THE RACE TO OCCUPY THE FAR SIDE OF THE MOON

BBC Science Focus

THINK YOURSELF YOUNGER

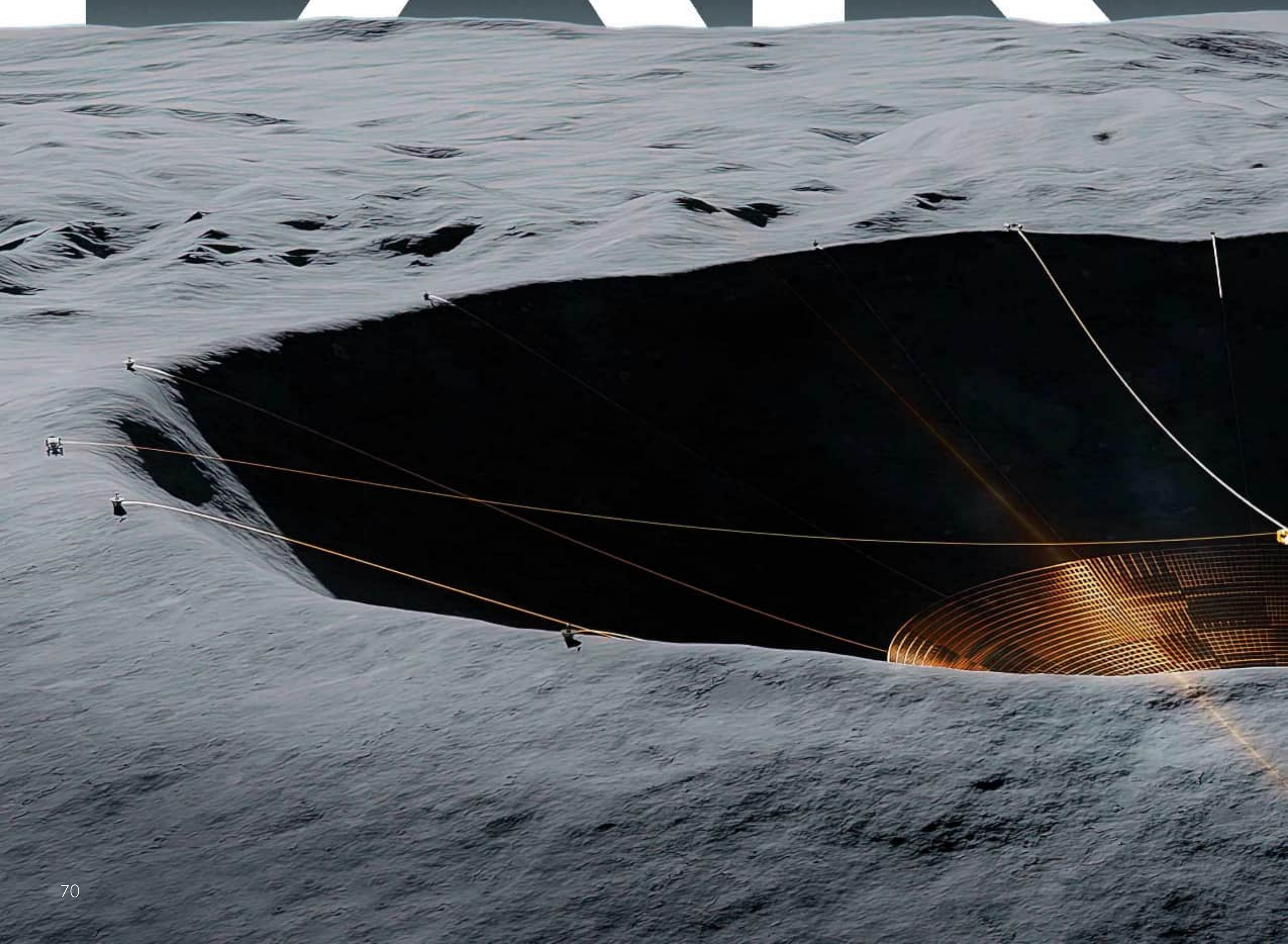
How a positive mindset slows biological ageing

