New calibration service paves way for next-generation radio cosmology experiments

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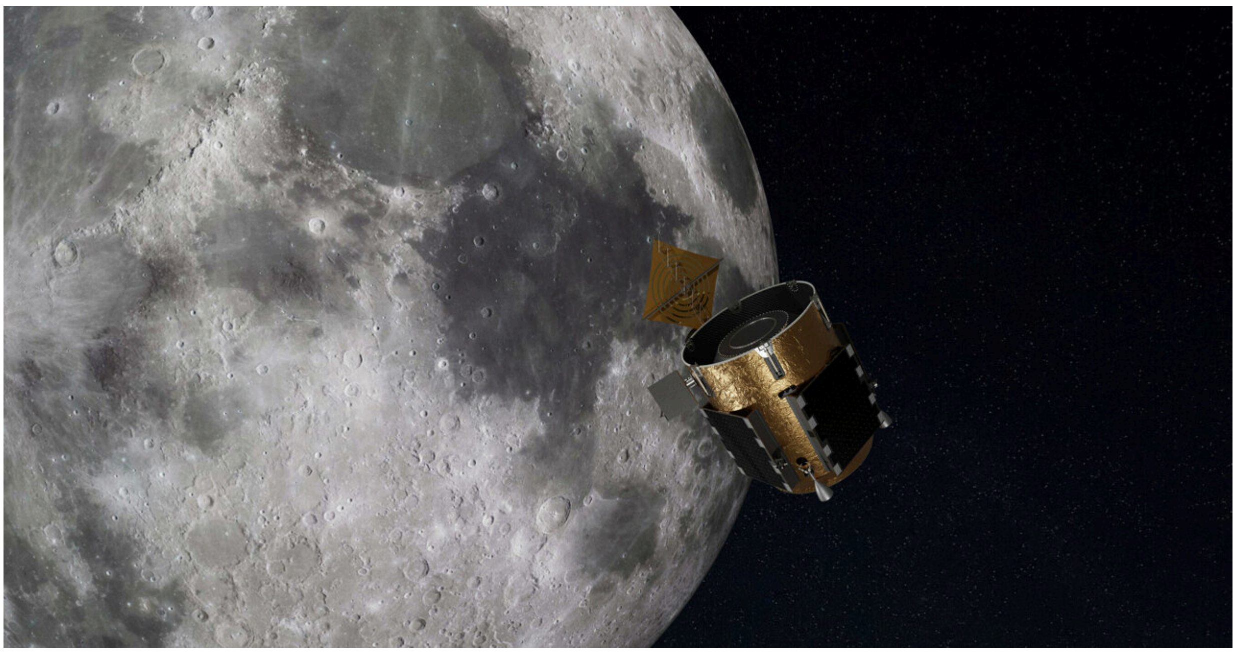

A rendering of the new calibration service. Credit: Firefly Aerospace

A unique "passenger" is joining an upcoming mission to the moon.

In 2026, physicists are planning to operate a radio telescope on the far side of the moon—an unforgiving environment that poses tremendous challenges for research equipment to survive, but also the promise of enormous scientific payoff. Called LuSEE-Night, the project aims to access lingering radio waves from the universe's ancient past, peering into an era of the cosmos that's never been observed before.

Now, thanks to new funding from NASA, the project has added a state-of-the-art calibrator to the mission. This calibrator will not only ensure measurements from LuSEE-Night are accurate but also set the stage for more sophisticated telescopes to reside beyond Earth.

A cosmologist's dream calibrator

All telescopes require calibration—a system of assessing the quality and wavelengths of light they collect—but calibrating LuSEE-Night is a substantial challenge.

First, the range of calibration techniques that can be applied to LuSEE-Night is far more limited than what is available for optical telescopes. Optical telescopes can move; they can focus on a star, look away, and then move back. By collecting measurements of known and unknown celestial objects, scientists can compare the two as a method of calibration. LuSEE-Night, on the other hand, will be completely stationary, operating with fixed antennas that "view" the entire sky at once.

So, how do scientists typically calibrate radio telescopes? They move the signal, not the telescope.

For traditional, ground-based radio telescopes, scientists have often tried to send a point source, usually an artificial radio source mounted on a drone, above the telescope. As the drone crisscrosses through the sky over the telescope, scientists can observe how the telescope responds and calibrate the instrument accordingly. But the way drones move and the chance for them to be blown off course by the wind makes it challenging to capture precise measurements. Not only is achieving this level of precision a necessity for a far-off lunar telescope like LuSEE-Night but flying drones from the moon is just not feasible.

