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OUTBACK OUTLOOK NEW AUSSIE MEGASCOPE SEEKS ALIENS & BIRTH OF UNIVERSE

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ISSUE 98

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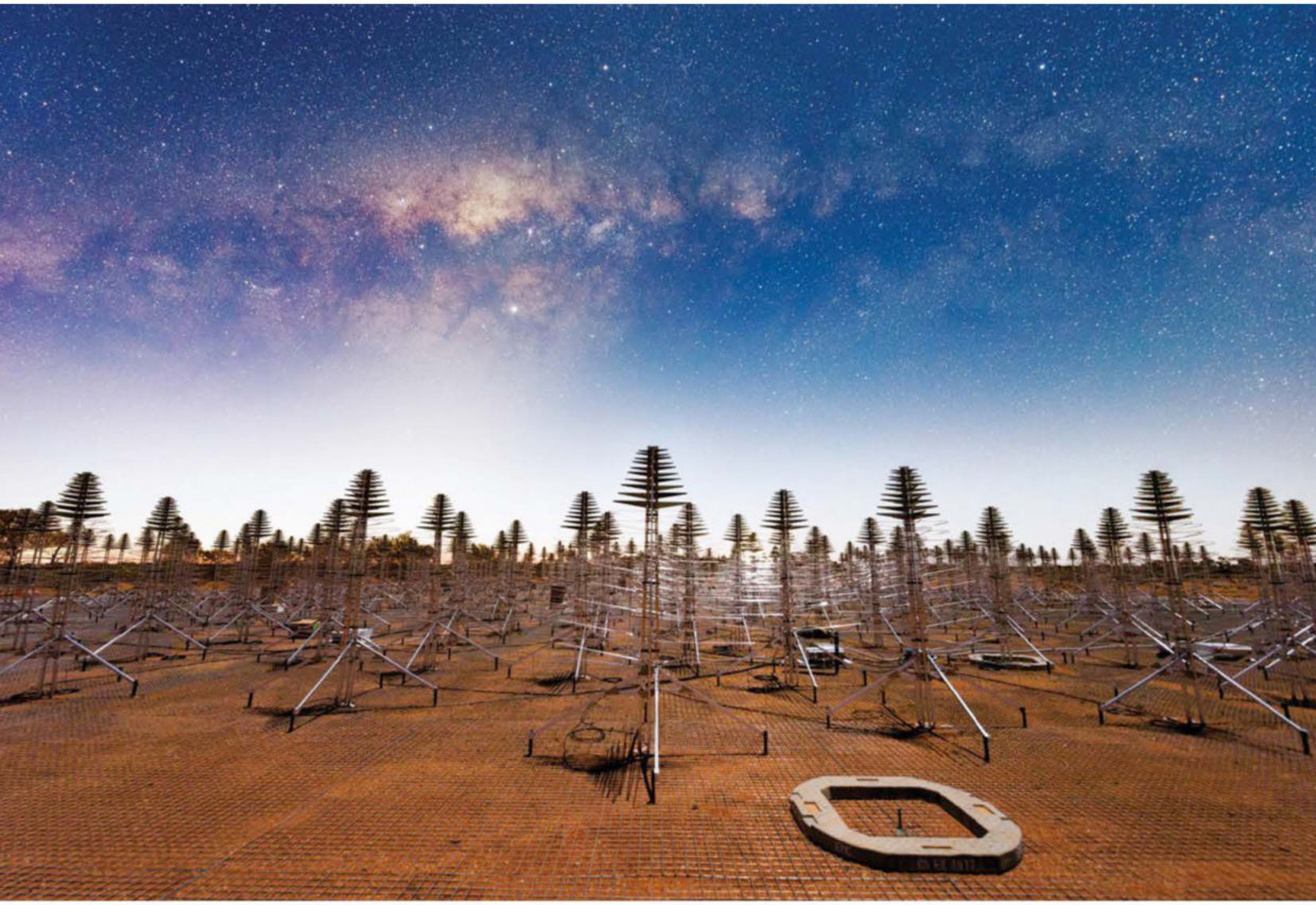
› Above WA: a satellite-streaked sky

Lit by reflected sunlight, countless satellites cross the skies above the Pinnacles Desert, in Nambung National Park, Western Australia, their time-lapse trails forming an alluring mantle. The delight of this magical image – shot by hobby astrophotographer Joshua Rozells and composed of multiple frames over 85 minutes – is lost, however, once context is added. About 400km north-east, on Wajarri Yamaji Country, the SKA-Low's 130,000 individual antennas are under construction at Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory. SKA-Low is smack in the middle of the Australian Radio Quiet Zone WA – but how quiet is it likely to be with this nightly mosaic? Increasing numbers of low-Earth-orbit satellites pose a genuine threat to scientific understanding of the distant universe. To learn more about SKA-Low (and its possible satellite problem) **turn to page 46.**

JOSHUA ROZELLS (INSTAGRAM / @JOSHUA_ROZELLS)



MICHAEL GOH, ICRAR-CURTIN

GALAXY IN THE DESERT

When SKA-Low, the Australian component of the SKAO is complete, it promises a revolution in knowledge about our universe, and the possibility of other life within it. But, as **Jacinta Bowler** reports, another technological advance could scuttle SKA's discoveries, and the enemy is hiding in plain sight.

