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WEEKLY September 3 - 9, 2022

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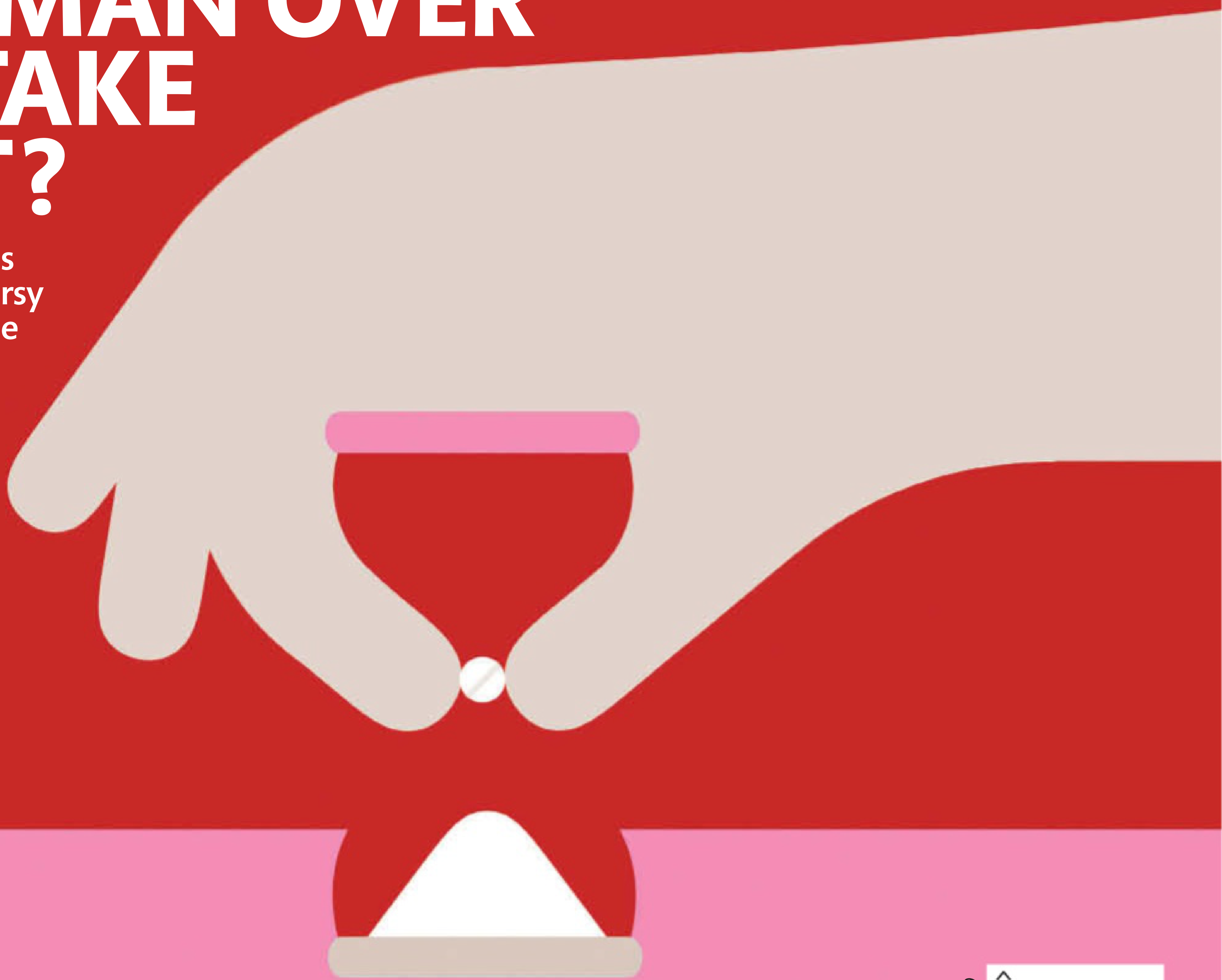

