

BIRTH OF A GIANT TELESCOPE



ABOUT THE WRITER

Eagle Gamma is a writer specialising in astronomy and astrophysics. In the course of his work he has visited most of the world's leading observatories.

The LMT is visible for miles around, thanks to its location on top of an extinct volcano

One of the world's biggest telescopes is taking shape in Mexico. **Eagle Gamma** investigates

Atop an extinct volcano, near the highest point in Mexico, sits a sizable new addition to the global astronomy community. After an almost two-decade gestation period, the Large Millimeter Telescope (LMT) is set to redefine observations in its wavelength. Its results will tell us a lot about the cosmos, from the dimmest planetesimals to the most luminous galactic cores.

With its unique design and construction, and its prime location, the device takes its place among the world's great scientific instruments. The innovative telescope is the largest in the world of its kind: a single-dish antenna observing radio waves in the range of one millimetre. As construction nears completion, the telescope is already beginning its programme of scientific research.

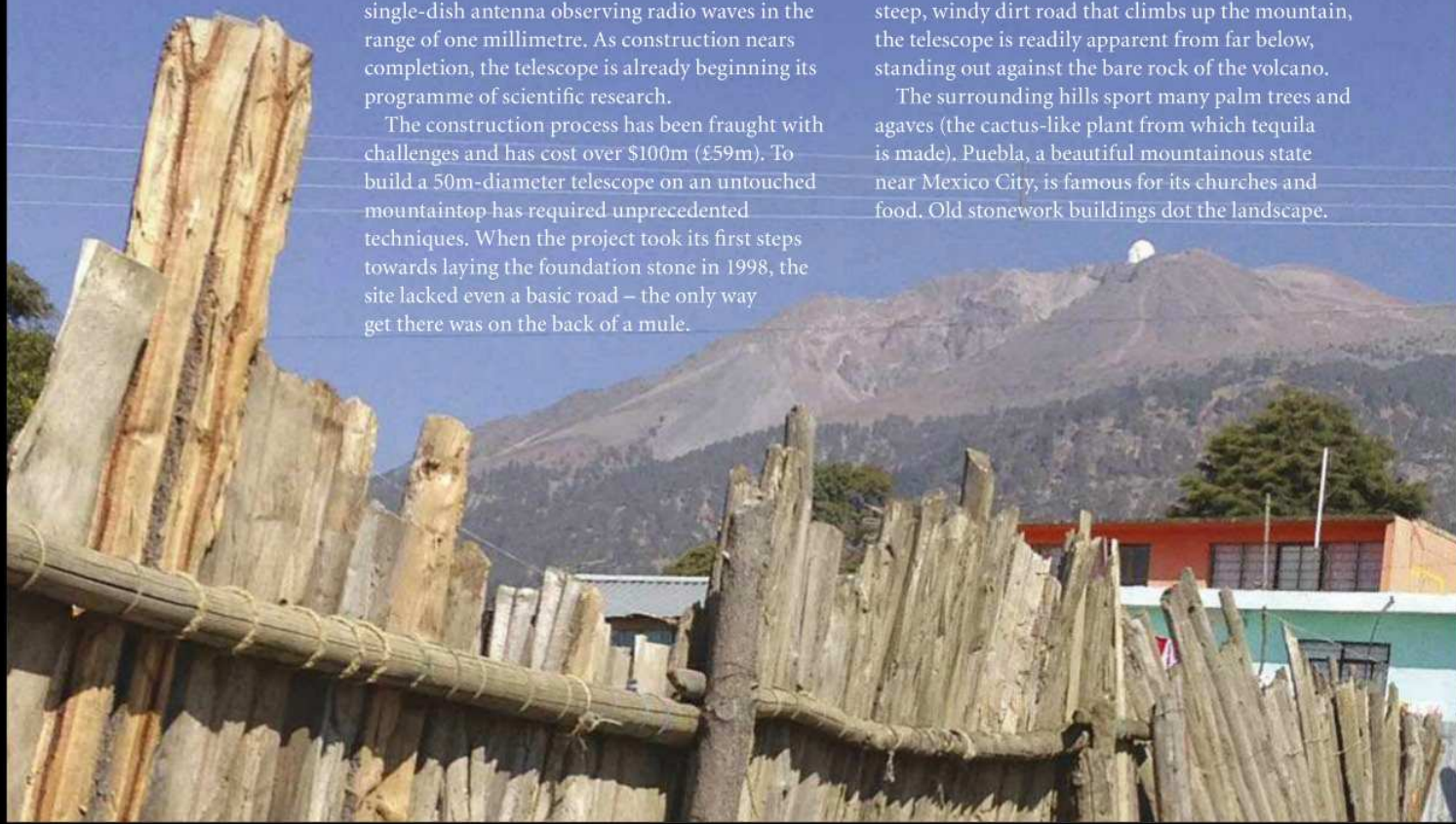
The construction process has been fraught with challenges and has cost over \$100m (£59m). To build a 50m-diameter telescope on an untouched mountaintop has required unprecedented techniques. When the project took its first steps towards laying the foundation stone in 1998, the site lacked even a basic road – the only way get there was on the back of a mule.

