What a really big Antarctic telescope could achieve

J. W. V. Storey, M. C. B. Ashley, M. G. Burton and J. S. Lawrence

School of Physics, University of New South Wales, Sydney NSW 2052, Australia
j.storey@unsw.edu.au
m.ashley@unsw.edu.au
m.burton@unsw.edu.au
jl@phys.unsw.edu.au

ABSTRACT. *Despite its diminutive size, the 60 cm SPIREX telescope at the South Pole produced a wealth of important publications from just two seasons of operation. What could a 2 m, 8 m, or even 25 m telescope achieve? With infrared sky backgrounds up to two orders of magnitude below those of the best temperate sites, plus cleaner, wider and more stable atmospheric windows, the Antarctic plateau provides a remarkable opportunity for the deployment of the next generation of ground-based telescopes. In addition to the obvious sensitivity gains, the atmospheric turbulence profile above Dome C has now been measured by two groups using independent techniques. The results are in excellent agreement and promise unrivalled spatial resolution across wide fields of view, and unbeatable levels of speckle suppression over small fields. Will the first direct detection of an earth-like exoplanet be achieved by an Antarctic telescope? If so, how big does this telescope need to be?*

RÉSUMÉ. *Malgré sa taille modeste, le télescope de 60cm SPIREX a produit au Pôle Sud de nombreuses publications importantes, en seulement deux saisons d'opération. Que peut achever un télescope de 2m, 8m ou même 25m? Avec un fond de ciel infra-rouge jusqu'à deux ordres de magnitude plus bas qu'aux sites tempères, et des fenêtres atmosphériques plus propres, larges et stables, le plateau Antarctique offre une opportunité formidable pour la prochaine génération de télescopes au sol. En plus de l'évident gain en sensibilité, le profile de turbulence atmosphérique a été mesuré indépendamment par deux équipes. Les résultats sont en parfaite accord et promettent une résolution angulaire exceptionnelle sur un large champ de vue et une suppression de speckle imbattable sur des petits champs. Est ce que la première détection de d'exoplanette terrienne sera achevée par un télescope en Antarctique. Si oui, quel dois être son diamètre?*

KEY WORDS: *optical, infrared, telescope, Antarctica, atmosphere, adaptive optics*

MOTS-CLÉS: *optique, infra-rouge, telescope, l'Antarctique, l'atmosphère, systeme optique adaptatif*

1. Introduction

Early predictions (Harper 1989; Gillingham 1991) that the high plateau of Antarctica would be an exceptionally good site for optical and infrared astronomy have now been largely confirmed. The extremely cold temperatures result in low infrared backgrounds, broader atmospheric windows and better transmission throughout the infrared (e.g., Walden *et al.,* 2005). In addition, above a thin, turbulent surface layer the seeing is the best on earth (Lawrence *et al.,* 2004; Agabi *et al.,* 2006), and the weak upper atmosphere turbulence implies substantial gains for interferometry, adaptive optics and precision photometry (Kenyon *et al.,* 2006). While there are some disadvantages that all high-latitude sites have in common—particularly in terms of diminished sky coverage and prolonged twilight—it appears that Antarctic plateau sites such as Dome C will deliver exceptionally favourable conditions even at visible wavelengths (Kenyon & Storey 2006).

Astronomical experiments have been in progress at the South Pole for over a decade. The French/Italian Concordia Station (Candidi & Lori 2003), which opened for year-round operation in 2005, is located on Dome C and is some 400 metres higher than South Pole—a site already known to be excellent for astronomy. Not only does the higher elevation of Dome C imply lower atmospheric opacity at all wavelengths, but the thinner surface layer means that it should be practical to place the telescope in stable air by means of a small tower.

At present the thickness of the surface layer is not known to good accuracy, but it appears likely from the site testing results to date that a telescope on a 30 metre high tower would enjoy seeing of less than 0.25 arcseconds (at 500 nm) for around 50% of the time. This result has now also emerged from modelling of the Antarctic atmosphere by (Swain & Gallee 2006), which shows a median surface layer contribution at Dome C of just 0.1 arcseconds at a 27 metre elevation.

Concordia Station is currently the best accessible astronomical site in Antarctica (Storey *et al.,* 2003; Fossat 2005). Over the next few years there will a major expansion of astronomical activity at Dome C and at other sites on the Antarctica plateau, as astronomers move to take advantage of the exceptional conditions offered (Storey 2005).

2. SPIREX—the South Pole InfraRed EXplorer

The pioneering SPIREX experiment (Hereld 1994; Fowler *et al.,* 1998) was designed to demonstrate the feasibility of conducting infrared astronomy from

Antarctica. Initially fitted with a 2 μm camera, SPIREX was substantially modified and fitted with an InSb array camera for the last two seasons of its operation. Although only 60 cm in diameter, SPIREX produced a wealth of important astronomical results, as reviewed by Rathborne and Burton (2006).

A similarly pioneering experiment, but for the mid-infrared, is planned for deployment to Dome C in 2007. IRAIT (International Robotic Antarctic Infrared Telescope) will have an 85 cm mirror and is designed to be housed in a modified shipping container, greatly simplifying the logistical and installation issues (Tosti *et al.*, 2004).

