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Science Goals for Antarctic Infrared Telescopes

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Abstract: Over the past few years, site-testing at the South Pole has revealed conditions that are uniquely favourable for infrared astronomy. In particular, the exceptionally low sky brightness throughout the near- and mid-infrared leads to the possibility of a modest-sized telescope achieving comparable sensitivity to that of existing 8–10 metre class telescopes. An 8 metre Antarctic telescope, if constructed, would yield performance that would be unrivalled until the advent of the NGST. In this paper we review the scientific potential of infrared telescopes in Antarctica, and discuss their complementarity with existing 8–10 metre class telescopes and future proposed space telescopes. In particular, we discuss the role that a 2 metre class infrared telescope plays in future plans for the development of an observatory on the Antarctic plateau.

Keywords: Antarctica — site testing — telescopes — instrumentation: miscellaneous — infrared: general — stars: formation — galaxies: formation — planetary systems

1 Introduction

The Antarctic plateau provides unique conditions on the Earth for the conduct of observational astronomy. The air is thin, dry and cold and the weather stable, attributes all offering significant sensitivity gains over temperate latitude sites. These conditions are utterly different to those experienced at Antarctic coastal locations, where high winds and violent storms are not infrequent.

The plateau is over 3,000 m in elevation, rising to over 4,200 m at Dome A. An average year-round temperature of -50° C, falling to -90° C at times, vastly reduces the thermal background in the near-IR (see, for instance, Valenziano & Dall'Oglio (1999) for meteorological data from Dome C). A reduced particulate content of the atmosphere lowers the emissivity of the atmosphere in the mid-IR, reducing backgrounds still further. The precipitable water vapour content of the air is typically around 250 μm (Chamberlin, Lane & Stark, 1997) and can fall below 100 μm, opening up new windows in the infrared and sub-millimetre regimes to ground-based observation. The lack of diurnal temperature variations at the Pole 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, enabling science programs that could only be tackled elsewhere with significantly more expensive facilities. In particular, Antarctic telescopes will greatly facilitate the pursuit of 'formation studies', through new observations in the infrared to millimetre spectral range. These include the study of events such as the formation of galaxies, the birth of the first stars in them and their subsequent evolution, the life cycle of the interstellar medium and the formation of individual stars and planets in our Galaxy. The primary reasons for this are that the continuum emission from these events peaks in the IR and the dominant cooling lines occur across this spectral regime.

In the remainder of this article we outline the results of the site-testing programs that have quantified the site conditions at the South Pole, and then discuss five science programs which could exploit this unique environment: studies of the large scale environment of star forming complexes, complete determinations of the embedded stellar population within star forming regions, surveys for proto-galaxies, searches for gravitational lensing from stars and planetary systems towards the galactic centre, and interferometric imaging of proto-planetary clouds and Jovian planets towards nearby stars. We end by discussing the route through which such a science program could be developed, and the complementarity it has with international plans for future space observatories. We examine the relative gains of intermediate-scale (2 m class) and large (8 m class) Antarctic telescopes in comparison to existing temperate latitude facilities, and also consider the role that an infrared interferometer might play in future developments on the plateau. This paper furthers the discussion from the conference presentation of Burton, Storey & Ashley (2000).

2 Results from Site Testing

2.1 Infrared Sky Brightness

From the extensive site testing program undertaken at the South Pole the following characteristics of the infrared background have been determined:

- Sky background in the K–dark window (2.27–2.45 μm) as low as $\sim$100 μJy arcsec^{-2} (20–100 times less than at temperate sites) (Ashley et al. 1996; Nguyen et al. 1996).
- Sky background in the L–band (3–3.8 μm) $\sim$100 mJy arcsec^{-2} ($\sim$20 times less than at temperate sites) (Phillips et al. 1999).

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Table 1. Relative S/N Ratios and Sensitivities for Different Telescopes

Telescope	Mauna Kea 8 m Gemini		SSO 3.9 m AAT		Antarctic 2 m DMT		Antarctic 8 m		
Waveband	Wide field	Point source	Wide field	Point source	Wide field	Point source	Wide field	Point source	
K	3×10^{-3}		3×10^{-3}		1.5×10^{-4}		1.5×10^{-4}		Background
(2.15 μm vs	1.0	1.0	0.5	0.2	1.1	0.3	4.4	4.0	Relative S/N
2.37 μm)	21.5	23.1	20.5	21.3	21.2	21.0	22.8	24.1	Sensitivity
L	2		3		0.1		0.1		Background
(3.65 μm)	1.0	1.0	0.4	0.2	1.1	0.3	4.5	4.5	Relative S/N
	16.7	17.8	15.3	15.5	16.9	16.4	18.4	19.4	Sensitivity
N	200		1000		20		20		Background
(11.5 μm)	1.0	1.0	0.2	0.1	0.8	0.2	3.2	3.2	Relative S/N
	11.8	11.5	9.9	8.9	11.2	9.5	12.7	12.5	Sensitivity

Sky backgrounds (in Jy/sq. arcsecond), relative signal-to-noise ratios, and sensitivities in magnitudes (5σ, 1 hour) comparing 4 telescopes in K, L and N bands for both wide-field (per square arcsecond) and point-source (i.e. diffraction-limited) imaging. For full details see the text.

