NATURE|Vol 438|24 November 2005

Seeing in the dark

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When darkness falls for Antarctica's long winter months, the sky becomes a spectacular canopy of stars. At one brand new base, astronomers are braving the extreme cold to build telescopes that they hope will rival space observatories. **Gabrielle Walker** investigates.

For the thirteen residents of Antarctica's newest scientific base, the winter is finally over. In early November, after nine months of isolation in temperatures dropping to 80 degrees below zero, the first relief planes arrived bearing fresh food, letters and — perhaps the biggest blessing of all — new faces.

On the relatively balmy Antarctic coastline, there are many permanent bases, but Concordia is the first year-round station to be built in the interior for 50 years. The site has been used by summer visitors since 1995 for a European ice-coring project, which was successfully completed last December[1]. This year, the first winter crew spent most of the dark months working to finish the wiring and plumbing of their brand new home — a joint venture between the French Polar Institute Paul Emile Victor (IPEV) and the Italian Antarctic Research Programme (PNRA).

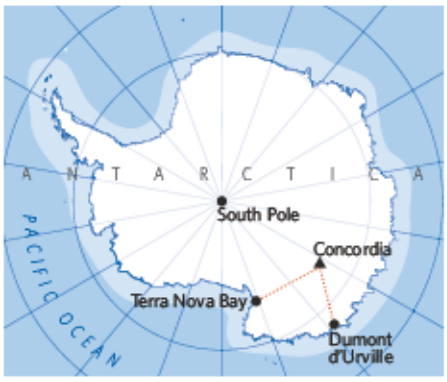
But they haven't laboured solely on construction jobs. Astronomer Karim Agabi from the University of Nice in France, part of Concordia's first winter crew, has good news to report about the site's potential for optical astronomy. Although more problematic than first thought, Concordia could be one of the best places in the world to site an optical telescope. The stars shine uncommonly steadily there, Agabi says. "You really have the impression that they're stuck to the sky".

The high Antarctic plateau has many potential advantages for astronomy, such as little atmospheric water vapour to distort incoming light. The US National Science Foundation, based in Arlington, Virginia, has been exploiting this potential for decades at the South Pole, which proved to be excellent for observing microwaves, but astronomers have been frustrated in their attempts to observe ordinary visible light. One reason is the frequent auroras, which interrupt any serious star gazing.

Eternal night

A bigger problem is that the South Pole lies on a slope, so winds tumble down from on high, generating a layer of turbulent air more than 200 metres thick. Turbulent winds aggravate what astronomers call 'seeing', a measure of the jitter they observe in starlight as it passes through packets of air of different temperatures before reaching the telescope.

Concordia, in contrast, sits on a flat-topped dome of ice where there is almost no wind. The base is also outside the normal region for auroras. And unlike other high spots in Antarctica, Concordia is relatively easy to reach. During the summer, people and sensitive equipment can be transported by ski-equipped planes from the Italian coastal station at Terra Nova Bay. Meanwhile, heavier material can be hauled over the ice by tractors from the French coastal base of Dumont d'Urville, 1,100 kilometres away (see map).



Many astronomers hoped that the seeing at Concordia would rival that available in space, but be much cheaper, with the additional benefit that humans would be on hand to fix equipment; transport costs on the traverse are just a few euros per kilogram, compared with many thousands for a space mission.

Agabi and other researchers from the University of Nice have been testing the site for the past five summers. Their white telescopes stand on a stylish 8-metre platform, graced with an arch modelled on the base of the Eiffel Tower — a design that one of the astronomers, Eric Aristidi, calls "the French touch". Alas, the architect's original vision was compromised a little when he persuaded the firms providing materials to hand over two of everything for the price of one, so now two golden arches stand side-by-side. As Aristidi acknowledges: "The idea was to copy the Eiffel Tower, not McDonald's".

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The group's summer results seemed promising, using bright test stars visible despite the 24-hour daylight. Although seeing was poor at midnight, when the sun was at its lowest, by mid-afternoon it was significantly better than at any other ground-based site. There were hopes

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Reaching for the stars: the telescope platforms at Concordia were modelled on the Eiffel Tower.

that seeing would improve further during winter darkness when optical astronomy would be possible. An automated Australian telescope left at Concordia during the 2004 winter reported seeing conditions that seemed to rival those observed in space[2].

Star gazers

But not everything went according to plan for the Australians. Left unattended, in a bulbous green building known as 'the kiwi fruit', the instruments stopped working after a few months, and the group only obtained data up to 5 May, just one day after the beginning of the permanent winter night. Also the instruments were sensitive only to the seeing from 30 metres upwards. Nobody knew what was happening closer to the ground.