3. PILOT—the Pathfinder for an International Large Optical Telescope

An important next step is the deployment to the Antarctic plateau of an optical/IR telescope large enough to be competitive with the world's largest telescopes for a range of scientific problems. A telescope of roughly 2 metre diameter can achieve this at Dome C. Such a telescope should be capable of wide-field imaging at optical wavelengths with a highly stable point-spread function. In addition, by taking advantage of the dramatically lower backgrounds in the thermal infrared, sensitivities on resolved sources should be comparable to those of 8m-class telescopes in temperate locations.

PILOT is proposed as a versatile 2.4 m telescope to be deployed to one of the high plateau sites such as Dome C (Lawrence *et al.*, 2005). Fitted initially with a fast tip-tilt secondary mirror, PILOT would be capable of conducting scientific programs that range from observations of near-earth satellite debris to detection of counterparts to gamma-ray burst sources at cosmological distance. A detailed science case for PILOT has been prepared by an international study team of 27 authors (Burton *et al.*, 2005).

In addition to its scientific role, PILOT also serves as a pathfinder for a third generation of more specialised facilities. These might include an interferometer based on multiple 2 metre class telescopes, a large High Angular Resolution telescope, a dedicated wide-field infrared survey telescope, and a large sub-millimetre telescope.

PILOT would be placed on a 30 m high tower of similar design to the DOT on La Palma (Hammerschlag *et al.*, 2003). Installation of an adaptive secondary mirror would give PILOT an imaging performance at visible wavelengths unlikely to be matched by any other ground-based telescope. With a spatial resolution comparable to that of the Hubble Space Telescope but achieved over a much wider field, PILOT will be capable of tackling a broad range of cosmological problems better than any existing telescope.

4. LAPCAT—the Large Antarctic Plateau Clear-Aperture Telescope

To take maximum advantage of the exceptionally low infrared backgrounds and uniquely stable atmosphere, an off-axis telescope is required. Traditionally, such telescopes have been avoided by optical astronomers because of difficulties associated with mirror fabrication and optical alignment. However, plans are now well advanced for the Giant Magellan Telescope (GMT), to be built at Las Campanas in Chile (Johns *et al.,* 2004). GMT will use six off-axis 8.4 metre mirrors surrounding a seventh (concentric) mirror. LAPCAT (Storey *et al.,* 2006) is conceived as a large optical/IR telescope for the Antarctic plateau using a mirror identical to one of the offset segments of the GMT. In this way, LAPCAT can leverage off the mirror-fabrication technology, metrology and alignment procedures developed for the GMT.

With a completely unobscured f/2.1 primary mirror, LAPCAT can use a cryogenically-cooled Gregorian focal station to perform diffraction-limited imaging at 5 μm with only a single "warm" (in this case ~220K) reflecting surface. Taking advantage of the desirable properties of off-axis telescopes for high dynamic range imaging (Kuhn & Hawley 1999), LAPCAT will be able to make the most sensitive searches ever for hot Jupiter-mass planets within a few AU of their parent stars.

LAPCAT will also have unrivalled performance at wavelengths at least as short as 800 nm where, with adaptive optics, the diffraction-limited resolution of 20 mas should be achievable with Strehl ratios of greater than 60%. In addition to its science goals, LAPCAT also paves the way for even larger telescopes, by proving much of the GMT technology in an Antarctic environment.

5. Extremely Large Telescopes (ELTs) in Antarctica

Once LAPCAT has been successfully commissioned, it will be time to consider the development of the ultimate single-aperture ground-based optical/IR telescope—an Extremely Large Telescope in Antarctica (ELTA). One such proposal has already been put forward: the deployment of a second Giant Magellan Telescope to Dome C (Angel *et al.,* 2004). The benefits of weak atmospheric turbulence and low infrared backgrounds apply equally well to an ELT as they do to smaller telescopes, implying that an Antarctic telescope that approaches the practical engineering limits on size can never be seriously challenged by one at a temperate site. In fact, because of the very low surface wind speeds on the Antarctic plateau and the absence of seismic activity, larger telescopes might be constructed in Antarctica than would be practical to build elsewhere.

An ELTA promises to deliver some of mankind's most sought-after astronomical prizes, especially in areas where deep, wide-field imaging or high-contrast, high spatial resolution is required. An ELTA just a little larger than the GMT could image, and ultimately perform low-resolution spectroscopy on, rocky exoplanets within the habitable zones of nearby stars.

6. Conclusion

The gains in sensitivity, resolution and measurement precision offered by an Antarctic telescope are compelling. Despite a popular image of Antarctica as a harsh and forbidding continent, conditions on the high plateau are remarkably benign. Construction of a 2m-class optical/IR telescope for Dome C should be commenced as soon as possible, as the next step towards increasingly larger telescopes of unprecedented capability. Ultimately, the Antarctic plateau could host mankind's greatest ground-based optical/IR telescopes, able to deliver inspirational scientific outcomes including the study of new, habitable planets around other stars.

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