Standing in the West Australian desert, at the site of what will one day be the SKA-Low, is uncomfortably hot, but beautiful. The only smells are outback breeze and sun-baked plastic marquee.

Red dirt littered with scraggly trees and tufts of grass goes on as far as the eye can see; the scrub has flowers I've never seen before. But this place is almost overwhelming in its remoteness – there's no WiFi, no phone signal – almost no way to contact the outside world.

But this lack of communication is by design.

The place was picked specifically for its inaccessibility. It's four hours' drive to the nearest town, Geraldton, and eight hours to make it back to Perth. The Shire of Murchison in which it sits has no recognised towns, a population of around 100 people and is approximately the size of the Netherlands.

By the end of the decade it will be home to a sprawling 65-kilometre long forest of metal trees. This eerie plantation will be quieter than most – its job will be to listen out for faint radio signals from the earliest parts of the universe, and record 'leaking' radio waves from nearby alien worlds.

To listen to the sounds of the universe, phone signal, planes, WiFi, even the reversing sensors on cars, will need to be silenced. If these antennas were ears, the radio signals blasting from our human made devices would be the piecing audio feedback squeal at a rock concert.

The area I'm standing on – Inyarrimanha Ilgari Bundara ("sharing sky and stars" in the local Wajarri Yamaji language), the CSIRO Murchison Radio-astronomy Observatory – has very minimal infrastructure. This makes the site radio quiet – an area where radio transmissions are restricted to ensure that the telescopes can do their job. The telescopes are bold projects, billions of dollars in the making. The most powerful of their kind on Earth, they will be able to peer further into the universe than any other telescope before. They could tell us more about black holes, gravitational waves and almost every part

Currently in place (opposite) at the Inyarrimanha Ilgari Bundara, CSIRO Murchison Radio-astronomy Observatory in WA, the Aperture Array Verification System 2.0 is a demonstrator for SKA-Low. When SKA-Low is completed (artist's impression, above), antennas will be arrayed in 256-unit clusters called stations. The observatory's 512 stations will have more than 131,000 antennas.

SKATELESCOPE.ORG

of the universe – back to the earliest days after the Big Bang. They could even help us listen to aliens.

But far above is another technological wonder – megaconstellations of satellites, beaming down radio waves to provide internet to the world, including these radio-quiet areas. One or two satellites is manageable, but with businesses shooting thousands of satellites into space – around 1600 in 2021 alone – the sky is beginning to get noisy.

Connect with each other, or hear into the origins of the universe? Which is more important, and are both possible? Proponents of both are in an uneasy partnership to find a solution.

The SKA pipe dream

Conceived in 1991, the SKA project envisaged antennas spread over thousands of kilometres to 'simulate' a single device with the collecting area of a square kilometre. This engineering feat would have created undoubtedly the largest radio telescope of its kind on Earth.

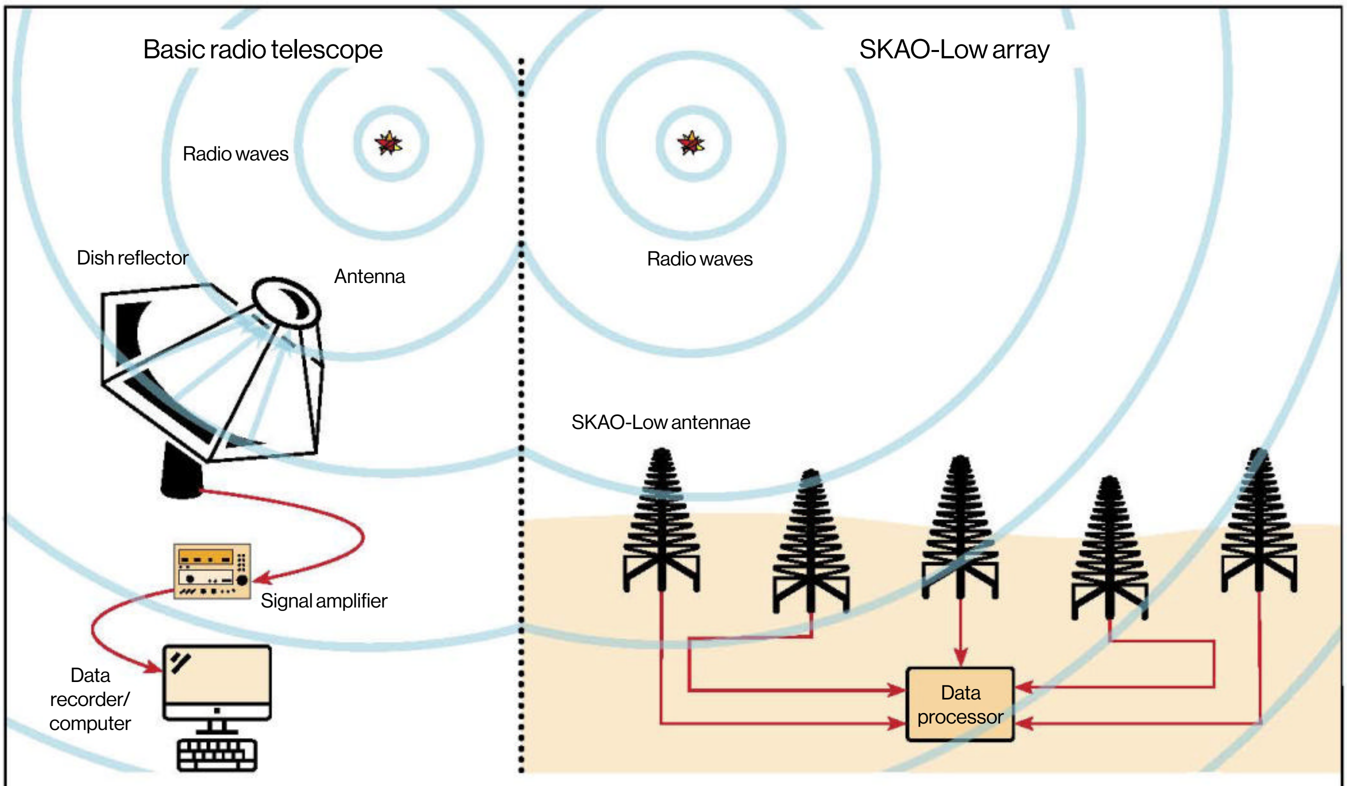
The final design, which has just begun construction in both South Africa and Australia, is two distinct giant telescopes – the SKA-Low in Murchison, and SKA-Mid, whose core station is inside the Meerkat National Park in South Africa. The whole thing is run by an intergovernmental organisation called the SKA Observatory (SKAO).

