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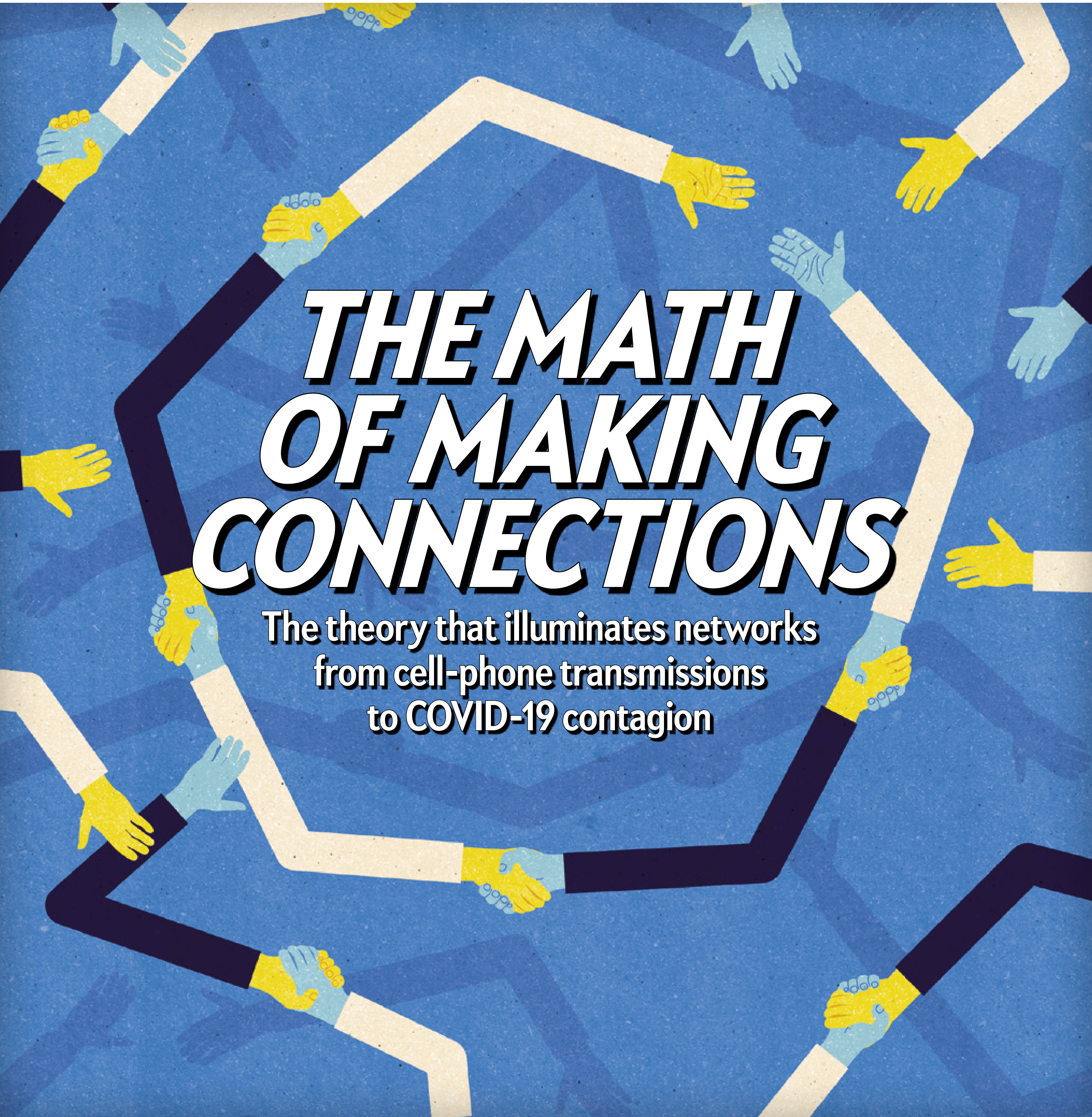