THE ULTIMATE GUIDE TO GETTING BETTER SLEEP

THE STRANGE TRUTH ABOUT QUANTUM TIME

HOW CLIMATE CHANGE CAN TRIGGER EARTHQUAKES THAT LEVEL MAJOR CITIES

ASTRONOMY FROM THE FAR



THERE'S ONLY ONE PLACE TO GO IF WE WANT TO CATCH SIGHT OF THE COSMIC DAWN

by DR ALASTAIR GUNN

SIDE

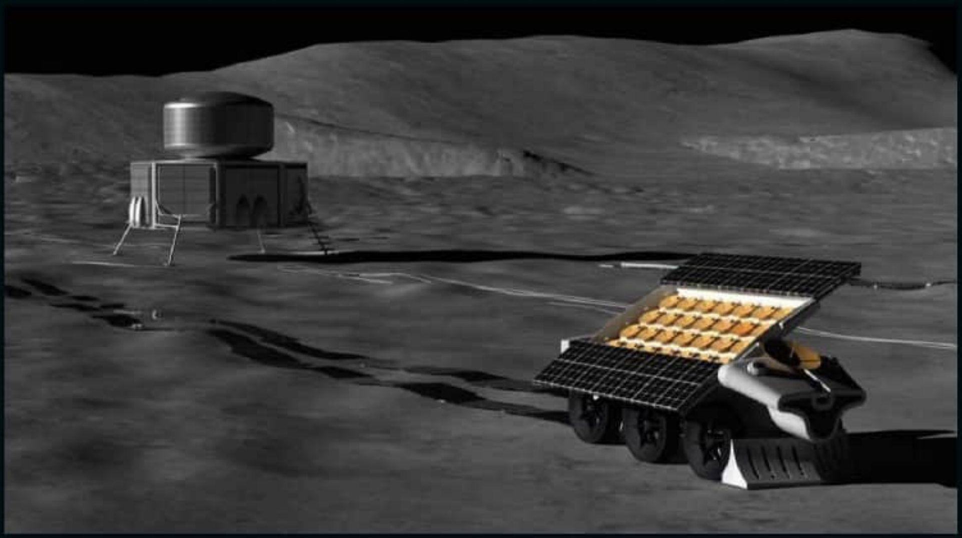
The Lunar Crater Radio Telescope project aims to build an observatory inside a crater on the far side of the Moon

VLADIMIR VUSTYANSKY/NASA

Astronomers love a challenge. They place their observatories on the highest mountains, in the driest deserts, on the coldest ice shelves, beneath the deepest oceans, in orbit around Earth and the Sun, and at the farthest-flung outposts of the Solar System. But now, they're planning to build telescopes on the far side of the Moon.

These instruments will probe one of the last unexplored windows on the Universe. Here, astronomers hope to get a glimpse of the elusive Cosmic Dawn, the moment when the Universe emerged from darkness, and stars and galaxies started to form (see 'Chasing the Cosmic Dawn', opposite).

But why take on the huge technical challenges and costs of building an observatory on the Moon? The reason is that, when it comes to detecting the Cosmic Dawn, nowhere else will do.



"ONE SOLUTION IS TO PUT ALMOST 3,500KM OF ROCK BETWEEN EARTH AND YOUR RADIO TELESCOPE"

THE 21CM LINE

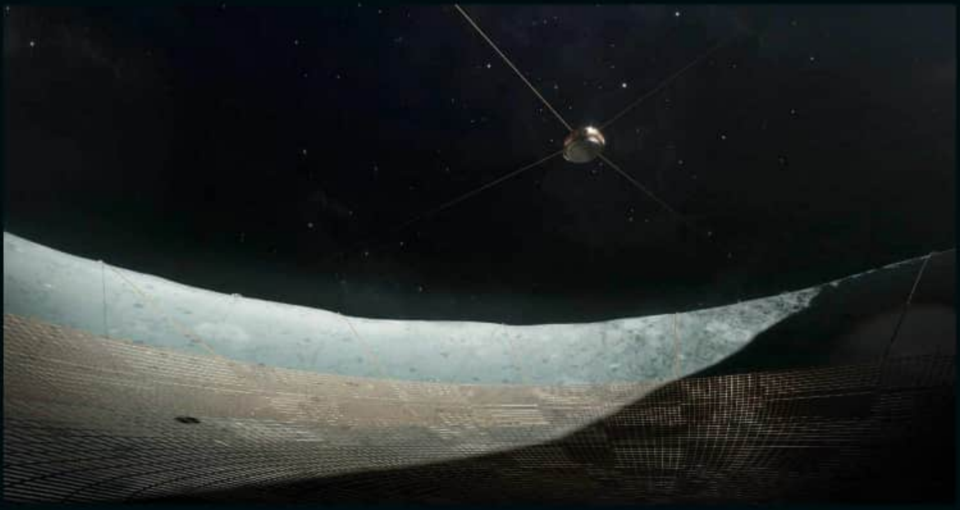
The all-important sign of the awakening Universe comes from neutral hydrogen atoms. Occassionally, the electron in a hydrogen atom flips over, releasing a photon with a tell-tale wavelength of 21cm (8.2in). If astronomers look at the radio waves being emitted by a cosmic gas cloud and they see a narrow spike in radio waves that are 21cm long (known as a 'spectral line'), they know the cloud contains neutral hydrogen. Although caused by an extremely rare (and random) transition, there's enough neutral hydrogen in the Universe to make the 21cm line easy to spot.