- Sky background in the N–band (8–14 μm) as low as $\sim$20 Jy arcsec^{-2} ($\sim$20 times less than at good temperate sites) (Chamberlain et al. 2000).

For background limited imaging of extended regions a 2 m telescope requires a 16-fold reduction in background if it is to achieve the same sensitivity as an 8 m temperate-latitude telescope. It has improved sensitivity for larger background reductions, or if the lower background is accompanied by superior atmospheric transmission.

This comparison is quantified further in Table 1, which shows the relative signal to noise ratios for performance limited by the sky background, obtained for observations using four different telescopes: an 8 m telescope on Mauna Kea (i.e. Gemini); a 4 m at Siding Spring Observatory in Australia (i.e. the Anglo Australian Telescope), a 2 m on the Antarctic plateau (i.e. the proposed Douglas Mawson Telescope), and an 8 m telescope in Antarctica. The comparison is for broad-band imaging at three representative wavelengths: K–band (2.2 μm), L–band (3.65 μm) and N–band (11.5 μm). (For K–band the performance of an Antarctic telescope at 2.37 μm is compared to that of a temperate-latitude telescope at 2.15 μm, where airglow emission dominates the background.) Two cases are shown: (i) wide-field imaging, used for extended objects, where the pixel size (in arcsec) is taken to be the same in each case, and (ii) point-source imaging, where diffraction limited performance is assumed to be achieved by each telescope. The S/N ratio is proportional to $(D\eta/\theta)S^{-0.5}$, where D is the diameter of the primary, θ is the spatial resolution, η is the atmospheric transmission and S is the sky background at that waveband. Performance comparisons have been normalised to the Mauna Kea telescope, all other factors being taken as equal.

Also shown in Table 1 are achievable sensitivities[1] in magnitudes, for a 5σ detection in 1 hour, taking into account telescope emission and system performance of the telescope + instrument + detector. By taking the same instrumental parameters at each site, this allows a direct comparison of the performance achievable as a result of the site conditions and telescope aperture. We note that for Siding Spring, in thermal wavebands, and in N–band at all sites, telescope emission is comparable to, or slightly greater than, the sky emission. The S/N relation above does not strictly hold in these cases and thus the sensitivities listed above (which have included telescope emission) are correspondingly slightly worse than the S/N numbers above would indicate. The S/N relation also does not hold for the comparison in the K–band, where the optimal observing wavelengths and bandpasses would be slightly different between Antarctic and temperate sites. Also listed in the table is the sky background in each waveband, for each site, in Jy/square arcsecond.

For wide-field imaging an Antarctic 2 m has similar sensitivity in the thermal infrared to that of an 8 m telescope on a good infrared site, such as Mauna Kea, but has potentially a much wider field-of-view (as well as the opportunity to devote substantial time allocations to specific projects). Both these telescopes have gains of 2–5 times over current 4 m class telescopes. If diffraction-limited imaging with an 8 m is achieved then these temperate-latitude telescopes are superior for point-source imaging. However, if an Antarctic 8 m were to be built it would be 3–5 times more sensitive than a temperate-latitude 8 m, for *all* types of observation.

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[1] Other assumptions made for these calculations include a system emissivity (telescope + instrument) of 3% (20% for Siding Spring), a detector quantum efficiency of 90%, system throughput (telescope + instrument) of 20%, dark current 1 e/s, read noise 10 e and well depth 10^6 electrons. Site temperatures were taken as 273 K, 288 K and 213 K for Mauna Kea, Siding Spring and Antarctica, respectively. For wide-field imaging, sensitivities are per square arcsecond. Bandpasses at K, L and N were taken as 0.3 μm (0.2 μm in Antarctica), 0.3 μm and 1.0 μm, respectively. For point-source imaging it is assumed that the diffraction limit is achieved, with fluxes summed over a 7 × 7 pixel box, with plate scale half the diffraction limit (in N–band, due to the high backgrounds, half this pixel size was taken, with 4 times as many pixels). In all cases an additional factor of $\sqrt{2}$ is included for measurement of an equivalent area sky field.

