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Foreword

Astrophysics at Dome C

A report on papers presented at the
Third International Workshop on Astrophysics at
Dome C, Hobart, June 28–29, 2001

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This paper summarises presentations made at the Third International Workshop on Astrophysics at Dome C, held in Hobart, Tasmania, on 28–29 June 2001. It also includes sensitivity estimates for proposed Antarctic telescopes, as well as the parameter space such telescopes might cover if used for galaxy number count studies in the thermal IR.

1 Introduction

The thin, dry and cold air above the Antarctic plateau provides unique conditions for observational astronomy. Compared to otherwise excellent temperate-latitude sites, in Antarctica infrared sky fluxes are reduced, atmospheric windows are cleaner and sky noise fluctuations are lower. Astronomical observations have been regularly conducted from Antarctica for over two decades, mostly from the South Pole. Recently, Concordia Station has opened at Dome C, on one of the summits of the Antarctic plateau. The conditions here are expected to be superior than the South Pole for astronomy. This has generated interest in the scientific possibilities offered by the site. This paper is a report on presentations at a meeting to examine these, the 'Third International Workshop on Astrophysics at Dome C'. It was held at the Australian Antarctic Division, near Hobart, Tasmania, on 28–29 June 2001. The previous two meetings on this topic were were held in Casaccia, Italy on 3 April 2000 and in Nice, France on 9–10 November 2000. Further details of the program may be found on the conference web-page, at URL www.phys.unsw.edu.au/astro/domec/.

2 Stations

Following an opening speech by the **Hon. Guy Green**, Governor of Tasmania, the meeting started with a review of how science is conducted in Antarctica, by **Attilio Ferrari** (INA, Italy). International collaboration has always been a feature of science in Antarctica, especially following the International Geophysical Year programs there in 1956–57. Indeed, the experience of Antarctica is often held up as the ideal model to follow for international collaborative activities in other human endeavours.

The US program at the South Pole has dominated Antarctic astronomy till now. **Dennis Peacock** (Office of Polar Programs, NSF, USA) described how the US National Science Foundation organises science at the South Pole. For the past 15 year the astronomical program has been run under the auspices of CARA, the Center for Astrophysical Research in Antarctica. **Jeff Peterson** (CMU, USA), on behalf of **Bob Pernic** (U. Chicago, USA, who for many years has been CARA's operational manager at the South Pole), reviewed the experiences and lessons learned. 'Fifteen years of mistakes! The summer is easy, the winter is hard!' are memorable quotes. The key to success in Antarctica is in the prior preparation on the mainland, before deployment. Staging before installation and critical readiness reviews are essential. In addition, anything that can be done inside should be done inside! The construction of (heated) dedicated workshops and laboratory space at the Pole in the mid-1990's has been directly responsible for many of the successes of the program. So too, has the accumulated knowledge base of the organisation, including learning how to care for its people during deployment to and on 'The Ice'.

The construction of the French/Italian Concordia Station, at Dome C, has now broadened the focus for astronomers, away from just the South Pole. There are aspects of the Dome C site which are superior to the Pole. At 3200 m, while only 300 m higher than the South Pole, it is on one of the high points of the Antarctic plateau. The katabatic wind, which dominates the air flow at the Pole, is therefore absent. **Maurizio Candidi** (IFSI/CNR, Italy) presented an overview of the Concordia project. The station consists of two self-jacking towers, each with three floors. It is accessed by a combination of Twin Otter air support from Terra Nova Bay (5 hours, for people and light cargo) and overland traverse from Dumont Durville (10 days, for heavy cargo). Winter-over operation is scheduled to start in 2004.

