The care and feeding of an Antarctic telescope

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Antarctica's Dome A region is an excellent site for housing telescopes that look at terahertz radiation. But getting the telescopes down to the continent and maintaining them once they're in place is a challenge.

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Even without a telescope, you can see thousands of stars at a dark site. A curious viewer of that astonishingly beautiful scene might well be inspired to wonder, "How were those stars formed?" We astronomers know that star formation happens inside swirling, dark clouds of dust and gas, but beyond that, our knowledge is surprisingly thin: The darkness of the clouds obscures the formation process. To learn more, we need to find a way of peering inside.

Telescopes sensitive to terahertz radiation offer one of the very few ways of having a look. (Loosely defined, terahertz radiation has a frequency of 0.5–5 THz, corresponding to wavelengths from 0.6 mm down to 0.06 mm.) If you have traveled through security at an airport, you may have been scanned by terahertz photons. They easily pass through your clothing and can also travel through dark clouds in the cosmos as they zip through the universe. Many atoms and molecules naturally emit terahertz photons, and by studying their emitted light, we can learn about the physical conditions where stars are being formed.

Unfortunately for astronomers, terahertz photons are at just the right frequency to excite vibrations in water molecules—and Earth's atmosphere contains lots of water molecules. If your eyes were sensitive to terahertz radiation, then at 20 °C and 70% relative humidity you would not be able to see farther than about 10 m.

High and dry

To see terahertz radiation, we need to get above Earth's atmosphere, or at least well away from any water molecules. An obvious approach is to put a terahertz telescope in space. The *Herschel Space Observatory* has dramatically increased our knowledge of the terahertz universe, but space missions are expensive and are limited by the lifetime of their cryogens. Launching a telescope in a balloon is another possibility, although such endeavors also are expensive, and they are limited to a few weeks of observing time per launch. The SOFIA (Stratospheric Observatory for Infrared Astronomy) project placed a telescope in a modified Boeing 747 and flies it above most of the atmosphere. That strategy, though excellent for targeted observations, does not afford sufficient time to conduct long-term surveys.

Fortunately, there is an alternative. In the center of Antarctica is a plateau that gently slopes up to a location called Dome A. The region around that site has the twin advantages of a relatively high altitude, above 4000 m, and more importantly, exceedingly dry air: The water vapor concentration in wintertime is less than that in a cylinder of commercial dry nitrogen. The remarkable dryness is a simple consequence of the coldness of Antarctic air, and it allows many astrophysically interesting terahertz photons to reach the ground.

The Dome A region is the best site in the world for a ground-based terahertz telescope, but running an observatory there presents obvious logistical problems. Foremost among them is that the telescope has to be completely robotic, since no one is on site except for about a month in summer. The observatory has to generate its own electrical power and communicate with the astronomers who inspect the data and control the telescope. Moreover, fabricating the telescope itself is not routine; the know-how required falls in the gap between the mature technologies of the IR and radio regimes.

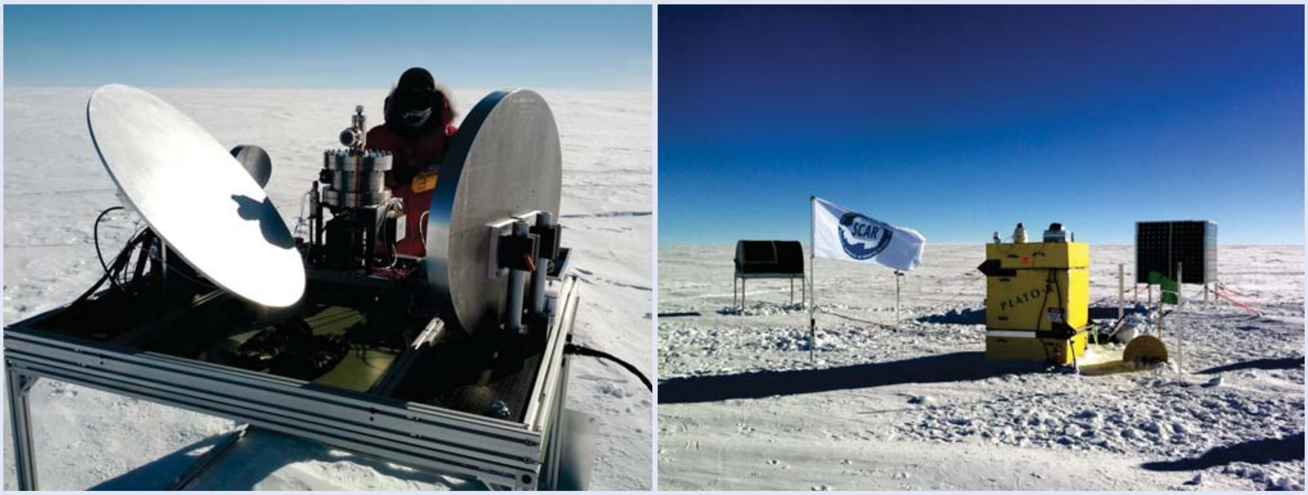
To solve those problems, in 2011 Craig Kulesa of the University of Arizona and I established a collaboration. Kulesa's group would build the telescope, and my colleagues and I at the University of New South Wales (UNSW) would design and build the observatory infrastructure. NSF's Office of Polar Programs would provide the logistics.

Power for a remote site

Ultimately, the logistics set the limit on how ambitious our observatory could be. Everything had to fit inside a Twin Otter, the standard aircraft used by NSF for landing at remote sites in Antarctica, and everything had to be deployable in five flights, each limited to 900 kg of cargo—people, camping equipment, and safety gear included. The observatory was to be located at Ridge A, a somewhat unimaginatively named site in the Dome A region, 930 km from the US Amundsen–Scott South Pole Station. Installation had to be completed in three days by four people.

