Antarctic Science 17 (4): 555–560 (2005) © Antarctic Science Ltd Printed in the UK DOI: 10.1017/S095410200500297X

Astronomy from Antarctica

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Abstract: Astronomers have always sought the very best locations for their telescopes. From observatories in city centres, astronomers moved first to nearby mountain tops, then to remote sites in distant countries, to aircraft, and into space. In the past decade we have come to realize that the best astronomical observing conditions on the surface of the earth are to be found on the Antarctic plateau. The combination of high altitude, low temperature, low absolute humidity, low wind and extremely stable atmosphere offers astronomers gains in sensitivity and measurement precision that can exceed two orders of magnitude over even the best temperate sites. In addition, spectral windows are opened up – particularly in the far-infrared and terahertz regions – that are otherwise only accessible from high-flying aircraft or from space. Established and highly successful telescopes at the South Pole are soon to be joined by a new generation of facilities at Concordia Station, including large telescopes and interferometers. It has even been suggested that the largest optical telescopes currently proposed, with diameters of up to 100 m, might achieve their science goals at a lower overall cost if they are built on the Antarctic plateau rather than at a temperate site. Such telescopes offer the possibility of not only detecting earth-like planets in other star systems, but also of analysing their atmospheres spectroscopically.

Received 16 November 2004, accepted 17 March 2005

Key words: Atmosphere, cosmology, infrared, planets, terahertz, turbulence

Introduction

Over the past decade, astronomy has become an increasingly important part of Antarctic science. There are many characteristics of the Antarctic continent that make it a uniquely favourable location from which to conduct observations of the universe. Currently, the world spends well over a billion dollars per year on ground-based astronomy, with most of the infrastructure investment going into the well-established sites in Chile and Hawaii. With site-testing results now pointing to Antarctica as the best continent on earth for a vast range of astronomical observations, a significant fraction of this annual billion-dollar expenditure may start to be directed towards new Antarctic facilities. Already, major programs at the South Pole, such as the particle astrophysics experiment AMANDA and the telescopes of the US Center for Astrophysical Research in Antarctica (CARA), have shown that the logistical challenges can be met and overcome. It is now up to the world-wide astronomical community to see if the apparently limitless opportunities for cosmic discovery from Antarctica can be realized.

With the majority of Antarctica science having been traditionally carried out around the coast, it is not surprising that the popular image of Antarctica is of a hostile, wind-swept environment, wracked by violent storms that can dump metres of snow in a few hours. Building even a modest-sized telescope to operate in such conditions would be a major challenge. However, it is the South Pole and the high plateau sites of Dome A, Dome C, Dome F and Vostok (see Fig. 1) that are of most interest to astronomers. At these sites, typically 1000 km or more inland, the climate is surprisingly benign. Although temperatures can drop below -85°C, wind speeds are very low and violent storms are non-existent. At Dome C, for example, the median wind speed is 2.8 m s^{-1}, and the highest wind speed ever recorded over a 20 year-period of Automatic Weather Station monitoring a mere 20 m s^{-1} (Aristidi *et al.* 2005).

Recent improvements to the infrastructure at South Pole Station reflect the enormous potential that that location holds for future scientific development, including astronomy. Meanwhile, at Dome C, the French and Italian Antarctic programs are about to open the Concordia Station for year-round operation (Candidi & Lori 2003). Some 400 m higher than South Pole and situated on a local maximum in elevation, Dome C offers certain advantages over South Pole (see, for example, Storey *et al.* 2003). The next decade should see major astronomical facilities being constructed at both stations. Dome A, higher still than Dome C, is likely to be the ultimate observing site on the surface of the earth. However, it may be several years before the construction of major facilities there is underway.

The history of Antarctic astronomy has recently been reviewed by Indermuehle *et al.* (2005). This paper will elaborate on the reasons why Antarctica is currently causing so much excitement amongst astronomers, and describe some future plans.

