The AASTO Program

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Abstract. The Automated Astrophysical Site-Testing Observatory, or AASTO, is a self-powered, self-heated autonomous laboratory. It is currently operational at South Pole station, and will later be deployed to remote, uninhabited sites on the high antarctic plateau. It is being fitted with a suite of astronomical site-testing instruments, so that potential observatory sites can be fully characterized over a wide range of wavelengths.

1. Introduction

Over the past few years, careful measurements at the South Pole have shown that conditions there are exceptionally good for certain kinds of astronomy. The advantages of antarctic sites over those at temperate locations stem principally from the extreme cold and dryness, combined with the high altitude and the stability of the atmosphere (eg, Burton et al. 1994).

- In the near-IR, the sky brightness has been shown to be between 20 and 100 times lower than at temperate sites (Ashley et al. 1996, Nguyen et al. 1996). A detailed analysis of data from the whole of 1995 confirms that exceptionally low near-IR backgrounds at the South Pole are not infrequent (Phillips et al. 1998).
- At 11 microns the summertime sky brightness at the South Pole is already an order of magnitude lower than at a typical temperate observatory in winter, and much more stable (Smith & Harper 1997).
- Above an altitude of approximately 200 meters, the seeing is exceptionally good. There is significant degradation of the seeing within the boundary layer, but calculations show that this can largely be removed by a low-order adaptive optics system, over a very wide field of view (Marks et al. 1996, 1997).
- At millimeter and submm wavelengths, atmospheric transmission is superior to that at other sites, and stability is greatly improved (Chamberlin & Bally 1994, Chamberlin & Bally 1995, Chamberlin et al. 1997).

However, despite the outstanding qualities of the South Pole, it is not necessarily expected to be the best astronomical site on the antarctic plateau. Other sites are considerably higher (Dome A, for example, is at over 4,000 meters), and are further away from the moist coastal air that from time to time sweeps inland. Only the South Pole currently has the infrastructure to support an astronomical program, yet without hard data from higher sites it is difficult to justify the establishment of new bases.

2. The AASTO

Acquiring site-testing data from uninhabited sites is always difficult—nowhere more so than from the high plateau of Antarctica. Fortunately, the geophysical community have for many years been developing the Automated Geophysical Observatory, or AGO (Doolittle 1986). There are now six AGOs deployed across the plateau. An AGO can operate autonomously and unattended for 12 months at a time, gathering data that are written to disk ready for collection during the annual servicing mission. Heat is provided by the catalytic oxidation of some 4,000 liters of liquid propane, while six thermoelectric generators provide electrical power.

The AASTO is, in effect, the seventh AGO and incorporates several small improvements over that design. It was built by Lockheed (who also built the AGOs) under contract to the University of New South Wales and the Australian National University (Storey et al. 1996). Like the AGOs, it is designed for field deployment from a ski-equipped LC-130 Hercules transport plane. The data acquisition and data control computers use GPS for timing, and write data to seven Iomega "Jaz" drives, giving a total of 7 gigabytes of storage capacity. Housekeeping data are transmitted back to the US in close to real time using the ARGOS satellite network.

In additional to the astronomical site-testing data, the AASTO also collects weather data such as temperature, wind speed and direction, and atmospheric pressure.

In designing instruments for the AASTO, the most important considerations are that they be reliable, capable of operating autonomously, and use very little power. A total of only 50 watts is available from the thermoelectric generators to run the experiments, and the use of liquid cryogens is of course precluded by the lack of access during the winter.

3. Instrumentation Currently Installed

The AASTO was officially opened at the South Pole on January 9, 1997 by Senator Robert Hill, the Australian Minister for the Environment and Leader of the Government in the Senate. Three instruments are currently operational in the AASTO. Two of these, the NISM and MISM, are installed in well-insulated boxes mounted on top of the AASTO roof. The third, the AFOS, is on a 7.5 meter high tower placed some 35 meters upwind of the AASTO itself. Brief details of these three instruments are given below.

