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Why Antarctica?

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Abstract: The dry, cold, tenuous and stable air above the Antarctic Plateau provides superb conditions for the conduct of many classes of astronomical observations. We review in particular the rationale for undertaking near-IR, mm and particle astronomy in Antarctica, disciplines where telescopes are now operating at the US Amundsen–Scott South Pole Station.

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1 Introduction

The Antarctic Plateau (Figure 1) provides unique conditions on the Earth for the conduct of observational astronomy. Simply stated, the air is thin, dry and cold and the weather stable, attributes all offering gains to the observational astronomer. These conditions are quite different to those experienced at coastal locations, which are frequently subject to violent storms, and thus unsuitable for most forms of observational astronomy.

The Plateau is over 3000 m in elevation, rising up to 4300 m at Dome Argus. An average year-round temperature of −50°C, falling to below −90°C at times, vastly reduces the thermal background in the near IR. The precipitable water vapour content of the air is typically around 250 μm and can fall below 100 μm, opening up new windows in the infrared and submillimetre regimes to ground-based observation. The lack of a diurnal temperature cycle and the low wind speeds on the highest parts of the Antarctic Plateau provide conditions of extraordinary stability, benefiting a wide range of observational programs.

Taken together these conditions provide for an unsurpassed observing environment for Earth-based astronomers across wide ranges of the electromagnetic spectrum. The new science it can engender will be significant. In particular, it will allow us to pursue what I will call 'formation studies' through new observations in the near-IR to millimetre spectral range. This includes the study of events such as the formation of galaxies, the birth of the first stars in them and their subsequent evolution, the evolution of these galaxies, the life cycle of their interstellar media, and the formation of individual stars and planets. There are three primary reasons for this: the continuum emission from such events peaks in the IR, the dominant cooling lines occur across this spectral range, and the microwave background peaks in the millimetre.

In the remainder of this article I will briefly discuss the specific gains that can be expected for near-IR, sub-mm/mm and particle astronomy. A comprehensive discussion of the scientific issues, including the expectations for work in other wavebands, can be found in the report of the Australian Working Group for Antarctic Astronomy (Burton et al. 1994).

2 Near-IR Astronomy

As demonstrated by the new results presented at this conference from the South Pole site testing program (IRPS, Ashley, Brooks & Lloyd 1996; Ashley et al. 1996; SPIREX, Nguyen et al. 1996), there

Table 1. Parameters assumed for comparison between observatories

Each telescope is assumed to have 5% emissivity, a total system throughput of 50%, and to use detectors with 90% quantum efficiency, 1 e readout noise and $0\cdot1\ \mathrm{e\,s^{-1}}$ dark current

Site	Telescope	Diameter (m)	Seeing (arcsec)	Precipitable water vapour (mm)
Australia	AAT	4	0·5	11
Chile	VLT	16	0·25	1·2
Antarctica	Federation	2·5	0·25	0·25
Antarctica	LASIRT	8	0·25	0·25
Space	SIRTF	0·85	diffraction	0

