An Automated Astrophysical Observatory for Antarctica

Storey, J.W.V., Ashley, M.C.B. and Burton, M.G.
School of Physics,
University of New South Wales, Sydney 2052, Australia
email jwvs@newt.phys.unsw.edu.au

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Abstract

Conditions on the high antarctic plateau would appear to be extremely favourable for a wide range of astronomical research. Before a decision can be made on constructing an observatory, data are required on site conditions at the most promising locations. To enable these data to be collected, a Lockheed Automated Geophysical Observatory is being purchased. This facility will be fitted with a suite of astronomical site-testing instruments, and deployed to several sites on the antarctic plateau. This program will allow a definitive assessment of the site conditions to be made by the end of this century.

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1 Introduction

Interest in the development of a major astronomical observatory high on the antarctic plateau is rapidly gaining momentum. The scientific rationale for such an observatory was recently examined by the Australian Working Group on Antarctic Astronomy. Their report (Burton et al 1994) was very positive, and concluded that *"...the case for development of antarctic astronomy is overwhelming."*

However the development of an observatory on the antarctic plateau is a massive logistical undertaking, which will require a major international effort and a commitment of significant funds by all participants. Such a commitment cannot of course be made until the advantages of the site have been established beyond all doubt. The importance of obtaining comprehensive site-testing data has therefore been stressed at both international and national levels:

- In August 1994 a special session of the XXIII STAR/SCAR meeting in Rome was devoted to antarctic astronomy. A resolution was subsequently passed by STAR (the Solar-Terrestrial and Astrophysics working group) in support of further astronomical research in Antarctica, and urging: *"The acquisition and analysis of directly comparable site testing data (preferably with identical instrumentation) at high altitude sites including the South Pole, Vostok, Dome C and Dome A."*
- In January 1995 the National Committee for Astronomy of the Australian Academy of Science, in its report " Australian Astronomy beyond 2000", ranked an International Observatory on the antarctic plateau as the equal highest priority for next-generation facilities, and specifically recommended (R12) that: *"Australia should participate in site testing for an international observatory on the antarctic plateau, with a view to participation in the development of such an observatory should it prove feasible."*

There are already several projects underway to explore the potential offered by the antarctic plateau, most notably those of the US group, CARA, which is operating three telescopes at the South Pole. Some information is also available from other sites on the high plateau, particularly the Russian base at Vostok (Burova et al 1986). The US operated a base (known as the Plateau Station) at 79°15′S, 40°30′E from 1965 to 1969, and at Dome C (74°30′S, 123°10′E) for several years from 1974. In addition, there are a number of automatic weather stations scattered around the plateau gathering basic meteorological data. Very little is known, however, about many of the site properties of greatest relevance to astronomy.

2 The Automated Geophysical Observatory (AGO)

In 1981 the geophysical community faced a challenging problem: how to gather data from remote, uninhabited sites throughout the long, dark antarctic winter. To address this issue, the US National Science Foundation embarked on an eight-year program with Lockheed to develop a self-powered, self-heated field station. The result is the Automated Geophysical Observatory, or AGO (Doolittle 1986, Doolittle and Mende 1995).

The AGO, of which six were built, is a very well insulated, small portable laboratory. Short-term accommodation is provided for up to four people, who accompany the AGO to its destination, set up the experiments over a period of about one week, then leave the AGO to operate autonomously for the next 12 months. A major challenge that Lockheed had to face was how to provide heat and electrical power for the full twelve months that the AGO would sit on the ice in sub-zero temperatures. There is little wind on the plateau, it is dark for six months of the year, and environmental and cost considerations rule out radioisotope generators. The solution chosen is a propane-fueled catalytic oxidiser, which produces 2.5 kW of heat, plus 50 watts of electrical power via a thermo-electric generator.

Data taken by the AGO are recorded on optical disk, and retrieved at the end of the 12-month deployment. However the health and status of the experiment can be monitored in close to real time via transmissions to polar-orbiting Argos satellites.

The AGO is designed to fit exactly into the cargo hold of a ski-equipped LC-130 ("Hercules") transport plane. In the initial "put-in" flight, the AGO is placed on the snow, together with the science team of three or four persons and enough fuel for three weeks. Approximately one week later the Hercules returns with a year's supply of fuel and retrieves the science team. The AGO remains on the ice for the next twelve months, gathering data in an autonomous mode very similar to that of a deep-space spacecraft.

3 From AGO to AASTO

Examination of the AGO specifications suggests that an AGO would also be well suited to housing astronomical instruments. Consequently, in June 1994 the University of New South Wales and the Australian National University signed a Memorandum of Understanding establishing JACARA (the Joint Australian Centre for Astrophysical Research in Antarctica). A proposal to jointly purchase an AGO from internal funds was approved by both universities. With revised specifications and upgraded performance, this seventh "AGO" becomes an Automated Astronomical Site Testing Observatory, or AASTO.