When the SKA-Low is complete, around 2030, 131,072 total antennas will form a 65km-wide spiral pattern, reminiscent of one of the galaxies it will be able to listen to. (The SKA-Mid looks a little more traditional, with 197 steerable dishes and 150km between the furthest two.)

Radio astronomy had humble beginnings. In 1939 amateur Grote Reber erected a 9m dish in his Illinois backyard and started surveying the sky.

Australia didn't get in the act until 1945 during World War II, when scientists from the CSIRO and the Air Force used a radar station to observe radio waves coming from the Sun that had been messing with radio equipment. This sort of experiment could be done today with a TV antenna – if there weren't louder TV signals getting in the way.

Sixteen years later, Australia got its first big radio astronomy telescope – the 64m diameter Parkes radio telescope, which received the live images of the Apollo 11 Moon landing in 1969.



In its simplest form (at left), a radio telescope has one or more antennas for picking up radio waves, a receiver and amplifier to boost the signal to a measureable level, and a device to keep a record of the signal. The SKA-Low (at right) is described by its parent organisation SKAO as a "mathematical" telescope that filters out what's not desirable in the observable sky. The SKA-Low array's 131,072 individual antennae are fixed, so astronomers will use data processing to "point" them – a technique known as "beamforming". The data volumes generated will be astonishing: multiple terabytes per second, which next-gen supercomputers will process at as-yet-unachieved speeds.

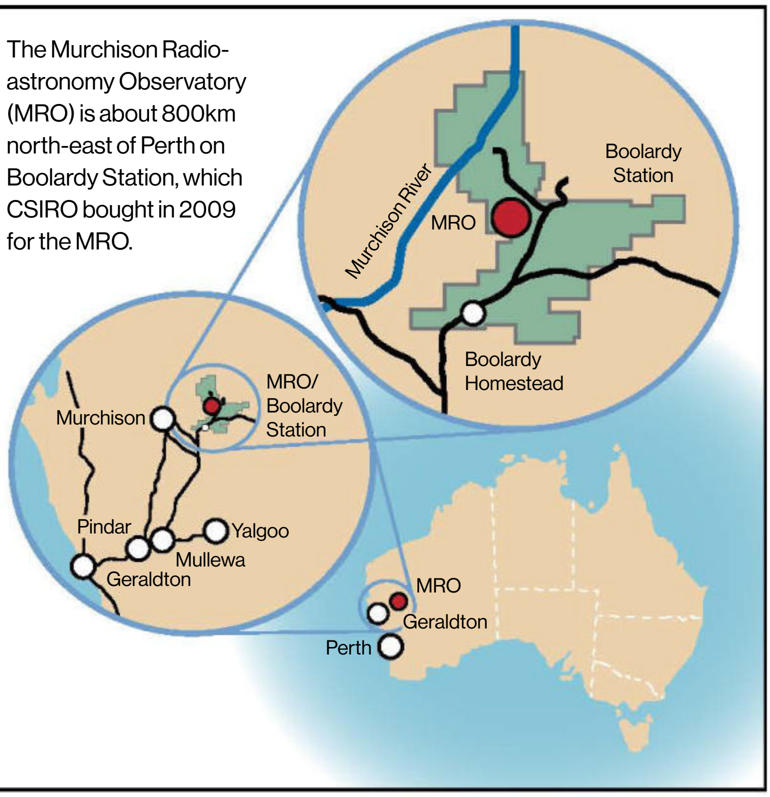
GREG BARTON X2

Despite our slow start, radio telescopes are particularly well placed in the Southern Hemisphere. There are fewer people, and therefore less interference from human radio signals. But the Southern Hemisphere is also looking at a whole different patch of sky to scientists' northern colleagues.

