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Sky at Night

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RUBIN RISING

Why the Vera Rubin Observatory is going to change everything we know about the Universe

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First light for Vera Rubin Observatory

New science facility captures cosmic phenomena on unprecedented scales

The Vera C Rubin Observatory has released its first images, capturing millions of galaxies and stars, along with thousands of asteroids. Taken during just 10 hours of test observations, the images mark the culmination of over two decades of work. They show fractions of the night sky in extraordinary definition, but the observatory will soon target a feast of cosmic phenomena, from asteroids and comets to supernovae.

Rubin Observatory sits at the summit of Cerro Pachón in Chile, where the combination of dry air and dark, clear skies creates excellent observing conditions. It is named after American astronomer Vera C Rubin, who provided the first compelling evidence for the existence of dark matter, the invisible material that permeates our Universe. Exploring the nature of dark matter and dark energy will be one of the new observatory's biggest scientific missions. rubinobservatory.org

► Read more in our feature on page 28

The new observatory hopes to lift the lid on the invisible forces shaping the Universe

Inside the Vera C Rubin Observatory

The brand-new observatory is about to begin its 10-year survey of the night sky. **KR Callaway** visited the facility to find out how it will shed light on the Universe's darkest mysteries

Driving up dusty mountain roads flanked by cacti and colourful bursts of wildflowers, it's hard to imagine these quiet peaks in the Chilean Andes are home to some of the most sophisticated astronomical instruments on Earth. Atop Cerro Pachón, 2,715 metres (8,900ft) above sea level, the newly constructed Vera C Rubin Observatory is ready to reshape our understanding of the cosmos. Its 10-year Legacy Survey of Space and Time (LSST) is slated to start later this year.

Visiting the facility in May, it was a marvel to see the telescope whirring to life. Gathered on a platform inside the dome with scientists and other visitors, I watched as the massive teal-coloured structure rotated and angled towards the sky. We were seeing it move at only a fraction of its maximum speed, but it was already fast and fluid, gliding between positions. At full speed, the telescope will complete scans of the entire Southern Hemisphere sky in just three or four nights, collecting thousands of detailed pictures with its 3,200-megapixel digital camera, the world's largest. ▶

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A new era of sky watching
– Rubin will map the most
ambitious 3D time-lapse of the
Universe ever attempted



► Vera Rubin, whose work offered early evidence for dark matter, lends her name to the observatory



The Cosmic Treasure Chest shows 10 million galaxies, just a taste of the 10 billion Rubin will chart over the next decade

► The camera's first images, released in June, were a preview of what to expect from the decade-long LSST survey. One, a widefield view of the southern Virgo Cluster called the Cosmic Treasure Chest, looked deeply into just a small percentage of what Rubin can see. It revealed a startling level of clarity, with around 10 million galaxies springing forth in rich detail.

"Any image is very exciting," says Vincent Riot, former LSST Camera project manager. "It basically means that everything works." But Riot admits he is even more excited to see data released after the survey starts. Yet more comprehensive images covering wider fields of view will emerge as the telescope traces the sky night after night, creating a dynamic portrait of the Universe.

A telescope with a mission

Named after the late American astronomer Vera Rubin (1928–2016), whose research on galaxy rotation yielded the first solid evidence for dark matter, the observatory started as an idea for a dark matter telescope in the early 1990s. Scientists wanted to create an optical system that could see galaxies near and far, giving us a better understanding of how dark matter and dark energy guide their structure and arrangement. However, creating a telescope with such a sensitive optical system and wide field of view meant it would be capable of much more than looking for the unseen.

"We knew that if we were going to be successful, we had to cover a broad range of science," says Željko Ivezić, director of the observatory.

Looking for faint, faraway galaxies also holds lessons about their formation. Large galaxies like our own are thought to be the product of many smaller galaxies merging. Rubin's intricate optical system



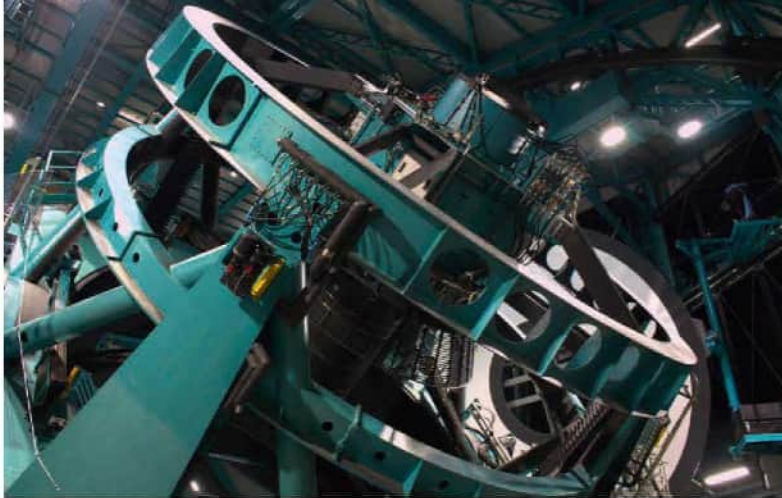
is expected to pick up on faint remnants of these mergers and other signs of the Milky Way's evolution.