SIGNALS FROM SPACE

Time-lapse telescope offers best chance yet of finding alien life

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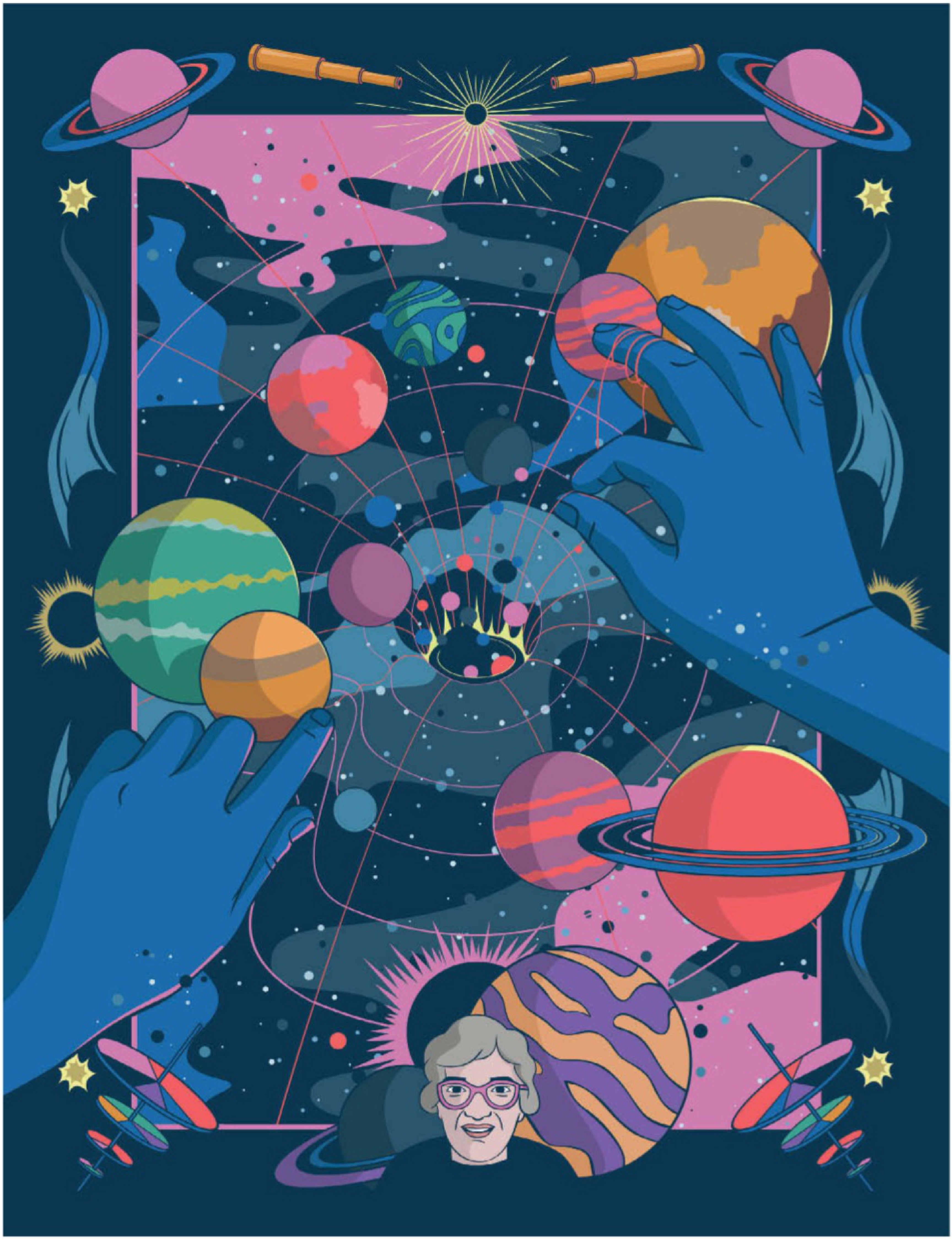

GILLES & CECILIE

Space oddities

A new telescope is about to start the biggest-ever survey of the night sky, and astronomers are getting ready for an onslaught of weird discoveries. **Stuart Clark** reports

IN 1967, astronomer Jocelyn Bell Burnell was searching the night sky for quasars, super-bright sources of light in the centre of some galaxies, when she spotted something unusual. It was a pulsing radio signal from space that seemed too regular to have a natural source. With her supervisor Antony Hewish, she half-jokingly dubbed it LGM-1 – short for little green men.