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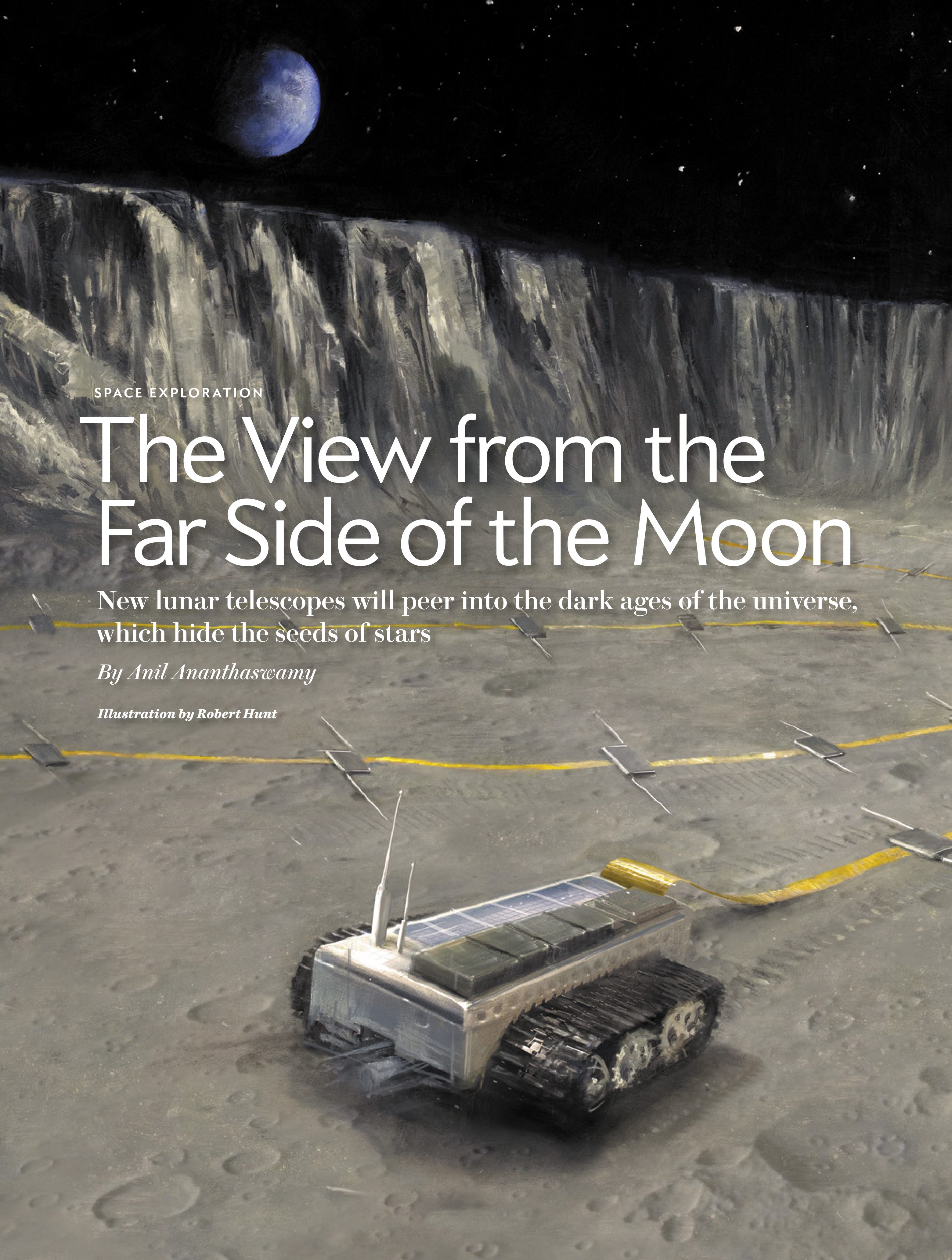


