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ASTROPHYSICS FROM DOME A

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Abstract. Dome A, the summit of the Antarctic plateau, is expected to have even better atmospheric conditions for ground-based astronomy than Dome C. However, the logistical constraints are very stringent. Current instrumentation at Dome A exemplifies the requirements imposed by these constraints. Future instrumentation and infrastructure will exploit the qualities of the site much more fully.

1 Introduction

Dome A is the highest point of the Antarctic Plateau, the point from which the katabatic winds start. It is probably the coldest point on the continent; coupled with its elevation, this should make it the driest point as well. Because it is the source of the katabatics, there is no expected prevailing wind direction, and

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pictures of the snow surface from the first Chinese traverse to Dome A (2005/6) show a delicate crystalline surface rather than the wind-sculpted sastrugi common over the whole plateau. This supports the idea that there is no overall prevailing wind direction, and also suggests that windspeeds are generally low.

The fact that Dome A is the source of the katabatics also suggests that the turbulent boundary layer should be thinner there than elsewhere, and this is supported by modelling results, which predict a boundary layer significantly thinner than that over Dome C. The colder environment will reduce the thermal background from wavelengths of $2\,\mu$m to a few mm, yielding improved sensitivity, particularly in the thermal infrared. The very low levels of precipitable water vapour in the atmosphere should yield very low atmospheric opacity in the submillimetre-wave/THz regime, which may be low enough to open new atmospheric windows to ground-based instruments. The low level of water vapour is also likely to yield very low sky noise, as it does at the South Pole, increasing the sensitivity of measurements in this region of the electromagnetic spectrum.

Dome A was visited by a Chinese traverse in the austral summer of 2005/6, and there is no permanent presence there. Another traverse reached Dome A in 2007/8, and the Polar Research Institute of China plans to send further traverses, leading to the establishment of a permanent summer base and eventually a year-round crewed station.

The exceptional conditions of Dome A, together with the ambitious plans to develop it as a research station, give it great potential for ground-based astrophysics. This paper outlines the current plans to fully characterise the site and to begin to use it to deliver science, and compares it to Concordia.

2 Current Instrumentation for Dome A

2.1 General Considerations

Instruments for Dome A must be designed and built within very stringent logistical constraints. In the absence of a permanent station, they must be designed to operate entirely autonomously. Ashley *et al.* 2004, Strassmeier *et al.* 2007 and Tothill *et al.* 2008 have discussed the principles and practice of automated instruments for Antarctic astronomy. Without any human presence at Dome A following deployment, instruments must be designed to run without outside intervention, requiring very high reliability. The majority of the development effort should therefore be devoted to power, control and communications systems.

Further constraints on the design and operational models of Dome A instruments arise from the very limited communications bandwidth available: There is no independent satellite communications facility at Dome A (as there is at Concordia and South Pole Stations), so instruments must provide their own communications, which must also be very robust. The limited bandwidths available also strongly affect the data models of current and future instrumentation.

Fig. 1. The PLATO Engine and Instrument Modules begin the journey south

2.2 Site-testing Instrumentation

At the time of writing, the Chinese PANDA traverse is at Dome A; one of their tasks is the deployment of PLATO, an autonomous site-testing observatory (Lawrence *et al.* 2008), consisting of two modules (Fig. 1). With limited time available, as well as limited thermal and power budgets, the instruments mounted on PLATO had to be simple and conservatively-engineered, where instruments for a crewed station could afford to take more risks.

PLATO supports a set of instruments designed and built by teams from Australia, China, the USA and the UK. Some of these instruments (SNODAR, Bonner *et al.* 2008; and sonic anemometers, Travouillon *et al.* 2008) are designed purely to characterise the atmosphere in order to infer the site quality. Other instruments carry out test astronomical observations (CSTAR, Xu *et al.* 2008; Gattini, Moore *et al.* 2008; and preHEAT, Kulesa *et al.* 2008).