3.1. Near-Infrared Sky Monitor (NISM)

This is the simplest instrument, with an InSb detector and fixed $2.35\,\mu$m filter cooled to 77K by a low-power Stirling cooler. A gold-coated reflective chopper wheel chops the received signal at a frequency of 77Hz between two beams 45° apart in elevation. Making a differential measurement in this way greatly improves the precision and removes many calibration uncertainties. The entire instrument is hermetically sealed, and looks out through a sapphire window. The optical system is arranged so that the two beams pass through exactly the same portion of the window, ensuring that any ice crystals that may have accumulated will affect both beams equally. A stepper motor drives the instrument about its elevation axis, allowing "sky-dip" measurements to be carried out. Placed to one side of the instrument is a black-body calibration source, heated by the warmth of the AASTO building via a short length of OFHC copper rod.

The chopper is driven by a 3-phase brushless sensor-less motor, as only this type of motor will operate reliably and efficiently at the very low temperatures. A phase-locked loop is used to maintain a precise chopping frequency. Data acquisition and instrument control are carried out by a low-power PC104 based computer running under the real-time multitasking operating system RTKernel.

3.2. Mid-Infrared Sky Monitor (MISM)

The MISM is similar in concept to its near-IR counterpart, but uses a Stirling-cycle cooled HgCdTe detector. A chopping frequency of 1kHz is used to avoid 1/f noise. An ambient-temperature filter wheel, driven by a stepper motor, carries a set of ambient temperature filters, giving spectral coverage from 4 to $14\,\mu$m. To reduce the background flux and improve the sensitivity, the instrument temperature is allowed to drop to $-30°$C. This temperature is maintained by a methanol-filled self-regulating heatpipe which transports warmth from the AASTO shelter to the MISM box.

3.3. Antarctic Fiber-Optic Spectrometer (AFOS)

The AFOS consists of a small telescope feeding a grating spectrometer and CCD detector via a bundle of six optical fibers. By observing bright stars, a direct measure of atmospheric transmission from the UV cut-on to about 800 nm is obtained. In addition, sky emission arising from aurorae and airglow can be monitored.

The telescope itself is a 30cm diameter f/3.5 Newtonian. Athermalization is achieved by using an Astrosittal mirror (a Russian-made ceramic similar to Zerodur) and an Invar telescope tube. The telescope tube is fully sealed (although provision is made for pressure equalization through a bi-directional blow-off valve), and has a 30cm diameter optically flat fused-silica entrance window. A canister of CaH_2 ensures that the partial pressure of water vapor inside the telescope remains below that which would condense out as ice, even at $-80°$C.

To achieve good transmission across the entire wavelength range, a dichroic beamsplitter within the telescope tube directs light to a set of either "blue" (wet) or "red" (low OH) fibers. Each set consists of three fibers, each subtending a field of view of 20 arcseconds on the sky. The central fiber is used to look at the star; the other fibers to acquire reference spectra from the sky. The dichroic beamsplitter (together with the poor blue transmission of the "red" fibers) also acts as an order-sorting filter for the grating.

The spectrometer is a Jobin Yvon CP200 fixed-grating imaging spectrometer with extremely good scattered light performance. The individual spectra from all six fibers are simultaneously dispersed onto a 256×1024 pixel virtual phase, thermoelectrically cooled CCD. The spectral resolution is approximately 2.4nm.

During 1997 the AFOS is mounted on a simple elevation mount to allow testing of the basic concept. At the end of the year it will be attached to a fully steerable high precision mount along with a differential image-motion monitor. A full description of the AFOS, together with preliminary results, has been prepared by Boccas et al. (1998).

4. Instruments to be installed in 1997–8 season

Two additional instruments will be installed during the coming austral summer.