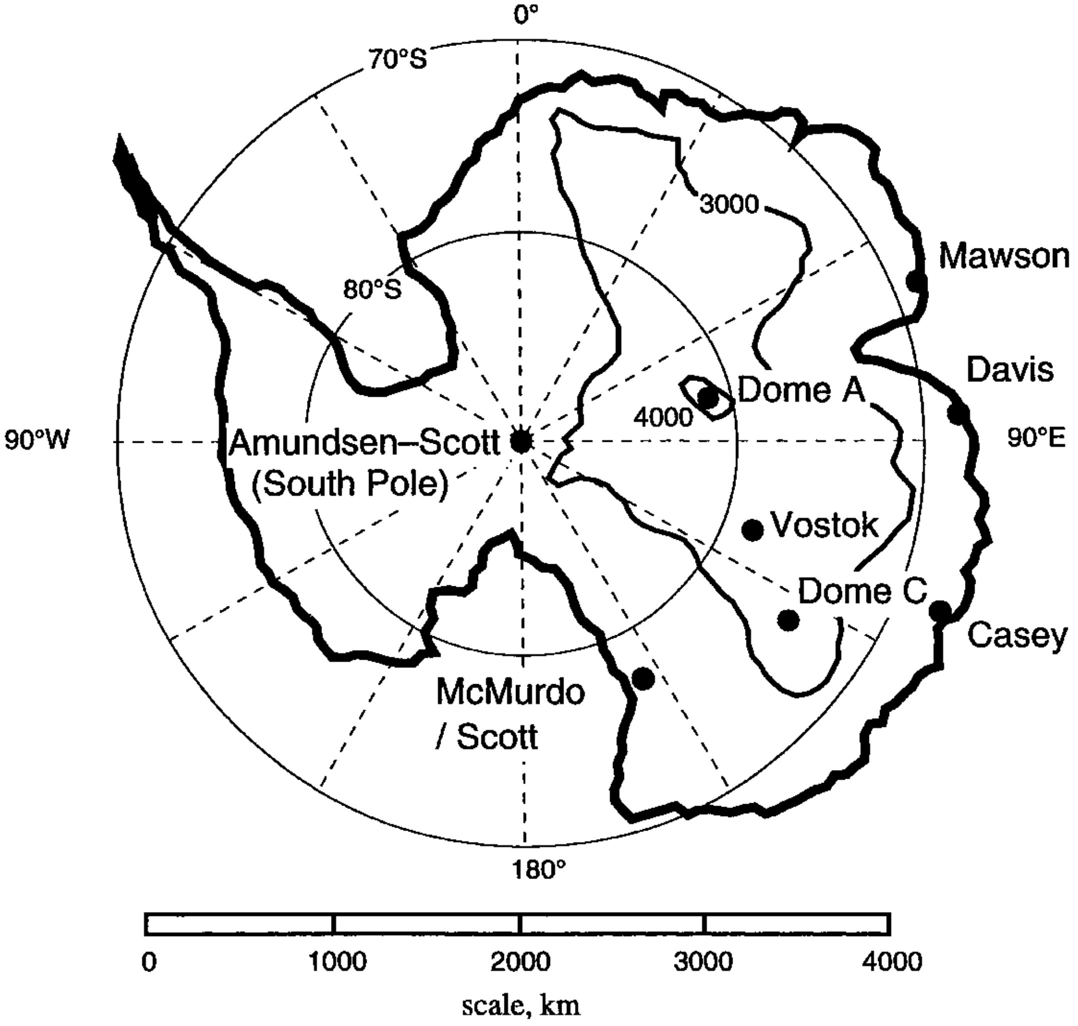

Figure 1—Map of Antarctica, showing the Plateau bases at the South Pole (USA) and Vostok (Russia). The high Plateau sites being considered for a future Antarctic observatory lie inside the 3000 m elevation contour, and are at Dome A and Dome C. The South Pole is supplied through the US coastal station at McMurdo. The Australian coastal stations at Mawson, Davis and Casey, and the New Zealand Scott Base, are also shown.

are significant reductions in the near-IR thermal backgrounds from 2·3–5 μm. We can expect gains in S/N of 2·5–5 magnitudes over the equivalent observations made with a telescope on a good mid-latitude site, corresponding to speed gains of factors of 10–100. Figure 2 shows the sensitivities calculated for broad-band photometry in the near-IR for the AAT compared to those expected for four telescopes of the future: the 16 m VLT in Chile (see e.g. Moorwood 1994), the 0·85 m SIRTF (see e.g. Werner 1995) in space, and two Antarctic telescopes, the modest 2·5 m Federation and the 8 m LASIRT (Large Antarctic Sub-mm IR Telescope) (see e.g. Burton et al. 1996; Bally et al. 1996). Table 1 lists the parameters that have been assumed in order to derive these sensitivities. We can see that from 2·3–2·5 μm no other telescope can compare to the Antarctic telescopes, and above 3 μm only the billion-dollar space mission can out perform it.

As can also be seen from Figure 2, the most sensitive observations that can be made will be those from Antarctica in the 2·3–2·5 μm 'K–dark' window. In K-dark, airglow emission is virtually absent, and the thermal emission is dramatically reduced in Antarctica. Fortuitously the zodiacal emission also has a minimum in the near IR, between sunlight scattered off solar system dust at shorter wavelengths and thermal emission from it at longer wavelengths. We are close to being limited by the minimum zodiacal emission itself in Antarctica. This is thus the darkest window we can find to observe through in the inner solar system!