2.2 *Seeing*

The ice-level seeing at the South Pole is relatively poor (~1.5″). However the degradation occurs almost entirely in the lowest ~200 m of the atmosphere, with the free seeing above the boundary layer believed to be ~0.3″ (Marks et al. 1996; 1999). For a telescope at ice-level, adaptive optics will be able to remove much of the seeing. The correction of the boundary layer contribution will result in an isoplanatic angle of ~60″ (Marks 2001) at 5000Å, ~30 times greater than achievable on sites like Mauna Kea. This is possible because the seeing is caused by a narrow layer close to the ground, rather than having some components arising from a high-altitude jet stream. For infrared observations virtually all the sky will have a star brighter than $m_{\rm K} = 10$ within the isoplanatic patch, and therefore be suitable for adaptive optic correction. Because of the uniquely favourable conditions on the Antarctica plateau, multi-conjugate adaptive optics (MCAO, e.g. Rigaut, Ellerbroek & Flicher 2000), with its immense complexity, should be completely unnecessary.

On the summit of the high plateau, there is reason to believe that, based on measurements of the temperature inversion close to ice-level at several locations on the plateau (e.g. see Schwerdtfeger 1984), the boundary layer will be confined to an even lower altitude than at the Pole. The seeing within the boundary layer depends on the wind shear within the boundary layer and on fluctuations in the vertical temperature gradient (Marks 2001). Wind shear is minimised on the summit of the plateau where the slope of the ground is zero. A tower might be built to raise a telescope above the boundary layer on a high plateau site. However, even without a tower, the decreased height of the inversion layer improves the prospects for adaptive optics corrections still further, as it increases the isoplanatic angle. The AASTO program, which is currently site-testing high plateau locations (e.g. see Storey, Ashley & Burton 2000), is aimed at quantifying such issues.

2.3 *Model Calculations for Atmospheric Emission and Transmission*

In Figure 1 are shown measured sky spectra from the South Pole, from 2 to 14 μm, overlaid with a model fit using the atmospheric modelling program MODTRAN (see AFRL/VSBM). From the parameters to the fit a typical value of 164 μm for the precipitable water vapour, with an aerosol visibility of 100 km, was obtained (Hidas et al. 2000). This has permitted estimates to be made of the sky background and transparency for wavelengths not covered in the site testing programs. Figure 2 shows the model transmission calculated for these parameters. New windows for ground based astronomy are opened in the mid-IR between 20 and 50 μm, and even windows at 200 and 220 μm may be accessible.

3 Science Programs for an Antarctic Infrared Telescope

Having established that the Antarctic plateau provides the best conditions for infrared astronomy on the Earth, it is necessary to consider the demands of the site before determining what programs might best be pursued there. Clearly, constructing 8 m size telescopes in Antarctica is a formidable challenge (though easier than facing the same

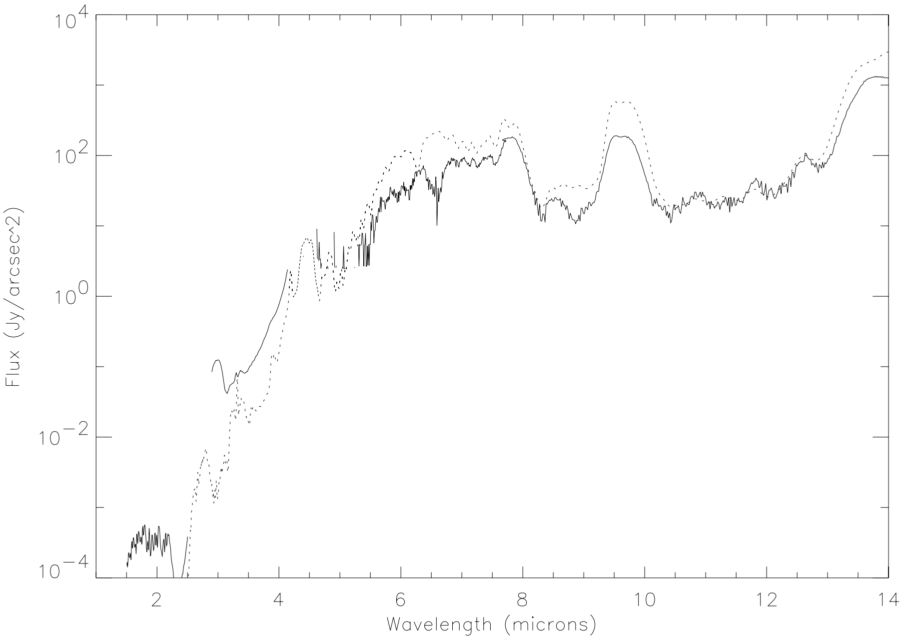

Figure 1 The measured near-IR sky spectrum (Phillips et al. 1999) (from 1.5–2.5 μm and 2.9–4.1 μm) and mid-IR sky spectrum (Chamberlain et al. 2000) (5–14 μm) at the South Pole. Over-plotted, with a dashed line, is a model spectrum, corresponding to 164 μm of precipitable H_2O, plus an aerosol visibility of 100 km. The model fails below 2.3 μm because of the neglect of airglow emission.