LuSEE-Night will also take on the challenge of exclusively measuring very faint, low-frequency radio waves.

"The lower the radio frequency you're trying to measure, the harder the instrument is to calibrate," said LuSEE-Night science collaboration spokesperson Anže Slosar, a physicist at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory. LuSEE-Night is a collaborative effort between NASA and DOE, with Brookhaven Lab leading DOE's role in the project and DOE's Lawrence Berkeley National Lab providing key technical support.

All these challenges encouraged NASA to support a cosmologist's dream calibrator: a calibrator in orbit around the moon. NASA achieved this by purchasing a calibration service in the free market.

"The calibration service will be coming from a satellite in orbit. It is like the ultimate drone, an ideal point source," Slosar said. "You know exactly where it is; it is very stable and it is, for all practical purposes, infinitely far away—the same as real celestial sources."

Launching a satellite into orbit is far too expensive for calibrating ground-based telescopes.

"It's still not an easy task, but with DOE and NASA collaborating, we made it possible," Slosar said.

The development and launch of the calibrator, like the rest of the LuSEE-Night project, relies on NASA's Commercial Lunar Payload Services (CLPS) initiative. Through CLPS, NASA contracts private companies to carry out low-cost missions to the moon. And now, NASA has contracted Firefly Aerospace, Inc., the company already tasked with launching LuSEE-Night, to build the new calibrator; it's the first time NASA has asked for a calibration service from the CLPS pool of providers.

"The calibrator will be a sophisticated radiofrequency transmitter with a downward-looking antenna," said Paul O'Connor, a senior scientist in Brookhaven's Instrumentation Division and LuSEE-Night Project Instrument Scientist. "It will be in lunar orbit and emit a calibration signal every time it rises above the horizon, and LuSEE-Night will pick the signal up.

"Because we will always know exactly where the calibrator is and its signal intensity, we will also know exactly how much space radiation is coming from each direction we are studying. This will enable us to understand the nuances of our instrument's response, such as its sensitivity to polarization and how the incoming radiation interacts with the lunar regolith."

This design will enable the LuSEE-Night collaboration to achieve "absolute calibration," which Slosar says can rarely be achieved from the ground, let alone from the moon. Scientists expect the calibrator to reduce uncertainty from 20% to about 1%.

"While the basic technique is similar to that of drone calibration, this technique is ultimately much more sophisticated," Slosar added. "Instead of blinking or beeping an intermittent noise that we would have to distinguish from other noises in space, this calibrator will give us a known signal we can easily recognize, even when it is drowned in the much brighter emission from our own galaxy."

Ready for launch

The calibrator will travel into space on the same rocket as LuSEE-Night, becoming the latest passenger among a suite of scientific instruments headed to the moon—each with its own destination and timed arrival.

"When the transfer vehicle gets close to the moon, first, the landing equipment and the European Space Agency's Lunar Pathfinder communications satellite will detach and go into orbit. Then, the lander will shuttle the telescope to the moon's surface. Finally, the communications module for the lander and the calibrator go into orbit, where the calibrator will remain," Slosar said.

Five Earth days after LuSEE-Night lands on the lunar far side, Firefly Aerospace will remotely turn on the calibrator to ensure it is working. Since the lander will still be emitting interfering signals, these early data will require careful analysis. But once the first lunar sunset arrives and the lander turns off, then the true scientific mission of LuSEE-Night begins.

After 50 Earth days, the team will have gathered sufficient data from the telescope to achieve single-percent-level calibration.

"Our instruments are set up to do calibrations and normal science operations simultaneously so that we can collect data throughout the first lunar night," Slosar said.

By the second lunar night, the calibrator gets switched off because, in addition to demonstrating the calibration technique, launching this satellite into orbit is also an exercise in international relations.

"People long ago realized that the far side of the moon is unique space. It is one of the most radio-quiet places in existence," Slosar said. "Therefore, international treaties were signed, stating that nobody should pollute the lunar spectrum at radio frequencies below 300 megahertz, which are the most precious for radio astronomy. But now we have this calibrator that will emit radio frequencies, so the Federal Communications Commission must request a time-limited waiver from the International Telecommunications Union. In this case, we will have one and a half lunar days, or 50 Earth days, before it must switch off."

As the 50-Earth-day clock ticks down, scientists at Brookhaven Lab, empowered by interagency collaboration and public-private partnerships, will carry out one of the most ambitious radio cosmology experiments in history. Their work could help uncover answers to some of the universe's biggest mysteries, such as the formation of the universe itself.

Provided by Brookhaven National Laboratory

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