The 21cm line is extremely important to astronomers. Not only does it trace a large fraction of the gas that makes up galaxies, it can also penetrate clouds of dust that obscure the Universe at other wavelengths. It was observations of the 21cm line that first revealed the spiral structure of our galaxy, the Milky Way.

During the Universe's Dark Ages, the only photons were those created by neutral hydrogen. So, the 21cm line is the only way astronomers can probe the early phases of the Universe.

ABOVE Robotic rovers are expected to distribute the 100,000 lunar antennas required for NASA's FarView project

BELOW The Lunar Crater Radio Telescope project aims to make use of the Moon's natural features



This doesn't always mean astronomers are only looking for wavelengths of 21cm, however. The Universe is expanding and as it does so, it stretches out the light travelling through it to longer wavelengths – a process known as redshift. The further away an object is, the bigger the redshift, meaning the 21cm line from different eras in the Universe's evolution will be shifted to different wavelengths. The epoch of reionisation, for example, can be seen at wavelengths of a few metres. But the Cosmic Dawn signal can only be seen at wavelengths of about 10m (over 32ft) or more.

And that's where the problem lies. Earth's ionosphere begins to absorb, distort and reflect radio waves from space at precisely this wavelength. So, Earth-based instruments can only probe the later epoch of reionisation. Finding the Cosmic Dawn signal requires getting beyond Earth's ionosphere.

There's another problem, however. On Earth, or in orbit around it, there's nowhere to hide your radio telescope from the interference caused by satellite megaconstellations and FM radio transmissions. These, and other sources of interference, completely swamp the extremely faint radio signal from the early Universe.

One solution to these problems is to put almost 3,500km (close to 2,200 miles) of rock between Earth and your radio telescope. "The far side of the Moon is a unique location," says Prof Jack Burns, a researcher at the University of Colorado at Boulder and a long-time advocate of the lunar observatory idea. "It's the only locale that's truly radio quiet."

THE PROJECTS VYING FOR SUCCESS

There are various plans to construct lunar observatories that could detect the Cosmic Dawn. In Europe, ESA is exploring an array of inflatable antennas called DEX (Dark Ages Explorer), where a single lander would deploy over 1,000 antenna elements on the Moon, the signals from which will be combined to simulate a large radio telescope.

"This is no easy task" says Dr Christiaan Brinkerink, an engineer at Radboud University in the Netherlands, and lead investigator for DEX. "We'll not only need to bring all antennas there, but also a way to place them, to power them and to do data processing and communication." Despite the difficulties, Brinkerink is optimistic. "We aim to develop the technologies for DEX to make deployment in the mid-to-late 2030s possible," he says.

In the US, there are even more ambitious plans for a similar array called FarView, a project led by Burns. He describes FarView as the "ultimate cosmology telescope". It'll consist of 100,000 small antennas, distributed over about 200km^2 (approx 77 sq miles), built in situ by robots extracting aluminium from the lunar rock. The FarView team hopes to deploy the first prototype arrays to the Moon before the end of this decade, with the full instrument to be built in the 2030s.

The Chinese also have plans for a lunar surface array. Their design has 7,200 butterfly-shaped antennas spread across 30km (18.6 miles) of lunar real estate. First, unmanned missions (Chang'e 7 and 8) would deploy 16 test antennas using robot landers. Crucially, though, the core of roughly 100 antennas would be constructed by astronauts, something the US and European plans have dismissed. The final array will be completed after a permanent lunar base is established. Even so, the pace of China's space programme means there's every chance this observatory will be the first to detect the Cosmic Dawn.