If the Parkes telescope is movie famous because of the Australian classic *The Dish*, the movie *Contact* ensured the larger Arecibo Telescope's fame. Arecibo was a 305m diameter radio telescope built into a natural sinkhole in Puerto Rico and was well known for programs to search for extraterrestrial intelligence. In 1974 the telescope was used to transmit a simple pixel picture message for aliens to nearby globular cluster Messier 13.

Compared to Arecibo and Parkes, the SKA telescopes are, technically, ginormous. SKA-Low's array forms a virtual radio telescope 65km in diameter, with a collecting area of more than 400,000 sq.m. The SKA-Mid acts like a 150km diameter telescope.

Understanding the marvel of SKA-Low starts at the high-tech metal Christmas trees. At 2m tall, they have solid metal 'branches' near the top, which become larger wire branches below. These lower branches look just like wire coat hangers, but upside down, becoming larger as the tree gets closer to the ground.



The Murchison Radio-astronomy Observatory (MRO) is about 800km north-east of Perth on Boolardy Station, which CSIRO bought in 2009 for the MRO.

Each tree works in a similar way to the antenna on your car, picking up radio waves. Except while your car radio might be trying to pick up the 'loud' FM signal band of 87.5–108 megahertz (MHz), the antenna is trying to pick up any faint signal from a wider range: between 50MHz and 350MHz. This includes everything from television and radio broadcasts, to police scanners, CT scans and cordless phones. More importantly for the telescope, ancient hydrogen, galaxies and other space objects can also be mapped.

The SKA telescopes are ginormous. SKA-Low's array forms a virtual radio telescope 65km in diameter, with a collecting area of more than 400,000 sq.m.

The antennas will be in groups of 256, each one called a station (although they look a bit like little forests). There are 512 stations – 131,072 total antennas. Some of these stations will cluster in the centre, while the rest arc out in three spiral arms. About 65km will separate the ends of the longest spiral arms – a 40-minute journey at highway speeds.

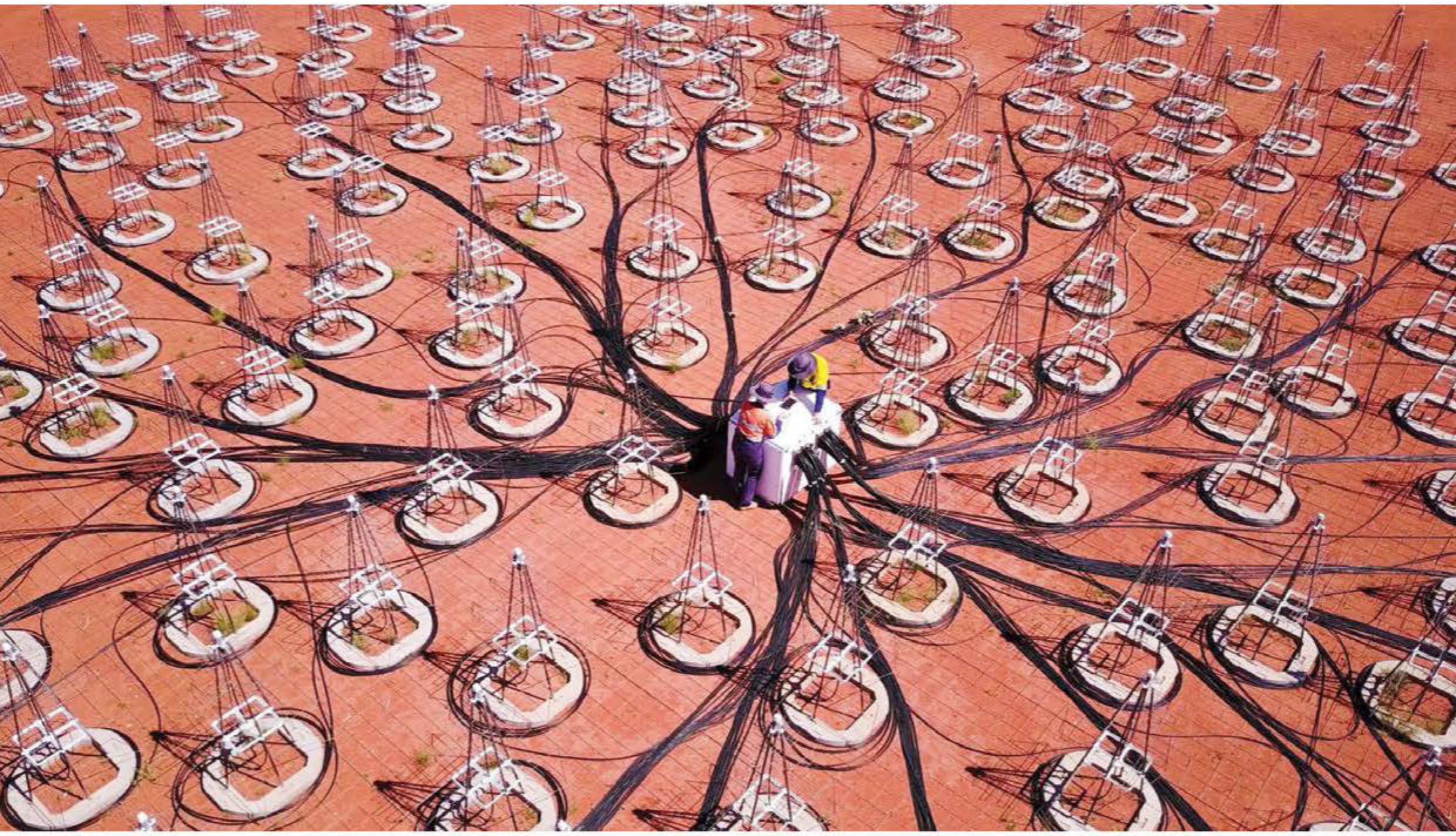
From the air, it will look a little like a glinting metal galaxy – perhaps like a Hubble or Webb image, with red shimmering in the background.