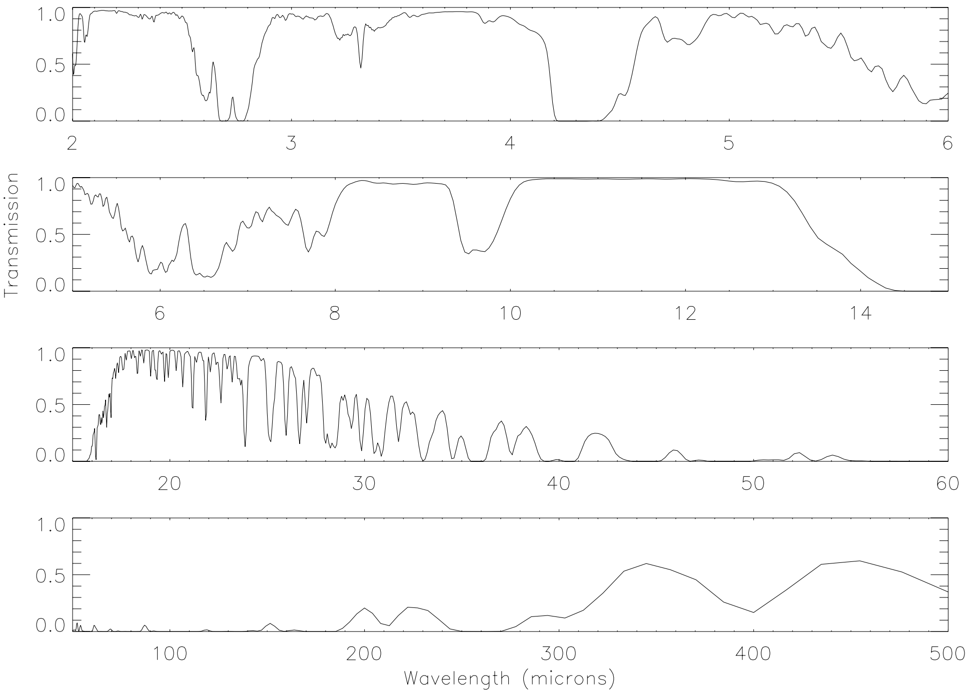

Figure 2 Model calculation of the atmospheric transmission at the South Pole across the thermal infrared, from 2–500 μm, corresponding to 164 μm of precipitable H_2O, plus an aerosol visibility of 100 km (see Hidas et al. 2000).

challenge in space), and the development of Antarctic astronomy will be through smaller facilities first. These will establish the necessary infrastructure, as well as provide test-beds for developing appropriate engineering technologies and operating practice, needed before large-scale facilities can be built. Indeed, through the operation of the SPIREX 60 cm telescope (Hereld, Rauscher & Pernic 1990) with the Abu infrared camera (Fowler et al. 1998), a prototype system has already demonstrated that infrared astronomers can successfully conduct significant scientific program from the South Pole over the Antarctic winter (Burton et al. 2000; Brooks et al. 2000).

In view of this necessary staged development program, consideration of proposed intermediate scale infrared facilities must pay regard to providing complementary functionality to the large (8 m) telescopes elsewhere, and to exploiting areas where the Antarctic facility clearly provides the most powerful tool for the job. Although Table 1 provides a direct comparison of sensitivity, it must be stressed that the costs of the facilities being compared differ enormously, with a 2 m Antarctic telescope projected to be over an order of magnitude cheaper than existing 8 m facilities. In addition, instrumentation for a small telescope is much less expensive than instrumentation for a large telescope, because the Area–Omega product, $A\Omega$, of the telescope propagates through the whole system. Giving regard to such costs, for subsequent developments beyond a 2 m facility it may prove practical to consider developing a suite of such telescopes, each designed for a specific project with a tailored instrument. These telescopes may also be linked together to form an interferometer. The particularly stable level of the sky fluxes in the mid-IR window may make this an attractive proposition.

There are three particular areas where an intermediate size (2 m class) Antarctic telescope can be superior to any other telescope on Earth:

- Wide-field thermal infrared imaging. The reduced sky background and improved transmission allow a 2 m size Antarctic facility to be at least as sensitive as a temperate 8 m class facility for imaging. Moreover, the Antarctic telescope can survey large areas of sky rapidly because of its wider field of view. The telescope, and the instrumentation, is vastly cheaper. Such a facility can complement the 8 m telescopes by finding the sources for the larger facility to study in depth with high resolution spectrometers.
- Continuous observation at 2.4 μm, where the sky background is lowest, on sources which are always above the horizon. In the thermal infrared continuous observation is possible year-round, and is not just confined to dark periods.
- Mid-IR interferometric imaging, exploiting both the greatly reduced background in the 8–14 μm range, and the improved sky stability. Such an interferometer may also provide a test-bed for the ambitious space-based projects which aim to detect Earth-like planets around other stars.