A radically different approach is the Lunar Crater Radio Telescope (LCRT), a project proposed by the NASA Institute for Advanced Concepts (NIAC). Again built entirely by robots, the LCRT would consist of a 350m (1,150ft) wire-mesh dish stretched across a 1.3km-wide (0.8 mile) impact crater on the Moon's far side. One spacecraft would deliver the telescope's mesh and a lander would deploy rovers to shimmy down the crater's sides with supporting cables.

LCRT was first proposed in 2020 and has undergone several phases of study by scientists and engineers at NASA's Jet Propulsion Laboratory (JPL). Now constructing a 200:1-scale prototype in California, the team is also preparing for the next design study. Dr Gaurangi Gupta, a researcher at JPL, is optimistic the project can become a reality. "If we can build scientific consensus and excitement, and prove the technological feasibility, reliability and maturity of the concept, there's a good chance that LCRT could happen in the next decade," she says.

The focus to date has been on observatories on the lunar surface. There is an alternative, however. This is to place a telescope in lunar orbit and observe the sky as the instrument disappears behind the Moon. Unfortunately, such orbiting instruments can't be built very large. So to achieve the required sensitivity, the instrument would consist of a swarm of small satellites that combine their signals.

China has revealed plans for just such an array. Called 'Hongmeng', the project envisages a 'mother' satellite that controls the array, processes data and relays it back to Earth, while eight 'daughter' satellites gather the cosmic signals. The scheme could be operating as early as 2026.

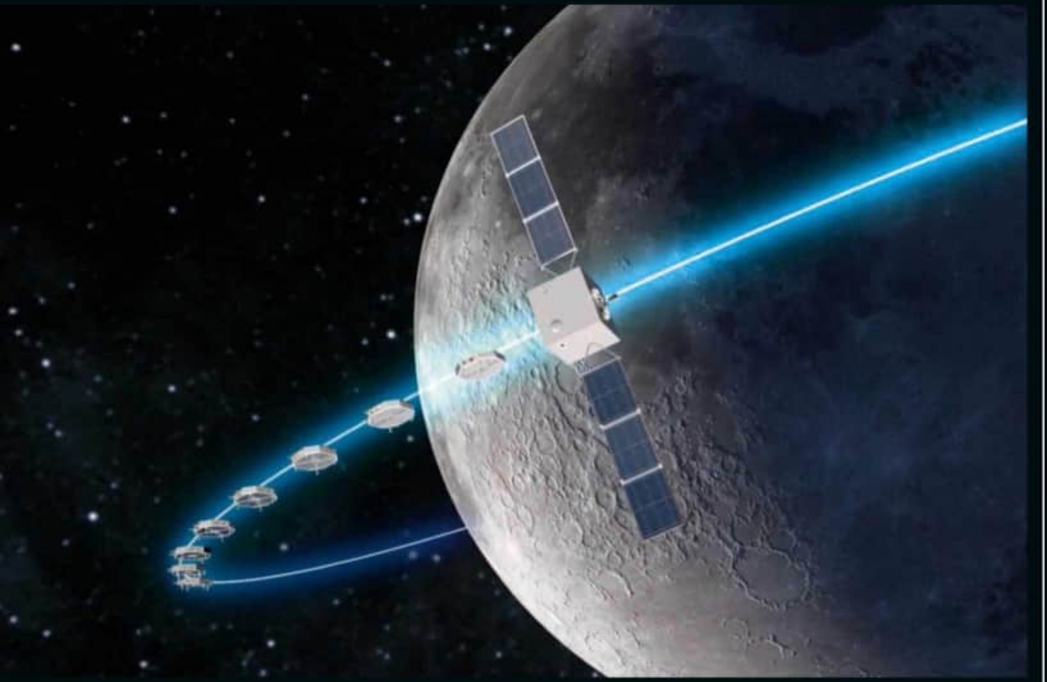
The UK is also getting in on the act. Portsmouth and Cambridge Universities are working with RAL Space to design a small long-wavelength radio receiver to detect redshifted 21cm-line emissions.