Just one Christmas-tree antenna isn't much better than your TV antenna – it picks up whatever it hears, with no ability to distinguish where it's coming from. Instead, you need antennas spread widely to create a larger bucket to catch those faint radio waves.

A traditional radio telescope is made up of one big three-dimensional dish. This dish receives the radio waves then redirects them towards a receiver in the middle of the telescope, which is a point above and in the centre of the dish usually elevated by pieces of metal. These dishes can also be manoeuvred to face a desired direction for radio signals.

But SKA's antennae are fixed. Instead, they are digitally pointed – a technique called "beamforming". With thousands of antennas spread over 65km, radio signals from the same source will hit the antennae at different times. Imagine a sphere of radio waves colliding with the sphere of our Earth. A 'point' of the sphere is going to be first to touch us. In this example let's assume that it's at the centre of the SKA-Low formation. First, the central antennas pick up the radio waves. Then, as more of the sphere interacts, it looks like a ripple effect, spreading outwards towards the edges.

To make sense of this, the technology behind the telescope – the central signal processor – uses aperture synthesis to match up the radio waves. (Aperture synthesis was first formulated by Australian radio astronomers Ruby Payne-Scott and Joseph Pawsey



in 1946.) This creates a 3D telescope, but the third dimension isn't depth – it's time.

And SKA has the potential to find aliens.

Human communications, broadcasts and later televisions and mobile phones have been gushing radio waves since we started radioing to ships a century ago. Some of these regular radio waves are blocked by the ionosphere, but some – especially TV broadcasting and those from satellites – can leak outside of our planet: Earth's technosignature.

If another alien civilisation in our cosmic neighbourhood was doing the same, the SKA is the first telescope that could potentially pick up other technosignatures. When complete, each SKA is so sensitive it could detect a signal from a mobile phone on Mars – 225 million kilometres away.

"It doesn't necessarily need to be beamed towards us or deliberate," says Professor Cathryn Trott, SKA-Low's Chief Operations Scientist.

But while some might be fascinated by the alien component, Trott is more excited by SKA's other important strand of research: identifying ancient hydrogen that spewed into our universe shortly after the Big Bang. This hydrogen could allow researchers to map what the universe looked like at its "epoch of reionisation" over 13 billion years ago. This could help scientists understand when the first galaxies formed, and what else was happening in these first years of the universe.

The SKAO didn't emerge fully formed in the recent past. The astronomy community's desires and ideas that led to it first coalesced in the late 1980s. A shortlist of potential technologies was known in 2005. The SKA Organisation was created in 2011; the dual site selection of Australia and South Africa was settled in 2012. In 2018, the first prototype (opposite top) SKA-Low station – Aperture Array Verification System, AAVS1 – was completed. AAVS1.5 (above) swiftly followed, in 2019.

This cosmic number of antennas, plus the interferometry and beamforming to make it work, requires thousands of processing modules worth of computing power from the central signal processor. But this pales in comparison to the mind-blowing amount of data that comes out of it.

Whenever they are running, both SKA telescopes will produce up to five terabytes per second of measurement data each: equivalent to downloading 200 HD movies every second.