3.1 Environmental considerations

With the exception of the South Pole, all the sites to which it is planned to deploy the AASTO lie within Australian Antarctic Territory. We therefore have a special responsibility to ensure that the site testing is carried out with the least possible environmental impact. The deployment of the AASTO to the antarctic plateau represents a particularly good example of how vital research data can be gathered over a year-long period with an absolute minimum of disturbance to the environment. For example:

- The AASTO operates by itself, without human presence. Life support systems and the problems of waste management, etc., are completely avoided. Apart from a brief period of about one week during set-up, there are no human operators.

- The AASTO is flown in by Hercules LC-130 transport plane, which lands directly on the ice. The aircraft stays there only as long as required for unloading, and returns to pick up the set-up crew when required. The AASTO can be flown out again at the end of the operation, leaving nothing but footprints and landing-skid marks in the snow.

- The power source for the AASTO is liquid propane, which is oxidised cleanly and at relatively low temperatures over a platinum catalyst. The exhaust consists almost entirely of water vapour and carbon dioxide.

- The astronomical instruments themselves are entirely "passive". That is to say, they simply measure the incoming light, and make no disturbance whatsoever to the environment.

3.2 The role of the AASTOWG

In May 1994 the Automated Astronomical Site Testing Observatory Working Group (AASTOWG) was established to coordinate Australian and US plans for site testing from the AASTO. At its first meeting in Boulder, the working group agreed upon a provisional suite of instruments and recommended the purchase of an AGO.

The second meeting of this group, in April 1995, reviewed the status of the project and discussed the conceptual design of individual instruments.

After ruling out some instruments with excessive power requirements, the following set was retained for further consideration.

UV/visible sky monitor

All-sky camera

Isoplanameter

Differential image-motion monitor (DIMM)

Near-IR sky monitor

Mid-IR sky monitor

Sub-mm bolometric tipper

Water-vapour radiometer

Microthermal sensor set

Rocket sonde.

The design of the DIMM by Mount Stromlo Observatory is already well advanced, and is discussed elsewhere in this issue(??). Three of the instruments are to be built at the University of New South Wales, and are described in more detail in section 4 below. Other instruments are to be contributed by US and Australian groups.

4 Instrument considerations

The AASTO provides heat, power, shelter, data acquisition and status telemetry. In many ways, the astronomical site testing instruments to be deployed are far more demanding than the geophysical instruments currently in the field. While much of the electronics and computing equipment can be housed in the warm environment of the AASTO, obtaining realistic site-testing data requires that some of the sensors be placed well away from the shelter itself. For these instruments, the telescopes, tilt mirrors, and dewars must operate in the ambient environment, which can reach temperatures as low as -85 °C.

The power output of the thermo-electric generator is approximately 50 W. Of this, the data acquisition computer and other AASTO "housekeeping" functions consume about 10 W. The remaining 40 W must be shared by the science instruments. Fortunately, not all the instruments need to run all the time, as some of the site properties to be measured are expected to change only slowly throughout the day. Nevertheless, great attention must be paid to reducing the power consumption of each instrument to very low levels.

Use of thermoelectric coolers for CCDs and other detectors is effectively ruled out on power consumption grounds. Fortunately, the snow outside the AASTO is sufficiently cold to reduce the dark current of a modern multi-pinned phase CCD to negligible levels. Heat pipes, or simply well-insulated solid copper rods, can be used to pipe "cold" in to the detector.

Liquid cryogens are also ruled out because of the enormous quantities that would be required to keep an instrument running for a full 12 months. Miniature Stirling-cycle coolers, such as the RC-1 manufactured by Inframetrics, offer a suitable alternative. This cooler has a capacity of 150 mW at 77 K, while consuming only 3.5 watts of electrical power.

The standard technique for keeping optical surfaces free of ice is to heat them a few degrees above ambient. While this is practical if heat from the AASTO is used directly (some 2.5 kW is available), electrical power is too precious a resource to be used this way. Some instruments can be placed in or on the AASTO, and kept warm. Others, such as the DIMM and the water vapour monitor, must be placed well away, as the AASTO is itself a substantial source of both heat and water vapour. These instruments will require particularly careful design to allow them to operate completely independent of any heat source.

The three instruments to be built at UNSW are described briefly below, in order to illustrate some of the challenges—and possible solutions—to the construction of AASTO instruments.