So this year, Agabi volunteered to test the Nice telescopes during winter. An Antarctic veteran used to working at temperatures of −40 °C, Agabi discovered that winter was quite another challenge. Going outside, the crew risked instant frostbite. Faces and hands were worst off. As temperatures dropped below −70 °C, face masks frosted over in seconds, but working without them was unbearable. "Everybody got burned," Agabi says. Fiddly tasks such as changing screws became interminable using thick mittens, yet the researchers could slip them off and work with glove liners for only a few seconds at a time. On a mild night, perhaps only −60 °C, Agabi would venture outside to admire the sky and take photos. He felt confident that they were going to have a good winter.

But to Agabi's dismay, as winter darkness approached, the seeing seemed to grow steadily worse. "I told myself, that's normal, the atmosphere just needs to settle down," he says. However, by the end of May, after four weeks of complete darkness, he realized there was a serious problem.

How could the seeing be so poor when the Australian instruments had found it to be exceptional? Agabi launched weather balloons to measure the amount of turbulence from the ground upwards[3]. He discovered that around 90% of the turbulence at Concordia lay below 30 metres. "The Australians started just above the interesting part," says Aristidi.

Concordia's turbulence is caused by an extremely steep temperature difference between the snow and the air above it. The air contains scarcely any water vapour — the Earth's principle greenhouse gas — and therefore retains little of the Sun's warmth. So the switch from 24-hour daylight to total darkness has little effect on its temperature. The snow, however, a much better heat-retainer during summer, steadily loses heat during the winter darkness, cooling the air immediately above, and creating layers of air at different temperatures. Although the air at Concordia is extremely still, the slightest breeze ruffles the layers, making stars viewed through a telescope skip frustratingly from side to side.

Although Agabi was disappointed with his findings, they weren't yet disastrous; many telescopes are built on platforms 25 metres high. But to be sure that the layer stayed reliably low during the winter, Agabi needed to make continuous measurements. So in early July, with only five weeks of darkness left, Agabi persuaded the station manager to let him put a telescope on the roof of Concordia, at a height of 24 metres.

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Balloons showed that a layer of turbulent air was disrupting observations of stars at Concordia.

It was a difficult project. The roof slopes and the only access is a narrow spiral staircase with an overhead trapdoor. The Concordia team had to build a platform for the telescope in complete darkness and at temperatures of nearly −80 °C.

Towering task

The results were worth it. At last, from its vantage point above the turbulence, the telescope recorded the exceptional seeing for which the astronomers had hoped. "The window was dirty but I have cleaned it," Agabi says. "And through it I've seen the true quality of the site."

Back in Nice, Agabi's colleagues are busy thinking of ways around Concordia's unexpected turbulence layer: a large windbreak or a new form of adaptive optics that might counteract the stars' skipping. At Concordia the wind comes mostly from the same direction, so a single barrier might prevent even the faintest breeze from stirring the air. If neither of these options work, the answer would be to build towers. "At 30 metres we'd have practically the same performance as in space," says Aristidi.

John Storey, from the University of New South Wales in Sydney, who is a member of the Australian team, agrees. "Thirty metres is a bit disappointing, but it's not a show-stopper," he says. "Most of the world's 4-metre telescopes are at 30 metres or so above the ground." His team has begun to model the aerodynamics of potential towers and snow-hills on which a future telescope could be sited.

Aristidi has already arrived in Antarctica to take over from Agabi in preparation for Concordia's second winter. With him are instruments to locate the turbulent layers more precisely, and to take infrared measurements. The cold temperatures and absence of water vapour mean that background infrared noise should be very low even in summer. A group from the University of Perugia in Italy hopes to have an infrared telescope installed by January 2007.

In the longer term, suggestions for big astronomical projects at Concordia are plentiful. One idea is to build an array of 50 small telescopes, which could look for Earth-like planets. The only rival technology at the moment involves space launches, although if every single telescope needs a high platform, the project could lose its appeal.

In that case, Agabi thinks that one very large dish might be the answer. Constructing a single tower would be easier, and they could transport large components overland. Either way, he says, it is important to think big. "It really is a super site," he says, "and it's going to be worth truly grand projects." ■

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1. EPICA members *Nature* **429**, 623–628 (2004)
2. Lawrence, J. S. *et al. Nature* **431**, 278–281 (2004).
3. Agabi, A. *et al. Pub. Astr. Soc. Pacific* (in the press).