After finding more of these signals, they turned out to be coming from pulsars, dense, rapidly rotating stars that send regular bursts of energy our way. No little green men, after all. But the discovery demonstrated that astronomers need an open mind.

Now, this is truer than ever. In July 2023, the Vera C. Rubin Observatory in Chile will start studying the universe. It will scan the entire southern sky in an unbelievably rapid three nights, then start over. For 330 nights a year, over 10 years, Rubin will produce the Legacy Survey of Space and Time (LSST). It will change how we see the universe, especially our view of the mysterious objects that are pulsing, blipping or otherwise changing in unexpected ways.

Such signals are buried in a tapestry of electromagnetic waves that hurtles our way every night. Until now, we could only unpick the most obvious of threads. But armed with Rubin's telescope and the power of artificial intelligence, we will see more detail than ever before. Some of it will help us unravel current mysteries, while other aspects will be entirely unexpected. The next time someone writes "LGM" next to a strange signal, they might not be doing it with their tongue in their cheek.

For a long time, we thought of the universe as a serene – even heavenly – place where hardly anything changes. Stars were as close to eternal as you could get and stood in stark contrast to the fevered comings and goings of humankind. But as telescopes extended our senses, so we began to glimpse the truth. Now we know there is plenty of change out there. We have glimpsed exploding stars called supernovae, the pulsating stellar corpses of pulsars, black holes devouring gas clouds and planets drifting in front of stars. But we know there must be much more that we simply haven't had the ability to see yet because we have never had a telescope like Rubin's before.

Traditionally, telescopes that scan the entire sky, known as all-sky surveys, have taken months or years to do this. The UK Schmidt Telescope at Siding Spring Observatory, Australia, was built in the 1970s to survey the southern skies. It took 13 years to complete its survey, capturing its images on 35-centimetre-wide square glass plates. Since then, there have been many other similar efforts at different wavelengths and with different instruments. In 1990, the Röntgensatellit (ROSAT) spacecraft took six months to complete an all-sky survey of celestial X-ray sources. Now, Rubin will take a matter of days. Never before have astronomers been able to compare the almost day-to-day appearance of so many celestial objects. All-in-all, this represents a coming of age for a discipline called time-domain astronomy, which seeks to understand how celestial objects change with time.

"It is going to be a giant leap," says Mario Jurić, director of the Institute for Data Intensive Research in Astrophysics and Cosmology (DIRAC Institute) at the University of Washington in Seattle, who is a data management project scientist for the LSST. "We're going to see 10 per cent of everything that's in the Milky Way with this one machine." That accounts for around 20 billion stars, and because of Rubin's light-gathering power and speed, it will detect even slight changes in the brightness and position of objects.

"Each night, you are going to see a 1 in 10 million event happening"

"We're going to see 10 million things changing in the sky every night. So, each night, you're going to see a 1 in 10 million event happening," says Jurić. That statistic marks a seismic shift in the very nature of the objects and events that astronomers can investigate, since even rare celestial events will now appear almost every night. That means there are all sorts of previously exotic events that astronomers are hoping Rubin will find in much greater numbers.

First, there are the fast blue optical transients (FBOTs), which are pretty much what their name implies: fast pulses of blue light. Only five of these have been seen so far. They could be supernovae that are surrounded in dense clouds of dust and gas, which alters the colour of the light they emit. Finding more with Rubin will allow astronomers to make a much better determination of their properties and hopefully reveal their true identities.