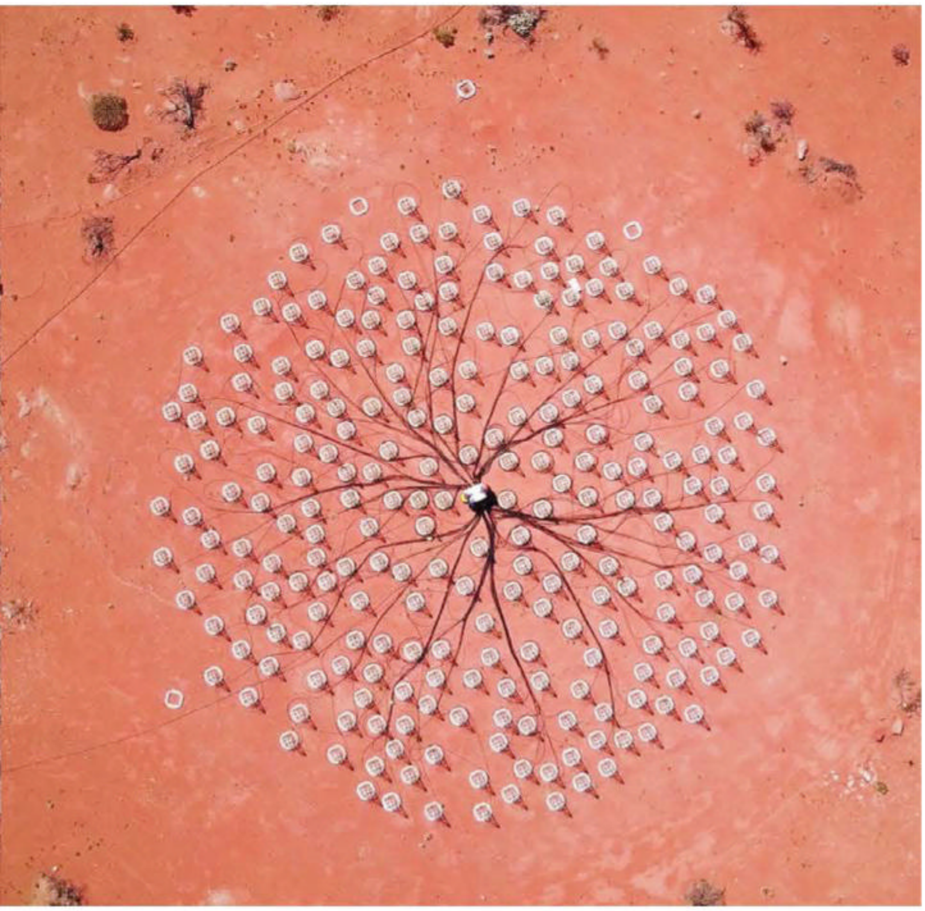
This data travels through optical wires to the Pawsey Supercomputing Centre in Perth, almost 800km south-west, where the vast amount of material is analysed at a processing speed of around 135 petaflops – that's almost 100,000 times faster than a top-of-the-line smartphone.

Once the supercomputer is fully operational, it'll be 25% faster than the current fastest supercomputer in the world.

While the SKA telescopes are still in their early stages, the excitement is palpable. There's so much out in the universe yet to be uncovered.

But the long-planned, multi-billion-dollar project only works if the telescopes aren't just overhearing our planetary chatter.

SKATELESCOPE.ORG X2



Shuttle was being reused back in the 1980s), the company has recently succeeded in creating partially reusable launch systems, pushing down the costs of rocket launches.

Smaller, cheaper components have also allowed more institutions and companies to launch satellites for a fraction of the previous cost.

This, along with the drive to give rural and remote areas internet access, has led to 'mega-constellations' of satellites. Starlink has launched more than 3000 of a planned 12,000 strong satellite fleet. Amazon has 3,000 satellites planned and OneWeb is deploying another 600.

The more satellites there are, the more of the planet gets access to regular and reliable internet. The more companies, the more competition – potentially pushing down the price.

But for astronomers, according to Dr Phil Diamond, the SKAO Director General, "they're a pain in the arse".

Federico Di Vruno has broad shoulders, a bald head and eyes that crinkle up when he smiles. Originally from Argentina but now living in the UK, he spent our Zoom call sipping on maté – out of a silver curly straw.

He lives on the other side of the world to both SKA-Low and -Mid, and yet he's a key to the multi-billion-dollar projects being a success.

Satellites far above

Almost a lifetime ago, the first artificial satellite was catapulted to the skies. The Soviet Union's Sputnik 1 was launched from Kazakhstan in October 1957 and for 21 days it transmitted a single repetitive beep tone that could be heard by any curious amateur radio operators.

Since then, we've been slowly adding satellites to our low earth orbit, launching around 100–200 objects into space every year.

Having eyes far above the Earth's surface is critical for science. There's the International Space Station, along with weather, fire and greenhouse-gas-monitoring satellites. Satellite phones and internet have long been a mainstay of rural life.

When the Hubble Space Telescope launched into low Earth orbit in 1990, there were about 400 active satellites buzzing around.

By 2000 there were 700. Ten years later that number had just scratched 1,000. But in the mid-2010s launch numbers began to skyrocket. By the time you read this, there will be over 10,000 satellites in Earth's orbit, around half of them active.

This explosion of satellites has been spurred on by two technological advances. Although Elon Musk's SpaceX wasn't the first to design reusable spacecraft or launch components (NASA's Space

Because Starlink's job is to provide satellite internet access around the planet, even radio-quiet areas are at risk from stray internet radio beams.

The spectrum manager tells me that he used to be a satellite engineer; he's still an engineer at heart.

