HIGH AND DRY

Two decades after plans were set in motion for the world's most powerful ground-based telescope, astronomers are bracing themselves for a downgrade to curb escalating costs. Jeff Kanipe reports.

The view from the sprawling Llano de Chajnantor plateau perched in the Andes Mountains of northern Chile is spectacular all year round. The plateau lies some 5,000 metres above sea level, with the skies above forming a deep blue backdrop to the tawny, windswept desert floor and the distant badlands of low hills and volcanoes.

Inhospitable to life, the plateau has become destination number one for radio astronomers, who probe the mysteries of the Universe by measuring radio waves emitted by celestial objects (see 'Transformational telescopes' on page 528). The high altitude and dry atmosphere are perfect for observing objects that emit submillimetre wavelengths; these wavelengths are in the spectral window that lies between the far infrared and high-frequency radio bands. Some of these wavelengths are absorbed by water vapour, ruling out observations at lower altitudes. Radio astronomers have been hoping for decades to be able to explore this window with the right telescope at the right location.

They will eventually get their wish when the international Atacama Large Millimeter Array (ALMA) is built on the Chajnantor plateau. By combining 64 radio antennas, each 12 metres in diameter, ALMA was originally projected to be 10 to 100 times more sensitive than current high-altitude telescopes. During a meeting with astronomers in Washington DC last month, Adrian Russell, ALMA's US project director, described recent progress on the project, almost as if he could not believe it himself. "ALMA is actually happening," Russell announced. "It's real."

Attendees at the American Astronomical Society meeting had come to hear Russell and Fred Lo, director of the National Radio Astronomy Observatory (NRAO), which is responsible for US construction and operations, update them on the status and scientific prospects of ALMA. After their talks, Lo and Russell fielded technical questions from the audience, but one caught them flat-footed: how much was the project going to cost? Lo replied that because the National Science Foundation (NSF) was reviewing ALMA's US funding, it would be "damaging to the review process" to say more at this stage.

What went unsaid is the fact that ballooning costs for commodities such as petroleum and steel are forcing ALMA scientists to consider the unthinkable: whether to reduce the size and sensitivity of their dream telescope. Instead of the hoped-for 64 antennas, they may have to do with 50 or even fewer.

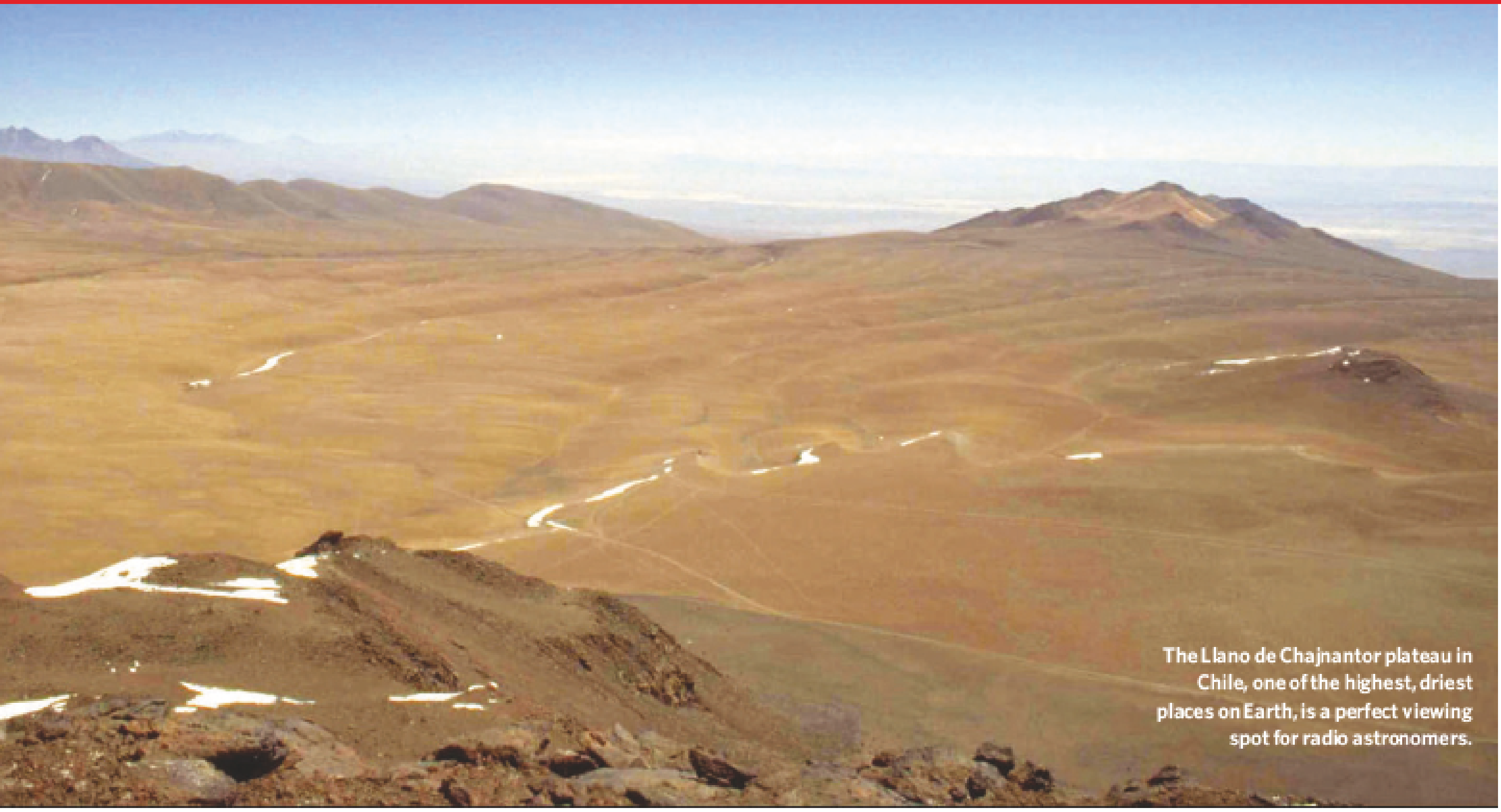
> "It is critical that we do this instrument right, not halfway." — Lee Mundy