Of particular scientific interest will be exploiting the K-dark window for deep surveys, e.g. for

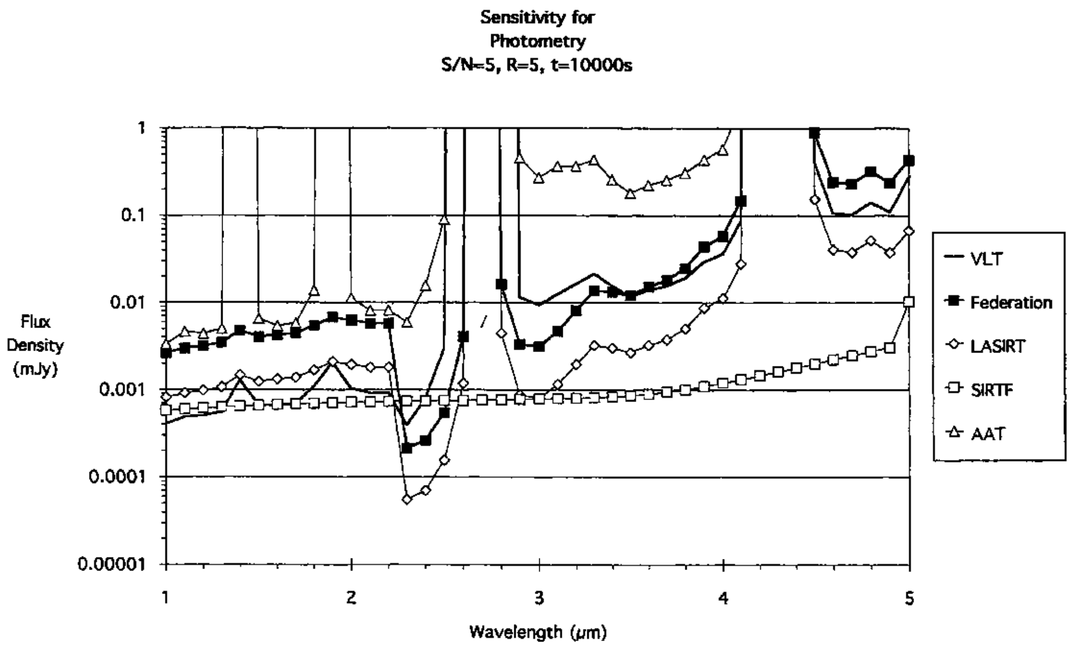

Figure 2—Predicted sensitivities in mJy for broad-band photometry from five different telescopes in the near IR: the 4 m AAT in Australia, the 16 m VLT under construction in Chile, the proposed 0·85 m SIRTF space satellite, and two Antarctic telescopes (the 2·5 m Federation and an 8 m near-IR version of LASIRT). The sensitivity is calculated for a S/N ratio of 5 and 10 000 s integration time for observations with a spectral resolution $R = 5$.

faint stars, embedded star-forming clusters and for protogalaxies. For instance, for redshifts in the range $z = 3$–10, where galaxy formation occurs, the peak of the mean stellar spectrum is shifted into the near IR. It is also worth noting that, while the gains are less impressive in the 3-4 μm window than in the K-dark, they are still significant, and that limited work has been done in this band to date. Studies of the low-mass end of the stellar mass function in star-forming clouds, and searches for brown dwarfs, will be particularly enhanced.

3 Millimetre and Submillimetre Astronomy

The gains for millimetre and submillimetre astronomy stem from the tremendous improvement in the atmospheric transmission above the plateau. As can be seen in Figure 3, many windows in the sub-mm band are opened up that have only been accessible to date from airborne and spaced-based platforms. Not evident in this figure, but equally significant, is the stability of the atmosphere. The windows are open virtually continuously and the sky emission in them is stable, allowing accurate background subtraction and flux calibration. Interferometry at submillimetre wavelengths on a regular basis will only be possible from Antarctica. The scientific possibilities are tremendous:

- There is negligible extinction at these wavelengths, allowing us to peer within the deepest and coldest clouds, near the peak of their black-body continuum emission.
- The fundamental rotational transitions of molecules such as CO, CS, and HCO^+ and the light hydrides (e.g. CaH, NaH) occur here. Several transitions can be measured per molecule, allowing their excitation state to be determined.
- Neutral carbon, which has recently been shown to be surprisingly abundant in molecular clouds, has its cooling lines at 370+610 μm.
- While the dominant cooling lines of the molecular clouds surrounding active star-forming regions will still be inaccessible (e.g. [O I] 63+146 μm, [C II] 158 μm) in the Galaxy, at modest redshifts they will be brought into view. This opens up the exciting possibility of observing the onset of star formation in protogalaxies.