3 Site Testing

As a result of the site testing program at the South Pole, there is growing confidence that the scientific potential of the Antarctic plateau can be utilised for large-scale astronomy projects. The experiments conducted there have not only quantified the site conditions, but they have served as technology demonstrators of the autonomous operation needed over an Antarctic winter. **Michael Ashley** (UNSW) presented a summary of the results from the Australian JACARA program (Joint Australian Centre for Astrophysical Research in Antarctica), started at the South Pole in 1994. This was initially predicated on the predictions of an extremely low-background window at 2.4 μm (the 'cosmological window', Harper 1989) and for 'super-seeing' (i.e. $\ll 1''$, Gillingham 1991). Neither prediction turned out to be quite true, but other, equally exciting opportunities became apparent. The 2.4 μm sky background, while still far lower than at any temperate-latitude site, was not as low as expected. The strong surface inversion layer was found to significantly degrade the seeing at ice-level. However, sky background reductions of about a factor of 20 were found right across the thermal-IR band, from 3 to 15 μm. In particular, the mid-IR sky flux was lower than expected, due to the different aerosols present in Antarctica compared to temperate sites. The seeing was found to originate almost entirely from the surface boundary layer, implying a wide isoplanatic angle, about 30 times larger than at good temperate sites. A secondary advantage, which stems from this, is the low scintillation noise, a limiting factor for measurements requiring high photometric precision.

Equally impressive are the gains in the sub-mm part of the spectrum. **Jeff Peterson** (CMU, USA), presented results from sub-mm sky measurements at the South Pole, and compared them to similar data from Mauna Kea and Chajnantor (the ALMA site, a 5000 m plateau in northern Chile). Average sub-mm sky opacities were found to be lower at the South Pole, but more significant are the frequent long periods where the sky noise is stable. Peterson speculated on the possibility of even drier conditions above Domes A and C.

Site testing at the South Pole continues. **Tony Travouillon** (UNSW) presented data obtained over winter from an acoustic radar. This was used to measure the micro-turbulence in the boundary layer, the primary cause of the seeing. It furthered the pioneering work of **Rodney Marks**[1] (UNSW) (Marks et al. 1996, 1999, Marks 2002), who undertook microthermal measurements from a mast and from a balloon for his PhD thesis. A clear signal of a boundary layer was seen in Travouillon's data over most of the winter, averaging 300 m height. In the coldest month, July, it fell to ~200 m. Large isoplanatic angles and coherence times were also inferred. **Jon Lawrence** (UNSW) discussed near- and mid-IR sky flux measurements, including those made with a low-powered, autonomous instrument operating at 2.4 μm, with the detector and filter cooled to cryogenic temperatures.

[1]Rodney Marks died tragically at the South Pole in May 2000, while wintering there for the second time.

Site testing has now started at Dome C, though the few results presented from there are still preliminary and derive from summer operation only. **Paolo Calisse** (UNSW) presented the first data from a sub-mm experiment, deployed during December 2000. He also gave a presentation, on behalf of **M. Nordino** (CNR, Italy) on the characterisation of surface turbulence at the site. **Eric Fossat** (U. Nice, France) discussed the possibilities for extremely low scintillation noise at the site, and the design of a 'generalised seeing monitor' to quantify the seeing conditions. **Giorgio Dall'Oglio** (U. Roma, Italy) described the results of sky noise measurements made at mm-wavelengths (see the paper by **Pascucci** in this volume).

4 Science

The first plans for telescopes in Antarctica concentrated on the prospects for imaging in the near-IR, spectroscopy in the sub-mm, and CMBR anisotropy measurements. As site data has accumulated, it has become clear that the Antarctic plateau offers unique opportunities for a wider and more varied range of investigations than just these.

The success of the SPIREX/Abu project, a 60 cm telescope equipped with a 1–5 μm 1024 $\times$ 1024 camera, has shown what the potential for thermal IR imaging is. The deepest, high spatial resolution images ever obtained at 3.6 μm, to L = 19, of the 30 Doradus star forming region in the Large Magellanic Clouds, were acquired with SPIREX/Abu. **Jill Rathborne** (UNSW) presented SPIREX/Abu data of the Carina and NGC 6334 galactic star forming regions. They reveal the galactic ecology — the interactions of the stars and the gas, seen through H_2, PAH and H Brα lines emitted from 2.4 to 4.1 μm.