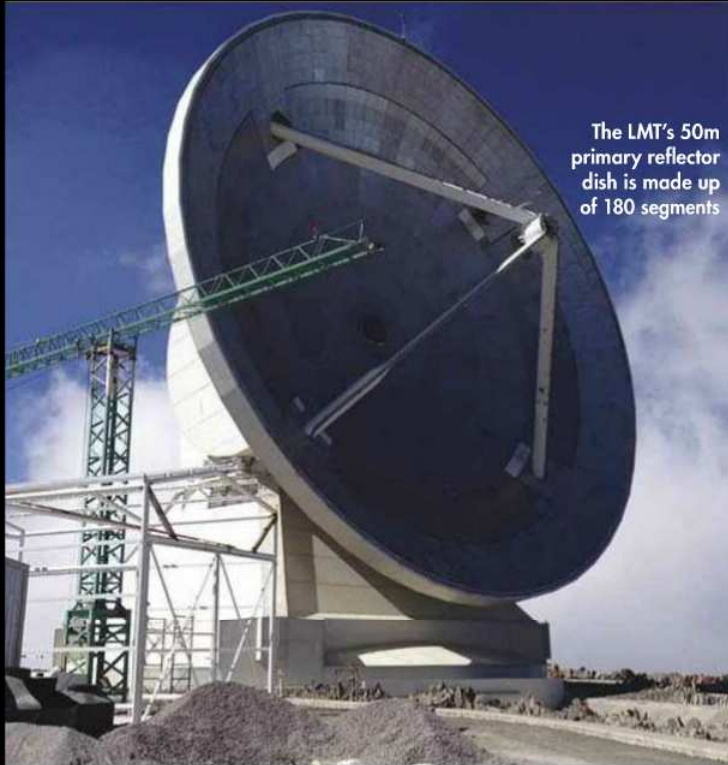
It took until 2006 to finish the civil engineering. Tests performed between 2007 and 2011 led up to the LMT's first light. As science starts, expansion will bring the primary dish to its final size over the next two years, at which point the project will become a fully operational observatory.

A mountain to climb

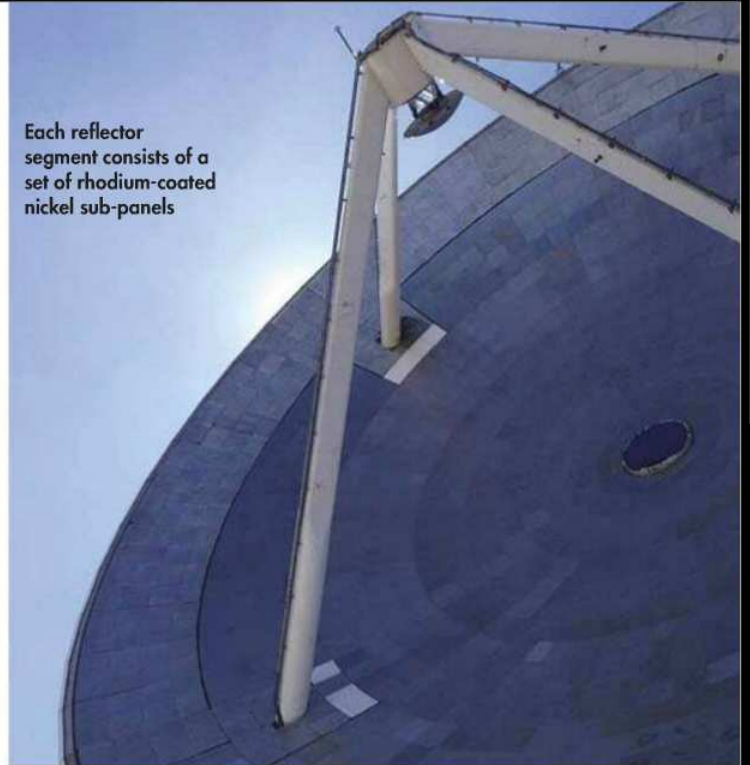
Sitting atop Volcán Sierra Negra at an ear-popping altitude of 4,600m, the LMT is an impressive beast. Currently only the inner 32m is operational, yet placeholder panels fill out the full 50m diameter of the reflector dish. Driving in a 4x4 pickup along the steep, windy dirt road that climbs up the mountain, the telescope is readily apparent from far below, standing out against the bare rock of the volcano.

