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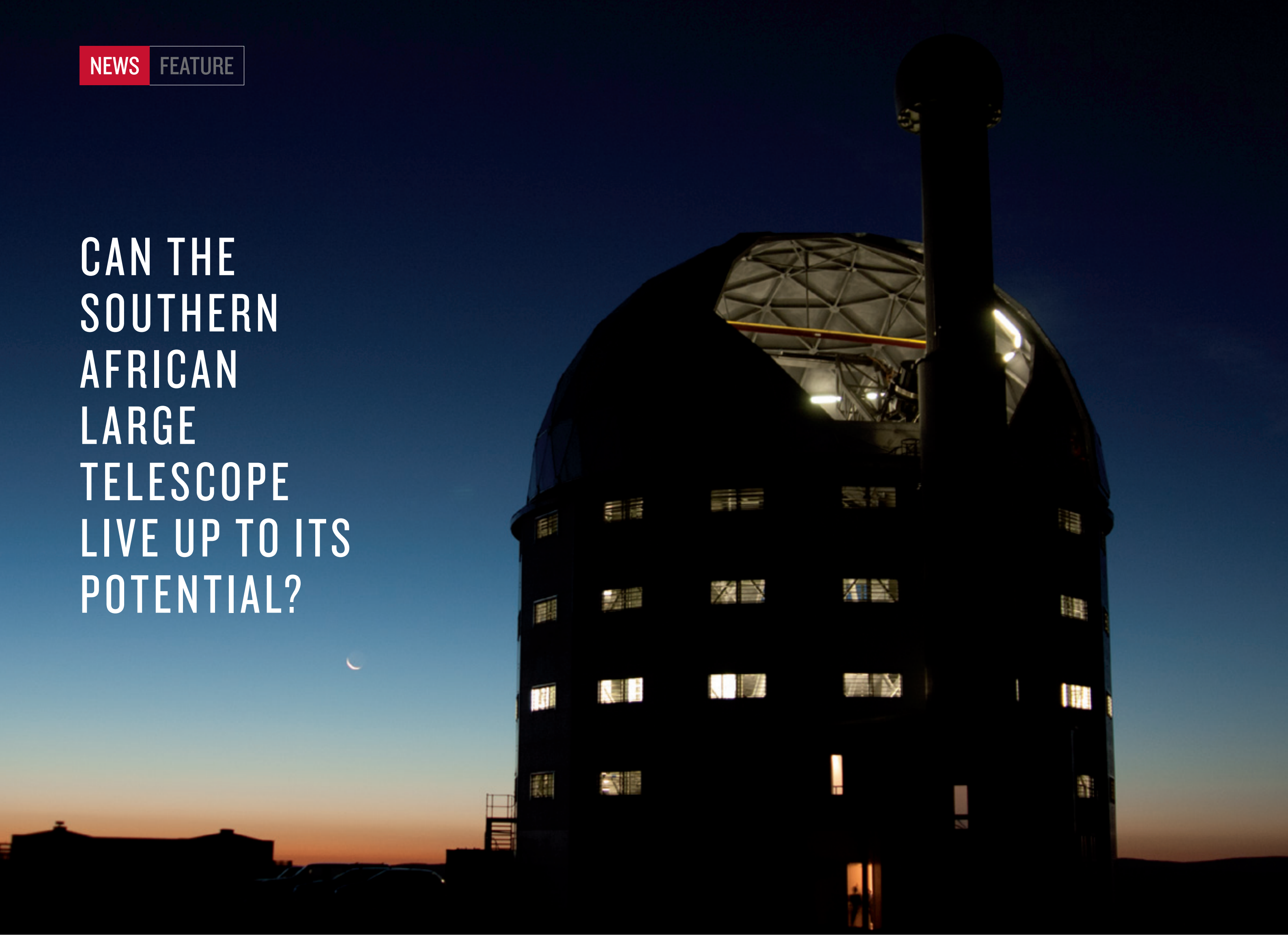


CAN THE SOUTHERN AFRICAN LARGE TELESCOPE LIVE UP TO ITS POTENTIAL?