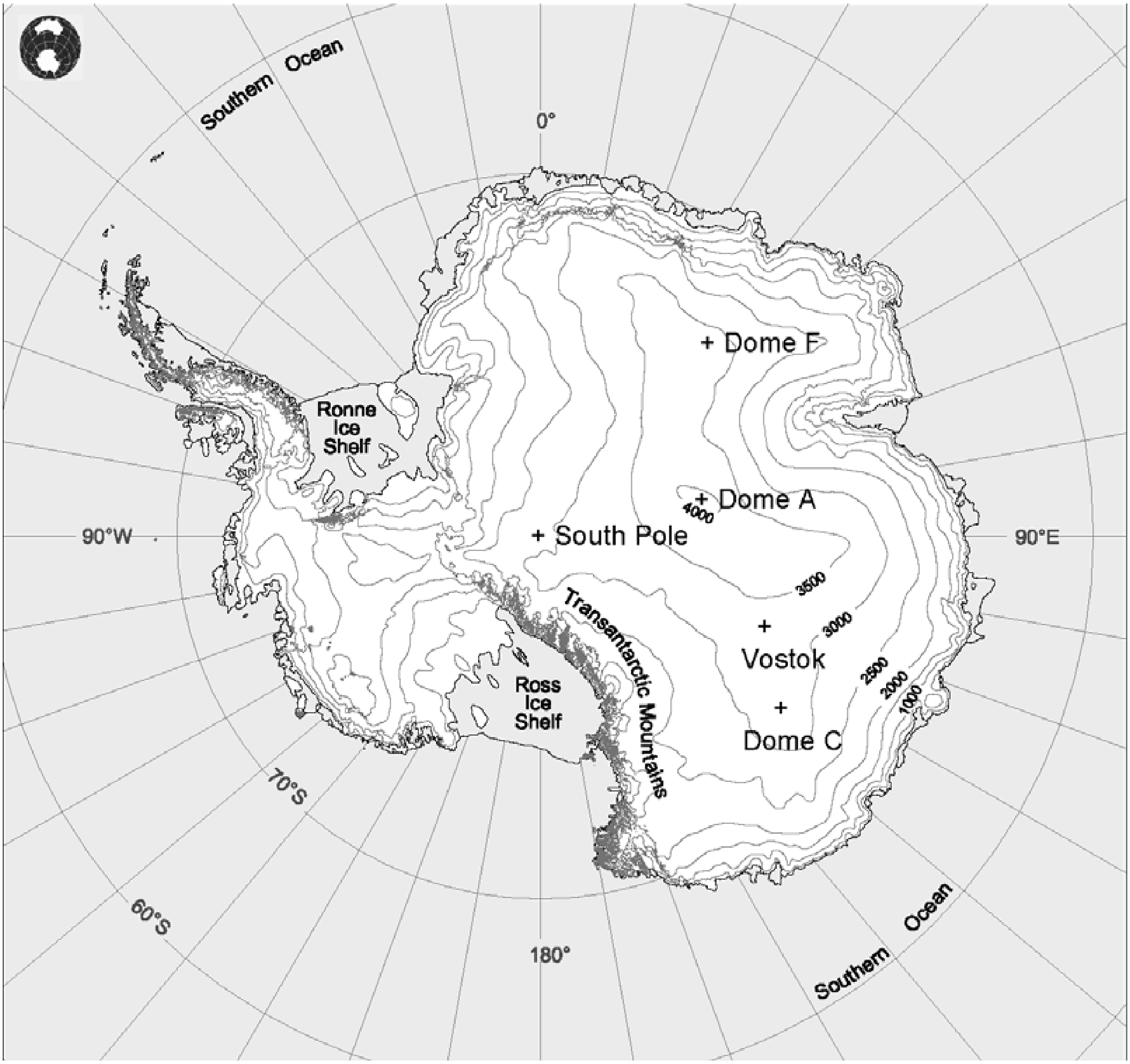

Fig. 1. Map of Antarctica, showing the locations of existing and proposed observatory sites. (With thanks to Jon Lawrence. Basic map courtesy the Australian Antarctic Data Centre.)

