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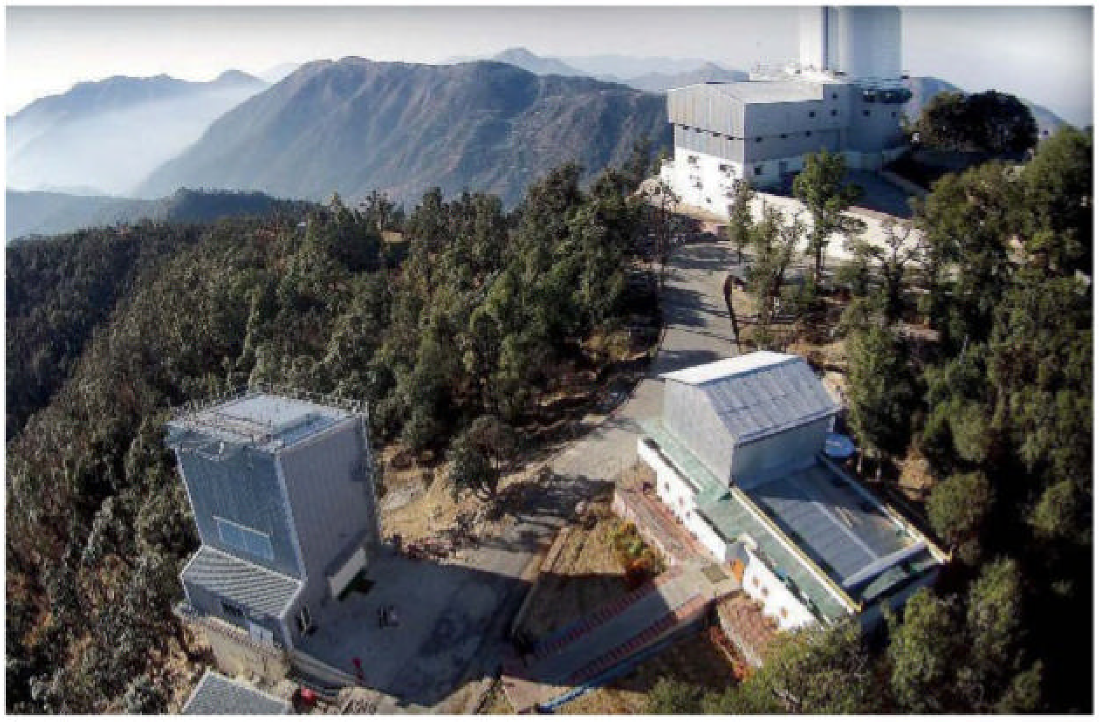
THE LIQUID TELESCOPE

A unique telescope with a liquid mirror has finally opened its eye on the universe. This innovative design could pave the way for an observatory on the moon, says **Sushmita Pathak**



JEAN SURDEJ

A 4-metre liquid mirror telescope with a retractable roof (left) sits next to two optical telescopes in the Indian Himalayas

ATOP an Indian mountain sits a 4-metre-wide reflecting basin, its ripple-free surface mirroring everything above it. It is as if someone scooped up a piece of the Bolivian salt flats, the world's largest natural mirror, and put it in the Himalayas. But unlike South America's Salar de Uyuni, where the salt plains covered by water produce incredible reflections that draw many sightseers, the basin on the mountain is filled with liquid mercury. And this is no tourist hotspot: it can only be accessed by a small group of scientists who use it to observe the heavens.

