

Antarctic astronomy—its potential importance for research into the interstellar medium

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1. Why Antarctica?

The popular image of Antarctica is of a bitterly cold, hostile landscape, swept by terrifying winds and storms; of monumental icebergs, savage sea-lions and heroic (but often dead) explorers. It is hard to imagine an environment less suitable for a modern astronomical observatory. The reality, however, is that the high antarctic plateau has—apart from the extreme cold—a very benign climate. On the plateau, wind speeds are very low. Like the icebergs and sea lions, the blizzards are confined to the coast, and, with modern aircraft and tractor-traverse equipment, even astronomers with only modest pretensions of heroism stand a good chance of surviving the experience.

The antarctic plateau offers the opportunity to conduct observations that are simply impossible from anywhere else on earth because of atmospheric absorption. Even in atmospheric windows in common use at other observatories, it may be possible to conduct experiments in Antarctica with much smaller telescopes because of the sensitivity gains that result from the dramatically lower sky backgrounds. The costs savings then extend not only to the telescope itself, but also to the instrument package which can be very much smaller—since the reduced $A\Omega$ propagates through the entire optical chain. These savings must of course be weighed against the costs of operating an observatory in Antarctica—though this is not nearly as expensive as commonly thought. An overview of the scientific potential of antarctic astronomy has been given by Burton et al 1994.

2. Site testing at the South Pole

Evidence is rapidly accumulating that the South Pole is the best infrared and sub-millimetre site currently in operation anywhere on earth. The excellent conditions are a result of the extreme cold, high altitude (the Pole itself is at 2900 m), low wind, very low humidity, and lack of any diurnal cycle.

2.1. Near-infrared

Three independent experiments have now demonstrated the exceptionally low sky background at near-infrared wavelengths. The first two (Ashley et al 1996, Nguyen et al 1996) showed that the sky brightness at around $2.4 \mu\text{m}$ falls to a level some two orders of magnitude lower than is observed at temperate sites. This so-called “cosmological window” falls between the OH line emission to shorter wavelengths, and the rapidly rising thermal emission at longer wavelengths. Ashley et al 1996 also showed that, even in L-band ($3.5 \mu\text{m}$) where thermal emission dominates, the sky brightness is some 20–40 times lower than at other sites. This lower sky brightness helps in several important ways. First, there is the obvious improvement in sensitivity arising from the lower photon shot-noise and the lower $1/f$ fluctuations in the background. But there is also

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a technological advantage, in that the lower backgrounds allow wider optical bandwidths to be used. For example, the entire L-band window can be used without exceeding the well capacity of contemporary detector arrays.

A comprehensive study of the sky brightness from 1 to 5 μm , using a dedicated photometer, has just been concluded by Phillips et al 1999. The earlier results are confirmed, and data from an entire winter's observing season analysed.

2.2. Mid-infrared

Observations by Smith & Harper 1998 in the summer (January) of 1996 show a decrease in sky brightness across the mid-infrared "N" window of at least an order of magnitude. A detailed study of wintertime conditions with the Automated Astrophysical Site-Testing Observatory (AASTO; see Section 4) has just been concluded (Chamberlain et al 1999). The sky flux between 8 and 9 μm has been shown to drop to as low as 10 Jy/arcsec². In both experiments the sky stability was also found to be excellent, suggesting the possibility of long, staring observations without the need for chopping.

2.3. Seeing

At the present time the seeing at the South Pole has not been completely characterised. Measurements by Loewenstein et al 1998 with a Differential Image-Motion Monitor (DIMM) show a median seeing at ground level of 1.7 arcsec. However, Marks et al 1996; Marks et al 1998 have made microthermal measurements of the atmospheric turbulence and show that the bulk of the seeing degradation comes from the lowest couple of hundred metres of the atmosphere. Above this boundary layer the seeing appears to be excellent, with a typical value of 0.37 arcsec.

Because the seeing degradation occurs in a single layer close to the ground, adaptive optics correction is simplified. Furthermore, the isoplanatic patch should be very large, allowing well-corrected images over a field of view of several arcminutes.