We see at least five science programs where these advantages will enable significant advances to be made in our knowledge of the universe:

- Near-IR studies of the environment of embedded star forming complexes, imaging the molecular, neutral and ionized gas through their infrared spectral features.

- Near- and mid-IR imaging of the embedded population of star forming regions, determining their complete population and in particular identifying the youngest members, and the incidence of disks around them.
- Near-IR surveys for proto-galaxies and the early stages of star formation in galaxy evolution.
- Microlensing studies of the stars towards the Galactic centre at 2.4 μm, utilising the low sky background and high surface density of stars, in particular to identify the incidence of secondary lensing from planetary systems.
- Mid-IR interferometric imaging of nearby star systems to search for proto-planetary disks, zodiacal dust clouds and Jovian-size planets around them.

We discuss these programs in more detail below. There are, of course, many other science programs which might be considered, for instance continuous observations of variable sources, removing aliasing problems which can occur if sampling is interrupted every 24 hours.

3.1 The Environment of Star Forming Complexes

While massive star formation is one of the most spectacular events in the Galaxy, paradoxically it is poorly understood. This is because of both the short timescales for the various stages of the process, and because of the many interacting phenomena for which it is hard to disentangle cause and effect. The environment of such star forming complexes, which dominate the southern Galactic plane, can be studied in the thermal infrared through the spectral features from ionized, neutral and molecular species that are present. HII and ultra-compact HII regions can be traced in the Brα 4.05 μm line, even when deeply embedded. Polycyclic Aromatic Hydrocarbons (PAHs), organic molecules that are fluoresced by far-UV radiation from the young stars and trace the edge of photodissociation regions, are visible through a spectral feature at 3.3 μm. They can be imaged at high spatial resolution, unlike other prime tracers of these regions, such as the far-IR [CII] 158 μm line. Excited H_2 emission, resulting from either shocks or UV-fluorescence, can be imaged in the $v = 1$–0 Q–branch lines at 2.4 μm, which are both stronger and suffer less extinction than the commonly used 1–0 S(1) line at 2.12 μm. Several solid state absorption features are also present, for instance the ice band at 3.1 μm.

As an example of the potential for this kind of study, Figure 3 shows an $18' \times 18'$ region of the star forming complex NGC 6334, observed with the SPIREX/Abu camera from the South Pole (Burton et al. 2000), in the PAH and Brα features, as well as in the L–band continuum at 3.5 μm. The pixel scale in this image is $0.5''$, and combining the $1.5''$ diffraction limit with 1 hour of unguided tracking, the typical resolution achieved was $\sim 3''$. Shells of photodissociated gas surround bubbles of ionized gas in which embedded, massive protostars reside. Despite the modest size of the SPIREX telescope (just 60 cm), these are the deepest images yet obtained at these wavelengths at this spatial resolution. The small aperture, however, also made possible the wide field of view with a similarly modest instrument.

3.2 Complete Population Census of Star Forming Regions

A key goal for studies of star formation is to undertake a complete population census of star forming clouds in order to determine the number and types of stars that form in them, and how this varies between different complexes. To do so requires observations in the thermal infrared ($\lambda > 3$ μm). These wavelengths not only penetrate to the depths of cloud cores, but also allow us to distinguish between the embedded population and background stars. In simple terms, young stellar objects are surrounded by warm (few hundred K) disks which emit strongly at $\lambda > 3$ μm, and thus are readily distinguished in infrared colour-colour diagrams (e.g. [1.65 μm–2.2 μm]/[2.2 μm–3.8 μm]) from reddened stars. Near-IR colour-colour diagrams (e.g. [1.25 μm–1.65 μm]/[1.65 μm–2.2 μm]), while relatively easy to construct because of the better sensitivities available, show only small IR excesses from the disks. These excesses are readily confused with reddening, and the surveys fail to identify the most deeply embedded sources.

The problem has been that at 3.8 μm sensitivities are typically 4–5 magnitudes worse than at 2.2 μm from most observing sites, thus limiting the work that has been done in this waveband. Needed are deep, wide-field surveys of comparable sensitivity to those conducted at 2.2 μm in order to determine the complete stellar membership of a star formation region. Such an opportunity is afforded by an Antarctic telescope through the greatly reduced thermal background at these wavelengths over temperate sites.

Brown dwarfs — cool sub-stellar objects — may also be identified through the deep absorption band at 3.4 μm, using narrow band filters on and off the band to determine 'colours'. Even cooler protostellar objects would be detectable in the mid-IR, for instance embedded sources within 'hot molecular cores' (e.g. Walsh et al. 2001), suspected of being the first stage in the process of massive star formation. Imaging through narrow band (1 μm wide) filters at 8.5, 10.5, and 12.5 μm, where the background is at a minimum in the mid-IR window, will allow determination of spectral colours of these cooler objects, and thus help to place their evolutionary state.