"It gives me a really interesting perspective, because I understand satellite people," he says.

"These constellation operators are engineers. Of course, they care a lot about astronomy, and they want to try to use space in a sustainable way."

In 2018, when SpaceX launched the first few Starlink satellites, astronomers knew that these satellite constellations could be problematic.

And because Starlink's job is to provide satellite internet access around the planet, even remote or radio-quiet areas like Inyarrimanha Ilgari Bundara and Meerkat National Park and their highly sensitive radio telescopes are also at increased risk from stray internet radio beams.

Generally, the frequencies of radio waves are carved out for different purposes, including broadcasting, radar, or mobile phones.

Even outside radio-quiet zones, radio astronomy has teeny slivers cut out of the allocations to allow for scanning the heavens. Today's radio astronomy needs access to the full spectrum of frequencies – galaxies have a different frequency to pulsars, which have a different frequency to ancient hydrogen. To do full sky surveys you need to listen across multiple wavelengths to get a proper picture.

This is why radio-quiet zones are so important.

"This unprecedented level of radio frequency interference control was a significant factor in Australia's successful bid to host SKA-Low," writes CSIRO radiocommunications engineer Carol Wilson. "It has already led to world-class astronomy results in frequency bands that cannot be used elsewhere in the world, particularly in 700–1000 MHz."

But zone regulations are only enforceable on the ground, not in the air or in space. Satellites can legally do whatever their owners like.

SKAO's analysis suggests that without mitigation, SKA-Mid is likely to lose data between 10.9 and 12.75 GHz – the radio wavelength that satellites use to contact the ground. But with hundreds of thousands of satellites constantly beaming down, the Band 5b receivers – which range from 8 to 15 GHz – could be completely lost.

SKA-Low – which is observing in a lower frequency range – will have fewer issues. However, CSIRO is still studying the impact of having the satellite internet user terminals near the site.

Di Vruno's job is to work with satellite companies to come to an agreement on how megaconstellations and radio telescopes can exist in harmony.

In November 2019 (above), a batch of 60 Starlink satellites are readied for deployment from the upper stage of a Falcon 9 launch vehicle.

"Lower Earth orbit is big but not huge – and definitely not infinite," he says. "The numbers [of satellites] we are managing right now: they're large, but not so scary.

"But the plans out there to launch all these satellite constellations is quite scary because the numbers get up to 500,000 satellites." In true engineer understatement, he adds: "That's a lot."

This has led to virtual meetings and straight talking with the world's largest tech and space companies. It has taken him to the United Nations Committee on Peaceful Uses of Outer Space (COPUOS) to advocate on behalf of ground-based telescopes worldwide for access to 'dark and quiet' skies.

The February meeting of the COPUOS Scientific and Technical Subcommittee was the second time that dark and quiet sky protection was a distinct agenda item – Di Vruno and the team were ecstatic about the result.

"We have over 160 members now, and the four hubs are working in many different work packages like coordinating satellite observations, engaging with industry and others," he says.

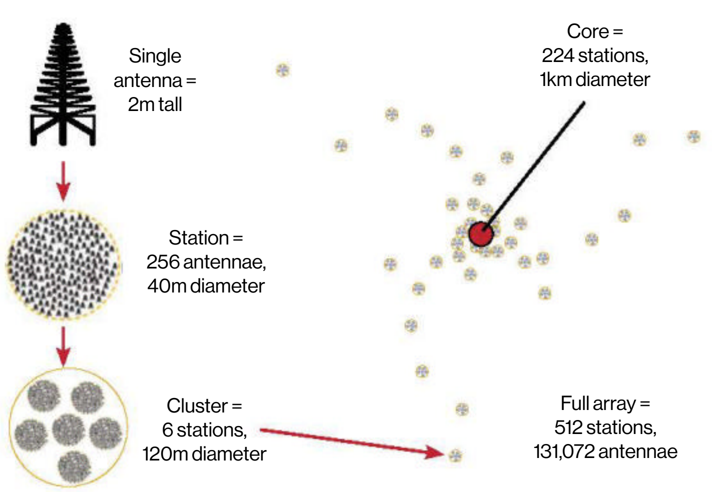
"It's interesting to see how things have changed [since] we started having this conversation."

Sharing Sky and Stars

Astronomers themselves are beginning to come up with answers. The team behind an SKA 'precursor' called the Murchison Widefield Array (MWA) have found a way to cancel out radio interference.

"We're trying to do radio astronomy here on the MWA with satellites creating all sorts of interference," says Professor Elanor Huntington, a CSIRO executive director. "The people who were doing that

Schematic view of the proposed SKA Low configuration



Once completed later this decade, SKA-Low will spread over an area that's 65km wide at the furthest points. Spiral arms will extend out from the station-dense centre; the array will be so sensitive it could detect a mobile phone signal on Mars.