2.4. Sub-millimetre

Sky-dips at 225 GHz show zenith optical depths, τ , comparable to those from Atacama, and significantly better than Mauna Kea. At 492 GHz, τ is consistently low and falls below unity for weeks at a time. Lane 1998 uses these data to compute the transmission at 350 μm , and shows that the South Pole is vastly superior to Mauna Kea at this wavelength and significantly better than Atacama.

3. Other antarctic plateau sites

Little is known about site conditions higher on the plateau. Water vapour measurements from Vostok have been analysed by Townes & Melnick 1990, and suggest a significant improvement again over South Pole opacities in the submm. A research station is currently under construction at Dome C by the French and Italian communities. Summertime measurements at Dome C (Valenziano et al 1998) show not only very low precipitable water vapour values (typically 700 μm), but also very flat power spectra in the atmospheric emissivity at millimeter wavelengths—suggestive of very little boundary layer turbulence. The wind speed at Dome C is also exceptionally low (averaging 2.8 m/s; Sironi, 1998). This suggests again that the boundary layer could be very thin, leading to extraordinarily good seeing from a telescope mounted just a few metres above the ground.

4. The AASTO

Site testing at remote locations is always challenging; nowhere is this more true than in Antarctica. In order to quantify the site conditions, not just at inhabited sites such as the South Pole but also at remote, unattended locations, the AASTO experiment is being conducted. The AASTO (Automated Astrophysical Site-Testing Observatory, see Storey, Ashley & Burton 1996; Storey, 1998) is based on technology developed by Lockheed Missiles and Space for the US Automated Geophysical Observatory (AGO) program (Doolittle 1986) but incorporates a number of significant improvements.

The AASTO itself is a propane-powered, well insulated shelter that keeps itself warm and generates approximately 50 watts of electrical power via a thermoelectric generator. It will eventually be equipped with a full suite of site-testing instruments, including the Antarctic Fibre-Optic Spectrometer (Boccas et al 1998), a Differential Image-Motion Monitor (Dopita, Wood & Hovey 1996), sky monitors for the near- and mid-infrared (Storey et al 1999), and an acoustic sounder.

At present the AASTO is operating at the US Amundsen-Scott station at the South Pole. In 2000 or 2001 the AASTO will move to Dome C, where it will remain for at least 12 months. Beyond that it is hoped to explore still higher sites on the plateau, to the extent that logistics will allow.

5. High plateau observatories

The last few years have seen several major facilities developed for the antarctic plateau. These include:

SPIREX/Abu. The South Pole Infrared Explorer (SPIREX) is a 60 cm IR-optimised telescope with a fast tip-tilt secondary mirror. It is used with “Abu”, a near-infrared camera with a 1024×1024 indium antimonide array (Fowler et al 1998). The SPIREX/Abu project was developed as an international collaboration between CARA, NOAO and UNSW, and will be offering common-user access to the US and Australian communities in 1999.

AST/RO. The Antarctic Sub-mm Telescope/Remote Observatory (AST/RO) is a 1.7 m aperture offset-fed sub-millimetre telescope (Stark et al 1997) that began operation at the South Pole in 1995. It is used primarily for study of the 492 GHz line of neutral carbon.

Python. Since 1992 the Python experiment at the South Pole has collected data on the anisotropies of the cosmic microwave background at intermediate angular scales (Platt et al 1997).

APACHE. More recently, the APACHE series of experiments (Valenziano et al 1998) has begun at Dome C, mapping CMBR anisotropies at four wavelengths between 1.1 and 3.0 mm.

6. The future

Over the next few years, the infrastructure available to support astronomy on the high plateau will be greatly improved. The US Amundsen-Scott station at the South Pole is undergoing a substantial upgrade, while the Italian/French base at Dome C is currently under construction and will soon be ready for year-round operation.

As reviewed in this paper, the benefits of an antarctic observatory extend right across the infrared and sub-millimetre. Not only do spectral lines that are otherwise inaccessible become amenable to study, but substantial sensitivity gains can be achieved across almost the entire spectrum. Particularly enticing is the prospect of achieving very high sensitivity infrared images, corrected across a large field of view, at wavelengths that have previously been little studied. For example, SPIREX/Abu has already produced large mosaic images of NGC6334 and the Large

Magellanic Cloud at 3.5 microns. This will allow the determination of the initial mass function of star formation to be extended to much lower masses than previously possible.

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