3.3 Protogalaxies and the First Star Formation

The star formation history of the Universe is being probed through deep pencil-beam surveys, of which the Hubble Deep Fields (HDF, Williams et al. 1996) are the most prominent examples. At the faint end of the samples the relative number of peculiar or disturbed galaxies rises dramatically, suggesting that processes to do with star formation (e.g. mergers, starbursts) are active in these sources. However, these galaxies also correspond to the most distant in the samples, with the highest redshift, and in the visible the rest frame being imaged is that of the far-UV. Here star formation is not at its most apparent, and dust absorption can be significant. An Antarctic telescope can search extraordinarily deeply in the 2.4 μm

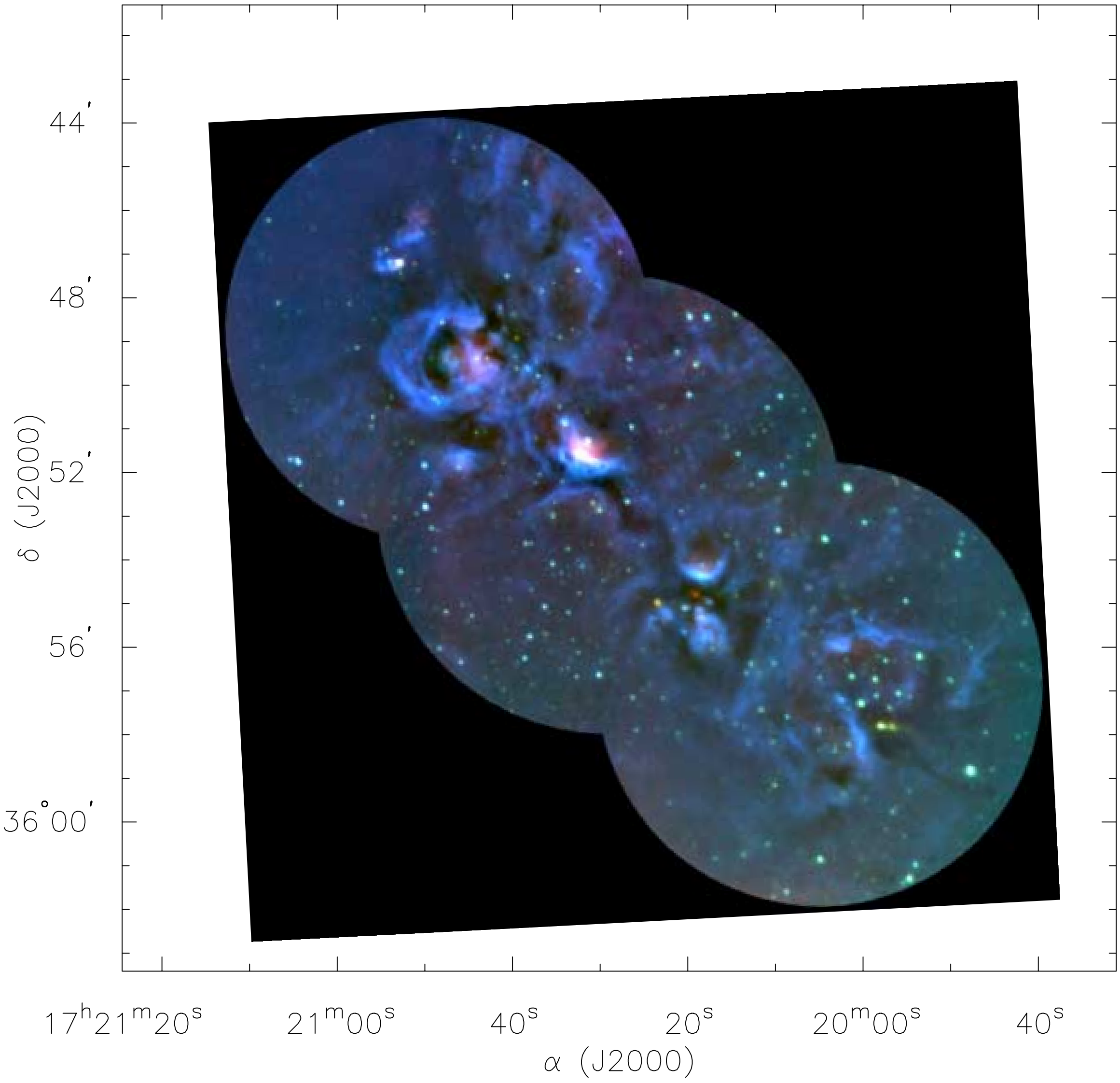

Figure 3 Infrared image of a 20′ section of the molecular ridge of NGC 6334, obtained with the 60 cm SPIREX/Abu telescope at the South Pole (from Burton et al. 2000). It shows the extensive PAH emission features at 3.3 μm arising from photodissociation regions surrounding five sites of massive star formation. The electronic version of this picture, obtainable from the journal website, is in 3 colours and shows the photodissociation region surrounding bubbles of ionized gas and embedded sources (blue: 3.3 μm PAH, green: 3.5 μm L–band, red: 4.05 μm Brα).