The seeds for ALMA were sown in 1982, when an NSF committee proposed building an array of antennas up to two kilometres across, which would operate at millimetre wavelengths. A decade later, the National Research Council gave the project — then called the Millimeter Array — its blessing. In that incarnation, the array would have consisted of 40 8-metre radio dishes that could be switched from an array 70 metres across to one 3 kilometres in diameter.

Plans afoot

It is not unusual for radio arrays to have movable antennas. Changing the diameter of the array affects the fine detail seen by the telescope — what astronomers call angular resolution — and the whole movable array also works a bit like a zoom lens. For example, astronomers who want to map the large-scale structure of a galaxy use the smallest configuration; otherwise they would have a limited viewing angle (like looking at a freckle on someone's nose rather than on their whole face). If an interesting 'freckle' is detected then they can 'zoom' in and observe it in detail using the larger configuration.

Around the time the United States was planning the Millimeter Array project, European astronomers were discussing plans for an array



NRAO/AUI

The Llano de Chajnantor plateau in Chile, one of the highest, driest places on Earth, is a perfect viewing spot for radio astronomers.

in the Southern Hemisphere — the Large Southern Array — whose combined resolution would be equivalent to a dish 10 kilometres across. Despite the fact that the European array was not originally intended to work in the crucial submillimetre range, both sides began discussing a partnership in 1997. Two years later, an agreement was signed to merge the projects into ALMA. Today, Canada, Chile, Japan and Taiwan have all joined the collaboration, making it one of the first truly global projects in ground-based astronomy. And like most big projects it has a big price tag — about $650 million — making it, so far, the most costly ground-based telescope ever.

ALMA's specialty will be observing cooler parts of the Universe the details of which are easiest to make out in the submillimetre spectrum. From interstellar dust to star-forming giant molecular clouds, many cold features in the cosmos have been glimpsed only by using high-altitude telescopes and special imaging techniques, or with long observation times. Scientists predict that ALMA will be able to image galaxies that formed up to 500 million years after the Big Bang — when the Universe was dark and star formation was just beginning. "These galaxies are truly spectacular, with star formation rates up to a thousand times that of the Milky Way today," says Jason Glenn, an astronomer at the University of Colorado and ALMA science advisory committee member. ALMA will give astronomers data on how fast the galaxies formed, and on the evolving structure of the Universe.

Most of ALMA's multi-million-dollar budget will be spent on antenna construction. The original plan called for enough antennas to form an array diameter that ranges from 150 metres to 14 kilometres across. In this plan, the smaller array size could be used to detect planet-forming disks around multiple stars in a galaxy, whereas the larger array would allow astronomers to scrutinize each disk more carefully, say, for the presence of Jupiter-size planets.