In addition to creating the deep, composite images that make seeing faint objects possible, repeatedly photographing each area of the night sky enables Rubin to track any changes that occur, such as asteroids moving through the Solar System, bright supernovae explosions and other objects that change position or brightness over time. It took careful planning and a unique design to create an instrument powerful enough to address all these science goals with the same dataset. "You start with some high-level science goals, and then you trickle that down into the various subsystems," explains Kevin Fanning, commissioning scientist and member of the camera project team.

Scientists in dozens of countries helped plan and build the observatory's highly customised instruments and software, beginning in the late 2000s. Then, piece by piece, everything from the

▲ Telescope components, like the huge 8.4-metre mirror shown here, had to be carefully transported up Cerro Pachón mountain

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◀ The telescope is designed for speed and precision, capturing around 1,000 images a night and scanning the entire Southern sky every three nights



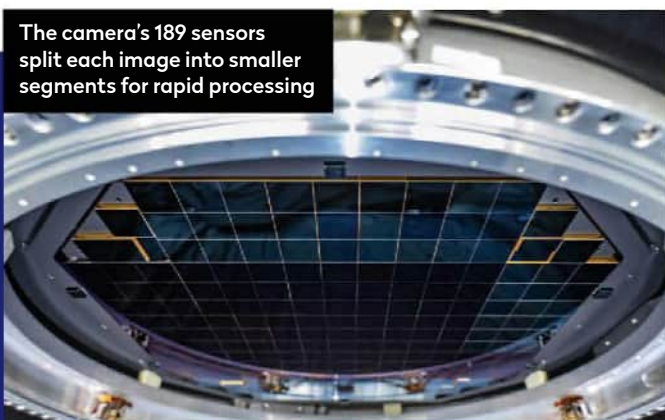
▲ The primary mirror, pictured in the on-site silver-coating chamber

telescope's mirrors to the camera itself was carefully transported – often thousands of miles – to the summit of Cerro Pachón. Now fully assembled, the observatory is able to quickly and precisely turn particles of light from distant celestial objects into processed data.

These particles – photons – first strike the telescope's primary mirror. At 8.4 metres (27.5ft) in diameter, it is one of the largest telescope mirrors ever produced as a single piece of glass. Its large size means it will be able to capture an immense amount of light, including from very faint and distant galaxies. The mirror was cast in Arizona by heating glass at temperatures over 1,000°C (1,800°F) on a mould placed within a spinning oven. Then, after months of careful preparation, polishing and additional testing, it was transported by ship to Chile, where it was coated with silver on site.

Built for speed

From the primary mirror, photons bounce to the telescope's 3.5-metre (11.5ft) secondary mirror – one of the largest convex mirrors ever made – and then back down to a tertiary mirror embedded in the primary. Because its first and third mirrors are combined into a single structure, Rubin is much smaller than a telescope with similar capabilities and three separate mirrors might be. This compact silhouette also means the telescope can move fast, an essential feature considering it is expected to ▶



The camera's 189 sensors split each image into smaller segments for rapid processing



At the summit control room, teams oversee the flow of Rubin's massive data stream

Taming a data mountain

The sheer volume of information Rubin will gather demands a completely new approach

Every time the Rubin camera captures a new patch of sky, it generates a fresh stream of data about the Universe. While this will be a massive treasure trove for astronomical research, handling it poses a unique challenge.

Previous astronomical surveys, such as the Sloan Digital Sky Survey, used software designed for large datasets, but nothing on the scale that Rubin

demands. With a 3,200-megapixel image captured roughly every 30 seconds, the observatory will generate about 20 terabytes of data a night, requiring a complete rethink of how astronomical data is handled.

"It was a giant effort over a decade," says Ivezić. The key lies in its modular design. The camera has 189 sensors, each of which splits its image data into 16

parts when it's time to read out the data. Because these segments are processed in parallel, the camera can read out the entire image in about two seconds. Once out of the camera, this data – too large to be downloaded by individual scientists – is stored online and in the cloud, relying on advances in storage and bandwidth that didn't exist when the observatory was first conceived.