4.1. Differential Image-Motion Monitor (DIMM)

Based on a commercially available 35.5cm Schmidt-Cassegrain telescope, the DIMM will use multiple sub-apertures to allow the wavefront to be better characterized than would be possible with a more conventional two-aperture DIMM. The DIMM will be mounted on one port of the "G-mount", a high precision telescope mount designed for very low power operation under antarctic conditions. The other port of the G-mount will be occupied by the AFOS, allowing simultaneous acquisition of seeing data and stellar spectroscopy. Both the DIMM and G-mount are presently under construction at Mount Stromlo Observatory.

4.2. Sub-mm tipper

Constructed by Carnegie Mellon University, the sub-mm tipper uses a room-temperature pyroelectric detector to monitor $350\,\mu$m radiation. A stepper motor drives an off-axis paraboloid mirror, allowing the instrument to scan from zenith to horizon. Two prototypes were completed in January 1997: one is currently undergoing trials on the roof of the AST/RO building at the South Pole; the other is undergoing further development.

5. Proposed experiments

5.1. Acoustic wind profiler—SODAR

Recent work (Marks et al. 1996, 1997) has demonstrated that the bulk of the seeing disturbance on the antarctic plateau arises from the turbulent boundary layer, with a height generally less than 300m. This is in contrast to the situation at temperate observatory sites, where significant contributions arise from several layers distributed throughout the atmosphere—all the way from ground level to above the tropopause. Within the polar vortex there is no jet-stream, and the majority of the atmosphere behaves as a single, orderly layer.

It is important to be able to measure the height of the boundary layer. If atmospheric seeing can be reduced by a factor of five simply by placing the telescope above this layer (Marks et al. 1997), it clearly makes a big difference to construction costs whether the layer is a few meters thick or if it is several hundred meters. At the South Pole, the balloon measurements have shown that this layer generally extends less than a few hundred meters above the ice. At Dome C, and other high plateau sites, the wind speed is much lower than at the Pole. This in turn should lead to a much thinner boundary layer, possibly as low as a few meters in some circumstances.

Since balloon measurements are impractical from an uninhabited location, we propose to use an acoustic wind profiler, or "SODAR". This is the acoustic analog of a radar and measures microthermal turbulence directly, as the intensity of the echoes is directly proportional to $\mathrm{C}_{\mathrm{T}}^2$. Range gating is used to determine the distance to the elements of air responsible for each reflection, while Doppler analysis allows wind velocities to be calculated. By employing three acoustic beams (one vertical, two slanted at 45°), the three-dimensional wind profile can be obtained.

Because of the very low values of $\mathrm{C}_{\mathrm{T}}^2$ expected on the plateau, the returning echoes will be much weaker than the instrument normally encounters. This is mitigated to some extent by the low temperature and humidity (which reduces the acoustic absorption of the atmosphere), and the very low ambient acoustic noise and ground clutter at the antarctic sites.

5.2. Mm phase stability

The antarctic plateau also offers the potential of superb observing conditions at millimeter and sub-millimeter wavelengths. Not only is the atmospheric transmission much better than at any other location, but the stability of the thermal emission from the sky is also greatly superior. In addition we expect the phase fluctuations through the atmosphere to be very much reduced, offering the promise of unprecedented "seeing" for mm-wave interferometry. This hypothesis appears straightforward to test by placing two small receiving antennae some distance apart and monitoring the beacon transmissions from polar-orbiting satellites passing overhead. A phase comparator will be used to monitor phase fluctuations caused by the atmosphere. This experiment is similar in concept to systems using geostationary satellites and already deployed at Mauna Kea (Masson 1994) and Paranal (Saito et al. 1995).

6. Timetable

Once the full complement of instruments is operational, the AASTO will operate at the South Pole for at least one full year. It is then planned to deploy it to remote, uninhabited sites higher on the plateau. The most likely first site will be Dome C, with the ultimate goal being the 4,200 meter summit of Dome A.

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