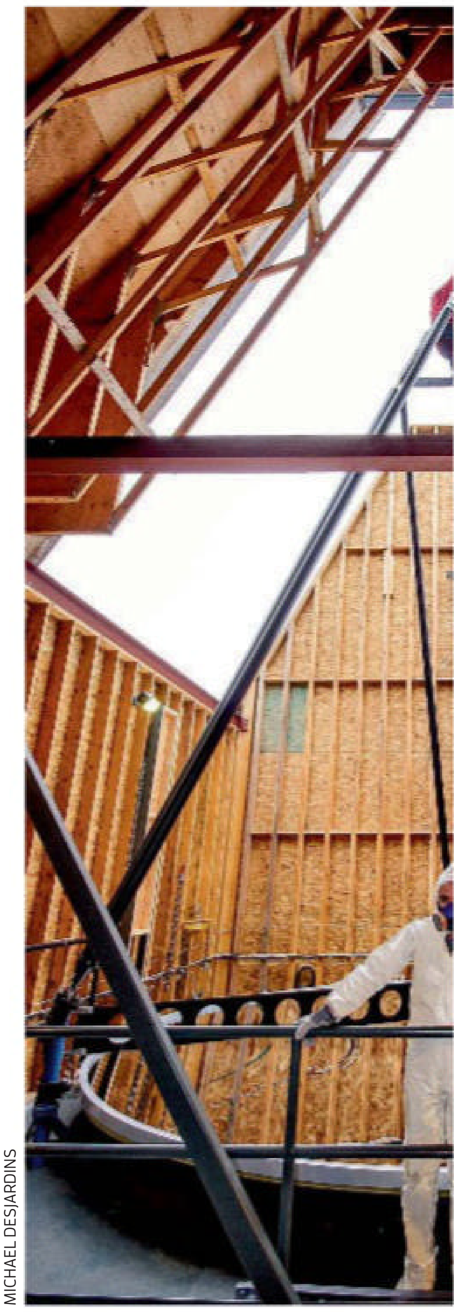
The basin is part of a unique telescope. Situated in an observatory in the northern Indian state of Uttarakhand, the International Liquid Mirror Telescope (ILMT) uses the pool of shiny metal to gather light from the skies.

Such telescopes have benefits over conventional ones. Most importantly, they are much cheaper to build. But although the idea of a liquid telescope has been around for centuries, creating a viable one has proven fiendishly tricky. The ILMT was in the works for more than a decade. This year, it opened its eye for the first time. It is the largest of its kind, and the first built to carry out astronomical observations.

The telescope scans the night sky in the hope of spotting new phenomena – when it isn't raining, that is. But astronomers hope the potential of these devices will one day reach far higher than Earth's mountain peaks. One day, they might even allow us to build a mega telescope on the moon to get a glimpse of the first stars in the universe.

The basic concept of a liquid telescope is surprisingly simple. Just like your morning coffee, if you stir a liquid, its surface will form a dish-like shape that, it turns out, is perfect for focusing light. "The idea was, if we can find a reflective liquid and rotate it with a very precise control system, it would focus light from above onto a detector and we could

"A liquid mirror telescope can only look straight up. That can be a bonus"



MICHAEL DESJARDINS

use that as a telescope," says Paul Hickson at the University of British Columbia in Canada, one of the main scientists on the ILMT.

This concept can be traced back to the 17th century and Isaac Newton. But it wasn't until the late 19th century that anyone tried to build one. The most notable attempt was by US physicist Robert Wood who, in the early 1900s, constructed a small prototype 5 centimetres in diameter. But Wood's creation was far from perfect: the mechanism he used to rotate the mirror created ripples in the mercury and he had trouble making the dish that held the metal spin at a constant speed. In 1922, a "monster telescope" 15 metres in diameter was suggested. The aim was to observe Mars and any inhabitants – the subject of fevered speculation in the early 20th century – as the planet came close to Earth in 1924. But the telescope never materialised.

For several decades, working liquid telescopes remained a figment of people's imaginations. Then, in 1982, Ermanno Borra at Laval University in Quebec, Canada, found a solution to the technical challenges, such as the ripples that had plagued Wood's creation and other early attempts. He suggested dampening vibrations by pumping a thin layer of air between the basin that holds the mercury and the motor that rotates it. Borra also suggested pouring a liquid resin on the dish surface first, letting it dry into the right shape, then pouring reflective liquid onto it as a coating, cutting down the amount of mercury needed.

These tweaks led to a flurry of projects. In 1994, Borra and his colleagues, including Hickson, built an experimental 2.7-metre-wide liquid mirror telescope near Vancouver, Canada. Hickson also worked with NASA on a 3-metre liquid telescope in New Mexico to observe space debris and, in the early 2000s, the University of British Columbia built the experimental 6-metre Large Zenith Telescope on a hilltop just outside Vancouver. "We used it mostly for engineering, to solve problems that arise when you go to larger and larger diameters," says Hickson. It was also used to study the sodium layer in Earth's atmosphere, but it wasn't suitable for space observations, because of the cloudy weather near Vancouver. It was decommissioned in 2016.