Cosmic Abundance: part of a Southern sky Rubin will return to night after night, building a dynamic portrait of the Universe



NSF-DOE/VERA, C. RUBIN OBSERVATORY X2 | RUBIN OBSERVATORY, NSF, AURA, S. MA | RUBIN OBS., NSF, DOE, NOIRLAB, SLAC, AURA, T. LANGE | RUBIN OBSERVATORY, NSF, AURA, A. PIZARRO D.

► catalogue the entire Southern Hemisphere sky a thousand times over by the end of its 10-year survey.

After passing these mirrors, the photons finally enter the LSST Camera. Weighing 2,800kg (6,170 pounds) and roughly the size of a small car, it's a colossus. When visiting the dome, you might expect it to be easy to spot, but it is so well integrated into the telescope that you can only catch glimpses of it at certain angles. Inside the camera are three lenses and a rotating carousel of filters that together focus light towards its image sensors and add colour to the pictures it creates.

The heart of the LSST Camera is its focal plane, a 64cm-wide (25-inch) array made up of 189 individual sensors placed just half a millimetre (0.02 inches) apart. Each sensor acts as a little eye for the camera,

collecting its own portion of the image data. And it's a lot of data: every image taken by Rubin's camera has a resolution of 3,200 megapixels – 260 times that of a modern smartphone camera – and covers an area of the sky equivalent to about 45 full Moons. Displaying all the data from a single Rubin camera image would require 400 high-definition televisions.

The images start their data-processing journey by first travelling through a tangle of wires to an in-house data centre below the camera. After an initial analysis, they follow a dedicated undersea fibre-optic cable from Cerro Pachón to SLAC in California. There, they will be compared to past pictures taken in the same direction, spotting changes in the night sky and sending out automatic alerts – anywhere between one and 10 million each night – to the

▲ Left: Rubin's 3.5-metre secondary mirror directs light from the primary onto the massive camera

Right: the LSST Camera mounted in the observatory is the world's largest digital camera, with a 3,200-megapixel sensor. For comparison, the iPhone 16 Pro has a 48-megapixel camera

With an exceptionally large field of view, Rubin catches sweeping nebulae scenes in a single frame



Expanding the realm of possibility with state-of-the-art optics and software systems, Rubin promises to generate much more data than any observatory before it – approximately 20 terabytes (20,000 gigabytes) per night. And unlike many observatories, which allocate time to astronomers pursuing specific research goals, Rubin's survey will produce a large, uniform dataset available to

science community. Finally, Rubin's images will join an extensive database that scientists can turn to to unravel the Universe's many mysteries.

Poised to rewrite astronomy

Creating the cutting-edge equipment that makes this process possible took nearly 30 years, from the first sketches of the proposed dark matter telescope in 1996 to first light earlier this year. Every scientist involved in the project seems to have a differing opinion on which part of the process posed the greatest challenge, but past difficulties only add to their pride in the finished product.

"This is a very challenging project, because our goals are very ambitious," says Aaron Roodman, deputy director at the observatory. "We have pushed what is possible to the limit, in many different directions, to achieve those goals."

researchers across many areas of astronomy.

Even before data collection for the survey officially begins later this year, excitement has been building both atop the summit and around the world. Thousands of people across six continents tuned in to see the unveiling of the observatory's first images. While impressive, these are just the opening few frames of what observatory scientists are calling a time-lapse movie of our Universe.

"I was in the control room when we took the first image," says Alexandre Boucaud, a software engineer at the French National Centre for Scientific Research (CNRS). "It felt like a great achievement – but five minutes later, it felt like just the beginning."

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KR Callaway is a freelance journalist and editor specialising in science, health, history and policy

Q&A with Alan Strauss

Rubin Observatory's outreach lead on why the science belongs to everyone



What is Vera C Rubin Observatory's education and public outreach programme?

Data from the observatory's cutting-edge equipment will be available to everyone,

from researchers at elite universities to citizen scientists and even school children. It's all part of the observatory's public outreach initiative, an effort to bring more people into the discovery process.

To my knowledge, this is the first time that the US government has funded education and outreach as part of the construction and operation of an observatory.

Long before it took its first images, Rubin's nascent outreach team came together to envision the many audiences the observatory could serve: the science-interested general public, teachers and their students, researchers in the Rubin science community, and citizen scientists who want to volunteer their time to analysing data.

Why is connecting with the public crucial, even before the survey begins?

We want people to get excited about this. Rubin is a unique project in the way data is being provided to every US astronomer, every Chilean astronomer, and other data rights holders.

Some initiatives, such as workshops for teachers and astronomy-related citizen science projects, are already available. And as survey data becomes available, there will be more ways for people interested in Rubin's science to get involved.