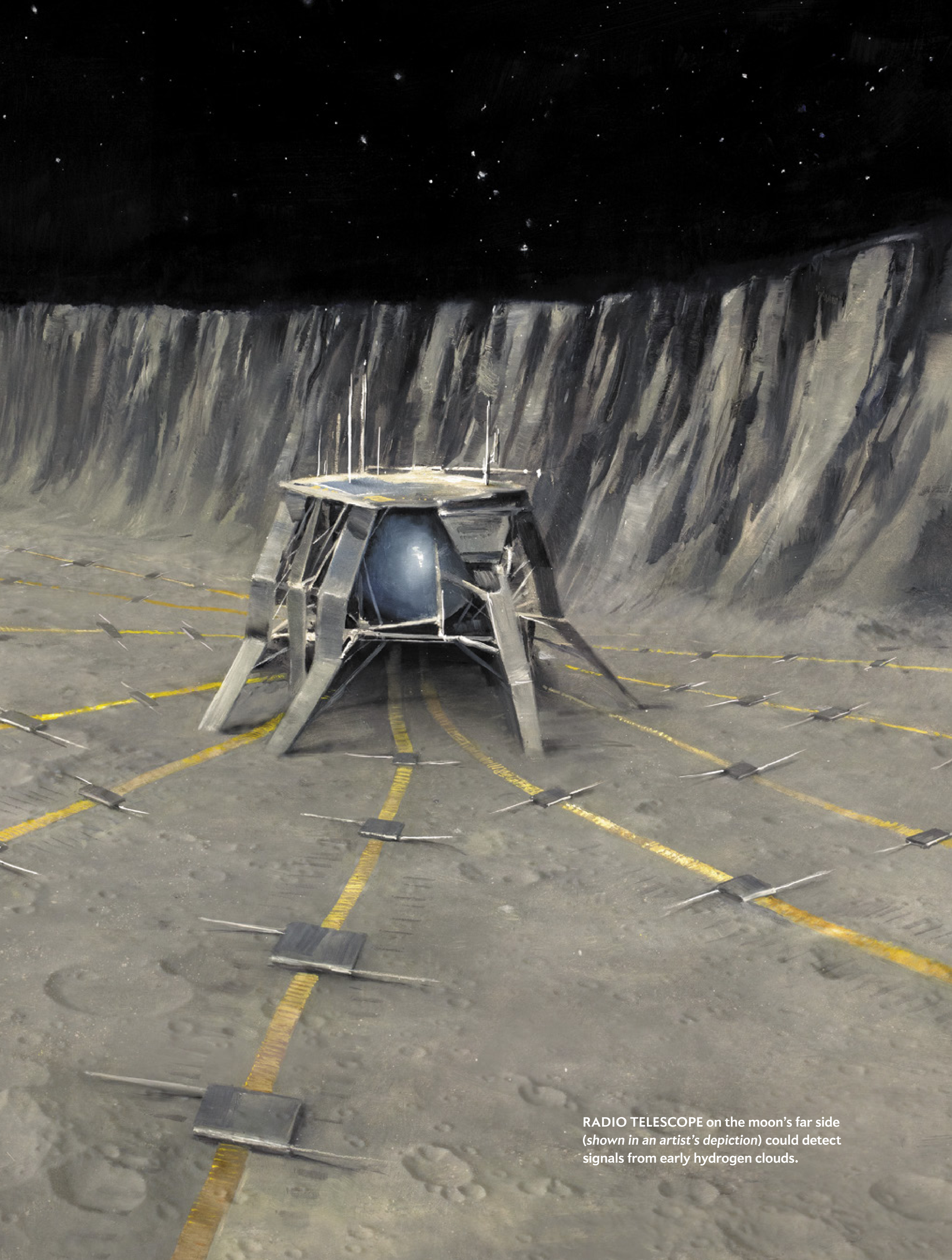
SPACE EXPLORATION

The View from the Far Side of the Moon

New lunar telescopes will peer into the dark ages of the universe, which hide the seeds of stars

By Anil Ananthaswamy

Illustration by Robert Hunt



RADIO TELESCOPE on the moon's far side (*shown in an artist's depiction*) could detect signals from early hydrogen clouds.

Anil Ananthaswamy is author of *The Edge of Physics, The Man Who Wasn't There* and, most recently, *Through Two Doors at Once: The Elegant Experiment That Captures the Enigma of Our Quantum Reality.*

THE FAR SIDE OF THE MOON IS A STRANGE AND WILD REGION, QUITE DIFFERENT FROM THE FAMILIAR and mostly smooth face we see nightly from our planet. In 1959 the Soviet Luna 3 space probe took the first photographs of this hidden region. Instead of wide plains, the images showed a moonscape spiked with mountains. Observations since then have shown that the far side is also full of rugged craters, and within them there are yet more craters. Soon this rough terrain and the space just above it will have even stranger features: it will be teeming with radio telescopes, deployed by a new generation of robotic rovers and lunar orbiters.

Astronomers are planning to make the moon's distant side our newest and best window on the cosmic dark ages, a mysterious era hiding early imprints of stars and galaxies. Our universe was not always filled with these bright objects that shine across today's skies. About 380,000 years after the big bang, the universe cooled, and the first atoms of hydrogen formed. Gigantic clouds of this element soon filled the cosmos. But for a few hundred million years, everything remained dark, devoid of stars. Then came the cosmic dawn: the first stars flickered, galaxies swirled into existence and slowly the universe's large-scale structure took shape.