The surrounding hills sport many palm trees and agaves (the cactus-like plant from which tequila is made). Puebla, a beautiful mountainous state near Mexico City, is famous for its churches and food. Old stonework buildings dot the landscape.





The LMT's 50m primary reflector dish is made up of 180 segments



Each reflector segment consists of a set of rhodium-coated nickel sub-panels

The route to the mountaintop intersects a smattering of life: horses, donkeys and dogs walk along the lone road; passing pickups carry hitchhikers.

Construction workers carry on with the completion of the telescope. According to David Hughes, the British director of the LMT, the challenges have included welding steel and pouring cement. "We had to build the cement plant at the site, and we needed to be able to make cement at 4,600m, with the low temperatures, the humidity issues, and the mix of bone-dry days, snow and ice. The construction company had to develop a new formula to make cement that would set."

A thorough investigation of the tough, basaltic rock also had to take place before

drilling into it, adds project scientist Miguel Chávez: "It required a detailed analysis of the soil, because it's an extinct volcano. Many of the drills broke when they were used." During construction in this harsh environment, a truck and a tower crane also broke.

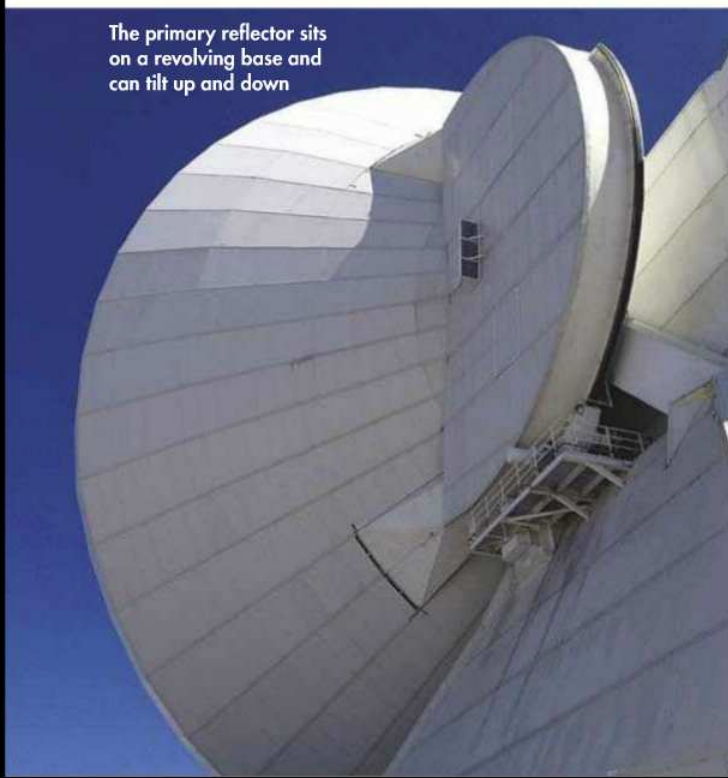
Primary concerns

The immense primary reflector has a metallic grey surface consisting of 180 segments, arranged in five concentric rings. To create each panel, workers electroform high-precision sub-panels out of nickel, with a rhodium coating. The components rest on a complex system of stainless steel framing and aluminium plating. Even the secondary reflector is

