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SITE-TESTING IN ANTARCTICA

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RESUMEN

Los sitios en el Plateau de la Antártica como el Domo A, el Domo C y el Polo Sur, ofrecen condiciones favorables para la astronomía que resultan únicas y excepcionales. La evaluación de sitio realizada en la última década ha revelado emisión de fondo infrarroja extremadamente baja, vapor de agua bajo, transmisión infrarroja excelente y niveles bajísimos de turbulencia atmosférica. Aunque ya se ha construido grandes desarrollos en la Antática y están en curso muchos más, queda mucho por estudiar de este único y hermoso lugar.

ABSTRACT

Sites on the Antarctic Plateau such as Dome A, Dome C and South Pole, offer unique and exceptionally favourable conditions for astronomy. Site testing over the past decade has revealed extremely low infrared backgrounds, low water vapour, excellent infrared transmission and very low levels of atmospheric turbulence. Although several large facilities have already been built in Antarctica and plans for many more are well underway, there is still much to learn about this unique and beautiful place.

Key Words: **ATMOSPHIC EFFECTS — SITE TESTING**

1. INTRODUCTION

Site testing over the past decade or so suggests that the Antarctic plateau has much to offer as a site for an astronomical observatory (see, for example Fossat 2005; Storey 2005). It is of course extremely cold, and this leads to greatly reduced infrared backgrounds and very low atmospheric water vapour content. This means that the atmospheric transmission from infrared to millimetre wavelengths is dramatically improved. As a result, millimetre, sub-millimetre and infrared astronomers have been the first to take advantage of the conditions. However, the stable middle and upper atmosphere, combined with the thinness of the surface layer, result in unparalleled seeing and exceptionally favourable conditions for high-resolution imaging. As a result, proposals for large optical telescopes are now also under consideration.

The Antarctic continent is very large—at 14 million square kilometres it is roughly twice as large as Australia. The Antarctic plateau makes up a large part of this area, and rises to an elevation of over 4,000 metres. Temperatures in winter time can drop to nearly −90° C. For most of the time, much of the plateau is within the atmospheric Polar Vortex, which means that the high altitude jet-stream winds rarely intrude over the site. It is these winds that are responsible for the upper atmosphere turbulence that is prevalent at most other locations on earth.

Wind on the plateau is predominantly katabatic; that is, a stable breeze of cool air flows down from the highest point (known as Dome A) to the coast. The average wind speed at Dome C is one of the lowest on earth (Aristidi et al. 2005a). For most of the winter, an intense inversion layer is created close to the ground, as the surface cools radiatively by as much as 30 degrees below the temperature of the middle atmosphere. This surface layer is often turbulent, but unlike the situation at most other observatory sites, it is typically only 20–30 meters thick at the high elevation Antarctic sites.

With these obvious advantages, it is not surprising that there is a major effort underway to fully characterise the most promising of the Antarctic plateau sites. In this paper we review some of the past studies, describe ongoing efforts, and look towards some possible future developments.

2. PRECIPITABLE WATER VAPOUR

With temperatures that can fall below that of dry ice (solid carbon dioxide), it is reasonable to assume that the air will be exceedingly dry. Measurements at the South Pole using millimetre-wave radiometers have shown that it has the lowest average water vapour content of any site so far studied (e.g., Chamberlin et al. 1997). At Dome C, higher on the plateau, preliminary measurements (Valenziano & dall 'Oglio 1999; Calisse et al. 2004) suggest that conditions there may be even better still.

At these temperatures the absolute humidity is exceedingly low. As an example, at 50% relative hu-

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Fig. 1. The French-Italian *Concordia* station at Dome C opened for year-round operation in 2005.

Fig. 2. A satellite communication dish is lifted onto the roof at Dome C. Infrastructure already in place at South Pole and Dome C is well suited for the construction of astronomical facilities.

midity, air at −60° C contains three orders of magnitude less water vapour than it does at 25° C. Measurements at Dome C with conventional humidity sensors (for example, balloon radiosondes) suggest that the relative humidity hovers around 30–50%. However, it is also known that, at Dome C, any exposed object whose temperature falls even slightly below ambient will quickly acquire a coating of ice. (Durand et al. 2007). While at first sight this might be thought to imply a relative humidity of close to 100%, at these very low temperatures the “frost point” can be very close to—or even above—the ambient temperature, even if the relative humidity is quite moderate. For example, at −60° C and 50% relative humidity, only a 0.8 degree drop in temperature is required to precipitate ice onto a surface.