SOUTHERN STAR

JANUS BRINK

BY LINDA NORDLING

On 30 August, the Cape of Good Hope lived up to its original name, the Cape of Storms. The cargo ship *Atacama* barely managed to find shelter in her berth at Cape Town before the harbour was slammed by towering waves, icy squalls and gale-force winds. A day passed before the tempest subsided and the ship could safely unload its cargo: an automobile-sized device known as the High Resolution Spectrograph (HRS).

It was a fitting welcome. The HRS's final destination, some 350 kilometres inland, was the Southern African Large Telescope (SALT) — a facility that has weathered many storms of its own. Officially completed in 2005, SALT is only now finishing its second year of normal science operations, and pressure is mounting for the facility to prove itself. Along with the Square Kilometre Array (SKA) of radio telescopes (see *Nature* **480,** 308–309; 2011), SALT is a major component of South Africa's effort to establish its scientific reputation and inspire a new generation of African scientists. Yet its teething problems have prompted questions about its design, the way it was built and how it has been managed so far.

SALT's defenders counter that problems could not have been avoided in building one of the world's largest telescopes on a shoestring. The telescope's first-generation suite of detectors wasn't even complete until the arrival of the HRS. And the spectrograph still needs to be tested and calibrated before it opens for routine use early next year. Nonetheless, Ted Williams, director of the South African Astronomical Observatory (SAAO), which manages SALT, knows that excuses won't suffice. "Our challenge in the coming years is to produce the nice science that will make people recognize that it's a major telescope that's living up to its potential," he says.

BUDGET BUILD

From the moment planning began in 1998, SALT has been an underdog — not least because the monies available to the SAAO and its partners were never anything like those at the disposal of northern observatories. The SALT team had to find ways to design, build and equip the 11-metre telescope for just US$30 million — a fraction of the cost of flagship instruments such as the European Southern Observatory's 8.2-metre Very Large Telescope (VLT) in Chile or the 10-metre Keck Telescopes in Hawaii, whose price tags were well in excess of $100 million. "If the VLT is like a Ferrari, SALT is more like a family car," says Darragh O'Donoghue, head of instrumentation at the SAAO.

Among other things, SALT's location also put it at a technical disadvantage. The site — a desolate hilltop near the town of Sutherland in South Africa's Northern Cape province — was chosen both because it is beautifully dark and because it already had roads and power. The SAAO had been operating a 1.9-metre telescope there since 1974, along with several smaller instruments that had been relocated from their original sites near Johannesburg and Cape Town because of light pollution. But the site stands just 1,798 metres above sea level, quite low by astronomical standards, so there would always be a comparatively thick layer of atmosphere above the telescope to blur the incoming starlight. SALT's images, although acceptable, would never achieve anything close to the clarity of those taken at world-class sites such as the 4,200-metre summit of Mauna Kea in Hawaii.

Nonetheless, SALT's location would allow it to fill a major gap in observations of the southern sky. When a star, galaxy or planet was at or below the horizon for the existing Southern Hemisphere observatories, most of which are in Australia or Chile, it would still be high overhead in South Africa. That is a big plus for astronomers such as Dimitar Sasselov of Harvard University in Cambridge, Massachusetts, who studies exoplanets (those outside the Solar System) by watching for 'transits': tiny, brief dips in a star's brightness as a planet orbits in front of it. "We are often faced with time-critical events like planet transits that make scheduling of observations in the Southern Hemisphere tricky," says Sasselov. So he sees SALT becoming an important complement to large telescopes elsewhere.

Recognizing the limitations they faced, SALT's designers decided to make their telescope world class in the realm of spectroscopy, which involves splitting the incoming light into its constituent wavelengths. Spectroscopy can provide a wealth of information about the composition and motion of celestial objects, but does not require the ultimate in crisp imagery — just a big mirror able to collect lots of light.