Microwaves and millimetre waves

This region of the spectrum (30–300 GHz) is rich in interstellar emission lines and thermal emission from warm, dusty star-forming regions. It is also important as the spectral range in which the Cosmic Microwave Background (CMB) peaks. However, it is also a difficult wavelength range to work in, as absorption in the earth's atmosphere (principally from water vapour, although there are also very strong absorption lines of molecular oxygen present) renders whole regions unobservable. Between the absorption bands, varying atmospheric opacity (and the accompanying variations in atmospheric emission) create fluctuations that reduce the sensitivity of experiments. The exceptionally dry and stable atmosphere above the Antarctic plateau offers considerable advantages. Perhaps nowhere is this more important than in studies of the CMB (Lay & Halvorsen 2000).

At the South Pole, the Viper experiment (Peterson *et al.* 2000) has made major contributions to cosmology through its studies of the spatial distribution of fluctuations in the CMB. The DASI (Degree Angular Scale Interferometer) experiment at the South Pole uses a different technique to provide complementary data to Viper. In addition, DASI has made the first unequivocal detection of polarization in the CMB. This result is of crucial importance to our understanding of the evolution of the universe (Kovac *et al.*

2002) and, by confirming theoretical predictions, lends strong support to current models of how the universe began.

Preliminary measurements at Dome C (Valenziano & dall'Oglio 1999) suggest that conditions there will be equally superb, and possibly even better. However, the South Pole will always have the unique advantage for cosmological studies that it allows observation of a source for months at a time with a completely constant elevation angle. This makes it easier to eliminate systematic effects during the very long integrations required to pull the incredibly weak signals out of the noise.

Sub-millimetre waves (terahertz)

At shorter wavelengths (300 GHz–3 THz), absorption by rotational lines of water vapour makes observations increasingly difficult. The best sites in the world are those with the lowest atmospheric water vapour content, which means Antarctica and the 5500 m peaks in the Chilean Andes. Measurements at the South Pole (for example, Chamberlin *et al.* 1997) have established South Pole as having the lowest average precipitable water vapour of any currently developed site. Comparisons with Dome C are still preliminary (Calisse *et al.* 2004), but hint at an advantage to Dome C consistent with its 400 m higher elevation. Dome A, at 4100 m the highest point on the Antarctic plateau, is expected to be the best sub-millimetre site on the planet by a wide margin. Modelling by Lawrence (2004a) indicates that observations should be possible from Dome A at wavelengths otherwise accessible only from high-flying aircraft or from space.

The next important step for sub-millimetre astronomers is the South Pole Telescope (SPT), currently under construction. SPT is a 10 m diameter off-axis paraboloid optimized for cosmological studies (Ruhl *et al.* 2004).

Infrared

The infrared region is a particularly important one for astronomy. Infrared radiation arises not only from stars but also from objects that are too cool to radiate at optical wavelengths, such as planets and proto-stars. In addition, infrared wavelengths are scattered far less by interstellar dust than is visible light, allowing study of dust enshrouded regions such as those in which stars are forming. Studies of the early universe must rely on infrared radiation because "normal" starlight – even light that originated in the ultraviolet – is red-shifted into the infrared by the expanding universe. From a technological point of view, however, the infrared region is a challenging one from most ground-based sites because of strong thermal emission from both telescope and atmosphere.

The crucial atmospheric parameters for infrared astronomy are the transparency (which will largely be determined by the water vapour content) and the sky brightness, which will also depend on the transparency and, additionally, the temperature. A cold, high, dry site will therefore be ideal for infrared astronomy.

Measurements from 1–5 microns at the South Pole (Nguyen *et al.* 1996, Ashley *et al.* 1996, Phillips *et al.* 1999, Lawrence *et al.* 2002) demonstrate conclusively that the sky brightness is between 10 and 50 times darker than at established observatories at even the best temperate locations. At longer wavelengths (8–14 microns) the sky is some 20 times darker than at temperate sites (Smith & Harper 1998, Chamberlain *et al.* 2000). Because the sensitivity of an infrared telescope goes as the square root of the background flux, a telescope at South Pole can expect to be 3 to 7 times more sensitive than an identical one at a temperate site. At Dome C, conditions are expected to be even better. Preliminary measurements throughout the infrared spectrum (Walden *et al.* 2005) point not only to very good transparency, but also to exceptionally good stability.