Second are the kilonovae. These are top of astronomers' most wanted list. A kilonova is an explosion, one with about a hundredth to a tenth the energy of a typical supernova. Again, astronomers know of only a handful, all detected serendipitously by different instruments. They are thought to be the collision of two dense stellar corpses known as neutron stars, or maybe a neutron star colliding with a black hole. They should be relatively common, but have largely flown under the radar because they fade so quickly.

"A good old-fashioned supernova lasts about a year," says Federica Bianco at the University of Delaware, who is co-chair

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of the LSST Transients and Variable Stars collaboration. "A kilonova last weeks, but the really bright emission evolves very rapidly, so you might only have a few days to see it."

With its three-day, all-sky coverage, Rubin is well suited to detecting them. This is particularly exciting because the detection in 2017 of a gravitational wave signal, caused by ripples in space-time, is thought to have been emitted by a kilonova produced by two colliding neutron stars. This was the sixth gravitational wave event detected by the Laser Interferometer Gravitational-Wave Observatory (LIGO), but the first one not to have been produced by the merging of two black holes. Because the LIGO detection was communicated in a speedy fashion, 70 observatories around the world and in space managed to observe the kilonova's aftermath using instruments that span the electromagnetic spectrum, from radio wavelengths to X-rays and gamma rays.

Sorting through chaos

Putting together data from different observational techniques is called multi-messenger astronomy. "This is very much a focus in modern astrophysics," says Bianco, and Rubin will be instrumental in spotting any visible counterparts to future gravitational wave detections. Its surveys will mean astronomers will be awash with information. But first, they have to work out how to drink from the fire hose without drowning.

Not all changes Rubin's telescope spies will be sudden or large, which is what usually triggers an alert for further observations on other instruments. Many celestial objects will be evolving over the course of years or decades. With each object in the LSST being observed between 800 to 1000 times during the first 10 years of the survey (adding up to a nearly continuous set of data for tens of billions of celestial objects), even the slyly shifting ones should show up. The LSST's archive will be a rich source of discoveries in the long run.

The problem is, sifting through that amount of data isn't easy. By any measure – the number of stars observed, the volume of space surveyed, the amount of data to sort through – Rubin is at least 10 times better than anything that has come before. When data starts coming in from July next year, it is probably going to seem like chaos, with signals changing all over the place without rhyme nor reason. Just keeping up with the data flow, let alone sorting through it all, is going to be a Sisyphean task. "None of

"One of the 'unknown unknowns' we really would like to see is evidence of alien life"

