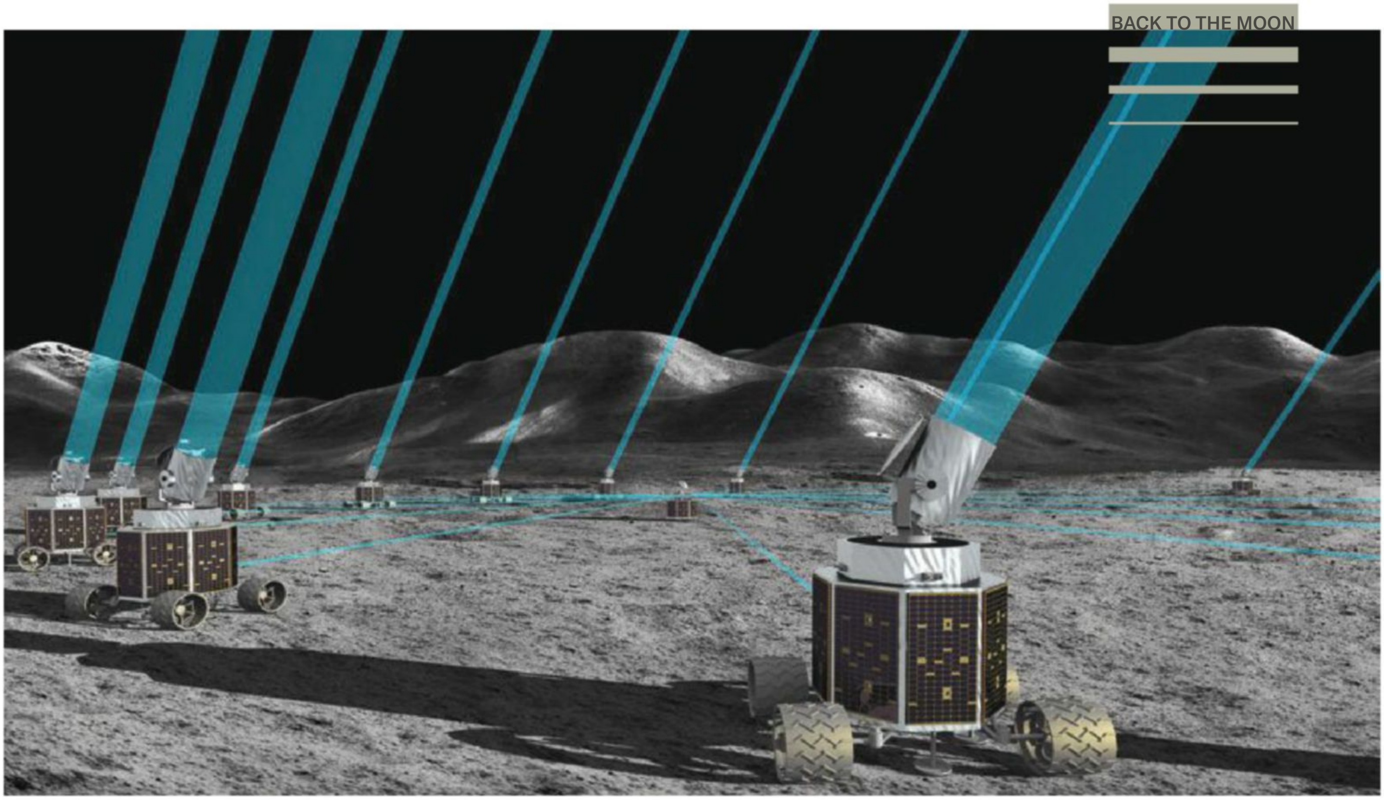
It was just 11 years ago that humans gained the ability to scan the skies for these elusive waves, using the Laser Interferometer Gravitational-Wave Observatory. Better known as LIGO, this project uses lasers to sense the subtle stretching of space and time caused by the cataclysmic merging of two gigantic black holes.

The European Space Agency’s upcoming Laser Interferometer Space Antenna (LISA) mission—essentially LIGO in space—will expand on the revolution LIGO started. Launching as soon as 2035, LISA could sense waves from mergers of black holes that are far more massive than those within LIGO’s purview. It will also spot the slower ripples of calmly orbiting binaries, emitted long before their death spiral begins. Both of these sources make waves with millions of kilometers between peaks, too long for any Earth-based instrument to register.