A small prototype telescope, SPIREX, was deployed to the South Pole to demonstrate that such sensitivity gains could be realized in practice (Hereld 1994, Fowler *et al.* 1998). The success of this experiment, including its creation of a map at 3.5 microns that was the deepest ever obtained at that time by any telescope, was remarkable. SPIREX was just 60 cm in diameter, and competed in an era of 8 and 10 m diameter telescopes in Hawaii and Chile.

Optical

As early as 1989 predictions were made that the stable upper atmosphere inside the polar vortex, in combination with the laminar flow of the katabatic winds, would result in extraordinarily good image quality being delivered to an optical telescope at a high Antarctic plateau site (Gillingham 1991). At any ground-based site, the light from a star is perturbed as it passes through turbulent layers in the atmosphere. If these turbulent layers contain cells of differing temperature, as is usually the case, the resulting refractive index inhomogeneities impose a distortion upon the incoming wavefront. When brought to a focus this wavefront will no longer create a point-like image. The standard astronomical measure of image quality is the full-width-half-maximum diameter of the image of a point source, and is known as the "seeing". For the best temperate sites on earth, the seeing at 550 nm is typically 0.5–1 arc second. Therefore, for telescopes larger than 10–20 cm in diameter, the achievable spatial resolution is determined not by the diffraction limit of the telescope, but by the vagaries of the atmosphere.

Measurements of the seeing at the Amundsen Scott Station at South Pole were initially disappointing (Loewenstein *et al.* 1998, Travouillon *et al.* 2003a), yielding a median value of around 1.8 arc seconds – considerably inferior to that at the best observatories. However,

https://doi.org/10.1017/S095410200500297X Published online by Cambridge University Press

measurements both from tower-mounted (Marks *et al.* 1996) and balloon-borne (Marks *et al.* 1999) microthermal sensors revealed that the bulk of this seeing degradation was occurring in the lowest 200–300 m of the atmosphere. Above that, the atmosphere was found to create less seeing disturbance than any other site on earth yet studied. Further studies with an acoustic radar confirmed this (Travouillon *et al.* 2003b), and prepared the way for automated studies of uninhabited sites such as Dome C.

The first summer measurements of seeing at Dome C (Aristidi *et al.* 2003) were encouraging, and the strong diurnal variation gave hope that, at certain times of the day during the summer, and for much of the night, the seeing would be superb. Indeed this has been shown to be the case – an automated instrument operating remotely during the first few months of 2004 revealed the best seeing ever observed on the planet (Lawrence *et al.* 2004c), with a median value of 0.27 arc seconds.

Image resolution, however, is not the whole story, as it is now possible with a technique known as adaptive optics to at least partially correct for atmospheric effects. Nevertheless, "seeing" itself remains a crucial parameter when assessing how well a range of instrumental techniques will perform at a given site. One such assessment is the fraction of sky that can be observed at high resolution using natural guide stars and adaptive optics (Lloyd 2004). That fraction goes as the seeing to the -6.5th power! Clearly, with median seeing between two and three times better than the best existing temperate sites, Dome C offers a quite extraordinary opportunity for astronomers (Lawrence 2004b).

Other optical astronomy techniques, such as interferometry where the light from two or more separate telescopes is combined in phase, also benefit enormously from the weak atmospheric turbulence in Antarctica (Storey 2004). Proposals to build a planet-hunting interferometer at Dome C are well advanced (Coude du Foresto *et al.* 2003, Lloyd *et al.* 2003, Swain *et al.* 2004, Vakili *et al.* 2004). Interferometry relies less on having good image quality at ground level, and so even the South Pole can offer substantial benefits over temperate sites. For example, Lloyd *et al.* (2002) have shown that a South Pole interferometer can measure the relative position of two closely spaced stars to a given precision 300 times faster than one at a temperate site. Such observations have the exciting potential to detect an entirely new class of planets orbiting nearby stars.

Finally, astronomers who wish to observe particular stars continuously over periods of days (for example, to detect sudden but brief drops in their apparent brightness as a planet passes in front to them) benefit from the long uninterrupted night during which the observed object never drops below the horizon. This of course is especially true at the South Pole. In addition, such measurements – which usually require very high precision photometry – benefit from the reduced high-altitude turbulence in Antarctica, turbulence that creates random variations in the observed brightness of stellar sources called "scintillation" (Schmider *et al*. 2002). (Scintillation is the phenomenon known popularly as "twinkling" of stars.)