Even if the most pessimistic assumption is made, 100% relative humidity throughout the atmosphere, the exceedingly low temperatures throughout the atmosphere above the Antarctic plateau imply that the sky transparency at infrared and submillimetre wavelengths will be unrivalled (Lawrence 2004). At Dome A, the highest point on the plateau, windows should open up at terahertz frequencies that are otherwise inaccessible except from space or from aircraft.

3. INFRARED SKY BACKGROUND

Measurements at the South Pole in the near-infrared (Nguyen et al. 1996; Ashley et al. 1996; Phillips et al. 1999) and mid-infrared (Smith & Harper 1998; Chamberlain et al. 2000) confirm the expected very low levels of thermal emission from the sky. Not only is the sky very cold, but the low water vapour content results in improved transmission and wider, more stable atmospheric windows.

Summer time measurements at Dome C (Walden et al. 2005) reveal an extremely stable and transparent sky, even when the sun is well above the horizon. The first telescope to exploit these conditions will be IRAIT (Tosti et al. 2006), an 80 cm infrared telescope to be deployed in 2008.

4. OPTICAL SKY BRIGHTNESS AND TRANSPARENCY

At the present time there has been little work done at the South Pole to monitor sky brightness at optical wavelengths. Interest from optical astronomers has focussed largely on Dome C, where conditions are expected to be more favourable. An automated camera operated at Dome C during 2001 and found 74% clear skies (Ashley et al. 2005). A web-camera operated for several months in 2003/4 and showed in excess of 90% clear skies (Ashley et al. 2004).Visual observations of the cloud cover by the Dome C wintering astronomer in 2006 suggest that the sky is cloud-free for over 84% of the time (Mosser & Aristidi 2007). Automated photometric measurements have also been made during 2006 (Moore et al. 2006) and are expected to yield quantitative data to complement this very encouraging figure.

Concerns about aurorae have led to an analysis of South Pole all-sky camera data and an extrapolation of this to Dome C using observed upper-atmosphere electron precipitation rates (Dempsey, Storey, & Phillips 2005). The conclusion of this work is that aurorae are unlikely to be a significant prob-

Fig. 3. The AASTINO is a robotic site-testing observatory that can operate completely unattended.

lem for most optical observations at Dome C. Further work (Kenyon & Storey 2006) looks at other contributions to optical sky brightness and concludes that, despite the long periods of twilight at these high latitude sites, Dome C in particular is likely to be extremely good for optical astronomy.

5. ATMOSPHERIC TURBULENCE

Gillingham (1991) predicted that the stable atmospheric conditions on the Antarctic plateau could result in extraordinarily good seeing conditions, compromised only by an extremely thin but intensely turbulent surface layer. These led to a series of experiments in the 1990s at the South Pole that produced results in general agreement with these predictions. Direct measurement of the seeing a few metres above the ground (Loewenstein et al. 1998) showed it to be poor (later confirmed by Travouillon et al. 2003a). However, microthermal measurements from mast and balloon (Marks et al. 1996, 1999) showed that almost all of the turbulence was confined to the surface layer. Unfortunately, at the South Pole this surface layer appeared to be some ∼200 meters thick. Acoustic radar measurements (Travouillon et al. 2003b) confirmed that the layer was almost always present, and that it extends to a sufficient height to preclude any easy solution such as placing the telescope on a small tower.

However, the lower wind speeds at higher sites on the plateau should lead to a significantly thinner surface layer (Gillingham 1991; Marks 2002). A detailed theoretical study (Swain & Gallee 2006) suggests a median surface layer thickness that ranges from 18 m at Dome A to 27 m at Dome C.