Kulesa calculated that the biggest telescope we could aim for had an aperture of 0.6 m and that such a telescope would require about 200 W of power, primarily to operate the cryocooler needed to get its detector down to 50 K. Fortunately, a 0.6-m telescope is good enough to achieve arcminute resolution and survey many tens of square degrees in the Milky Way's galactic plane. A high-resolution spectrometer on such a telescope would probe terahertz lines in regions of star formation that are too heavily obscured for optical or IR telescopes.

While Kulesa's group was busy building the telescope, shown in panel a of the figure, the UNSW team pondered how to provide a lightweight, reliable power system to supply the 200 W needed by the telescope. At UNSW we have had many years of experience with PLATO (Plateau Observatory) in Antarctica, which provides 500–1000 W of continuous power while requiring only yearly servicing missions. But PLATO weighs 8 metric tons and is the size of a 20-foot



Antarctic HEAT. (a) Craig Kulesa installs the HEAT (High Elevation Antarctic Terahertz) telescope at Ridge A in January 2012. Light bounces off the flat primary siderostat (rotatable) mirror onto the 0.6-m-aperture parabolic mirror at right. From there it is directed into an ellipsoidal tertiary that finally shunts it to a detector in the cryostat next to Kulesa. (Photo by Luke Bycroft.) **(b)** In this January 2012 scene at Ridge A, the HEAT telescope is to the left, sitting on stilts and protected by a terahertz-transparent material. The other objects are elements of the PLATO-R observatory. The yellow box is the instrument module, and the black object at right is a solar-panel array, which comprises eight 195-W panels arranged in a cube. On the roof of the instrument module sit various satellite antennas, web cameras, and an all-sky camera called HRCAM3. The blue-and-white flag is that of the Scientific Committee on Antarctic Research. The engine module that provides power when the Sun is down is 60 m away. (Photo by Craig Kulesa.)

shipping container, far too large for Twin Otter aircraft. We would need to find a way to trim it down.

PLATO is based on a bank of 6 small diesel engines, supplied with 4000 liters of Jet A-1 fuel. You might think we could use solar or wind power, but the Sun is continuously below the horizon for months during winter, and counter to most peoples' preconceptions of Antarctica, the Dome A region is one of the least windy places on Earth. Ideally, we would get electricity from a radioisotope thermal generator, but doing so is just too expensive. All things considered, it is difficult to improve on fossil fuels in terms of their energy density and compatibility with mature engine designs. To be environmentally friendly and save fuel, we can turn off the diesels during the summer and use solar panels. For redundancy, we incorporated many diesel engines in the original PLATO design. A year between servicing implies more than 8700 hours of operation. Compare that figure with the typical 200-hour service interval for a small diesel engine, and it is clear that we would be testing the limits of PLATO's engines.

We were able to trim 75% of PLATO's weight by reducing the number of engines to two, using fiberglass rather than steel construction, and employing a fuel bladder rather than a metal tank. Most important, the new design, called PLATO-R (see panel b of the figure; the "R" is for Ridge A), fit into a Twin Otter with just a centimeter or two to spare on all sides.

Meet me at the South Pole

Designing a PLATO is an interesting intellectual exercise. The observatory needs to be elegant and simple, but not too simple. The keys to success are to minimize the number of components whose individual failure will crash the system and to allow the system to be reconfigured in real time, in response to inevitable hardware failures and other problems. The number of possible failure modes is so high that humans (Kulesa and me) are left in the loop at the end of a satellite link to tweak the control software as necessary.

The Arizona and UNSW groups came together at the South Pole and, with the support of many people within the US Antarctic Program, successfully deployed the telescope at Ridge A on 23 January 2012. Given the difficulty of what we were trying to do, we were overjoyed when the experiment continued to run for months after the installation crew left. Finally, after 128 days of operation, the 800 liters of fuel we had provisioned ran out. That gave us a couple of days on battery power to process the last of the data and send back the results over our dual 2400 bits/s modems.

Our fuel usage was higher than anticipated; overheating in the engine module required us to operate powerful fans. It is ironic that overheating should be a problem when the ambient temperature is often below −60 °C, but thermal design is tricky to get right. The system has to be well insulated so that the engines do not rapidly freeze when idle and the batteries stay above their −25 °C minimum operating point. But it also has to be able to dissipate 2 kW of waste heat when the engines are running. The air at 4000-m altitude is just slightly more than half as dense as air at sea level, and that low density makes air cooling less effective.

The experiment lay dormant until October 2012, at which time solar power was sufficient for us to restart the computers. As I write this in early 2013, the first service mission has just been successfully completed. Now that we have a new, improved telescope featuring additional spectral channels, an upgraded PLATO-R, and extra drums of fuel, we eagerly wait for hitherto unseen images of star formation to begin trickling over our modems.

Additional resources

▶ H. Yang et al., "Exceptional terahertz transparency and stability above Dome A, Antarctica," *Publ. Astron. Soc. Pac.* **122**, 490 (2010).

▶ G. Sims, "Ridge A, Antarctica: South Pole Diaries 2012/13," http://www.phys.unsw.edu.au/~z3318051/spd.

▶ The Antarctic Diaries, https://theconversation.edu.au/pages/the-antarctica-diaries.

▶ HEAT, The High Elevation Antarctic Terahertz Telescope, http://soral.as.arizona.edu/heat.

▶ PLATO-R Ridge A Robotic Observatory, http://mcba11.phys.unsw.edu.au/~plato-r. ■