So compelling is the case for large optical/IR telescopes in Antarctica that it has even been proposed to build a 24-m Extremely Large Telescope (ELT) there (Angel *et al*. 2004). ELTs will rely on adaptive optics for their primary operating modes, making it crucial that they be sited only where the best possible atmospheric conditions occur. ELTs, costing up to one billion dollars each, are the next grand challenge of optical/IR astronomy, offering the potential to detect and to study earth-like planets in orbit around other stars. Lardiere *et al.* (2004), for example, believe that a 15 m diameter telescope in Antarctica could achieve results that would require a 30 m telescope elsewhere.

Particle physics

Some of the first scientific studies in Antarctica were of cosmic rays. Since 1956, neutron and muon detectors have operated at Mawson Station on the coast, and have since been joined by other such facilities.

Taking advantage of the vast volume of pure ice at the South Pole, the AMANDA (Antarctic Muon and Neutrino Detector Array) project has operated now for a decade (Halzen 1998). Consisting of hundreds of photomultiplier tubes lowered into bore holes in the ice, AMANDA detects the Cerenkov radiation of relativistic muons created when neutrinos interact with matter. Although the neutrino flux from the sun alone is around 10^{11} particles/cm^2/sec at the earth, their interaction with matter is so weak and infrequent that only a 100 or so neutrino events are detected each year by AMANDA.

AMANDA's successor, IceCube (Ahrens *et al.* 2004), will populate a cubic kilometre of ice with photomultipliers. Its improved sensitivity will herald a new era of high-energy astrophysics.

Meteorites are yet another example of a physical messenger from the cosmos, though not normally considered "particles". The concentration of meteorites by the movement and ablation of ice sheets, combined with the near pristine conditions in which the fallen meteorites are preserved, makes Antarctica a unique hunting ground for meteorite researchers.

Long Duration Balloons

A further characteristic of Antarctica that brings astronomers south is the presence of the circumpolar vortex. A high-altitude balloon launched from an appropriate site, such as McMurdo, travels around the continent at roughly constant latitude before overflying the launch site some two weeks later. In this way astronomers can achieve hundreds of hours of data from a single flight, receive constant solar illumination on the solar panels, and have a better-than-average chance of recovering the payload intact. The BOOMERanG experiment, a collaboration between Italian and US teams, has demonstrated the benefits that such long integrations can have in cosmological studies (de Bernadis *et al.* 2000).

Data from the first long-duration flight of BOOMERanG in 1998 produced the stunning result that the Universe appears to be geometrically "flat". This was later confirmed (in 2003) by the space mission, WMAP. One of the major implications of this result is that the matter we see around us (stars, gas, dust etc.) makes up less than 10% of the universe. The vast majority of the universe consists of something we currently know almost nothing about.

Disadvantages

No observing site is perfect, and there are certain limitations that are peculiar to an Antarctic location. For example, the further away from the equator that an observatory is located, the less of the sky that can be seen over a 24-hour period. The flip-side of this is that those sources that can be observed are above the horizon for longer. From the South Pole, the same patch of sky is observable continuously, with all objects beyond the solar system remaining at constant elevation. Some important sources (such as solar system objects) never rise far above the horizon and of course – as with any observatory site – there are some sources that are permanently unobservable.

The amount of astronomical "dark time", defined as the amount of time the sun spends more than 18 degrees below the horizon, is less (roughly 50%) than at temperate sites. However, exactly how dark the sky is in Antarctica when the sun is just below the horizon has yet to be quantified. This is of consequence only for a particular subset of science objectives at optical and near-infrared wavelengths. The effect of aurorae has yet to be fully quantified, although a preliminary study (Dempsey *et al.* 2005) suggests they will have little effect for most observations in the optical, and none at all in the infrared.