LEFT: GREG BARTON. ABOVE: YOUTUBE.COM/@SPACEX

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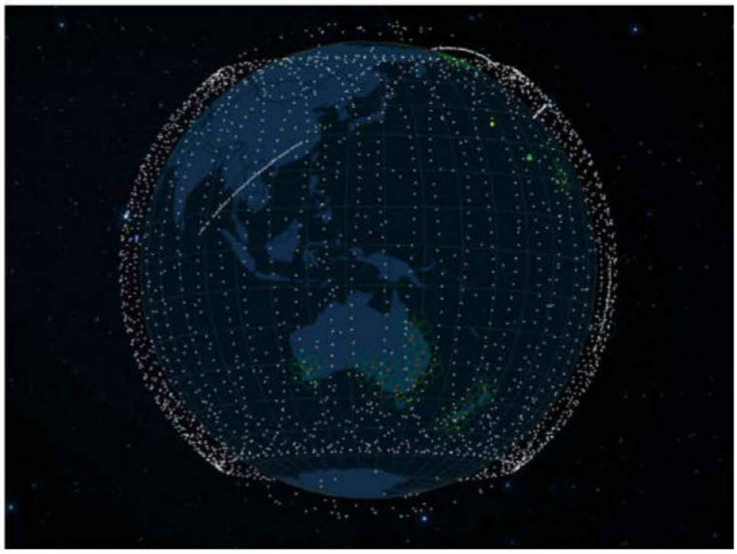

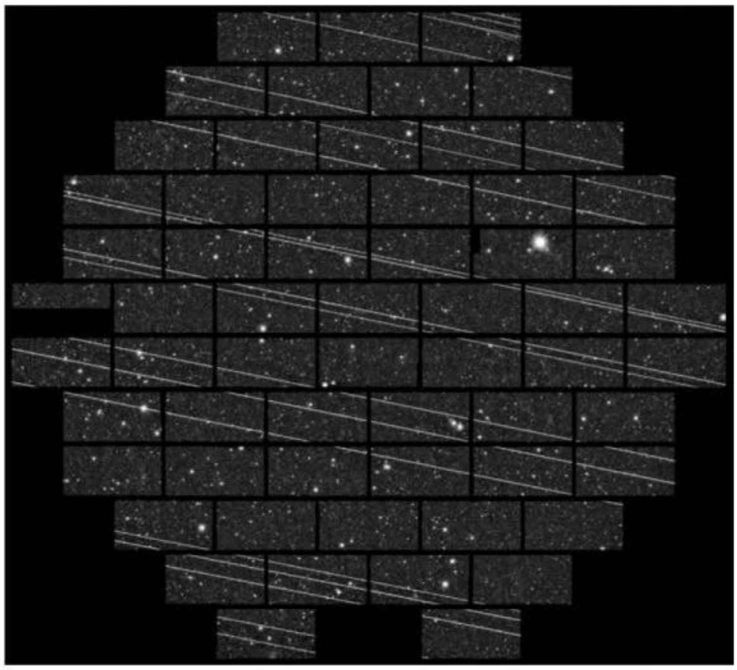

had to figure out a bunch of signal processing, to essentially look past all of the noise that the satellites were making."

Using the MWA as a passive radar, "they have now also figured out how to flip that round, so that they can make a company that is ... specially designed to look for those satellites for the space industry."

Coordinating where satellites are allows researchers to schedule observations around them – but more satellites means more cuts into observing time.

Industry is also engaged. Despite a difficult start – Elon Musk allegedly told astronomers that if they were clever, they would just put their telescopes into space – Starlink has been working to try and solve both the brightness and radio problems.

"Starlink is actively avoiding some radio observatories in the world," says Di Vruno. "That's something that is being implemented now."

Murchison's radio-quiet zone is a 260km-radius circle, and when Starlink launched in Australia, they left a 70km-radius hole over the most crucial inner area closest to the telescope.

Like many truces, this one is on uneasy territory. Recently, after assessing that the telescopes in the area use different frequency bands to the ones the satellites are using, that hole on the Starlink map quietly closed. And Starlink isn't just one satellite comms enterprise in the market. Di Vruno's bridge-building work is far from over. He's upbeat about his mission, although you can tell that there's tension there too.

"It is a challenge for sure. But I don't think that this is the end of radio astronomy at all."

This much is certain: The SKA telescopes are going ahead, satellite constellations or not, and its proponents and creators are consumed with the possibilities it brings to astronomical discovery.

"I was in CSIRO when the first science data started coming out of [SKA predecessor] ASKAP. Going to the meetings and morning teas with the astronomers as they started bringing the first images... that's amazing," says SKA-Low director Pearce.

"I must admit to having watched the press conference for the first James Webb Space Telescope images and thinking how exciting it's going to be when we can do the same."

A live snapshot (top) of Starlink satellites over Australia on 22 February 2023 shows their proliferation. In 2019 (above), optical astronomers at the Cerro Tololo observatory, in northern Chile, surmised that streaks on their images were due to a batch of satellites launched the week before.

FROM TOP: SATELLITEMAP.SPACE; CTIO/NOIRLAB/NSF/AURA/DECAM DELVE SURVEY

JACINTA BOWLER is a science journalist at Cosmos. Their last story for the magazine appeared in issue 96, and a previous story, on the hunt for dark matter, was included in *Best Australian Science Writing 2022*.