Still, the Vancouver project confirmed what many astronomers had suspected, that these telescopes are much cheaper to build than those with solid mirrors. Conventional instruments use glass mirrors to reflect light coming from stars and other cosmic objects. The mirror surface can't have even the slightest of bumps, which means polishing it to be precisely smooth to a fraction of the wavelength of light.

Achieving such accuracy becomes almost impossible in large telescopes. One workaround is making several smaller mirrors and then aligning them to form a big surface. But even then, it is a costly and complicated affair. The mirrors, which form a big chunk of the cost, can make a large telescope economically unviable. Liquid mirrors, on the other hand, cost a fraction of glass ones – 1 per cent of the cost, according to some estimates – making them ideal for large telescopes. The 4-metre ILMT cost around $2 million, whereas the 3.6-metre optical telescope it sits next to came with a price tag of $17 million.

Still, cost savings are irrelevant if we can't build a working liquid mirror telescope. The ILMT was conceived in 1996 and was expected to be ready for use in 2009. But the project faced several delays. Getting enough mercury to fill the dish, 50 litres of it, was one challenge. Then, the construction of its protective dome was delayed until late 2016. The following year, two cranes and a truck made a slow climb up the mountain to install the 4-metre dish and other elements. Then came the coronavirus pandemic, setting back the ILMT by another year or so. "Strong determination kept the project alive," says Jean Surdej, an astronomer at the University of Liège in Belgium who spearheaded the ILMT effort. In his eyes, it was worthwhile because of its cost-effectiveness and the opportunity for studying the skies in a unique way.

Unlike regular telescopes, which can point to different places, a liquid mirror telescope

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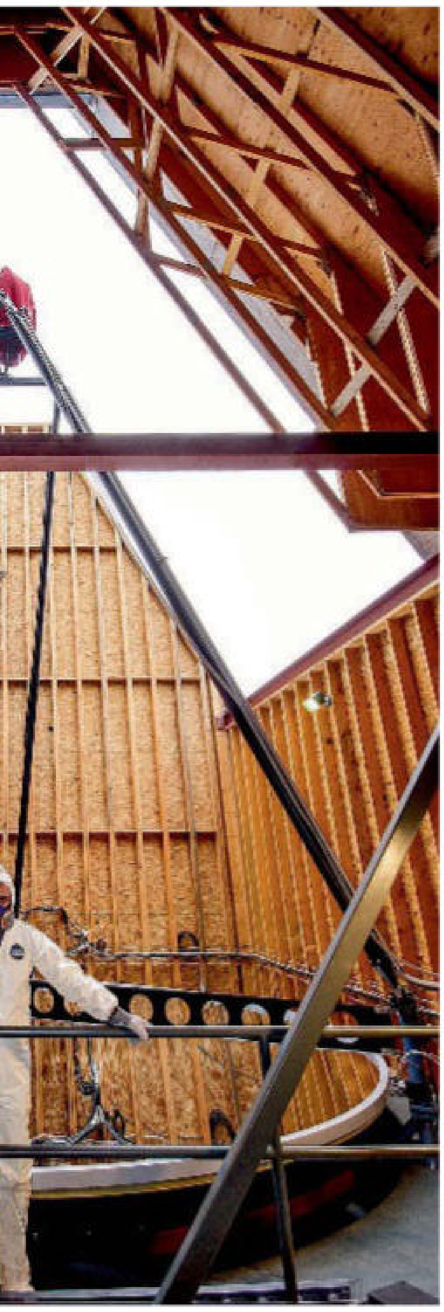
In a liquid mirror telescope, light reflects off a pool of mercury



A 6-metre liquid mirror telescope in Vancouver was used to study Earth's atmosphere

can only look straight up at the patch of sky overhead, which astronomers call the zenith. This was initially considered a grave shortcoming because there was no way to target specific objects. These days, however, only observing one spot can be a bonus. "By looking at the same region of sky over and over again, you get this sort of time-lapse picture," says Hickson. It is a good way of detecting objects that appear fleetingly, such as supernovae and passing asteroids.