Relationship to other Antarctic research

A distinction is sometimes drawn between studies "about Antarctica" and "studies using Antarctica as a platform", with astronomy clearly one example of the latter. However, astronomical research also reveals much about Antarctica itself. As astronomers strive to minimize the corrupting effect of the earth's atmosphere on their observations, much is learnt that is interdisciplinary in nature. It is a classic example of "One person's signal is another person's noise." For example, acoustic radar studies of turbulence and wind velocity profiles in the lower atmosphere are of equal interest to astronomers and meteorologists. The technique of SCIDAR (Scintillation Detection and Ranging), which requires a telescope of at least 1.5 m diameter, allows astronomers to measure both turbulence and wind-speed profiles throughout the atmosphere with great precision. What astronomers call "mid-infrared sky brightness" is known to climate modellers as "down-welling long-wave radiation". While radio astronomers use arrays of telescopes to measure the relative positions of celestial objects with great accuracy, the same technique can be used in reverse to determine the precise rates and directions of continental drift. As a final example, the "riometer" of ionospheric physics uses the background radiation of star-forming regions and supernova remnants throughout the galaxy to illuminate the ionosphere.

As astronomy becomes more established as a key Antarctic science, the opportunity for interdisciplinary studies involving astronomers and researchers from other disciplines will continue to grow. The result will inevitably be a greater appreciation not only of the richness and beauty of the Antarctica continent, but of the universe of which Antarctica is a part.

Acknowledgements

The author's research is supported by the Australian Research Council and the Australian Antarctic Division. Support from SCAR to enable presentation of the keynote talk in Bremen upon which this paper is based is gratefully acknowledged. I thank the reviewers for their comments on this paper.

References

Ahrens, J. *et al.* 2004. Status of the IceCube neutrino observatory. *New Astronomy Reviews*, **48**, 519–525.

Angel, J.R.P., Lawrence, J.L. & Storey, J.W.V. 2004. Concept for a second Giant Magellan Telescope (GMT) in Antarctica. *Proceedings SPIE*, **5382**, 76–84.

Aristidi, E., Agabi, A., Vernin, J., Azouit, M., Martin, F., Ziad, A. & Fossat, E. 2003. Antarctic site testing: first daytime seeing monitoring at Dome C. *Astronomy & Astrophysics*, **406**, L19–L22.

Aristidi, E., Agabi, K., Azouit, M., Fossat, E., Vernin, J., Travouillon, T., Lawrence, J.S., Meyer, C., Storey, J.W.V., Halter, B., Roth, W.L. & Walden, V. 2005. An analysis of temperatures and wind speeds above Dome C, Antarctica. *Astronomy & Astrophysics*, **430**, 739–746.

Ashley, M.C.B., Burton, M.G., Storey, J.W.V., Lloyd, J.P. Briggs, J.W. & Harper, D.A. 1996. South Pole observations of the near-infrared sky brightness. *Publications of the Astronomical Society of the Pacific*, **108**, 721–723.

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. Submillimeter site testing at Dome C, Antarctica. *Publications of the Astronomical Society of Australia*, **21**, 256–263.

Candidi, M. & Lori, A. 2003. Status of the Antarctic base at Dome C and perspectives for astrophysics. *Memorie della Societa Astronomica Italiana*, **74**, 29–36.

Chamberlain, M.A., Ashley, M.C.B., Burton, M.G., Phillips, A., Storey, J.W.V. & Harper, D.A. 2000. Mid-Infrared observing conditions at the South Pole. *Astrophysical Journal*, **535**, 501–511.

Chamberlin, R.A., Lane, A.P. & Stark, A.A. 1997. The 492 GHz atmospheric opacity at the Geographic South Pole. *Astrophysical Journal*, **476**, 428–433.

Coudé du Foresto, V., Swain, M., Schneider, J. & Allard, F. 2003. Interferometric spectrophotometry of Pegasides: APISD the Antarctic Plateau Interferometer Science Demonstrator. *Memorie della Societa Astronomica Italiana Supplement*, **2**, 212–216.

de Bernardis, P. *et al.* 2000. A flat universe from high-resolution maps of the cosmic microwave background radiation. *Nature*, **404**, 955–959.