The 1·7 m submillimetre AST/RO telescope is now spending its first year of operation at the South Pole in order to examine some of these opportunities (Balm 1996).

Of at least equal significance are the possibilities offered in Antarctica for studying the cosmic microwave background radiation (CMBR), the relic radiation from the hot Big Bang. It is the exceptional atmospheric stability that makes possible measurements of the background fluctuations ($\Delta T/T \sim 10^{-5}$). Following the detection by the COBE satellite of the first CMBR anisotropy, research in the field is beginning in earnest as fluctuations start to be measured on different angular scales, placing models for the Big Bang under close scrutiny. CMBR

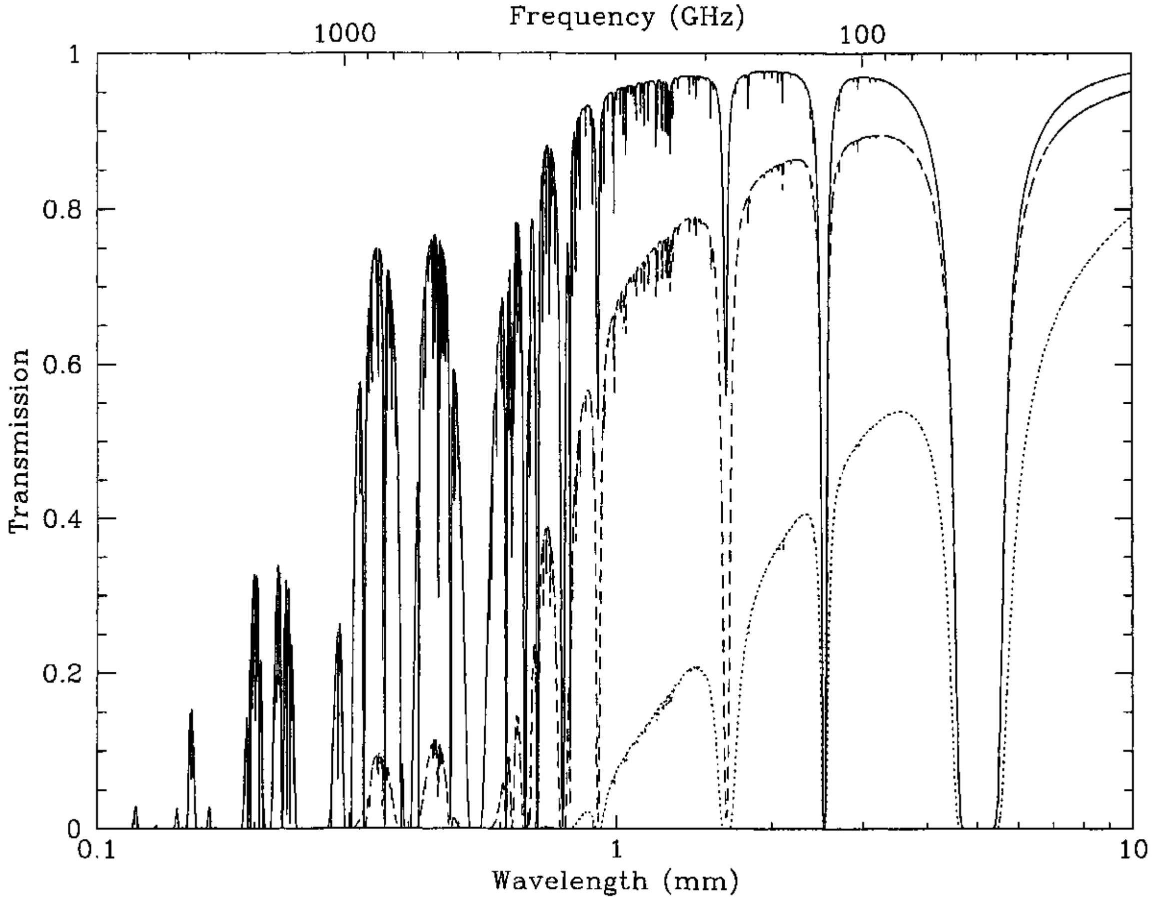

Figure 3—Calculated atmospheric transmission curves in the mm and sub-mm bands (using the ATRAN model, Lord 1993) for three different levels of precipitable water vapour: 250 μm, representing an average Antarctic day (solid line) 1·2 mm; representing Mauna Kea (dashed line); and 11 mm (dotted line), representing Siding Spring.

experiments have been underway at the Pole for several years now, with the COBRA experiments now regularly recording anisotropies (Peterson private communication). Fluctuations arising from the Sunyaev–Zel'dovich (SZ) effect, the upscattering of the background spectrum by both the hot gas surrounding galaxy clusters and the peculiar velocities of the cluster, should be observable on spatial scales of around 3 arcmin. This will permit direct determinations of the peculiar velocity of the galaxies from the Hubble flow, independent of their distance, and eventually may even yield rotation curves of individual galaxies. Thus strict constraints will be placed on the matter density of the Universe.

4 Particle Astronomy

There are also significant gains to be made for measurements of the cosmic particle spectrum from an Antarctic observatory, but for quite different reasons than those that apply to photon astronomy. The proximity to the magnetic pole allows low-energy cosmic rays to reach the ground (e.g. the neutron monitors at Mawson, Duldig et al. 1985). The long Antarctic night can be utilised to search for the faint Cerenkov light produced by gamma-ray interactions in the atmosphere (the GASP experiment, Morse & Gaidus 1989). Atmospheric cascades caused by the arrival of high-energy cosmic rays can be studied with air shower arrays. The constant zenith angle at the South Pole simplifies the identification with a cosmic source (the SPASE experiment, van Steckelenborg et al. 1993). The vast quantities of pure ice can be used as an absorber to detect neutrinos. The AMANDA experiment (Tilav et