Astronomers hope to find oddities like cosmic strings

LYNETTE COOK/SCIENCE PHOTO LIBRARY

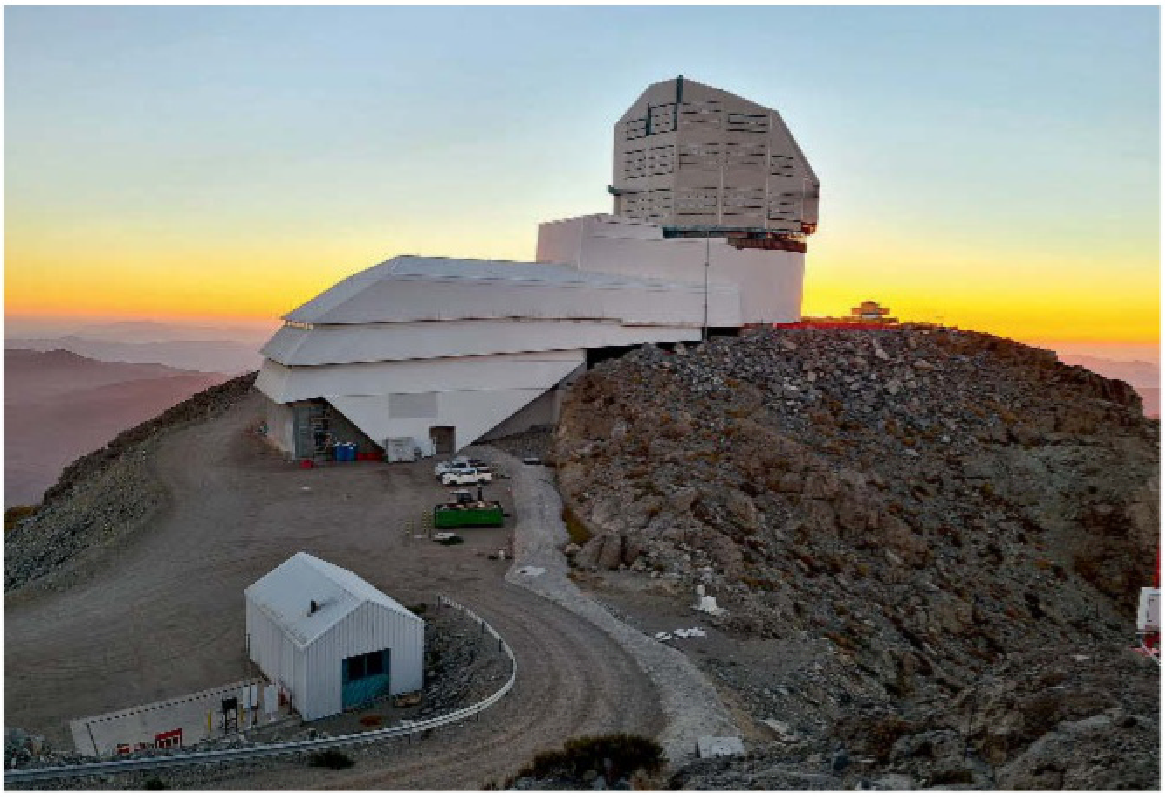
us working on the project would be able to figure it all out," says Jurić.

Thankfully, they don't have to. Instead, they have been developing machine learning and artificial intelligence programs to do the heavy lifting. Some of these are already in use, for example at the Zwicky Transient Facility (ZTF). ZTF is a precursor time-domain sky survey that has been used to pave the way for Rubin. It has now been working for three and a half years using instruments at the Palomar Observatory in California. Instead of Rubin's expected 10 million alerts for objects of interest each night, ZTF produces hundreds of thousands per night.

As Rubin's telescope scans the night sky, taking image after image, AI-powered systems look for anything that has changed, creating an automatic alert that is sent to a group of astronomers and observatories around the world dubbed "data brokers". They then distribute the information further so that the discoveries can be prioritised and followed up by other telescopes. Each of the data brokers has different areas of interest. For example, one may be searching for asteroids, while others may look only for supernovae. The same kind of alert stream will be employed by Rubin. Within 60 seconds of an image being taken, software will have identified the changing sources and alerted the data brokers.

As a result, machine learning and advanced statistical methods are emerging as a whole new branch of astrophysics. With the LSST as its focus, thousands of astronomers around the world have gathered into different groups to develop their own complementary algorithms for extracting as much information from the data as possible. The groups include one to find asteroids and other minor bodies in the solar system, one to study powerful, black-hole-fuelled galaxies called active galactic nuclei, a dark energy-mapping group, another tracing the structure of the Milky Way, one interested in explosive objects and more. "There is a big chunk of the community that is getting involved and getting their hands dirty," says Matthew Graham at the California Institute of Technology, project scientist for the ZTF.

The raw data from Rubin's 10-year observations will total around 60 petabytes, or 60 million gigabytes. Combining this in various ways to produce final images and other products that astronomers can then analyse will expand that to around half an exabyte, or about 500 petabytes. The AI routines can then comb through this data, correlating it this way and that, looking for any similar behaviours,



The telescope at Vera C. Rubin Observatory on Chile's Cerro Pachón mountain will start to map the sky in 2023 (left and below)

RUBIN OBS/NSF/AURA; H STOCKEBRAND/RUBIN OBS/NSF/AURA

grouping known objects and phenomena together and then spitting out anything else that seems strange enough for its human masters to investigate. This will undoubtedly reveal a plethora of unanticipated phenomena.