Dempsey, J.T., Storey, J.W.V. & Phillips, M.A. 2005. Auroral contribution to sky brightness for optical astronomy on the Antarctic plateau. *Publications of the Astronomical Society of Australia*, **22**, 91–104.

Fowler, A.M., Sharp, N., Ball, W., Schinckel, A.E.T., Ashley, M.C.B., Boccas, M., Storey, J.W.V., Depoy, D., Martini, P., Harper, D.A. & Marks, R.D. 1998. ABU/SPIREX: The South Pole Thermal IR Experiment. *Proceedings SPIE*, **3354**, 1170–1178.

Gillingham, P.R. 1991. Prospects for an Antarctic observatory. *Publications of the Astronomical Society of Australia*, **9**, 55–56.

Halzen, F. 1998. The AMANDA neutrino telescope**.** *New Astronomy Reviews*, **42**, 289–299.

Hereld, M. 1994. SPIREX – near infrared astronomy from the South Pole. *Experimental Astronomy*, **3**, 87–91.

Indermuehle, B.T., Burton, M.G. & Maddison, S.T. 2005. The history of astrophysics in Antarctica. *Publications of the Astronomical Society of Australia*, **22**, 73–90.

Kovac, J.M., Leitch, E.M., Pryke, C., Carlstrom, J.E., Halverson, N.W. & Holzapfel, W.L. 2002. Detection of polarization in the cosmic microwave background using DASI. *Nature*, **420**, 772–787.

Lardière, O., Salinari, P., Jolissaint, L., Carbillet, M., Riccardi, A. & Esposito, S. 2004. Adaptive optics and site requirements for the search for earth-like planets with ELTs. *Proceedings SPIE*, **5382**, 550–559.

Lawrence, J.S. 2004a. Infrared and submillimetre atmospheric characteristics of high Antarctic Plateau sites. *Publications of the Astronomical Society of the Pacific*, **116**, 482–492.

Lawrence, J.S. 2004b. Adaptive optics performance of Antarctic telescopes. *Applied Optics*, **43**, 1435–1449.

Lawrence, J.S., Ashley, M.C.B., Burton, M.G., Calisse, P.G., Everett, J.R., Pernic, R.J., Phillips, M.A. & Storey, J.W.V. 2002. Operation of the near infrared sky monitor at the South Pole. *Publications of the Astronomical Society of Australia*, **19**, 328–336.

Lawrence, J.S., Ashley, M.C.B., Tokovinin, A. & Travouillon, T. 2004c. Exceptional astronomical seeing conditions above Dome C in Antarctica. *Nature*, **431**, 278–281.

Lloyd, J.P. 2004. Optical turbulence in the Antarctic atmosphere. *Proceedings SPIE*, **5491**, 190–198.

Lloyd, J.P., Oppenheimer, B.R. & Graham, J.R. 2002. The potential of differential astrometric interferometry from the high Antarctic Plateau. *Publications of the Astronomical Society of Australia*, **19**, 318–322.

Lloyd, J.P., Lane, B.F., Swain, M.R., Storey, J.W.V., Travouillon, T., Traub, W.A. & Walker, C.K. 2003. Extrasolar planet science with the Antarctic planet interferometer. *Proceedings SPIE*, **5170**, 193–199.

Loewenstein, R.F., Bero, C., Lloyd., J.P Mrozek, F., Bally, J. & Theil, D. 1998. Astronomical seeing at the South Pole. *In* Landsberg, R. & Novak, G., *eds*. *Astrophysics from Antarctica*, *ASP Conference Series*, **141**, 296–302.

Lay, O.P. & Halverson, N.W. 2000. The impact of atmospheric fluctuations on degree-scale imaging of the cosmic microwave background. *Astrophysical Journal*, **543**, 787–798.

Marks, R.D., Vernin, J., Azouit, M., Briggs, J.W., Burton, M.G., Ashley, M.C.B. & Manigault, J.F. 1996. Antarctic site testing – microthermal measurements of surface-layer seeing at the South Pole. *Astronomy & Astrophysics Supplement Series*, **118**, 385–390.