al. 1993), now in its first stage of operation, is using photomultiplier tubes buried 1 km into the ice to record muon-generated Cerenkov radiation from the rare interactions with the ice from neutrinos entering the Earth from the North Pole. The background count rates, from both radioactive and biological materials, must be minimised to pick up the low count rates and make detection possible. This is best achieved deep within the Antarctic ice sheet.

It should be noted that the selection criteria for an observatory site for particle astronomy are quite different to those for more traditional astronomy.

While the latter may benefit most from an observatory at the highest elevations, the gains to be achieved by moving away from the South Pole for particle astronomy are less clear.

5 Conclusions

Antarctica offers unprecedented opportunities for the advancement of the science of astronomy. Several issues do remain to be answered from the site-testing programs under way, however, before we can properly assess the true level of the gains. In particular, we must determine at what height a telescope must be placed above the ice to benefit from superb seeing. It is clear, however, that at wavelengths beyond 10 μm the Plateau is the pre-eminent observatory location on the Earth, and the prospects for the near-IR are excellent.

To construct the observatory we desire presents a formidable challenge. Tremendous technological, logistical and political hurdles have to be overcome. However, as the CARA observatory at the South Pole now demonstrates (Harper 1994), it is now a practical reality and the obstacles can be surmounted. The CARA telescopes are still small instruments, but are bringing back their first scientific results. They have proved that, with sufficient determination, constructing a major observatory on the Antarctic Plateau is a realistic dream.

To achieve this dream we have to do more than just be good scientists, pursuing our subject in the belief that knowledge is good. We also have to recognise that we are explorers, venturing to the most remote part of our planet in order to explore the most distant regions of our Universe, that this quest requires the efforts of the best people from a wide spectrum of our society, and that the spirit of this quest must be brought back to the public. We need to explain to society the reason for the quest and the excitement of first-rate science. We need to demonstrate the many benefits to society that promoting such a program can bring. The development of a successful outreach program is thus an essential ingredient in the drive towards an international Antarctic observatory.

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