Other speakers also discussed the prospects for IR surveys from Antarctica. **Michael Burton** (UNSW) and **Paolo Persi** (IAS/CNR, Italy) examined how this would impact on studies of star formation. In addition to following the interactions between the ionized, neutral and molecular gas through spectral lines (as done with SPIREX/Abu), the thermal IR will reveal the most embedded sources (particularly at 10 μm), and can be used to quantify the incidence of disks (for which the IR excess at 3.6 μm is considerably greater than at 2.4 μm).

Massimo Stiavelli (STSCI, USA) discussed the prospects for contributing to the study of protogalaxies, especially in light of the imminent launch of SIRTF and plans for the NGST. To usefully complement the deep, but narrow field surveys that will be conducted with these facilities, he estimated that a wide-field survey should aim to reach 1 mJy at 3.6 μm and 10 mJy at 11.5 μm, over 1000 square degree fields.

Figure 1 illustrates the parameter space that could be studied using an Antarctic telescope operating at these wavelengths, adapted from Stiavelli's presentation. Shown as a function of flux reached is the area coverage that could be expected from surveys that last for a month, and a year, respectively. The calculations were made for a 2 m and a 6.5 m telescope, each with either a $10'$ or a

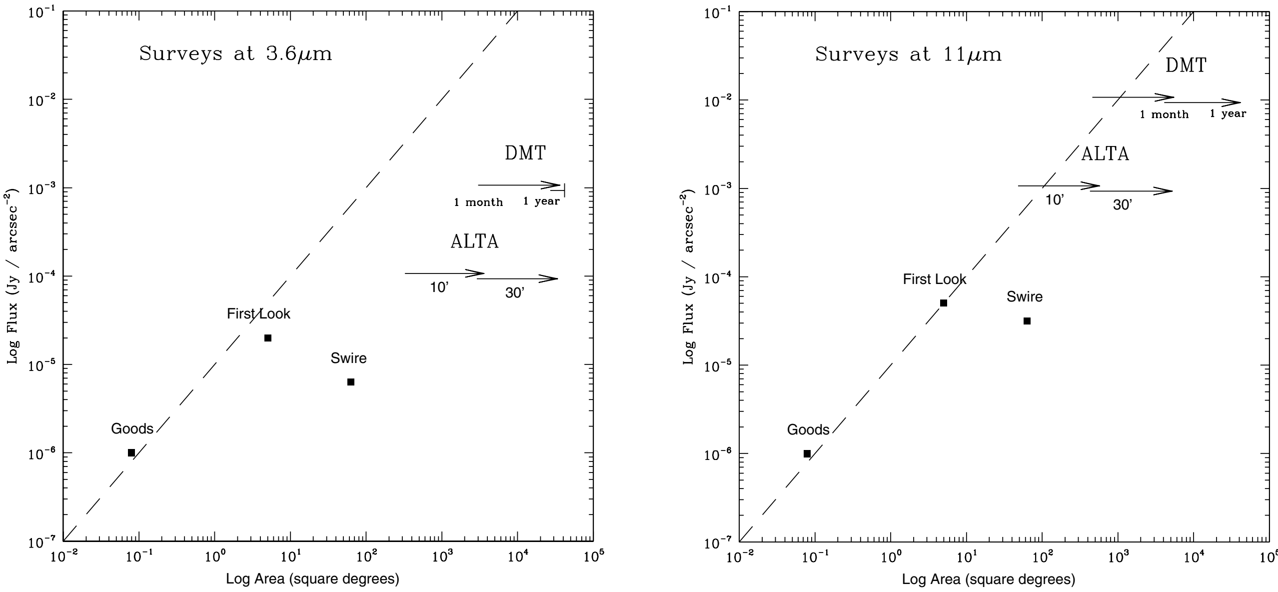

Figure 1 Parameter space for galaxy number counts studies that could be explored by Antarctic telescopes working at 3.6 μm and 11 μm. Plotted, as a function of the achievable sensitivity (in Jy/arcsec^{-2}), is the sky coverage in square degrees that could be surveyed by the 2 m DMT and the 6.5 m ALTA. For each telescope, the arrow shows the area covered if the field of view was 10′ (left) and 30′ (right). The length of the arrow shows the range in areal coverage if the observing time varies from 1 month to 1 year (with a 33% assumed observing efficiency). The dashed line shows the relation for equivalent surveys (i.e. total number of sources detected) if the number of sources were inversely proportional to their flux. Also shown are the anticipated coverage/flux limit of three surveys planned for the SIRTF space telescope; 'Goods', 'First Look' and 'Swire'. Note that the DMT survey at 3.6 μm with a 30′ FOV is truncated when complete sky coverage is reached (which requires just 1.5 months).

30′ field of view. The dashed line shows the relation that would be followed by equivalent surveys (in the number of sources found), if the source number density is inversely proportional to their flux (i.e. $N \propto 1/S$). As is apparent, an Antarctic telescope could contribute significantly to this field, readily surveying areas of 1000 square degrees to flux limits that would provide useful constraints on the source number density. The surveys would be particularly valuable at 3.6 μm, where they would reach well below the $N \propto 1/S$ relation.