Summer time measurements at Dome C with a DIMM (Differential Image-Motion Monitor) (Aristidi et al. 2003, 2005b) revealed periods of exceptionally good seeing. Combined with the excellent cloud cover statistics, this implies that Dome C should be a remarkably good site for solar astronomy (e.g., Arnaud, Faurobert, & Fossat 2006).

The first measurements of the turbulence profile of the atmosphere above Dome C were conducted from an unmanned robotic observatory called the AASTINO (Lawrence, Ashley, & Storey 2005). Using a combination of MASS (Multi Aperture Scintillation Sensor) and acoustic radar, these wintertime measurements showed that, above a possibly turbulent surface layer, the seeing was the best ever observed on earth, with a median value of 0.27 arcseconds (Lawrence et al. 2004). Furthermore, the acoustic radar measurements placed an upper limit of 30 m on the thickness of the surface layer.

Following the opening of the station to year-round operation in 2005, measurements could be conducted throughout the year without the need for fully robotic instrumentation (Agabi et al. 2006). While the DIMM data showed that the night-time seeing measured from just above the ice was consistently poor, the balloon microthermal data showed that, as at South Pole, the turbulence was confined to a region close to the ground. However, at Dome C this layer was only about 30 m thick, in agreement with the acoustic radar data of Lawrence et al. The key atmospheric parameters of isoplanatic angle and coherence time, as measured by the three independent techniques (MASS, DIMM and balloon profiling), are in reasonably good agreement, and indicate that Dome C is a site with unparalleled potential for high-resolution imaging and interferometry. In addition, measurements of the scintillation (Kenyon et al. 2006a) show that it is the lowest on earth, making Dome C the ideal location for precision photometry observations.

6. FUTURE MEASUREMENTS

Although enough is already known about Dome C to encourage the deployment of large astronomical facilities there, much is still to be learned. Perhaps the most pressing piece of missing information concerns the statistics of the intensity and height of the turbulent surface layer, as this dictates how high a telescope should be placed to enjoy free-atmospheric conditions. A number of techniques can be used to make these measurements, including direct microthermal measurements from a tower, high-resolution acoustic radar, and lunar shadow-band scintillometry (SHABAR).

TABLE 1

SUMMARY OF DOME C BENEFITS

Parameter	Advantage over other sites	Performance Impact
Isoplanatic angle	2–3 ×	4–9 × in AO sky coverage and corrected field
Coherence time	2.5 ×	1–2 magnitudes in guide star required brightness
Low-IR background	20–100 ×	1–3 magnitudes in point source sensitivity
Image size	2–4 ×	2–4 × spatial resolution in visible;
		0.5–1.5 magnitudes in point source sensitivity
Scintillation	3–4 ×	3–4 × gain in photometric and astrometric precision

Fig. 4. A tractor-train arrives at Dome C. Three such traverses take place each year, with each traverse bringing in about 150 tonnes of supplies.

Fig. 5. The Twin Otter aircraft are a fast and efficient way to bring people and small items of cargo to Dome C.

Better statistics are also needed on the turbulence profile throughout the atmosphere, extending over several years. In addition to direct balloon-borne radiosonde measurements, scintillation techniques such as MASS and SCIDAR can also be used.

Further measurements of sky brightness and transmission, from optical wavelengths through to the submillimetre, are also needed. For example, at the present time no measurements have been made for astronomical purposes of the spectrum of the night sky above Dome C. A fibre-fed spectrometer has recently been developed for this purpose (Kenyon et al. 2006b).

Other sites on the plateau must also be explored. Perhaps the most promising of these is Dome A, which will be the subject of a Chinese-led expedition later this year. Astronomical site-testing instruments to accompany this expedition are being developed by a number of research groups. A robotic laboratory, PLATO (Lawrence et al. 2006), will host these experiments and provide heat, power and communications throughout the long winter.