‘cosmological window’ to where, for example, the Hα line is red-shifted at $z = 3$. It could undertake the first high spatial resolution, wide-field surveys at 3.8 μm (L–band), where the visible light from $z = 5$ galaxies would be observed. While the magnitude limit of the HDF ($I \sim 28$ mags.) will remain far deeper than that which an Antarctic 2 m telescope will reach at 3.8 μm ($L \sim 19$ mags. in 24 hours), the colours of high–z galaxies are particularly red. For instance, an E/S0 galaxy at $z = 1.4$ has an unreddened colour of $V - L \sim 10$. Thus a galaxy with $V = 28$ and $L = 19$, barely detectable in the HDF, would be detectable with an Antarctic 2 m telescope in a day of integration. Moreoever, redder and presumably more interesting galaxies, not seen in the HDF, would also be detectable.

3.4 Microlensing towards the Galactic Centre

Gravitational microlensing occurs if the geodesic from a star to us passes sufficiently close to a massive, foreground object that its path is bent, or lensed, splitting the light into multiple images (Paczynski 1986). If there is a planet near one of the images an additional lensing effect can occur (Gould & Loeb 1992). The amplitude and light curve of such an event depends on the geometry of the orbit and mass of the planet, but typically will cause a perturbation on the microlensing light curve with a magnitude of a few percent for a few hours. If there is a planet present in the lensing system the probability of detecting a lensing signature from it is reasonably high if the sampling is frequent and the photometric accuracy high (Albrow et al. 1999). To maximize the possibility of finding such events a dedicated telescope should continuously image the same region of sky where the stellar density is high. Nowhere is this more so than towards the Galactic centre. Furthermore, the Galactic centre becomes readily detectable at 2.4 μm (extinction precludes observation at much shorter wavelengths), the very waveband where the sky background is lowest in Antarctica. Moreover, the Galactic centre is always visible from the South Pole. For example, a 2 m telescope equipped with only a single 1024^2 array with $0.6''$ pixels, mosaicing on a 4×4 grid, could image a $40' \times 40'$ region roughly every 20 minutes, achieving a sensitivity of ~17.5 mags at 2.4 μm. Towards the Galactic centre every pixel would contain at least one star! As calculated by Gould (1995), the optical depth for lensing is then unity, i.e. we would always expect to find at least one lensing event underway. Such a facility would be a powerful tool for exploring the incidence of planetary systems through the secondary lensing signature imposed on the microlensing light curve.

3.5 Interferometry of Proto-Stellar Disks and Jovian Planets

One of the great challenges facing astronomy, and the focus of major national programs such as NASA's Origins program, is the search for Earth-like planets. Several grand design projects have been envisaged towards this goal, for instance NASA's Terrestrial Planet Finder (Beichmann, Woolf, & Lindensmith 1999) and ESA's Darwin (Penny et al. 1998). These are space-based nulling interferometers, a suite of telescopes operating in mid-infrared where the unfavourable contrast between star and planet is least. Such facilities are not likely to be built before the middle of the 21st century, and many major technological issues remain to be addressed first. Several ground-based interferometers are now under construction, such as the Very Large Telescope, the Large Binocular Telescope and the Keck Telescopes, with the intermediate goal of imaging circumstellar disks, zodiacal dust and Jovian planets in nearby stellar systems. An Antarctic infrared interferometer (AII) is an obvious next step after a 2 m class telescope, exploiting the reduced background, the improved sky stability compared to temperate sites, and the constant airmass of sources. We envisage the AII as a suite of 2 m size telescopes, initially with just two connected interferometrically, but readily expanded for relatively low cost by the addition of more telescopes, to explore the optimal configuration for imaging other solar systems. It would provide the most powerful ground-based instrument for this purpose.