Usefully, the image quality for a telescope is best at the zenith, too. "The zenith is where the [incoming] light rays cross the smallest amount of atmospheric layer of the Earth, which means that transparency is the best there," says Surdej. Another advantage of the ILMT is its location, right next to India's biggest optical telescope. If astronomers spot something interesting through the ILMT, they can follow up with the other instrument.

Even though they are much cheaper to build than their glass counterparts, liquid mirrors come with their own tricky requirements. In the ILMT, the mirror dish floats on an air layer about 10 micrometres thick, much thinner than a human hair. The layer of mercury in the ILMT is about 3 millimetres thick and the mirror rotates once every 8 seconds. To prepare the surface of the dish that holds the mercury so it assumes the required paraboloid shape, scientists had to mix several buckets of chemical resin, climb on a beam directly above a spinning disc and pour the liquid onto the spinning surface before it hardened so it could take the desired shape. Getting the resulting 4-metre-wide dish up to the observatory, which is at an elevation of 2450 metres, was also quite an expedition. It even required breaking down a wall to widen the road at one spot.

Finally, in early 2022, Hickson and Surdej flew to India to assemble the telescope along with Indian scientists. They snapped on their protective masks, to stop them inhaling mercury vapour, poured the shiny liquid metal onto the surface and aligned the camera that captures its reflected light. "The first images were terrible, which is normal because the camera was not adjusted to the right position," says Hickson. After tweaking the settings, the team achieved its first viable observation in the second week of May. "We were all very happy when we got the first images," says Hickson. "We opened a bottle of wine."

The telescope is only operational for about eight to nine months a year, taking a break between July and October during the main part of India's monsoon season. The mercury is removed and the sliding roof that opens when the telescope is observing is covered. The team will carry out tests to align all the elements, before restarting observations in early January.

New visions

Observations so far include a rich stellar field in the Milky Way and NGC 4274, a galaxy in the Coma Berenices constellation. These are known objects. The hope is that the ILMT will find something entirely new. "Many discoveries that have been made in recent years have just been sort of unexpected," says Hickson. "You don't know what might turn up."

There is a lot riding on the ILMT. If it proves successful, it could lead to new liquid telescopes in other parts of the world. The University of British Columbia had plans for an 8-metre telescope on a peak in Chile, but the project is on hold because of a lack of funding.

Many hope the future of liquid mirror telescopes lies further afield. NASA is conducting experiments to see if fluids can be used to make other parts of a telescope in space. Without gravity, any blob of liquid eventually takes a perfect spherical shape, which can be used to make a giant lens. When tested in simulated microgravity environments, liquid lenses have proven as good as or better than glass lenses, and only take a fraction of the time to make.

The ultimate dream, for astrophysicist Anna Schauer at the University of Texas at Austin at least, is to build a giant liquid telescope on the lunar surface, to peer at the first stars in the universe. Schauer and her colleagues are studying the viability of a 100-metre-diameter version to look at an elusive group of objects called Population III stars – thought to be the first stars to have formed after the big bang and to be made entirely of hydrogen and helium. These are believed to exist in smaller clusters and are so faint that even the James Webb Space Telescope is unlikely to be able to see them. To do so, scientists would need a telescope with an incredibly large mirror. This would be practically impossible to manufacture and extremely expensive to put on the moon – unless it is made of liquid.

A lunar telescope won't be made of mercury, though, as the metal is too dense to work properly on the moon's surface. One alternative is an ionic liquid, a salt in liquid form. Whatever the material, the instrument would be nestled in a crater near one of the moon's poles, and it would send data to a satellite in lunar orbit. Such a huge project is likely to take decades to materialise. But the ILMT's opening, after years of preparation, makes Schauer hopeful. "Reviving this technology and putting it to work on Earth is amazing," she says. "It's a great step in the direction of finally creating a liquid mirror telescope on the moon." ▮

Sushmita Pathak is a freelance writer based in Delhi, India