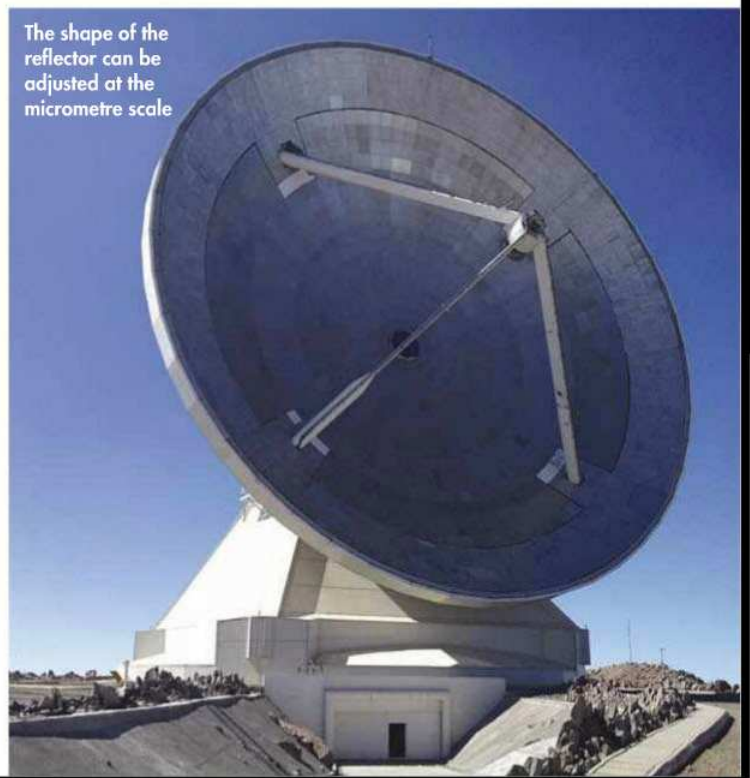
impressive, at 2.6m in diameter and with a 30-micrometre accuracy, and the device also has a tertiary reflector. The entire antenna weighs in at around 2,000 tonnes and rotates very smoothly on a rail track. Perched on top of the revolving base, the reflector itself tilts up and down to provide a comprehensive view of the sky.

The telescope has an active surface that can be adjusted in shape on a scale of micrometres, and this compensates for gravity and temperature. It uses holography to establish an ultra-precise surface. "If it was physically large, but had a bad surface, it would have been a waste of money," notes Hughes. By comparing high-frequency wavefronts coming from a satellite against the same waves after ▶

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The primary reflector sits on a revolving base and can tilt up and down



The shape of the reflector can be adjusted at the micrometre scale



◀ The LMT's high altitude and remote location made construction tricky; a new type of cement that would set at wildly varying temperatures had to be developed



► hitting the primary reflector, scientists can map the shape of the dish.

The LMT has already undertaken early observations, studying the formation of structure in the Universe to uncover troves of new galaxies. Seeing cold, dark, young objects, the telescope most importantly informs us about the early stages of the Universe's evolution. The millimetre wavelength also offers a way to penetrate cosmic dust, revealing how the Universe constructs itself. By peering into the depths of the cosmos, the LMT can see the beginnings of planets and stars (see 'Across the Universe', opposite).

The instrument combines its great size, sensitivity

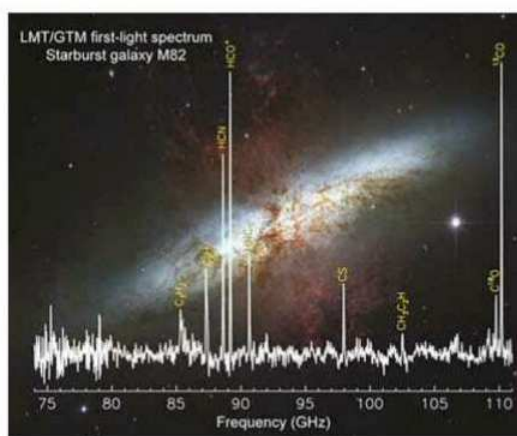
and speed with an excellent location.

Among the many scientific benefits, the device will provide a thorough map of the cosmic microwave background, which radiates at the millimetre wavelength. Very high mapping speeds enable surveys of massive volumes of space, revealing structure.

"That's where the LMT comes in," says Hughes. "You can detect not hundreds, but tens of thousands, hundreds of thousands,

millions of galaxies, allowing three-dimensional statistics. And that's what makes the LMT an exciting experiment."

The bent Cassegrain telescope employs a range of custom instruments, including a camera and



▲ First light results from the LMT, showing a spectrogram of emissions from the Cigar Galaxy, M82

EXPERT INTERVIEW

Dr David Hughes is the British director of the Large Millimeter Telescope, and its principal investigator in Mexico



When David Hughes first visited the site of the LMT there was nothing there. "I came to Mexico in 1999, for this project. And at that point they were starting to level the site and put in the foundations." Hughes

converses fluently in English and Spanish, explaining that the main science case driving the LMT involves distant, high-redshift galaxies. "That's the contribution I've made personally, the detection of the sub-millimetre galaxy population."

Between Mexicans looking for a telescope and Americans looking for a location, Hughes sees the joint LMT as an ideal arrangement. "This is where I'd say it was the best decision. The LMT is a unique facility. There's no one planning a bigger single-dish telescope, and it doesn't cost you a billion Euros, in contrast with other new instruments."