Marks, R.D., Vernin, J., Azouit, M., Manigault, J.F. & Clevelin, C. 1999. Measurement of optical seeing on the high antarctic plateau. *Astronomy & Astrophysics Supplement Series*, **134**, 161–172.

Nguyen, H.T., Rauscher, B.J., Severson, S., Hereld, M., Harper, D.A., Loewenstein, R.F., Mrozek, F. & Pernic, R.J. 1996. The South Pole near-infrared sky brightness. *Publications of the Astronomical Society of the Pacific*, **108**, 718–720.

Peterson, J.B., Griffin, G.S., Newcomb, M.G., Alvarez, D.L., Cantalupo, C.M., Morgan, D., Miller, K.W., Ganga, K., Pernic, D. & Thoma, M. 2000. First results from Viper: detection of small-scale anisotropy at 40 GHz. *Astrophysical Journal*, **532**, L83–L86.

Phillips, M.A., Burton, M.G., Ashley, M.C.B., Storey, J.W.V., Lloyd, J.P., Harper, D.A. & Bally, J. 1999. The near-infrared sky emission at the South Pole in winter. *Astrophysical Journal*, **527**, 1009–1022.

Ruhl, J. *et al.* 2004. The South Pole Telescope. *Proceedings SPIE*, **5498**, 11–29.

Schmider, F.X., Fossat, E., Vernin, J., Martin, F., Azouit, M., Agabi, K., Clausse, J.M. & Grec, G. 2002. The Concordia Antarctic Station: an opportunity for asteroseismology and planetary search. *Proceedings of the First Eddington Workshop on Stellar Structure and Habitable Planet Finding*, *ESA,* **SP-485**, 219–224.

Smith, C.H. & Harper, D.A. 1998. Mid-infrared sky brightness testing at the South Pole. *Publications of the Astronomical Society of the Pacific*, **110**, 747–753.

Storey, J.W.V. 2004. Antarctica: the potential for interferometry. *Proceedings SPIE*, **5491**, 169–175.

Storey, J.W.V., Ashley, M.C.B., Lawrence, J.S. & Burton, M.G. 2003 Dome C – the best astronomical site in the world? *Memorie della Societa Astronomica Italiana Supplement*, **2**, 13–18.

Swain, M.R., Walker, C.K., Traub, W.A., Storey, J.W.V., Coude du Foresto, V., Fossat, E., Vakili, F., Stark, A.A., Lloyd, J.P., Lawson, P.R., Burrows, A.S., Ireland, M., Millan-Gabet, R., van Belle, G.T., Lane, B., Vasisht, G. & T. Travouillon, T. 2004. The Antarctic planet interferometer. *Proceedings SPIE*, **5491**, 176–185.

Travouillon, T., Ashley, M.C.B., Burton, M.G., Storey, J.W.V., Conroy, P., Hovey, G., Jarnyk, M., Sutherland, R. & Loewenstein, R.F. 2003a. Automated Shack-Hartmann seeing measurements at the South Pole. *Astronomy & Astrophysics*, **409**, 1169–1173.

Travouillon, T., Ashley, M.C.B., Burton, M.G., Storey, J.W.V. & Loewenstein, R.F. 2003b. Atmospheric turbulence at the South Pole and its implications for astronomy. *Astronomy & Astrophysics*, **400**, 1163–1172.

Vakili, F., Belu, A., Aristidi, E., Fossat, E., Maillard, A., Abe, L., Agabi, K., Vernin, J., Daban, J.B., Hertmanni, W., Schmider, F-X., Assus, P., Coude du Foresto, V. & Swain, M.R. 2004. KEOPS: Kiloparsec Explorer for Optical Planet Search, a direct-imaging optical array at Dome C of Antarctica. *Proceedings SPIE*, **5491**, 1580–1586.

Valenziano, L. & dall'Oglio, G. 1999. Millimetre astronomy from the high Antarctic Plateau: site testing at Dome C**.** *Publications of the Astronomical Society of Australia*, **16**, 167–174.

Walden, V.P., Town, M.S., Halter, B. & Storey, J.W.V. 2005. First measurements of the infrared sky brightness at Dome C, Antarctica. *Publications of the Astronomical Society of the Pacific*, **117**, 300–308.