The trick was to build such a mirror on a very tight budget. The SAAO accomplished this by copying the radical cost-saving design of the Hobby–Eberly Telescope (HET), an 11-metre-wide instrument completed in 1996 at the McDonald Observatory near Fort Davis, Texas. One big cost saving for this instrument came from a technique pioneered in the 1980s at Hawaii's Keck Observatory. This involved piecing together the telescope's mirror from many hexagonal segments of glass, each of which could be manufactured and shipped to the site independently — a much cheaper proposition than trying to fabricate, polish and transport a single giant mirror.

Another big saving came from designing the dish-like mirror to have a spherical curvature. Spherical mirrors cannot bring starlight to a sharp focus; that requires a slightly different shape known as a paraboloid. But paraboloids are much more complex and costly to make from segments because each one has a curve that depends on its position. A spherical mirror's segments are identical — meaning that SALT's 91 hexagonal mirror elements could be mass-produced relatively cheaply. And the imperfect focus could be fixed by passing the light through an optical system called a spherical aberration corrector (SAC) before sending it on to the detectors (see 'Inside SALT').

"IF THE VERY LARGE TELESCOPE IS LIKE A FERRARI, THE SOUTHERN AFRICAN LARGE TELESCOPE IS MORE LIKE A FAMILY CAR."

However, as SALT was taking shape, its designers decided to tweak the design of the SAC and other elements to achieve better image quality, which had turned out to be chronically poor at the HET. The changes also allowed for a bigger field of view. But once the construction of SALT was completed in 2005, the telescope faced problems of its own.

The most serious was that, despite the design improvements, SALT's image quality was poor. In images produced by SALTICAM, its main optical camera, and the Robert Stobie Spectrograph (RSS), stars often looked smudged or stretched. However, on rare days, for no obvious reason, the images were perfect.

Solving this mystery took the project team several years. The first potential culprit was SALT's main mirror. The team wondered whether some of the mirror segments were imperfectly aligned, which would prevent them from sending light to the SAC with the required precision. It took nine months of testing the segments to rule out the mirror as the source of the image-quality problems.

The team then moved on to the second suspect: the revamped SAC. This contains auxiliary mirrors up to half a metre in diameter, which needed to be hung to micrometre precision. Checking and testing these mirrors took more than a year.

In the end, the culprit turned out to be the way the SAC was attached to the telescope. The support structure was made out of metals that expanded and contracted differently with changes in temperatures, which affected the alignment of the SAC and explained the variability from day to day. And, during design, the weight of the telescope's instruments had increased, so there had been pressure to keep the overall weight of the SAC down. This had resulted in the use of a design too flimsy to keep the SAC correctly positioned.

In an ideal world, the SALT team would have foreseen these problems, says Phil Charles, who was the SAAO's director until 2011 and now heads the astronomy group at the University of Southampton, UK. But, given the real-world constraints on time and money, they simply assumed that the Texas group had got this element of the design right. "We now know that HET suffered from all the problems that SALT did," says Charles. "It's just that their basic image quality was so bad that you couldn't see the underlying problems in the mechanical design."

In the end, it was not until August 2010 that a new and better support structure could be hoisted up and mounted on SALT, putting an end to the device's imaging nightmares.

While all this was going on, the team also had to grapple with another major problem, this time with the RSS. Built by one of SALT's major partners, the University of Wisconsin-Madison, it was designed to be the world's most sensitive spectrograph in the near-ultraviolet (UV) range. But, once mounted on the telescope, it managed only average performance at best.