The dry air above Antarctica opens atmospheric windows in the sub-mm. **Maria Hunt** (UNSW) discussed molecular lines that could be observed as probes of dense cores, during early stages of star formation.

The stable background at mm wavelengths offers significant gains for CMBR measurements. There is a long history in this area at the South Pole, and for balloon-launched experiment into the circumpolar air flow. For instance, the cosmological parameters obtained from the BOOMERANG (de Bernardis et al. 2000) and DASI experiments (Pryke et al. 2001) are among the most important to be obtained so far in this field. At this meeting **Giorgio Sironi** (U. Milano–Bicocca, Italy; see also the paper in this volume) discussed the prospects for polarization measurements of the CMBR from Dome C, with the possibility of determining whether re-ionization occurred in the early history of the Universe.

Perhaps the most exciting new concept to be aired at the meeting came in the presentation by **Jamie Lloyd** (UC Berkeley, USA; see also this volume). He described how the Antarctic plateau offers outstanding prospects for the conduct of astrometric interferometry. The spatial measurement error made during the determination of the position of a source is proportional to $\int h^2 C_N^2(h)dh$, where $C_N^2(h)$ is the refractive index structure function, the contribution to the seeing due to microthermal fluctuations at a height h. On the Antarctic plateau the contributions to the error are confined within the narrow surface layer, rather than arising from a high-altitude jet stream. The greatly reduced h^2 factor in the error term then provides enormous gains over temperate latitude sites, equivalent to a two order of magnitude improvement in speed. Scientific applications include the facilitation of exo-planet detections, galactic dynamics and direct parallax measurements to the LMC.

5 Telescopes

Three infrared telescopes have been proposed for the Antarctic plateau, building on the success of the SPIREX prototype. **Michael Burton** (UNSW) and **John Storey** (UNSW) both talked about the Douglas Mawson Telescope (DMT), an Australian proposal for a 2 m class telescope to be located at Dome C. It would undertake wide-field imaging in the thermal-IR, from 3 to 30 μm, studying both star and galaxy formation. It is also seen as a pre-cursor to a 6.5 m telescope, ALTA ('A Large Telescope in Antarctica'), which would be the most sensitive ground-based IR telescope available. **Peter Gillingham** (AAO; see also this volume) discussed design issues relating to the DMT for both the telescope and camera.