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REFERENCES

Agabi, A., et al. 2006, PASP, 118, 344

Aristidi, E., Agabi, A., Vernin, J., Azouit, M., Martin, F., Ziad, A., & Fossat, E. 2003, A&A, 406, L19

Aristidi, E., et al. 2005a, A&A, 430, 739

———. 2005b, A&A, 444, 651

Arnaud, J., Faurobert, M., & Fossat, E. 2007, Mem. Soc. Astron. Italiana, 78, 105

Ashley, M. C. B., Burton, M. G., Storey, J. W. V., Lloyd, J. P., Bally, J., Briggs, J. W., & Harper, D. A. 1996, PASP, 108, 721
Ashley, M. C. B., Burton, M. G., Lawrence, J. S., & Storey, J. W. V. 2004, Astron. Nachr., 325, 619
Ashley, M. C. B., Burton, M. G., Calisse, P. G., Phillips, A., & Storey, J. W. V. 2005, Highlights of Astronomy, 13, 932
Calisse, P. G., Ashley, M. C. B., Burton, M. G., Phillips, M. A., Storey, J. W. V., Radford, S. J. E., & Peterson, J. B. 2004, PASA, 21, 256
Chamberlain, M. A., Ashley, M. C. B., Burton, M. G., Phillips, A., Storey, J. W. V., & Harper, D. A. 2000, ApJ, 535, 501
Chamberlin, R. A., Lane, A. P., & Stark, A. A. 1997, ApJ, 476, 428
Dempsey, J. T., Storey, J. W. V., & Phillips, M. A. 2005, PASA, 22, 91
Durand, G., et al. 2007, EAS Publication Series, 25, 77
Fossat, E. 2005, J. Astrophys. Astron., 26, 349
Gillingham, P. R. 1991, Proc. Astron. Soc. Aust., 9, 55
Kenyon, S. L., Ashley, M. C. B., Everett, J. R., Lawrence, J. S., & Storey, J. W. V. 2006c, Proc. SPIE, 6267, 62671M
Kenyon, S. L., Lawrence, J. S., Ashley, M. C. B., Storey, J. W. V., Tokovinin, A., & Fossat, E. 2006b, PASP, 118, 924
Kenyon, S. L., & Storey, J. W. V. 2006a, PASP, 118, 489
Lawrence, J. S. 2004, PASP, 116, 482
Lawrence, J. S., Ashley, M. C. B., & Storey, J. W. V. 2005, Aust. J. Elec. Electr. Engineering, 2, 1
Lawrence, J. S., Ashley, M. C. B., Tokovinin, A., & Travouillon, T. 2004, Nature, 431, 278
Lawrence, J. S., et al. 2006, Proc. SPIE, 6267, 62671L
Loewenstein, R. F., Bero, C., Lloyd, J. P., Mrozek, F., Bally, J., & Theil, D. 1998, ASP Conf. Ser. 141, Astrophysics from Antarctica, ed. G. Novak & R. Landsberg (San Francisco: ASP), 296
Marks, R. D. 2002, A&A, 385, 328
Marks, R. D., Vernin, J., Azouit, M., Manigault, J. F. & Clevelin, C. 1999, A&AS, 134, 161
Marks, R. D., Vernin, J., Azouit, M., Briggs, J. W., Burton, M. G., Ashley, M. C. B., & Manigault, J. F. 1996, A&AS, 118, 385
Moore, A. M., et al. 2006, Proc. SPIE, 6267, 62671N
Mosser, B., & Aristidi, E. 2007, PASP, 119, 127
Nguyen, H. T., et al. 1996, PASP, 108, 718
Phillips, A., Burton, M. G., Ashley, M. C. B., Storey, J. W. V., Lloyd, J. P., Harper, D. A., & Bally, J. 1999, ApJ, 527, 1009
Smith, C. H., & Harper, D. A. 1998, PASA, 110, 747
Storey, J. W. V. 2005, Antarctic Science, 17, 555
Swain, M. R., & Galleé, H. 2006, PASP, 118, 1190
Tosti, G., et al. 2006, Proc. SPIE, 6267, 62671H
Travouillon, T., et al. 2003a, A&A., 409, 1169
Travouillon, T., Ashley, M. C. B., Burton, M. G., Storey, J. W. V., & Loewenstein, R. F. 2003b A&A, 400, 1163
Walden, V. P, Town, M. S., Halter, B., & Storey, J. W. V. 2005, PASP, 117
Valenziano, L., & dall'Oglio, G. 1999, PASA, 16, 167