"This is my favourite thing to think about, how can Rubin support and foster the discovery of 'unknown unknowns' or true novelties in the sky," says Bianco. In most cases, it seems certain that to understand these new phenomena, astronomers will need additional observations, probably with other facilities. To understand a new phenomenon or object, you first have to gather as much information about it as you can.

Extraterrestrial signals

One thing that could show up is evidence of exotic cosmological objects, such as cosmic strings. These are hypothetical creases in the fabric of space that would behave like gravitational lenses, producing mirror images of distant galaxies. Finding one would be a gift for cosmologists. The strings are thought to have formed in the early universe as the various forces of nature became distinct from one another and the space-time continuum settled into its current form. Cosmic strings are a bit like the cracks that can appear in blocks of ice as water freezes, so finding and studying one could tell us about the condition of the early universe.

"One of the unknown unknowns that we really would like to see is evidence of alien life, right?" says Bianco. Time-domain astronomy has had a few close brushes with the extraterrestrial already. As well as the discovery of pulsars in the late 1960s, in 2015, the world was gripped by the story of Tabby's star. Tabetha Boyajian at Yale University and her colleagues reported that star KIC 8462852 was undergoing dramatic dips in its brightness. Up to 20 per cent of the star's light was being obscured from view for between five and 80 days at a time over a roughly three-year period.

It was an unprecedented observation, prompting speculation that it might be the result of something an alien civilisation would build. The idea was simple: extraterrestrials would gradually surround their sun with technology designed to capture its light and transform it into electrical power. As this half-built megastructure orbited the star, it would occasionally block out a large fraction of the star's light, giving rise to what astronomers call a "technosignature", an inevitable by-product of an advanced civilisation.

But the apparently random nature of subsequent dimming events convinced astronomers that the most likely explanation for Tabby's star's variability was obscuring clouds of dust that started out dense and then dissipated. It was suggested that the clouds came from a moon that fragmented.

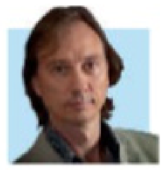
Although the alien hypothesis turned out to be a false alarm, it is exactly the kind of initially inexplicable observation that we should expect to become commonplace with Rubin. Perhaps this time, one of them really will be extraterrestrial in origin. "This question – are we alone? – is fundamental, not only for science and technology, but for philosophy and for society," says Zaza Osmanov at Free University of Tbilisi, Georgia.

Intrigued by the behaviour of proposed megastructures of the sort initially suggested to explain Tabby's star, Osmanov began a series of calculations to determine whether there would be any other observational signatures from them. In 1960, physicist Freeman Dyson showed that such structures should radiate their waste heat as infrared rays to maintain themselves in thermal equilibrium. Osmanov realised a structure in thermal equilibrium is never precisely steady in terms of its radiation output, and will instead oscillate around its equilibrium condition. In the case of a megastructure, this means it could produce a detectable signal that varies with time.

According to his calculations, the oscillation period could be anything from minutes to centuries and could effectively make its host star look like some kind of previously unknown variable star. As such, it could be exactly the kind of weird signal that the machine-learning algorithms are designed to unearth in Rubin's data.

"When it comes to the search for extraterrestrials, that is exactly what you want," says James Davenport, associate director of the DIRAC Institute, "the outliers, the things that do not match any expectations or can't fit with any astrophysical model."

Ultimately, whether it is keeping an eye open for ET or not, there are very few corners of astronomy that Rubin won't progress. By allowing us to access the universe in a way we never have before, it is guaranteed to be transformational. "Any time you look at a new wavelength or a new temporal domain, you can guarantee you will find something you don't understand," says Davenport. "By definition, you're going to find strange things. They may not be aliens, but the likelihood that you're going to find something incredible is almost 100 per cent." ■



Stuart Clark is a consultant for *New Scientist*. His latest book is *Beneath the Night* (Faber)