2.3 Submillimetre-wave instrumentation

One of the instruments hosted by PLATO is preHEAT (Fig. 2), a submillimetre-wave tipper/telescope. Its primary goal is to measure the atmospheric opacity at $\lambda = 450\mu$m throughout the year at Dome A. Because the atmospheric opacity is a fundamental input not only to submillimetre-wave site quality, but to the

Fig. 2. preHEAT mounted on the side of the PLATO Instrument Module

calibration of astronomical observations in this regime, opacity measurements are readily available for all submillimetre observatory sites, polar and temperate. The South Pole Station has an independent opacity monitor operating at $\lambda = 350\mu$m, with identical tippers operating at temperate sites (Mauna Kea and Chajnantor) for comparison: The results of several years of monitoring have been summarised e.g. by Stark *et al.* (2001). SUMMIT, a modified version of the same instrument was fielded at Dome C on the AASTINO, and early results suggested better conditions than at the South Pole (Calisse *et al.* 2004). SUMMIT has now been upgraded at CEA, Saclay, and returned to Dome C. The opacity data obtained by preHEAT will therefore allow the submillimetre-wave potential of Dome A to be directly compared with that of other sites.

A subsidiary goal is to take spectral scans of molecular gas in our Galaxy. The instrument uses a Schottky mixer, enabling heterodyne spectroscopy as well as broadband opacity measurements. The receiver has a fixed tuning that includes the ^{13}CO $J = 6{-}5$ line, which traces warm dense gas in regions like the Galactic Centre and Eta Carinae. Since the instrument only has one axis of motion (elevation), spectra must be obtained by drift-scanning.

A pair of baffles have been installed on either side of the preHEAT beam path, in order to reduce the solid angle of cold sky seen by the tipper window. By filling much of the view from the window with an ambient-temperature load ($>$190 K), rather than a sky-temperature load (generally $<$100 K), the radiative cooling of the window should be reduced, and this should in turn ameliorate the icing problem, known from Dome C (e.g. Durand *et al.* 2007), which we also expect to encounter at Dome A.

3 Future Instrumentation for Dome A

3.1 HEAT

HEAT, the successor to preHEAT, is a 0.5 m aperture THz telescope. Like preHEAT, it is fully automated, and will rely on PLATO for infrastructure support. Its purpose is to explore the lifecycle of the interstellar medium, particularly the formation of molecular clouds in the galaxy. HEAT will survey large areas of the galactic plane in THz transitions of atomic carbon and carbon monoxide (CI and CO, both at 0.8 THz), ionised nitrogen (NII at 1.4 THz), and ionised carbon (CII at 1.9 THz). This survey programme will require a great deal of very dry weather, and it is this requirement that makes it a particularly good fit for Dome A, where we expect to find the highest fraction of THz conditions in Antarctica.

3.2 AST3

AST3 is a successor to CSTAR, consisting of 3 0.5 m aperture Schmidt telescopes with very large CCDs and fixed filters, designed to obtain time-series multi-colour photometry. Like HEAT, it will use the PLATO infrastructure.

4 Dome C and Dome A

Although Dome A is at a much earlier stage of development than Dome C, it is possible to compare the two. We expect the meteorology of the sites to be quite similar; certainly, they should have more in common than either has in common with the South Pole. Dome A should be colder and drier, and should have a thinner turbulent boundary layer. Because of its more southerly latitude, stars will move through a smaller range of airmass, which might improve photometric reproducibility, and should reduce the sky brightness at noon in winter, since the sun will be further below the horizon. However, the more southerly Dome A will also be able to see less of the sky, and will have worse access to satellite communications, making it more difficult to secure adequate bandwidth.

The presence of Concordia at Dome C makes a tremendous difference to the design and potential capabilities of instruments. Instrument automation becomes a matter of convenience rather than necessity: Functions may be automated so as to increase the productivity of the instrument, to reduce the workload on the winterovers, or to reduce the communications bandwidth requirement. But functions that are most easily done by a human (such as some maintenance or oversight functions) or not routine (such as occasional equipment restarts) may be left to the winterovers. By contrast, until a human presence is established at Dome A, all functions must be automated.

Clearly, for the next few years, only small instruments will be fielded at Dome A. Moreover, the need for automation will tend to cut back their functionality to the bare minimum required to fulfil their scientific goals. Concordia is therefore the only high-altitude plateau site able to host more ambitious facilities in the near- to medium-term.

The year-round human presence at Concordia also offers the opportunity to develop techniques for Antarctic instrumentation, since more debugging can be done. An outstanding example of this approach is the GIVRE programme of experiments (see elsewhere in this volume) to understand and ameliorate the icing problem encountered at Dome C (and which may also occur at Dome A). Technology developed or assessed at Concordia may end up being deployed at Dome A to take advantage of better atmospheric conditions there.

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