The seeds of this structure must have been present in the dark-age hydrogen clouds, but the era has been impossible to probe using optical telescopes—there was no light. And although this hydrogen produced long-wavelength (or low-frequency) radio emissions, radio telescopes on Earth have found it nearly impossible to detect them. Our atmosphere either blocks or disturbs these faint signals; those that get through are swamped by humanity's radio noise.

Scientists have dreamed for decades of studying the cosmic dark ages from the moon's far side, shielded from earthly transmissions and untroubled by any significant atmosphere to impede cosmic views. Now multiple space agencies plan lunar missions carrying radio-wave-detecting instruments—some within the next three years—and astronomers' dreams are set to become reality.

"If I were to design an ideal place to do low-frequency radio astronomy, I would have to build the moon," says astrophysicist Jack Burns of the University of Colorado Boulder. "We are just now finally getting to the place where we're actually going to be putting these telescopes down on the moon in the next few years."

THE HYDROGEN HEARTBEAT

THE IDEA THAT TELESCOPES could detect neutral hydrogen goes back to the 1940s, when Dutch astronomer Hendrik Christoffel van de Hulst predicted that hydrogen atoms can spontaneously emit pulses of electromagnetic radiation. This happens because each atom of hydrogen can flip between two energy states, emitting or absorbing radiation at a wavelength of 21 centimeters (or a frequency of 1,420 megahertz). Such emissions are the "heartbeat" of hydrogen and can add up to detectable signals when clouds of the gas accumulate on cosmic scales.

Such signals should have first emerged about 380,000 years after the big bang, when the universe cooled enough for protons and electrons that previously filled space to coalesce into atoms of hydrogen. Besides forming the raw material from which all subsequent objects would arise, this event had the added benefit of making the universe transparent rather than opaque, liberating the fossil radiation produced by the big bang to stream through the cosmos. We now see this radiation—the big bang's afterglow—as the cosmic microwave background (CMB). Thereafter, neutral hydrogen pervaded the dark universe for perhaps the first few hundred million years, until the break of cosmic dawn, when the first stars and galaxies began to shine.

Cosmologists are particularly interested in the dark ages because they offer a glimpse of the universe when it was relatively pristine, free of confounding astrophysical effects. Back then, the distribution of neutral hydrogen still carried the imprints of primordial quantum fluctuations that had been profoundly magnified by the universe's rapid expansion in the first fractions of a second of its history—unsullied by the emergence of stars, galaxies and galaxy clusters. It is possible that the 21-centimeter signals from the dark ages could carry indications of new physics or deviations from the standard model of cosmology. "It's a playground for testing cosmology," Burns says.

The first radio telescopes on and above the far side of the moon will be simple. They will gather hints of this shadowy slice of otherwise unseen cosmic time. As more sophisticated instrumentation comes online, the 21-cm signals will emerge in richer detail, allowing astronomers to create dynamic, high-resolution maps of hydrogen clouds.

"The nice thing about neutral hydrogen is that it's not just a snapshot in time like the CMB," says Kristian Zarb Adami of the

University of Oxford. By tracking the fluctuating 21-cm signal over cosmic time, telescopes can chart the evolution of the early universe through the dark ages all the way up to the cosmic dawn and even beyond. After the dawn came the epoch of reionization, when the radiation from the first massive stars and other violent astrophysical phenomena sufficiently reheated the remaining neutral hydrogen to transform it back to plasma. That epoch ultimately extinguished the 21-cm signals.

FAR-SIDE PIONEERS

SOME PATHFINDER INSTRUMENTS are already in operation. They are part of China's Chang'e-4 lander on the moon's far side, as well as a lunar orbiter named Queqiao ("Magpie Bridge"), which relays signals from the lander to Earth. Queqiao was launched in May 2018, and Chang'e-4 reached the lunar surface in January 2019. "This was the first time there was a soft landing on the far side of the moon," says Bernard Foing, executive director of the International Lunar Exploration Working Group and a planetary scientist at VU Amsterdam. "It was a great success."

Both Chang'e-4 and Queqiao carried radio antennas. But those on Queqiao, built in collaboration with Dutch scientists, did not extend completely, and Chang'e-4's single antenna is hindered by radio-frequency interference (RFI) coming from the lander's electronics. Future dark-age-surveying lunar spacecraft could include additional shielding to minimize RFI. They could also deploy multiple antennas across tens or hundreds of kilometers of lunar soil.