Price hike

ALMA's construction phase started in earnest in November 2003. But in 2004, the estimated costs started to balloon. Chinese demand for structural steel drove steel prices through the roof. Petroleum prices, too, more than doubled, inflating the cost of antenna dishes made from petroleum products. Even a boom in the Chilean economy translated to increased operational costs in that country.

The NSF, which is responsible for half of ALMA's construction costs, has to spread its funding across several high-priority projects, including the IceCube Neutrino Observatory at the South Pole and the EarthScope project in North America. Although ALMA's share jumped from $29.8 million in 2003 to about $50 million in 2004, it hasn't risen since. With commodity prices unlikely to decline anytime soon, this means that ALMA could easily spend its $650 million before all the antennas are built. Facing the prospect of cost overruns, the NSF decided late last year to do a spending review.

Price cut: as costs rise, the number of antennas proposed for the new ALMA telescope is shrinking.

The chances that ALMA will be downsized to 50 or even 40 antennas alarms some radio astronomers. Fewer antennas will mean reduced sensitivity and much longer exposure times to obtain the same resolution. Last year, the US National Academy of Sciences issued a report on the effect a smaller array would have on ALMA's three primary science goals.

The first of these, to detect Milky-Way-type galaxies that formed two to three billion years after the Big Bang, would help trace these galaxies' evolution — something about which astronomers know next to nothing. The second, to obtain high-contrast images of nearby protostars and planet-forming disks around young stars, would help astronomers study the formation of these cosmic structures. And the third, to produce precise images at very high angular resolution, would help reveal the motions of gas within objects such as giant molecular clouds.

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The academy's report was discouraging. In their view, the first two requirements for these goals, involving sensitivity and high-contrast imaging, would not be met by either a 40- or 50-antenna array. With 40 antennas, the third requirement would also be at risk, even if extremely long exposure times were allowed. Reduced speed and image fidelity would be among the biggest challenges. For example, the time taken to observe a nearby stellar disk would increase from three days (with 64 antennas) to a week (with 40), and

Transformational telescopes

Here are just a few of the radio telescopes responsible for making discoveries that transformed science. They were all created at a fraction of ALMA's cost.

Bruce Array Karl Jansky's primitive rotating radio telescope was the first to detect radio waves emitted by the Milky Way, back in 1933.
Cost: unknown.

Reber's Antenna The world's first parabolic dish, 9 metres across, was built by Grote Reber with his own money. In 1938, he used it to confirm Jansky's discovery and to detect radiation from charged particles.
Cost: $4,000 (about $45,000 today after inflation).

64-metre Parkes Radio Telescope, Australia In 1961, this telescope pinpointed the location of a radio source that was later confirmed to be the first known quasar.
Cost: $1.2 million ($6.2 million today after inflation).

Bell Labs Holmdel Horn In 1963, astronomers Arno Penzias and Robert Wilson first thought pigeon droppings might be slightly raising their antenna's temperature. It turned out to be the cosmic microwave background radiation.
Cost: $25,000 for the computer; a Palm Pilot would suffice today.

305-metre Arecibo dish in Puerto Rico This impressive bowl-shaped antenna was used in 1965 to show that Mercury rotated every 59 days — not 88. It was also used to discover the first binary neutron star and gravitational radiation in 1974.
Cost: $9.3 million; $100 million to rebuild today.

University of Cambridge 1.8-hectare array Designed by Antony Hewish, this telescope was built using 190 kilometres of wire and cable, and used to discover the first pulsar in 1967.
Cost: £15,000 (about $303,000 today after inflation).

Arizona University's 36-Foot Telescope Now called the 12-Meter Telescope, it broke new ground in millimetre-wavelength molecular astronomy. Dozens of molecular species were first detected in interstellar gas by this instrument in the 1970s.
Cost: $1.5 million ($7 million today after inflation).

Ohio State University's Radio Telescope Known fondly as 'the Big Ear', this instrument was used between 1965 and 1971 to map 20,000 radio sources, 60% of which had never been observed before. It was torn down in 1998 to make way for a golf course.
Cost: $250,000; about $10 million to duplicate today.