Table 1. Sensitivity comparison for three telescopes

Telescope waveband	Mauna Kea 8 m Gemini	Antarctic 2 m DMT	Antarctic 6.5 m ALTA
K (2.15 μm vs 2.37 μm)	1.5×10^{-6}	2.1×10^{-6}	5.8×10^{-7}
L (3.65 μm)	5.6×10^{-5}	4.7×10^{-5}	1.5×10^{-5}
N (11.5 μm)	7.1×10^{-4}	1.2×10^{-3}	3.7×10^{-4}

Sensitivities in Janskies per square arcsecond (5σ, 1 hour) comparing 3 telescopes in K, L and N bands for wide-field imaging. In the K-band, the sensitivities are for observations at 2.15 μm from a temperate site, and at 2.37 μm from Antarctica.

As an illustration of the performance capability of possible Antarctic IR telescopes, shown in Table 1 are the calculated sensitivities for wide-field imaging (see Burton, Storey & Ashley 2001 for further details about the assumptions made for these calculations). Three telescopes are compared: an 8 m on Mauna Kea (e.g. Gemini), a 2 m in Antarctica (e.g. the DMT) and a 6.5 m telescope in Antarctica (e.g. ALTA). Fluxes, in Janskies per square arcsecond, are given for a 5σ detection in 1 hour, taking into account telescope emission and system performance of the telescope + instrument + detector. It is clear than an Antarctic 2 m telescope would have similar performance to a temperate-latitude 8 m telescope, but could operate with a considerably wider field-of-view.

Within Italy, construction of the IRAIT telescope is underway. This will be an 80 cm telescope at Dome C, working in the mid-IR from 8 to 14 μm. It will have an imaging camera, equipped with a 128×128 SiAs detector array, and have $10'$ field of view. **M. Busso** (Torino, Italy) discussed the telescope and the plans for its deployment. **M. Ferrari Toniolo** (IAS/CNR, Italy) discussed design constraints on its instrumentation. He also discussed the design requirements to build a large infrared telescope in Antarctica, in particular a 6 m class drift-scan survey telescope which might be deployed to Dome C.

US plans for infrared facilities centre around the AIRO telescope, a 2 m-class telescope for the South Pole. It will work in the 2–5 μm wavelength range, and be focussed on the study of star formation in the galaxy and in the LMC. **Jim Jackson** (Boston U., USA) discussed the design and deployment plans.

There is also interest in sub-mm instrumentation for Antarctica, initially to be placed on IR telescopes, but later to be used with dedicated sub-mm facilities. **E. Battistelli** (U. Milano–Bicocca, Italy) and **M. Zannoni** (U. Milano–Bicocca, Italy) both discussed MASTER, a triple heterodyne receiver for sub-mm operation. **Lucio Piccirillo** (U. Cardiff, UK; see also this volume) also discussed design issues for a millimetre wave bolometric interferometer for Dome C, involving 3 telescopes linked over a 4 m baseline.

6 Other Opportunities

The scientific opportunities for the Antarctic plateau are not limited to astronomy in the infrared to millimetre wavebands. There are other areas of astronomy that will benefit from the site, as well as other fields in the physical sciences.

P. Moretti (Capodimonte, Italy) discussed the prospects for a solar observatory at Dome C, with a view towards high spatial resolution measurements over long time periods. A 40 cm telescope is planned to determine the quality of the solar seeing (i.e. the seeing in the day-time towards the Sun), in order to assess the potential for such a project.

Marc Duldig (Antarctic Division) discussed the prospects for cosmic ray experiments from Dome C, in particular the utility of a neutron monitor and muon telescope to fill in gaps in coverage of the worldwide monitor network.

Gary Burns (Antarctic Division) discussed the possibility of making measurements from Dome C of the current in the geo-electric circuit. This is a current flowing between the ionosphere and the ground, maintained by global thunderstorm activity. It is of order 3 pA/m^2. Measurement of it is generally hindered by local meteorological activity. It would be facilitated from sites at high altitude, with clear skies and low wind speeds. Dome C appears to be an eminently suitable site for this.

In addition, the chief scientist for the Australian Antarctic program, **Michael Stoddart** (Antarctic Division) outlined Australia's science program in Antarctica, and how these related to the Australian government's goals for the continent.

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