To complete their coverage of the gravitational-wave spectrum, astronomers have their eyes on the moon. The Laser Interferometer Lunar Antenna (LILA) would close the gap between LIGO and LISA by tuning in to waves with intermediate wavelengths. These signals would include those from the mergers of white dwarfs, the astronomical objects that produce many of the supernovae we observe through their electromagnetic emissions. LILA would also capture the gravitational waves from neutron star and black hole binaries just as they began their final descent toward coalescence, providing an early-warning system that could alert LIGO to collisions two weeks before they happened. “There is no other place in the solar system where you can detect gravitational views in this mid-band,” says Karan Jani, an astrophysicist at Vanderbilt University who is a principal investigator of the LILA project. “There is only the moon.”

That’s because the moon is much more geologically inert than our rowdy planet. “It doesn’t have as active a core,” Jani says, meaning the lunar surface can be a quiescent platform for gravitational-wave-spotting laser systems custom-made for the mid-band.

LILA will essentially be built of mirrors mounted on rovers. The project team hopes to hitch a ride on an upcoming CLPS mission. When the lander opens onto the lunar surface, two rovers with mirrors will head in different directions, forming a triangle with five-kilometer-long sides, with the lander as the triangle’s third point. Then an instrument on the lander will beam lasers out-



The Artemis-enabled Stellar Imager (AeSI) will use an array of mirrors mounted on rovers to take high-resolution photographs of faraway stars at every stage of their life cycle.

Britt Griswold/GSFC

ward to the rovers to compare their distances with subatomic precision. "To be honest, we wouldn't be thinking about LILA if the United States were not going to the moon," Jani says. The LILA team is hoping to reach a later phase of the project that would be carried out in collaboration with NASA's Artemis program and rely on astronauts for operation and maintenance.

OBSERVATORIES such as the James Webb Space Telescope (JWST) and the Hubble Space Telescope—and, for that matter, your typical consumer-grade reflector telescope—are all based on the same design: a mirror curved just so to channel incoming light from many directions onto a single focal plane. Large telescopes use segmented mirrors to collect more light from faraway objects and produce a crisper image; JWST's primary mirror is composed of 18 sections.

Optical interferometry is a way to make a telescope's light-gathering surface far bigger by spreading out such segments over an even larger area. In this approach, individual mirrors are interlinked in an array, with each node channeling its light to a central facility that carefully corrects and combines these inputs, effectively forming a much more powerful telescope.

By piggybacking on the Artemis program, NASA scientist Kenneth Carpenter aims to build an optical-interferometry facility on the moon. This proposed Artemis-enabled Stellar Imager (AeSI) would consist of 15 to 30 rover-mounted mirrors, allowing for reconfiguration and other fine-tuning on the fly so the imager could fix on any target in the lunar sky. Besides being a potent technological pathfinder, AeSI could monitor many stars throughout a sizable swath of the Milky Way. By studying them in ultraviolet light that terrestrial observatories can't access because of Earth's UV-blocking ozone layer, the project could literally shed more light on the still-mysterious details of stellar activity across the galaxy. "We have wonderfully high-resolution data on the sun," Carpenter says. "But we still haven't come up with a good predictive model of future activity." Scientists' best solar models struggle to precisely predict flare-ups on our own, most familiar star. But the hoped-for expansive stellar datasets that AeSI could provide may help change that.

The project could also benefit from astronautical interventions, Carpenter says, meaning AeSI maintenance would be another possible task for the Artemis crews that NASA plans to land on the moon by 2028 and throughout the 2030s. If Carpenter's decades of experience working on the Hubble Space Telescope taught him one thing, it's that troubleshooting an experiment is infinitely more effective with a human on-site. "The space shuttle and Hubble were kind of designed with each other in mind," he says, pointing to the STS-61 mission in 1993, which included a spacewalk to fix a critical problem with Hubble's mirror. That historic telescope, Carpenter says, "probably would have been a failure without the collaboration of the human spaceflight program." ●