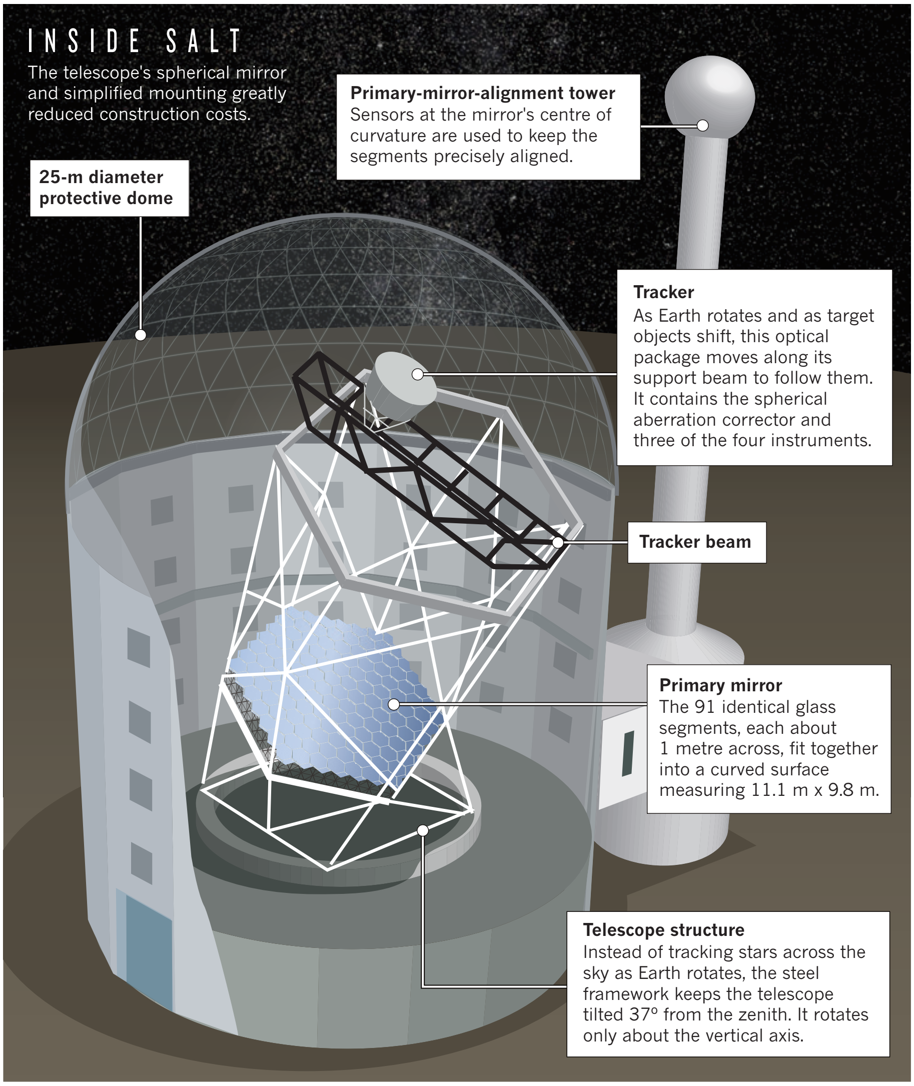
Yet another investigation revealed the culprit to be the spectrograph's plumbing. Because the instrument's large lenses expand and contract with temperature changes, they are mounted in a liquid that is contained in a system of plastic ducts and bladders. The manufacturers of the fluid and the plastics thought they had confirmed that the two would not react chemically, but react they did — producing contaminants that were particularly absorbent in the coveted near-UV range. The spectrograph's optics were dismounted and sent back to the United States, where they were cleaned and the fluid replaced with a different substance. Meanwhile, the cleaning process cracked one of the lenses, so that also had to be replaced. "That set us back as well," says Williams.

COLOUR BLIND

Given this history, it is not surprising that nerves were taut during the recent arrival and assembly of the HRS. And the assembly team soon discovered a problem with the instrument's 'blue camera', which captures and analyses blue light. In effect, the HRS was blind in one eye, recalls Jürgen Schmoll, an optics specialist who had flown in to help with the assembly from Durham University, UK, where the HRS was built.