4 Complementarity with Other Facilities

A 2 m Antarctic infrared telescope will provide a wide-field imaging facility with complementary functionality to the new generation of ground-based 8 m telescopes and, further afield, to the next generation space facilities. These facilities are focussing on the thermal infrared as they probe deeper towards the 'dark ages' of the Universe, and to the formation of stars and planets — processes whose detectable radiation lies in this waveband. While such facilities will be able to take extraordinarily deep images in the infrared, these will necessarily be of a narrow field of view. However, there is no equivalent of the optical Schmidt survey telescopes with which to guide these telescopes to interesting sources. The only substantive surveys at arcsecond resolution in the infrared are the DENIS (Fouqué et al. 2000) and 2MASS (Jarret et al. 2000) surveys, which only extend to K–band (2.2 μm, for $K < 14$ mags.) in wavelength. A mid-IR survey in selected bands from 4–25 μm has been undertaken from space with the MSX satellite (Price et al. 1999), but with $18''$ angular resolution (and limited sensitivity at 4 μm). No facility has been built to conduct wide-field imaging in the 3–5 μm and 8–14 μm atmospheric windows at arcsecond resolution, a consequence of the limited sensitivities achieved in these bands from small telescopes at temperate sites. An Antarctic 2 m will be able to fill this gap, providing the necessary capability at a small fraction of the cost of 8 m and space facilities.

Such a telescope will therefore play a role in the scientific output not just of the new generation of ground-based 8 m telescopes such as Gemini, but also in maximising the productivity of proposed space facilities such as NGST. An Antarctic 2 m telescope can not only provide multi-wavelength wide-field surveys around sources of interest (to characterise, for example, the overall properties of a star forming cluster and the contamination from field stars), but also to select the obscured sources to be spectroscopically observed with NGST. The reddest sources in distant galaxy clusters could be identified and serve as a finding list for NGST in the search and characterisation of protogalaxies. Further afield, an Antarctic 2 m telescope also provides an entry into the field of mid-IR interferometry, the focus of grand-design space programs such as Terrestrial Planet Finder (TPF) and Darwin. The combination of reduced sky background and improved stability over temperate sites means that the Antarctic plateau provides the best terrestrial location for a mid-IR interferometer, and therefore a proving ground to test the technology required for a space-based nulling interferometer.

4.1 The Douglas Mawson Telescope

We have proposed a 2 m thermal infrared telescope for the Antarctic plateau, the *Douglas Mawson Telescope*. This is aimed at the science outlined in this paper, builds upon the scientific legacy and tradition that Australia has established in Antarctica, and provides a springboard for further involvement in major international facilities in the coming decades.

Douglas Mawson, the pioneering Australian Antarctic explorer and scientist, was also, in a sense, the first Antarctic astronomer. The first meteorite to be discovered in Antarctica was found on his expedition of 1912. Mawson realised both what it was, and the significance of the discovery for science. Mawson Station, Australia's first base on the Antarctic continent, was named after the explorer and established in 1954. The Douglas Mawson Telescope would establish Australia's first permanent facility on the high Antarctic plateau, where the bulk of the Australian Antarctic Territory lies.

The development of scientific facilities in Antarctica offers unique advantages for Australia. This arises from the proximity of the continent, the tradition of Antarctic science within Australia, and from the existence of the Australian Antarctic Territory. A new scientific station (Concordia Station) is now under construction at Dome C by France and Italy, a site which has possibly superior observing conditions to the Pole and which is within this Territory. Australia is in the process of establishing air links to the continent which will greatly facilitate access. The technology and capability to build and operate instruments in the harsh environment has been established over the past seven years through the site testing program at the South Pole, in particular by the AASTO (Automated Astrophysical Site Testing Observatory) program.

A 2 m telescope has been chosen as the first intermediate-scale infrared facility to be developed, for a number of reasons. The size is large enough to be scientifically competitive, yet it is small enough to be relatively inexpensive. Instruments will also be small and therefore more readily fundable. The project does not need to challenge the technological envelope to succeed. A 2 m telescope can be obtained commercially without needing to commission a specific design (although existing production models will need winterising). It can also be accommodated in a Hercules C130 aircraft for transportation. It will provide a versatile facility that can accomplish a wide-range of scientific projects. Finally, it can be readily expanded, through the provision of further 2 m telescopes, to accommodate future developments and changes in direction.

5 Conclusions

The Antarctic plateau provides a unique environment for infrared astronomy. Intermediate scale, relatively low cost telescopes could undertake many important scientific programs far more efficiently than other, larger facilities. Furthermore, these Antarctic telescopes would complement in-depth studies planned for the 8 m class ground-based telescopes and, eventually, NGST. In particular, wide-field thermal IR imaging from 2.4–30 μm would enable comprehensive studies of the star formation, both of the embedded population and the environment in which it occurs within our galaxy, and when it first appears in protogalaxies. Subsequent Antarctic facilities might progress to large-scale (8 m class) infrared telescopes, but it may prove to be more scientifically rewarding to construct a mid-IR interferometer from an array of 2 m class telescopes. An Antarctic infrared interferometer would provide a powerful facility for the study of nearby solar systems, as well as providing a test-bed for future grand-design space-based facilities that are being planned for in the search for another Earth-like planet.

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