The next preparatory phase for far-side astronomy is set to begin with the launch of ROLSES (Radiowave Observations at the Lunar Surface of the photoElectron Sheath) this October. ROLSES will travel to the moon within a privately developed lander licensed by NASA as part of the space agency's Commercial Lunar Payload Services program. Although it will touch down in the Oceanus Procellarum region on the moon's near side, ROLSES's task of characterizing the RFI generated by lunar soil is crucial for future work identifying other radio signals on the far side. "This is real," says Burns, who is a member of the ROLSES team. "I have been working on this for 35 years. It's actually happening."

Another mission to characterize the radio-frequency interference on the moon—the Lunar Surface Electromagnetics Experiment (LuSEE)—is slated to launch as early as 2024. "LuSEE is going to the far side," Burns says. "It's going to go to the Schrödinger impact basin." The lander carrying LuSEE may also have another payload: DAPPER (Dark Ages Polarimeter Pathfinder), a telescope for detecting the 21-cm signal from the cosmic dark ages. "DAPPER was originally designed to be an orbiter around the moon, but it may go on this lander," Burns says. "NASA has funded us to work on the mission concept for DAPPER. We'll be ready to go."

Whether in orbit or on the lunar surface, DAPPER will be limited to a set of dipole antennas in one location. But astronomers have more ambitious plans for deploying arrays of antennas on the moon. These arrays, which combine signals from individual antennas spread over large distances, act as telescopes with resolutions far greater than would be possible with a single antenna and can effectively pinpoint sources in the sky.

THE ERA OF ARRAYS

XUELEI CHEN of the National Astronomical Observatories at the Chinese Academy of Sciences thinks lunar orbit is the best near-term site for creating dark-age-mapping lunar arrays. Antennas on a number of satellites could be configured into an array that carries out observations when the satellites are all on the far side. "This is a small experiment with moderate cost, and we could accomplish it with current technology," Chen says.

The tentative plan calls for a fleet of five to eight satellites flying in carefully choreographed formation to form an array. One of the satellites would be a larger mother ship that would host most of the electronics for receiving and combining the signals from other satellites and then relaying the results to Earth. "We want to have them launched as an assemblage, and then they will be released one by one," Chen says.

Putting such an array on the far side's surface will be far more challenging for many reasons, among them the moon's rugged terrain and the spacecraft-threatening chill of the 14-day-long lunar night. To begin preparing for this type of mission, Foing's team is planning to test the deployment of radio antennas using robotic rovers designed by the German Aerospace Center. The test will occur in June on the flanks of Mount Etna, an active volcano in Sicily meant as a proxy for the lunar surface. Scientists will control the rovers remotely; each rover will carry four boxes of antennas. "We will position them in different configurations to show that we will be able to do that in the future on the moon," Foing says.

Another way of deploying a radio array on the moon's far side would be to simply drop antennas from an orbiter to land and unfurl where they may. Adami and his colleagues are working on one such idea: a low-frequency interferometer, designed to precisely measure characteristics of radio emissions, that involves 128 fractal-like "mini stations." Each station has eight arms, and each arm combines 16 spiral antennas. "My idea would be that these fall off from the satellite and all land in different parts on the moon's surface," Adami says.

To minimize the number of moving parts, the team has figured out how to print these antennas as flat sheets that will take their final form after being rolled out on the lunar surface. "You could print antennas as fast as you print newspapers. We've been testing this technology for the past four or five years," Adami says. "We are in the process of prototyping these spiral antennas." The next step, he adds, is for the scientists to design a mini station and drop it from a drone in remote areas, such as an arid region of Western Australia, to see if it unfurls.

Meanwhile Burns is also leading a NASA-funded concept study for building another lunar radio telescope, aptly called FARSIDE (Farside Array for Radio Science Investigations of the Dark ages and Exoplanets). To design FARSIDE, Burns and co-principal investigator Gregg Hallinan of the California Institute of Technology have teamed up with NASA's Jet Propulsion Laboratory. The scientists are looking to land a payload of four rovers and 256 antennas, totaling about 1.5 metric tons, using lunar landers funded by NASA. The rovers would deploy the antennas, spreading them in four flowerlike petals over a region that is 10 kilometers in diameter. "We can do this with current technology," Burns says. "So this all looks very plausible [for] later in the decade."

FROM OUR ARCHIVES

The Dark Ages of the Universe. Abraham Loeb; November 2006.

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