In describing the world-class facility, Hughes points out a feature of how light

travels between stars and observers. "The really cool thing is you get a benefit in detecting distant galaxies, due to something called 'negative K correction'. If I have a light bulb, intuitively you know that this light bulb gets fainter as I walk away. However, in millimetre wavelengths, that's not the case.

"Looking back through time, there comes a point where the Universe is half its size. From that point and further back, objects have roughly the same brightness in the millimetre wavelength. It's a combination of the shape of the spectrum and the geometry of the Universe." Hughes draws a quick sketch, warning that the effect "is pretty outrageous".

Why innovate? "We've always looked up and tried to understand why we're here; what is the Universe around us? It's part of being human, asking these questions. Astronomy, and building big telescopes that let you understand the Universe, has enormous value. Imagine if we didn't understand the Sun, the Moon, the planets, the stars, our Galaxy."

Hughes acknowledges the value of technological spin-offs. "But for me, I think what's most important is the human part of it."

ACROSS THE **UNIVERSE**

The Large Millimeter Telescope primarily investigates structure in the Universe. But it will also contribute to other areas of astronomy, from the Solar System to exoplanets

PLANETESIMALS

Planetesimals, small leftover chunks from the early period of planetary formation, surround many stars including our own Sun. The LMT can identify planetesimals and other cold, dim bodies clearly. It will survey our Solar System, discovering and analysing planetesimals and comets, and giving new views of the structure and surface composition of asteroids. It could even shed light on the Oort cloud, which has never been observed.

EXOPLANETARY DISCS

Planets form in a spinning disc of gas and dust surrounding a young host star. As the dust clumps together it attracts more material, clearing out paths through the cloud as the accumulations become planetesimals and, eventually, planets. The LMT can reveal the presence of such new exoplanets, Hughes says. "We're detecting the earlier stage, as they start to sweep up dust and gas, and start to form planets."

INTERSTELLAR DUST

Large clouds of interstellar dust form the nests where stars are born. The cold dust, at mere tens of degrees Kelvin, emits millimetre radiation, ideal for the LMT. Clouds also scatter visible light, because the dust particles measure a micrometre or less, as do optical wavelengths. While observing star formation through the interstellar dust, the Large Millimeter Telescope can determine how and where the dust resides.

ACTIVE GALACTIC NUCLEI

At a larger scale, the LMT will observe active galactic nuclei to understand how the black holes at the centres of galaxies feed on their hosts. Observing their evolution and environments could reveal how these black holes help convert material into stars. Here, even gravity could have some surprises in store. Predictions describe how such a black hole would behave, says Hughes, but "now we can image it, so we can test those models."

a spectrometer, to measure the location and intensity of incoming radiation. Scientific instruments play as important a role as the dish itself. Chávez believes that even the initial configuration can make discoveries. "With its 32m antenna and its sensitive continuum camera, AzTEC, or the Redshift Search Receiver spectrometer, we should be able to observe what no one else has been able to."

SEQUOIA, a high-resolution, cryogenically frozen component, will be the third instrument. It can pick out the molecular content of objects within the Solar System and elsewhere in the Milky Way. SPEED, another tool under development, improves the camera

capabilities and enables it to record at four different frequencies simultaneously. An arsenal of additional receivers and cameras will come online later.

The LMT has another trick up its sleeve. Not only does it function as the most distinguished single-dish millimetre telescope currently in existence, it can also team up with other millimetre observatories around the world to form a unique interferometric array. Together with telescopes and smaller interferometers in Hawaii, the mainland United States, Chile, Europe, East Asia, Greenland and Antarctica, the Earth-sized Event Horizon Telescope (EHT) stretches over many thousands of kilometres.

Hughes points out the huge advantage of such a system: "You're talking about 200,000 times the resolution of the LMT." This monster telescope will look at the supermassive black hole at the heart of each target galaxy, including our own Milky Way.

After testing the Very-Long Baseline Interferometry (VLBI) setup last summer, the interferometer began making scientific observations in April 2014. This autumn, it will start to focus at a higher frequency and increased resolution, looking for the very first time at the digestive process of our own Galaxy's central black hole, watching it swallow the giant molecular cloud known as G2. **S**

LARGE MILLIMETER TELESCOPE X 6, EAGLE GAMMA & AVRIL OLACHEA, THINKSTOCK X 3, ESA / V. BECKMANN (NASA-GSFC)