Very Large Array The discoveries made using this telescope are legion. They include a mini-spiral of hot gas at the centre of the Milky Way (1983); traces of water ice on Mercury (1991); 'micro quasars' in the Milky Way (1994); and the detection of the first strong outburst from a magnetar, a supermagnetic neutron star (2005).
Cost: $78.6 million ($133 million today after inflation).

image fidelity would be reduced threefold.

Despite the finding that it would fail to complete two of its three goals, the report concluded that a pruned-back ALMA could still address many unanswered questions in astronomy. Michael Turner, the NSF's assistant director for mathematical and physical sciences, is similarly hopeful: "The original ALMA plan has so much more capability over what already exists — by more than an order of magnitude, closer to two orders of magnitude — that even if you cut back by 40% what it can do, it's still transformational."

But if ALMA is to be truly transformational, "it is critical that we do this instrument right, not halfway," argues Lee Mundy, a member of ALMA's science advisory committee and a radio astronomer at the University of Maryland. According to Mundy, "chipping away at the number of antennas and collecting area saves dollars but it doesn't make sense for an instrument that can produce premier science for the next 30 years and more."

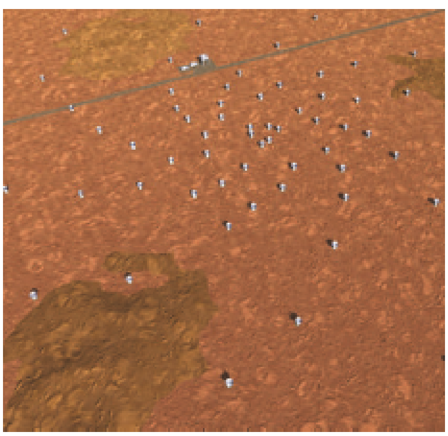
Lucy Ziurys, an astrochemist with the University of Arizona, says that a 50-antenna array is "okay, but disappointing". Although she believes that reducing the number of antennas is a better response to funding problems than reducing, say, antenna quality, she questions why certain costly decisions were made to begin with. "Funds could have been saved if only one antenna design had been chosen instead of two," she says. "That decision will, in all likelihood, increase the cost."

Ziurys is referring to two contracts signed last year. On the US side, the defense contractor General Dynamics, based in Falls Church, Virginia, agreed to supply 25 antennas in July. A similar contract was signed in December between the European Southern Observatory and Alcatel Alenia Space, a European consortium of manufacturers. Ziurys argues that having two antenna designs means maintaining "two of everything" — two sets of spare components and electronics.

Unknown Universe

This coming March, the international ALMA board will meet in Kyoto, Japan, to finalize a delivery schedule for the rest of the project. That's when the NSF's decision to finance 50, or fewer, antennas will be made public. Last October, however, ALMA scientists reconfigured the antenna array at the Chajnantor site for 50 antennas. So the decision may have already been made. Ziurys thinks the decision to go with 50 was probably made as early as January last year.

Although their research may be adversely affected, most astronomers associated with ALMA seem resigned to the smaller array. Many remain hopeful that they can still achieve worthwhile science with 50 antennas. "In general, science goals do not become impossible when the number of antennas is reduced slightly, they just take more observing time," claims Glenn. George Djorgovski, an astrophysicist at the California Institute of Technology, Pasadena, sums it up with a prediction: "What you have here is clearly a fiscal reality issue, and the politically considered response to it. We will see many more of those in the coming years."



The resolving power of the new telescope will be altered by changing the size of the antenna array.

NRAO/AUI; COMPUTER GRAPHICS BY ESO

Meanwhile, ALMA continues to move forward. Construction is under way at the site and the first of the antennas is scheduled to arrive in early 2007, with completion scheduled for 2012. For its part, the National Astronomical Observatory of Japan has agreed to build four 12-metre and twelve 7-metre antennas to create the Atacama Compact Array alongside ALMA. This will be used for imaging large-scale structures not well sampled by the main array.

Once the decision to go with 50 antennas has been made, could the project planners still build 64 at a later date? Not without an astronomical fairy godmother. "Buying more antennas would be hard," Turner explains. "You configure the array to work optimally based on how many antennas you have, and to add more would force you to reconfigure the entire array." That costs more money, which will be in short supply.

Will these few clouds spoil the view from Chajnantor? Paul Vanden Bout, former ALMA director, argues that new discoveries will erase any bleak memories. "Big projects are a long haul," he says. "But it's worth it. ALMA is going to be a great telescope and it's going to do exceptional science." ■

Jeff Kanipe is a writer based in Maryland.