4.1 UV/visible sky monitor

This experiment will monitor the atmospheric transmission from 300 to 1100 nm, and will also allow an assessment of the significance of the auroral emission lines throughout this range. Because there is negligible atmospheric thermal emission at these wavelengths, the atmospheric transmission must be measured directly by taking spectra of bright stars with a small telescope. Initially, we will construct a simple prime-focus instrument with a 20-cm diameter primary mirror. At the focus we will mount a group of 100-μm optical fibres, each defining a field of view of 1.2 arcminutes. These fibres direct the light back to the AASTO where a spectrometer with a passively cooled CCD array will cover the UV/visible region at a resolution of approximately 1 nm.

With bright stars such as Beta Centauri and Fomalhaut an integration time of a few tens of seconds is all that is necessary to achieve adequate photon statistics. The large field of view of each fibre also results in good sensitivity to airglow and auroral emission, receiving the same flux as a 0.5 arcsecond pixel would on a 7-metre diameter telescope.

A prototype of this instrument will be built with funding from the Australian Antarctic Foundation and a small ARC grant during 1995, and then followed with an upgraded instrument with a 30-cm lightweight metal mirror. This larger instrument will have sufficient sensitivity to also provide data on the quantitative concentration of atmospheric trace gases.

4.2 Near-infrared sky monitor

This instrument is planned to take measurements of the near-IR ($2.35\,\mu$m) sky brightness in the "cosmological window" (so-called because it will allow observation of the furthest galaxies). It will use a single InSb detector, cooled by a low-power Stirling engine. Containing only a single, cooled, 2.35-μm (or "K-dark") filter, this instrument will enable precise measurement of the background flux in this window. A stepper-motor driven tilt mirror will enable observations to be made as a function of zenith distance.

4.3 Mid-infrared sky monitor

To determine the transmission, emissivity, and stability of the mid-infrared (7–17$\,\mu$m) sky we are building a mid-infrared sky monitor experiment. The instrument will use a mercury cadmium telluride detector, cooled to 77K by a second Stirling engine, looking out at the sky in a 1-arcmin field of view through a selection of ambient-temperature filters. It will be able to detect emission from ice crystals to an emissivity level of a fraction of a percent, and by measuring the sky brightness as a function of wavelength will be able to accurately determine the atmospheric transmission. A black body of accurately known temperature will serve as a reference source.

The proposed filters would be a CVF (circular variable filter) covering 6–11μm, the standard IR astronomy "silicate filter set" and further fixed filters at 17 and 22$\,\mu$m. At 10.5μm the clear-sky radiance is very low (emissivities less than a few percent) for a typical antarctic water-level content. Ice crystals have maximum emissivity near 12.5$\,\mu$m with $\sim$ 15% of this at 10.5$\,\mu$m.

Thus, observations at these wavelengths can determine the radiance due to ice crystals. The sky radiance at 10.5 and 12.5 μm is only weakly dependent on precipitable water vapour (PWV) while a channel at 22 μm has a very strong dependence. Knowledge of the PWV then allows the transmission throughout the 20–30 μm window to be obtained from model atmosphere calculations.

5 Test Facility

Once deployed to Antarctica, the instruments must work reliably and without human intervention for 12 months at a time. Only by rigorous testing can this level of performance be assured. An environmental test facility is therefore being established at the Kensington campus of the University of New South Wales.

Smaller instruments will be tested in a modified 566-litre chest freezer, which is capable of maintaining -85 °C continuously. This freezer will form the main environmental chamber of the test facility. Larger instruments, such as the DIMM, will be tested in a dry-ice cooled cold box, which has a capacity of 1.5 m^3.

A complete AGO data acquisition system and control computer are being purchased, together with sufficient of the AGO power supply to allow all instruments to be tested together, and under realistic conditions, before they are despatched to Antarctica.

6 Timetable

This project depends on the scheduling of operations within the US Antarctic Program. While the timetable set out below is considered to be realistic, it must be recognised that placing the AASTO at the highest and most remote regions of the plateau is an enormously challenging logistical exercise.

1995: The AASTO will be purchased from Lockheed, and delivered to McMurdo early in 1996. The environmental chamber and AASTO power and data acquisition system will be installed at UNSW to facilitate instrument development.

1996: The AASTO, together with its complete instrument complement, will be deployed at the South Pole towards the end of the year to begin a 12-month shake-down period. Data gathered during this time will be essential for later comparison with the higher altitude sites.

1997: At the end of the year the AASTO will be deployed to Dome C, refuelled, and will begin a second twelve months of data acquisition.

1998: At the end of the year the AASTO will be recovered, refuelled, and deployed to a second high altitude site.

1999: By the end of the year, a comprehensive set of comparative data should be available from all three sites. The AASTO can either be recovered, or refuelled to continue data acquisition.

By the end of this century, the AASTO and its suite of instruments should have acquired all the information necessary for the sensible planning of a major high-plateau antarctic observatory.

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