Closer inspection of the blue camera showed that two of the three metal balls holding its detector chip to micrometre precision had come loose in transit, tilting the chip. The team deliberated over what to do. The safest, slowest and most expensive option was to take the blue camera to a dust-free room in Cape Town and fly a technician in from Durham to perform

SALT



the delicate surgery required to reattach the balls. In the end, however, the team decided to fix the problem on-site — a risky operation that involved opening the camera, gluing the balls onto screws, manoeuvring them back into place, breaking the screws loose and cleaning the glue off the balls before closing the camera again. Any speck of dust that entered the camera during this process could become a permanent fixture on the sensitive detector.

A tense few days followed, but on 22 September SALT team members were finally able to declare the operation a success. "The sun's back out, the spring flowers have thawed … &: we have a healthy blue camera again. Life is good," they trumpeted on the project's blog.

Once the HRS is fully up and running next year, the SALT team hopes that it will play an important part in restoring the telescope's global image. For example, the HRS should be very good at detecting the subtle shifts in a star's spectrum that show it is being orbited by an exoplanet — and should even be able to study the chemistry of the exoplanet's atmosphere. Upcoming projects will study the distribution of dark matter in galaxies, and explore the mechanisms by which galaxies form and grow.

But to stand a chance of playing in the big leagues, SALT needs to pick up its productivity, says Dennis Crabtree, an astronomer at the National Research Council Canada in Victoria who keeps tabs on the scientific output of telescopes larger than 3.5 metres. So far, he says, "SALT has had a pretty low profile because of its teething problems, which led to a low production rate of scientific papers".

Could the SALT project have avoided those problems? Probably not all of them, says Matt Mountain, the astronomer who oversaw the construction phase of the US Gemini project, which built twin 8-metre telescopes in Hawaii and Chile at an overall cost of $184 million. Technical glitches are par for the course when building the world's biggest telescopes, he says. The big question is how these problems are dealt with.

In the past, Mountain explains, when astronomers worked on telescopes roughly 1 metre across, fixing problems as they arose was fairly straightforward. But with today's giant telescopes, Mountain says, the astronomers need project leaders and experts from industry to fix problems. It has been a painful transition, he says, from the old astronomer-led system to the new one in which project managers are in charge. But South Africa will need to master that shift to complete its share of the SKA project, which is estimated to cost around US$2 billion and will involve building hundreds of radio dishes in the African and Australian outbacks.

Williams says that SALT was built through a mixture of the old approach and the new. For both the telescope and the HRS, construction was undertaken with strong project management. However, SALTICAM and the RSS were constructed through the more conventional, astronomer-led approach, he says.

SALT's supporters remain optimistic, despite the telescope's technical setbacks. O'Donoghue says that it has fulfilled many of its goals, including placing South Africa on the global astronomy map. "I firmly believe that the SKA would have never come to South Africa if it hadn't been for SALT as a technology demonstrator," he says. As evidence of SALT's influence, he points to the recent decision by the International Astronomical Union to set up an Office for Astronomy Development at the SAAO in Cape Town.

The telescope has also become a technological icon. "Between 2001 and 2003, an average of 50 people visited Sutherland annually," says Sivuyile Manxoyi, the SAAO's head of education and outreach. "In 2012 we had 12,205 visitors." Tourism in the town has also benefited. Today there are 40 guest houses, as well as more than a dozen guest farms, most of which offer stargazing as an attraction. Astronomy is also booming at the country's universities.

Meanwhile, Williams is trying to raise SALT's scientific profile by updating Sutherland's older, smaller telescopes, making it easier for astronomers abroad to carry out observations there by Internet connection (rather than by travelling to South Africa), and by making sure that the science done at SALT is presented at important conferences around the world.

But the output so far from the HET suggests that SALT may never be as productive as the more expensive, multi-purpose telescopes. In 2011, for example, only 26 papers were published on work at the HET, whereas mature telescopes averaged 85, according to Crabtree's database.

But such gloomy predictions don't seem to daunt the SALT team. After all, says one of its software engineers, the personality of SALT is "a South African upstart, doing things better and more cheaply than the competition". Besides, as Williams points out, wintry weather doesn't usually last long in Africa — and "pessimists don't build telescopes". ■

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