CHASING THE COSMIC DAWN

The Universe was born hot and dense. Eventually, about 380,000 years after the Big Bang, it had cooled enough for protons and electrons to combine and form neutral atoms of mainly hydrogen and helium. This early epoch is known as the cosmic 'Dark Ages' because neutral hydrogen absorbed photons, making the Universe opaque. But as the first stars and galaxies began to coalesce, roughly 100 million years later, that hydrogen gas gradually became ionised (stripped of electrons) by ultraviolet radiation. Marking the beginning of the 'epoch of reionisation', this Cosmic Dawn is when the Universe first became transparent to light. Precisely when the Cosmic Dawn occurred is a matter of debate, but the process appears to have ended about 1.1 billion years after the Big Bang.

RONALD POLIDAN NASA, VLADIMIR VUSTYANSKY/NASA, SCIENCE PHOTO LIBRARY

"ASTRONOMERS SHOULD FINALLY HAVE INSIGHTS INTO THE FORMATION OF THE FIRST STARS"



ABOVE China's 'Hongmeng' project involves a family of satellites in orbit around the Moon, gathering signals and relaying data to Earth

The satellite, called CosmoCube, will orbit the Moon, relaying its data back to Earth.

Although probably cheaper, there are disadvantages to the orbital approach. The ever-changing positions of the satellites mean data processing is much more difficult. More importantly, some of the scientific goals require dense arrays of antennas, which can't be provided by orbiting systems. Maintaining and upgrading such a system is also unfeasible.

The major surface-based observatories, such as DEX and FarView, will likely cost $1–5 billion each. Planning, designing and testing the technology for their deployment is a mammoth task. Despite the plethora of ideas and design studies currently underway, it's likely that any future lunar observatory will be a global collaborative effort. Nevertheless, astronomers have already taken the first steps towards the Cosmic Dawn.

THE UNEXPLORED UNIVERSE

In February 2024, a spacecraft called Odysseus, developed by Houston-based Intuitive Machines, was the first commercially produced probe to touch down on the Moon. Aboard was a NASA experiment called ROLSES1, which performed the first-ever radio astronomy from the lunar surface. Burns and colleagues, who describe the instrument as "a trailblazer for lunar radio telescopes", used it to measure the radio interference leaking through Earth's ionosphere. ROLSES2, the successor to ROLSES1, will investigate how to protect such instruments from lunar temperature extremes.

NASA is also developing LuSEE-Night, an experiment to understand the Moon's radio environment and test the performance of engineering platforms on the Moon. Sitting on top of the Blue Ghost 2 lander, it'll be delivered to the lunar surface, possibly in late 2026. This mission has the potential to glimpse the Cosmic Dawn signal for the very first time.

With these lunar observatories, astronomers are hoping to fill the enormous gap in our understanding between 380,000 years after the Big Bang and the later stages of the epoch of reionisation, about 1.1 billion years after the Big Bang. That's about five per cent of the Universe's lifetime, which remains completely unexplored.

Studying how the neutral hydrogen signal changes over time will reveal how the earliest structures formed in the Universe. Astronomers should finally have insights into the formation of the first stars, the evolution of galaxies, the role of black holes, dark matter and dark energy. Comparing the results to earlier and later times will tell us if our basic cosmology is correct, or whether new physics is required.

The redshifted 21cm line from the Dark Ages is visible because it absorbs the earlier light of the cosmic microwave background. This enables astronomers to probe even earlier epochs of the Universe, helping to further constrain cosmological models. Gupta is unequivocal about the scientific return. "Observations of the Dark Ages have the potential to revolutionise physics and cosmology," she says.

There are other areas of astronomy that would benefit from a long-wavelength lunar telescope. For example, it would be able to detect electromagnetic fields around exoplanets, perhaps providing critical insights in the search for habitable (or inhabited) worlds.

Interest in the Moon as a base for astronomical observations isn't new. Serious proposals were first discussed in the 1980s, but back then the technological challenges were insurmountable. But with recent advances in reliable, relatively cheap unmanned commercial spaceflight, advances in radio antenna design and autonomous robotics, a permanent radio observatory on the Moon is now within our reach. The technology has finally caught up with astronomers' ambitions.

The challenges are great and the costs huge. But astronomers love a challenge. It's difficult to say what our reward will be, what secrets the earliest photons may reveal, but we'll never know unless we try. And to try means we must take our radio telescopes to the far side of the Moon. SF

—

by **DR ALASTAIR GUNN**

Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester.