SPS2

Astronomy in Antarctica

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The Potential for Astronomy in Antarctica

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Abstract. The motivation for holding Special Session 2 at the 25^{th} IAU GA is described, together with an outline of the rational for pursuing astronomy in Antarctica.

The IAU General Assembly has provided a focal point for discussions on progress of Antarctic astronomy. In the 1991 GA in Buenos Aires a working group on the subject was established, and a resolution passed encouraging its development. At the 1994 GA in Den Haag, CARA, the US Center for Astrophysical Research in Antarctica, had just established itself at the South Pole, and talks focused on the potential of that site. By the 1997 GA in Kyoto, several facilities were in operation and their first results were reported. There was no specific Antarctic Astronomy meeting during the 2000 GA, but by time of the Sydney GA in 2003 several ice-breaking results had been achieved, particularly in measurements of the CMBR and with regards to neutrino detection, together with front-page coverage in journals as esteemed as Nature and the New York Times. Moreover, a new base at the high plateau site of Dome C was nearing completion, Concordia Station, with the first indications of the site's quite superb quality. The 25^{th} IAU GA therefore saw the opportunity for an more in-depth discussion on the opportunities offered by Antarctica. Special Session 2 of the GA on the 19^{th} of July was a meeting to discuss the current status of Antarctic astronomy. The next day at Taronga Zoo, overlooking Sydney Harbor, was held a meeting on 'Visions for Antarctic astronomy'—a blue-sky, free-wheeling discussion limited only by the imagination on what might be possible in Antarctica. In addition, a live video-link up with the astronomers at the South Pole station was held during the lunch break of SPS2, only slightly marred by the sporadic video signal from Pole. However the audio signal came in well, as did the video to Pole, so the Polies saw us and spoke to a power point presentation they had prepared. A fascinating exchange ensued. The papers for these two meetings are presented in this issue of Highlights of Astronomy. The full programs can be found on the meeting web site, www.phys.unsw.edu.au/sps2, which also includes many of the presentations.

For several years it has been clear that the high, dry and cold conditions of the Antarctic plateau provided superb conditions for a wide range of astronomy from infrared to microwave wavelengths. Precipitable water vapor columns falling below 250μm H_2O open new windows in the IR and sub-mm. Temperatures falling as low as $-80°$ C reduce sky backgrounds by factors of 10–100 times between 2.3 and 30μm. Less well known has been the low level of aerosols across the continent, reducing sky emissivities in the IR. The high geomagnetic latitudes has been put to good use for many years for cosmic ray detection through the lower energy particles accessible. The vast quantities of pure ice has been employed to build downward pointing neutrino detectors, with large collecting volumes and minimal levels of background contamination.

A decades experience of operating complex facilities at the South Pole has shown that operation on the plateau was quite feasible. It was readily accessible by aircraft. Conditions were generally calm, and there were never any gales. Working wasn't actually that hard, once one had adequately prepared for the conditions and designed experiments appropriately. And there were no Polar Bears or other distractions to worry about!

Two other facets of the Antarctic plateau were, however, only just becoming apparent by the time of the Sydney GA. The first was the incredible stability of the air column above the summits of the plateau. As the IAU GA was taking place, the first season of winter time measurements from Dome C was also occurring, made from the completely autonomous AASTINO laboratory. Thanks to the Iridium satellite communications system their results were available at the GA, suggesting that the skies were clear for nearly all the time and that the micro-turbulence in the boundary layer was much less than at South Pole. While further data is still required of the entire air column, the indications are that the isoplanatic angle will be well over an order of magnitude greater than at temperate latitude sites, and scintillation noise correspondingly reduced. The conditions thus appear extraordinarily favorable for adaptive optics correction. The second 'new' facet about the plateau was that it was tectonically stable. While this had in fact been known previously, the implications this has for the construction of the next generation of extremely large optical telescopes were only just becoming apparent.

With the quantification of the site qualities of the Antarctic plateau becoming pinned down, clear areas where the conditions provide particular niches for observational astronomy have emerged, for instance:

- The imaging of cosmic sources of neutrino emission.
- Precision measurements of the cosmic microwave background, including its power spectrum, polarization and the SZ–effect.
- Wide-field thermal infrared imaging, from 3 to 30μm, to uncover all sites of star formation across the Galaxy and the LMC.
- Continuous observation of objects, particularly in the dark 'cosmological' window at 2.4μm.
- Precision photometry, for instance for measurement of planetary transits of stars or stellar seismology.
- Mid-infrared photometry, for instance applied to the detection of planetary systems.
- Astrometric interferometry, with micro-arcsecond precision, with the capability of measuring three dimensional motions across the Galaxy.

In the following pages are papers on Antarctic astronomy which outline many of these results and developments.

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Particle Astronomy from Antarctica

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Abstract. A brief review of astroparticle activities in Antarctica is presented including balloon cosmic rays detectors and use of the clear ice sheet for large neutrino telescopes.

1. Introduction

Despite difficult logistics and harsh surroundings, Antarctica offers some unique opportunities as a platform for particle astronomy. The huge ice sheet is an excellent medium for large Cherenkov detectors for cosmic neutrinos. A particle detector has 24 hours coverage of astronomical objects, the magnetic cut-off for charged cosmic rays is very low, the unique wind conditions at high altitudes can be used for long duration balloon flights. The combination of air shower detectors for cosmic rays on the surface above a large neutrino telescope is not possible anywhere else.

2. High energy Cosmic ray detectors in Antarctica

The high energy cosmic rays bombarding the atmosphere are still a mystery 90 years after their discovery. Finding the sources of the cosmic rays is one of the main goals in particle astronomy. The chemical composition of the particles is important information about the sources of the cosmic rays. Since the cosmic ray particles will interact high up in the atmosphere it is necessary to put the detectors at high altitudes or in space in order to directly identify the incoming particles. The flux of particles is steeply falling and at 10^{15} eV it is only one particle per m^2 per year. The energy range around 10^{15} eV is specially interesting since the slope of the spectrum is steepening at a few times 10^{15} eV (the so-called 'knee'). Several cosmic ray experiments are launching balloons at the McMurdo station in Antarctica to an altitude of 35 km where only about 5-10 g/cm^2 of the atmosphere remains. The balloons travel with the wind in a circular path and return to McMurdo after 15-20 days. It is possible to make multiple turns allowing even longer exposure times. These experiments are able to directly identify the chemical composition of the incoming cosmic ray particles: ATIC (sensitive to H–Fe at $10^{10}-10^{14}$ eV), CREAM (H–Fe, $10^{12}-5\cdot10^{15}$ eV), TIGER (Fe–Zr, $10^{8}-10^{10}$ eV) and TRACER (O–Fe, -10^{14} eV). The sensitive area is, however, only a few square metres which limits the sensitivity above energies of 10^{15} eV. For higher cosmic ray energies large surface based air shower detectors are used. At the South Pole the SPASE-II telescope has been running for several years in coincidence with the AMANDA neutrino telescope (see below). The neutrino telescope is measuring the muon flux in the cosmic ray shower while the SPASE telescope measures the electron component in the shower. Knowing both the electron and muon components in the shower gives information about the chemical component of the primary cosmic ray particle. A recent review of cosmic ray balloon experiments can be found in Wefel (2003).

3. Neutrino telescopes in Antarctica

The worlds largest neutrino telescope, AMANDA, is situated 1500 m to 2000 m deep in the ice sheet at the Amundsen-Scott base at the South Pole and is searching for high energy neutrinos from cosmic sources. The neutrinos will point back to the source without being deflected by the magnetic field in space. The telescope consists of 677 optical sensors deployed in 19 strings and was completed in February 2000. The optical sensors are recording the Cherenkov light emitted from neutrino induced interactions in the ice. The ice is very transparent to optical light at large depths. The angular resolution for muon neutrinos is in the order of a few degrees. About three atmospheric neutrinos are observed per day. The main goals are to search for the highest energy cosmic ray sources and for neutrinos from dark matter annihilation in the center of the Earth and the Sun. The most sensitive limits so far for cosmic neutrino sources, diffuse neutrino flux, neutrinos from GRBs etc have been published by AMANDA. See review talk by Köpke (2003) at ICRC 2003.

Despite the large size of AMANDA it might not be enough to detect the cosmic neutrinos. The one cubic kilometer neutrino telescope IceCube will start to be constructed at the same site as AMANDA in 2004/2005 and it is expected to be completed in 2009. The IceCube telescope will consist of 4800 optical modules deployed in 80 strings at depths between 1400 m and 2400 m. On the surface above IceCube an air shower telescope, IceTop will be constructed. The IceCube strings will take data in coincidence with the AMANDA telescope allowing an increased sensitivity for cosmic neutrinos already from the beginning of the construction.

The possibility to use radio waves generated by high energy neutrino interactions in the ice have been investigated in the RICE experiment at the South Pole. The transmission of radio waves in ice is better than for optical light allowing larger spacing between sensors. The energy threshold is, however, higher for radio waves (>10 PeV). An experiment using both the large ice sheet of Antarctica and the balloon facilities in Antarctica is ANITA which in 2006 will search for very short radio pulses generated by high energy neutrinos in the ice sheet. The observable area is in the order of a million km^2 .

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The 23 November 2003 Total Solar Eclipse in Antarctica

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Abstract. Totality at the eclipse of 23 November 2003 will cross land only on Antarctica. Details of the path and contact information for safe observation are provided.

The total solar eclipse of 23 November 2003 will be visible only from Antarctica and the nearby ocean. The path of totality extends from Mirny at 93 degrees E to the Maitri Novolazarevskaya base at 12 degrees E. Totality lasts from 1 minute 54 seconds at Mirny with the Sun at an altitude of 14 degrees; to a maximum of 1 minute 57 seconds at greatest eclipse, halfway in toward Vostok, with the Sun at an altitude of 18 degrees; to 1 minute 20 seconds with the sun 2 degrees above the horizon where the path leaves the coast near Maitri. The rest of Antarctica will have only a partial eclipse, with the Sun's diameter 77% covered at McMurdo and 65% covered at the tip near South America. An ice-breaker passenger ship is planning a 28-day voyage and airplanes are being arranged for observation, including single-day overflights leaving from Melbourne, Australia, and from Punta Arenas, Chile. Scientific observations will include electronic imaging of the corona to compare with simultaneous space observations of the Sun. Links to maps and other items of coordination can be found at www.eclipses.info and www.totalsolareclipse.net, the sites of the IAU Program Group on Public Education at the Time of Eclipses and of the IAU Working Group on Eclipses, respectively. The NASA site with maps and other information is at sunearth.gsfc.nasa.gov/TSE2003/TSE2003.html. Special filters must be used to reduce the solar disk to a safe intensity during the partial phases; only during totality can one look safely without filters.

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Site Testing at Dome C—Cloud Statistics from the ICECAM Experiment

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Abstract. Analysis of sky images obtained from an automated experiment at Dome C, Antarctica, at 2-hourly intervals from February to November 2001 show cloud-free conditions 74% of the time. This augurs well for the prospects of future astronomical observatories at this site.

1. Introduction

Dome C on the Antarctic plateau is almost certainly one of the best astronomical observing sites on earth. Most of its characteristics are expected to be similar to or better than those of South Pole Station. However, the fraction of cloud-free skies during winter-time has been an entirely unknown quantity. We set out to measure this fraction in order to facilitate planning for a future observatory.

Determining the amount of cloud cover over an uninhabited site on the Antarctic plateau during winter time, when the sun is below the horizon for much of the time, is a surprisingly difficult problem. The current generation of earth-orbiting satellites cannot resolve the difference between cloud and ice.

Our solution was to build ICECAM, a small, low-powered, CCD camera system that can take images of the sky every two hours for a year and store them on a solid-state disk. ICECAM is completely automated, working at air temperatures down to −80°C, and is now in its third year of obtaining data from Dome C.

2. Instrumental design and challenges

Until Concordia Station at Dome C opens for winter-over operation, there is no electrical power or heating available at Dome C for the nine months beginning in February each year. Solar power cannot be used during the long dark winter, and wind power is also problematic given the low-to-zero wind speeds on the plateau for much of the year. With temperatures down to −80°C during winter, many off-the-shelf electrical and mechanical devices tend to fail.

Fortunately, ice is an excellent insulator, so that a few meters below the surface the temperature remains stable at the yearly average of about −57°C. This is sufficiently warm for many electronic devices to function, and for lithium thionyl chloride batteries to have a reasonable capacity.

To provide an unambiguous indication of cloud cover in a form that would convince a skeptic, we decided to use a CCD camera to take images of the sky. The camera, a low light level Watec 902-HS, was found to operate reliably at −80°C (although it was only rated to −10°C). We used a lens with a 30 degree field-of-view. The images from the camera were processed by a PC/104 computer (equivalent to a 66MHz Intel 80486, and drawing only a few watts) running MS-DOS (chosen for its small memory footprint and fast boot time), and stored on a 256MB CompactFlash disk (thereby eliminating any moving parts in the computer). There is sufficient space on the disk to store a year's worth of data, with images being taken every two hours. The entire system can be powered for a year from 5 kilograms of lithium thionyl chloride batteries. 99.6% of the time ICECAM is idle and using only a few milliwatts of electricity to operate a timer. For 30 seconds every two hours, the computer is turned on, ten images are acquired, averaged, compressed and written to the CompactFlash disk, and an ARGOS transmitter is programmed to send 32 bytes of status information to the ARGOS satellite network. The total amount of energy used during this two-hour cycle is 200J, about the same as used by a person to go up one step.

The ICECAM computer and ARGOS transmitter reside in a "crypt" some 7m below the ice surface, in order to take advantage of the warmer temperatures there. The CCD camera was mounted on a pole 3m above the ice.

At the end of each year, the CompactFlash disk is retrieved for analysis, and the lithium thionyl chloride batteries are replaced. Several years of data will be required for good statistics.

3. Results

During the first year of operation a blown fuse after three days of operation halted all ARGOS transmissions from ICECAM during 2001. We were therefore pleasantly surprised to find that when we returned almost a year later ICECAM had obtained 2095 images of the sky (fewer than the expected 3800 due to occasional boot problems and corruption of part of the file system on the CompactFlash disk). The PC real-time-clock had also reset itself on occasion once the temperature had dropped below −40C. The image times can be reconstructed from a careful analysis of the images themselves (e.g., by noting the positions of the stars, and the presence/absence of the moon). These instrumental problems were addressed during a servicing mission in January 2002. However, a modification to the CCD camera housing inadvertently led to persistent frost which resulted in much of the 2002 data being useless. We are currently waiting on 2003 data (a web-camera in our AASTINO experiment at Dome C has already shown >97% clear skies for 100 days beginning on 2003 February 9).

Figure 1 shows typical images from ICECAM at Dome C in 2001. A calibration light-emitting diode is visible at the top left of the post towards the bottom of each image. Figure 2 summarizes the data from 2001. 22% of the images were unable to be used (due to frost on the CCD window, or in some cases a corrupt image file). Of the usable images, 74% showed evidence of clear skies, and the remaining 26% showed some cloud.

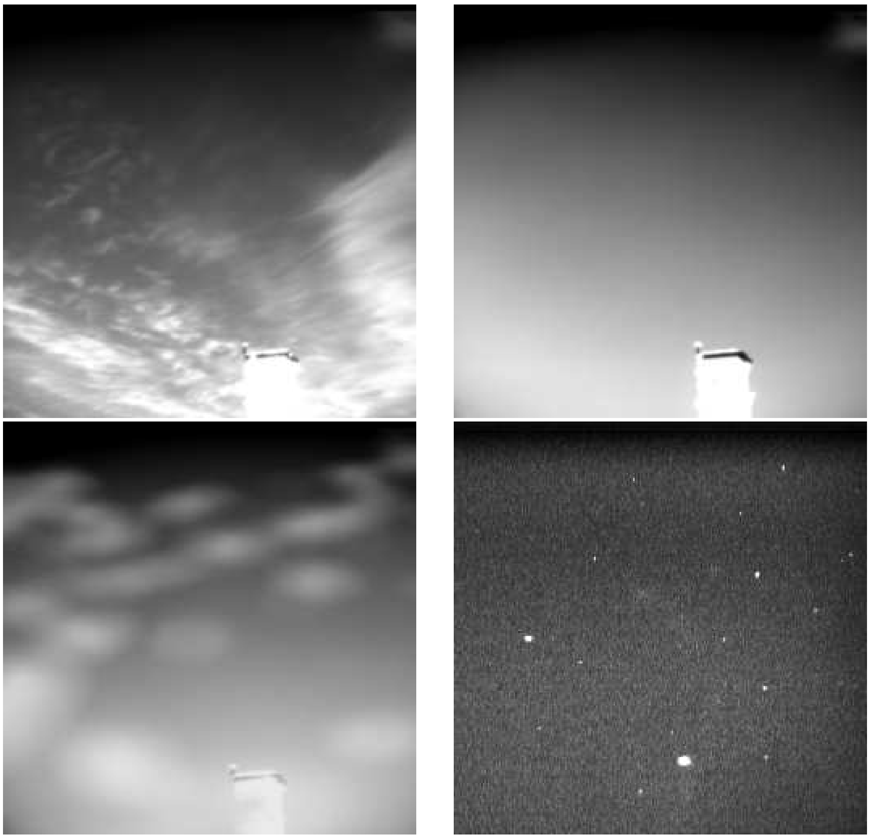

Figure 1. Sample ICECAM images from Dome C: clockwise from top left: circus cloud, clear twilight sky, patches of frost on the CCD camera window, and stars down to magnitude 6 observed during midwinter. The field-of-view is 30×30 degrees centered at a declination of $-53°$.

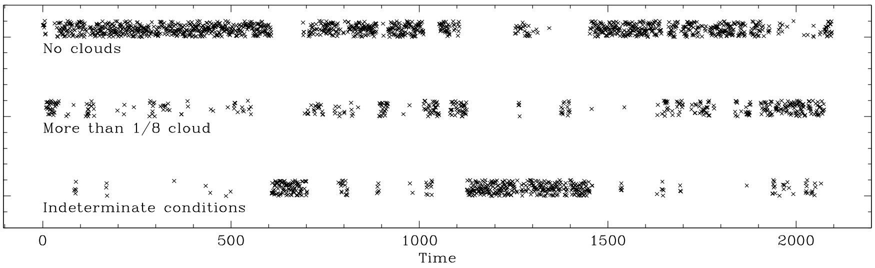

Figure 2. Summary of the 2001 ICECAM data for Dome C. Each cross represents an image, obtained at 2 hourly intervals from February to November. The X axis is image number. The images were characterized by eye as either showing clear conditions ("No clouds"), some evidence of cloud ("More than 1/8 cloud"), or ambiguous ("Indeterminate conditions"), usually due to frost on the CCD camera window.

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Millimetric Site Testing at Dome C: Results and Plans

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Abstract. Results relative to three campaigns at Dome Concordia, aimed to measure the millimetric sky noise, are presented. The atmospheric noise during summer seems to be definitely lower with respect to that measured with the same instrumentation in other geographical locations. We illustrate the scientific results obtained.

1. Introduction

The high Antarctic Plateau is generally recognized as the best site on our Planet for millimetric and sub-millimetric observations. Italy and France are building a new permanent station at Dome C. It will be open for year-round operations in 2004-2005. The Dome C site quality in the millimetric range has been tested in summer since 1995. Recent data from atmospheric studies allow us to extend the analysis to wintertime conditions.

2. Site testing observations

Some interesting informations can be derived from meteorological data: wind speed, temperature, humidity. Wind speed at Dome C (median value below 2 m/s) is always lower than at South Pole (Valenziano & Dall'Oglio 1999). This is mainly due to the relative location of the two sites: Dome C being on top of a dome, while South Pole is downhill, where katabatic regime is already present. Moreover, wind is almost absent at Dome C during the winter, being strongly correlated to the elevation of the Sun.

Temperature is strongly related to Sun elevation at Dome C, being quite stable around -60°C during the winter. Precipitable Water Vapor (PWV) is always very low at Dome C. Summertime values (Valenziano & Dall'Oglio 1999) are distributed around 0.6 mm. Relative humidity, measured with a set of capacitive sensors at three different location on an instrumented tower (Nardino et al. 2002), drops to very low values during the winter.

Planetary Boundary Layer observations, using SODAR and net radiation detectors (Argentini et al. 2002), show that the atmospheric turbulence is strongly related to the warming effect of the sun (Georgiadis et al. 2002). Net radiation (if positive is the the amount of energy available for turbulence genera-

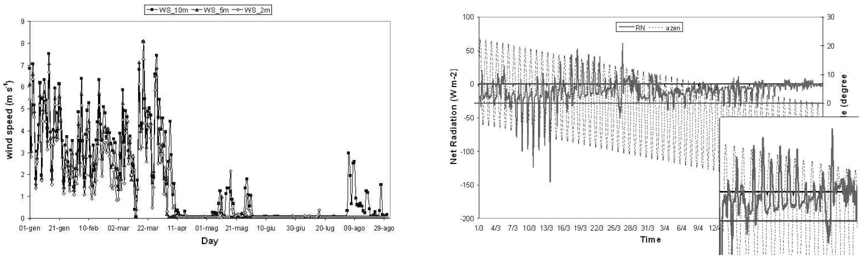

Figure 1. Left panel: Wind speed at Dome C in 2002. Note the abrupt change when the Sun is no longer above the horizon. Right panel: Net radiation measured at Dome C. Sun elevation is superimposed. Also in this case, values are dropping when the Sun is below the horizon. Note, in the box, the correlation between the net radiation and the Sun position, showing the presence of turbulence only during the central part of the day in summer. Data courtesy of M. Nardino, S. Argentini, T. Georgiadis

tion) is always very low and it is dropping below zero during the Antarctic night (see Figure 1). Moreover, the turbulent layer is confined close to the ground (lower than 300 m) by the strong thermal inversion during the summer. This is also confirmed by sky noise data measured by the authors in summer 1998.

3. Conclusions

While further test are in progress to definitively asses Dome C quality, present data strongly support the exceptional quality of the site in the millimetric range. The combination of very low PWV, wind speed, turbulence and temperature makes Dome C a very promising site for future, large aperture telescopes.

Acknowledgments. Authors are indebted to M. Nardino for kindly supplying Planetary Boundary Layer and meteorological data.

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Results from the South Pole Infra-Red EXplorer Telescope

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Abstract. The SPIREX telescope, located at the Amundsen–Scott South Pole Station, was a prototype system developed to exploit the excellent conditions for IR observing at the South Pole. Observations over two winter seasons achieved remarkably deep, high-resolution, wide-field images in the 3–5 μm wavelength regime. Several star forming complexes were observed, including NGC 6334, Chamaeleon I, η Chamaeleontis, the Carina Nebula, 30 Doradus, RCW 57, RCW 38, as well as the Galactic Center. Images were obtained of lines at 2.42 μm H_2, 3.29 μm PAH and 4.05 μm Br α, as well as 3.5 μm L–band and 4.7 μm M–band continuum emission. These data, combined with near–IR, mid–IR, and radio continuum maps, reveal the environments of these star forming sites, as well as any protostars lying within them. The SPIREX project, its observing and reduction methods, and some sample data are summarized here.

1. Introduction

The South Pole InfraRed EXplorer (SPIREX) telescope was a prototype system, developed to test the feasibility of building, operating, and maintaining an infrared (IR) telescope during an Antarctic winter. The initial driver for the SPIREX project was to exploit the conditions at the South Pole that make it an excellent site for 3–5 μm observations — that is the high altitude, the low temperatures, low precipitable water vapor content in the atmosphere, and the stable weather conditions (Burton et al. 1994; Marks et al. 1996; Hidas et al. 2000; Marks 2002).

The SPIREX 60 cm telescope began operations at the Amundsen–Scott South Pole Station in 1994 (Hereld et al. 1990). SPIREX was initially used as part of a campaign to measure the South Pole's thermal background, sky transparency, and the fraction of time useful for IR observations (see e.g. Ashley et al. 1996, Nguyen et al. 1996, Phillips et al. 1996 and Chamberlain et al. 2000 for further details on the IR sky conditions).

Due to the very low thermal background, SPIREX could perform longer integrations in the 3–5 μm regime, compared to temperate latitude facilities. In addition to continuum emission which, at these wavelengths pinpoints young embedded objects, there are many astrophysically significant molecular lines

Table 1. Parameters of the filters and achieved sensitivities for SPIREX/Abu.

Filter	Center μm	Width μm	Range μm	Time×Coadds [b]	Sensitivity [c] 3σ, $5'' \times 5''$, 1 hour
H_2 [a]	2.425	0.034	2.408–2.441	360 × 1	6×10^{-18} Wm^{-2}
PAH	3.299	0.074	3.262–3.336	60 × 3	1 mJy
Br α	4.051	0.054	4.024–4.078	10 × 18	5×10^{-17} Wm^{-2}
L	3.514	0.618	3.205–3.823	6 × 30	14.6 mags
L'	3.821	0.602	3.520–4.122	6 × 30	14.6 mags
narrow M	4.668	0.162	4.586–4.749	1.2 × 90	10.2 mags

[a] Covering the (1–0) Q(1)–Q(5) lines.

[b] Typical integration time (in seconds) × number of coadded frames per position.

[c] Achieved sensitivities were up to 1 magnitude worse than theoretical sensitivities for the site with optimal instrument performance.

accessible; e.g. those from hydrogen and PAH molecules. Observations at 3–5 μm are difficult at most temperate sites, making studies involving these lines limited, and thus the SPIREX dataset unique.

From 1994–1997 SPIREX was equipped with the GRIM (grism imager) camera. This detector contained 128×128 pixels and was sensitive from 1–2.5 μm. In 1998 the telescope was equipped and with the Abu camera, which incorporated an engineering grade 1024×1024 Aladdin detector (Fowler et al. 1998). This camera was sensitive from 2.4–5 μm, and provided a $10'$ field of view image with a $0.6''$ pixel scale. Six science filters were available with SPIREX/Abu. The three narrow-band filters were optimized to isolate emission from molecular hydrogen (H_2 at 2.42 μm), polycyclic aromatic hydrocarbons (PAHs at 3.29 μm), and hydrogen line emission (Br α at 4.05 μm). The three broad-band filters covered the L–, L'– and M–bands. The filter parameters and achieved sensitivities are listed in Table 1 (see Burton et al., 2000).

SPIREX/Abu was well suited for studies of star forming complexes. Young stars containing circumstellar disks have a color excess in the IR due to the absorption and re-emission of radiation from the central star by the surrounding material. Recent studies have found that the L–band may be the optimal wavelength for detection of star and disk systems. Compared to the (H–K) color [$\equiv$ 1.6–2.2 μm], the (K–L) color [$\equiv$ 2.2–3.5 μm] is more sensitive to the presence of a disk (Haisch et al. 2000; Lada et al. 2000; Kenyon & Hartmann 1995).

Observations of PAH molecular line emission across star forming complexes, allows one to study their environments. The fluorescent emission from PAH molecules trace regions (known as photo dissociation regions or PDRs), where stellar UV radiation is heating the molecular gas (Hollenbach & Tielens 1997). PAH emission delineates externally heated molecular clouds and reveals the interactions between nearby massive stars and any remnant molecular material.

The first astronomical results from SPIREX were obtained when Shoemaker-Levy 9 collided with Jupiter in 1994. Using the GRIM camera at a wavelength of 2.36 μm, images were obtained at 5 minute intervals and captured 16 of the fragments, showing evidence of impact with Jupiter in 10 cases (Severson 2000). An extended halo around the edge-on spiral galaxy ESO 240–G11 was also imaged using GRIM at 2.4 μm (Rauscher et al., 1998), reaching a sensitivity level of 25 mags/arcsec^2.

The following sections discuss a sample of data obtained from the two years of operation of SPIREX/Abu (1998–99) at the South Pole. Observations were conducted toward a number of different complexes. The characteristics of these range from young to old, low- to high-mass, and near and far star forming complexes. In particular, results are presented here for NGC 6334, Chamaeleon I, η Chamaeleontis, the Carina Nebula, 30 Doradus, RCW 57, RCW 38, and the Galactic Center. In addition, SPIREX was used to search for an infrared counterpart to the gamma-ray burst GRB990705 at 3.5 μm (Masetti et al., 2000), though no source was detected to a limit of 13.9 magnitudes after 2 hours of integration.

2. Data Acquisition and Reduction

For each source position, a series of frames were obtained at the specified integration time and then averaged. These parameters varied depending on the observing wavelength, the properties of the filter (narrow- or broad-band) and the weather conditions. Typical values for each filter are given in Table 1. All observations were conducted by the winter-over scientists at the South Pole station; Rodney Marks (1998) and Charlie Kaminsky (1999).

The sequence for all observations consisted of a set of sky frames followed by two sets of object frames. Each set consisted of five averaged frames offset by $\sim 30''$ from the previous. This sequence was repeated allowing the easy removal of sky emission and artifacts from the array. Archived images were used for dark subtraction and flat-fielding. Observations of standard stars were obtained before and after all on-source observations for flux calibration.

The majority of the data presented here was reduced by Joel Kastner using the SPIREX/Abu data pipeline[12] (the exceptions are NGC 6334 and the Carina Nebula). The data pipeline was a joint project of the Rochester Institute for Technology Center for Imaging Science (RIT CIS), the National Optical Astronomy Observatories (NOAO) and the Center for Astrophysical Research in Antarctica (CARA).

To cover the star forming complexes of NGC 6334 and the Carina Nebula, many adjacent positions were observed. Common stars in adjacent frames were used to align the images and create the final larger mosaic (using IRAF routines written by Peter McGregor[13]). The final PAH–band mosaiced image for the Carina Nebula contained a total of 72 individual images, and for NGC 6334 the mosaic PAH–band image contained 304 images.

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[12] See http://pipe.cis.rit.edu/

[13] See http://www.mso.anu.edu/observing/2.3m/CASPIR/

3. Results and Discussion

3.1. NGC 6334

NGC 6334 is a young massive star forming region at a distance of 1.7 kpc. It contains seven distinct sites of ongoing star formation along a central molecular ridge. Fig. 1(a) shows the 3.29-μm data toward NGC 6334.

The emission within this band comprises both PAH and continuum emission. A massive embedded star is seen at each of several sites of star formation along the ridge, each ~ 1 pc apart. They are surrounded by complex loops and filaments of PAH emission. These PDRs have formed on the edge of the remnant molecular cloud, as radiation from the young stars carves the material and ionizes their surroundings. Analysis of the PAH emission and PDR features across the central ridge of NGC 6334 have been presented in Jackson et al. (1999) and Burton et al. (2000). The data shown here expand on these studies, and further reveal the PDR structure adjacent to the central star forming ridge.

In addition to the PAH–band images shown here, L–band images were also obtained across NGC 6334. When combined with near–IR data from the 2MASS point source catalog they allow us to produce near–IR color–color diagrams (e.g., (J–H) vs. (H–K) and (J–H) vs. (K–L) diagrams). Results presented in Rathborne et al. (2003) find 11 sources with a large IR excess using the (K–L) color, compared to just a single source using the (H–K) color excess, confirming that the (K–L) color is far more sensitive to the detection of circumstellar disks.

3.2. Chamaeleon I

Containing in excess of 100 pre-main sequence stars, the Chamaeleon I dark cloud is one of the most active regions of nearby low-mass star formation. The central 0.5 deg^2 of the complex was observed in the L–band using SPIREX/Abu. These images reveal all of the known pre-main sequence stars (to an $L \leq 11$).

Kenyon & & Gómez (2001) combined JHK observations obtained at the CTIO with the SPIREX/Abu data, to construct near–IR colour–colour diagrams. They find the fraction of sources with an IR excess to be $58 \pm 4\%$ (complete to an $L < 11$). In addition, they also confirm that sources with an IR excess are more easily identified when using the (K–L) colour than (H–K).

3.3. η Chamaeleontis

The η Chamaeleontis cluster is one of the nearest to the Sun, lying just 97 pc away. It is also of intermediate age for a pre-main sequence system, ~ 9 Myrs old, and somewhat older than a number of other clusters where the formation and evolution of circumstellar disks has been studied. Importantly, its proximity and compactness mean that there is a complete population census for its members — 15 stars ranging from 0.2 to 3.4 $M_\odot$ in mass. Lyo et al. (2003) imaged the cluster using SPIREX/Abu in the L–band, finding 60% of the stars had IR excesses attributable to the presence of disks around them. Of those with disks, half showed a clear relation between the strength of the IR excess at 3.5 μm and the equivalent width of the Hα line emission, implying continuous accretion. The lifetime of the disks in η Chamaeleontis (~ 9 Myrs) is significantly longer than in a number of other systems that have been studied, with lifetimes of 3–6 Myrs (e.g., Haisch et al., 2001).

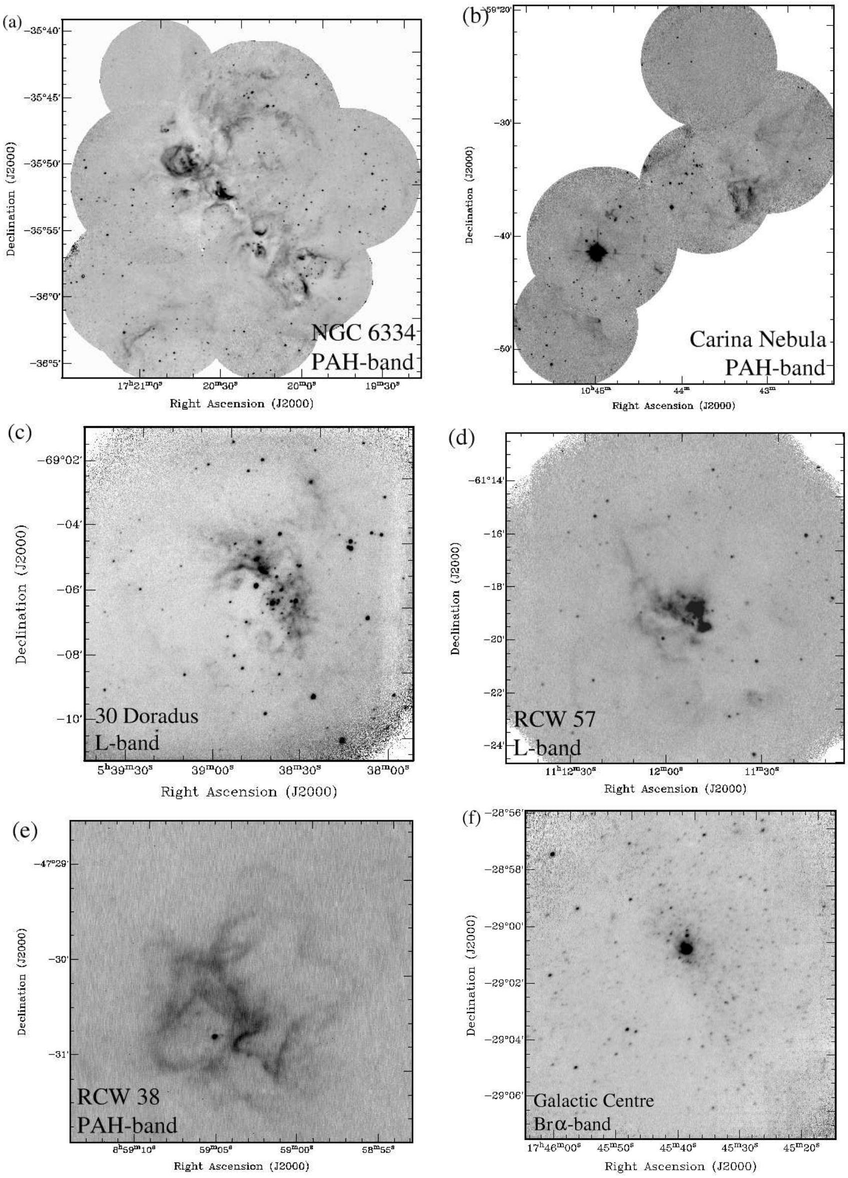

Figure 1. A collection of the images obtained with SPIREX/Abu. (a) NGC 6334 in 3.29 μm PAH emission (Burton et al., 2000, Rathborne et al., 2003), (b) The Carina Nebula in PAH emission (Rathborne et al., 2002), (c) 30 Doradus in 3.5 μm L–band emission, (d) RCW 57 in L–band, (e) RCW 38 in PAH emission and (f) the Galactic Center in the 4.05 μm Brα filter. The RCW 38 and 57 images were kindly provided by Chris Wright.

3.4. The Carina Nebula

The Carina Nebula is a massive star forming region at a distance of 2.2 kpc. Because no protostellar objects had been found within this nebula, it was thought to be ‘evolved’ and devoid of current star formation activity (e.g., Cox & Bronfman 1995). It does however, contain 53 O–type stars and includes the clusters Tr 14 and Tr 16. At its centre lies the massive star η Car and the Keyhole Nebula. Optical and near–IR images show a high amount of extinction toward this complex, with many dark lanes, globules, clumps, and filaments. Two large molecular clouds are located at the edges of the complex, in close proximity to the massive stars.

Fig. 1(b) shows the PAH–band emission across the central Carina Nebula (these data are also discussed in Brooks et al. 2000 and Rathborne et al. 2002). When combined with 2.12–μm H_2 line emission, MSX 8– and 21–μm images, SEST molecular line maps, and MOST 843 MHz radio continuum images, three different environments are revealed across the complex: (i) the Keyhole nebula containing discreet, dense molecular clumps with PDRs on their surfaces; (ii) PDRs at the edges of both the southern and northern molecular clouds; and (iii) heated dust, intermixed with the PDRs surrounding Tr 14 and the northern molecular cloud. Several 3.29–, 8– and 21–μm point sources were also located across the complex, with spectral energy distributions corresponding to compact H II regions. Interestingly, these were all found on the edges of PDRs which appear to have been carved out by the stellar winds and radiation from the nearby massive stars. These results suggest that star formation is indeed ongoing within the Carina Nebula and may in fact be triggered by the interactions resulting from the nearby massive stars.

3.5. 30 Doradus

The 30 Doradus region is the brightest H II region in the Large Magellanic Cloud. It contains a central cluster of massive stars surrounded by extended nebulosity in the near–IR, with many protostellar candidates. To study the nature of the embedded stellar population in more detail, L–band observations were obtained with SPIREX/Abu. The data presented in Fig. 1(c) are the most sensitive ever obtained of the 30 Doradus complex. The faintest start seen in the image, which required 9.25 hours of on-source integration, has L = 14.5 magnitudes. Many sources with an IR excess are revealed when the L–band data are combined with JHK observations. Several embedded massive stars are apparent and in addition, a population census of the young stellar objects can be conducted. This still remains the deepest, wide-field L–band image ever obtained, despite the small size of the telescope, with an extended source sensitivity (1σ) of 18.2 magnitudes per square arcsecond.

3.6. RCW 57

RCW 57 is a bright southern H II region. It contains a tight cluster of massive stars and shows extended infrared nebulosity. L–band observations of the central $10'$ of this complex were obtained with SPIREX/Abu (Fig. 1(d)). This image reveals many point sources, in addition to both bright and diffuse extended emission. Using JHK and the SPIREX/Abu L–band data, studies are currently underway into the star formation history of this complex.

3.7. RCW 38

RCW 38 is also a bright H II region containing a tightly packed cluster of stars. Near–IR images of this complex show extended nebulosity, with dust lanes and dark patches. Coincident with many of these features is extended 3.29– μm PAH emission, as shown in Fig. 1(e). These features trace the PDRs and delineate the molecular material. In addition, they wrap around the ionized material seen at 2 μm.

3.8. The Galactic Centre

Observations of the Galactic Centre obtained with SPIREX/Abu are far less affected by the extinction than at optical and near–IR wavelengths. The 4.05 μm image in Fig. 1(f) clearly demonstrates the advantages of this wavelength regime. Most of the 4.05 μm emission originates from heavily extincted sources, though there is also some Br α emission, pinpointing regions of ionized gas. Three sources, of roughly equal brightness, are prominent in the nucleus at 4 μm. This is in contrast to the view at 2 μm, which is dominated by the source IRS 7. These three sources are each separated by $\sim 7''$ and centred roughly on the presumed nucleus, Sgr A*. At the spatial resolution achieved with SPIREX they are associated with the sources IRS 1W, IRS 7/IRS 3 and IRS 13E/IRS 2L, respectively (as imaged by Clenet et al. 2001, in the L–band).

4. Conclusions

Although SPIREX/Abu was a prototype facility, it nevertheless obtained deep, high-resolution, wide-field images in the 3–5 μm regime toward many star forming complexes. These data are not only unique, but when combined with complementary near–, mid–IR, and radio continuum observations, reveal the inner environments of star forming complexes (by tracing the PDRs), and identify the youngest objects with circumstellar disks (through their high L–band fluxes). The success of the SPIREX/Abu system lends strong support to current plans to build larger IR telescopes on the Antarctic plateau, where they would provide the most sensitive facilities for 3–5 μm observations on the Earth.

Acknowledgments

The SPIREX project was a collaboration between the USA and Australia, involving the National Optical Astronomy Observatories (NOAO), the United States Naval Observatory (USNO), the Center for Astrophysical Research in Antarctica (CARA), Boston University, Goddard Spaceflight Center (GSFC), Ohio State University (OSU), Rochester Institute of Technology (RIT), the University of Chicago (UC), the University of New South Wales (UNSW), the Australian National University (ANU) and the Universities Space Research Association (USRA). We are indebted to the dedicated efforts of our many colleagues here who together have demonstrated that infrared astronomy can indeed be conducted from the Antarctic plateau.

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The AST/RO Survey of the Galactic Center Region

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Abstract. AST/RO is a 1.7m diameter submillimeter-wave telescope at the geographic South Pole. A key AST/RO project is the mapping of C I and CO $J = 4 \rightarrow 3$ and $J = 7 \rightarrow 6$ emission from the inner Milky Way (Martin et al. 2003). These data are released for general use.

The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) is a 1.7 m diameter single-dish instrument which has been observing in the submillimeter-wave atmospheric windows for eight years (Stark et al. 2001, Stark 2003). Essential to AST/RO's capabilities is its location at Amundsen-Scott South Pole Station, an exceptionally cold, dry site which has unique logistical opportunities and challenges. Observing time on AST/RO is available on a proposal basis.

The distribution of molecular gas in the Galaxy is known from extensive and on-going surveys in CO and ^{13}CO $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$; these are spectral lines which trace molecular gas. These lines alone do not, however, determine the excitation temperature, density, or cooling rate of that gas. Observations of C I and the mid-J lines of CO and ^{13}CO provide the missing information, showing a more complete picture of the thermodynamic state of the molecular gas, highlighting the active regions, and looking into the dense cores. AST/RO can measure the dominant cooling lines of molecular material in the interstellar medium: the $^3P_1 \rightarrow {}^3P_0$ (492 GHz) and $^3P_2 \rightarrow {}^3P_1$ (809 GHz) fine-structure lines of atomic carbon (C I) and the $J = 4 \rightarrow 3$ (461 GHz) and $J = 7 \rightarrow 6$ (807 GHz) rotational lines of carbon monoxide (CO). These measurements can then be modeled using the large velocity gradient (LVG) approximation, and the gas temperature and density thereby determined. Since the low-J states of CO are in local thermodynamic equilibrium (LTE) in almost all molecular gas, measurements of mid-J states are critical to achieving a model solution of the radiative transfer by breaking the degeneracy between beam filling factor and excitation temperature.

Among the key AST/RO projects is mapping of the Galactic Center Region. Sky coverage as of 2002 is $-1.^\circ3 < \ell < 2^\circ$, $-0.^\circ3 < b < 0.^\circ2$ with $0.'5$ spacing, resulting in spectra of 3 transitions at 24,000 positions on the sky. Kim et al. (2002) and Martin et al. (2003) describe the data, which are available on the AST/RO website[14] for general use. The C I emission has a spatial extent similar to the low-J CO emission, but is more diffuse. The CO $J = 4 \rightarrow 3$ emission is also found to be essentially coextensive with lower-J transitions of

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[14] `http://cfa-www.harvard.edu/ASTRO`

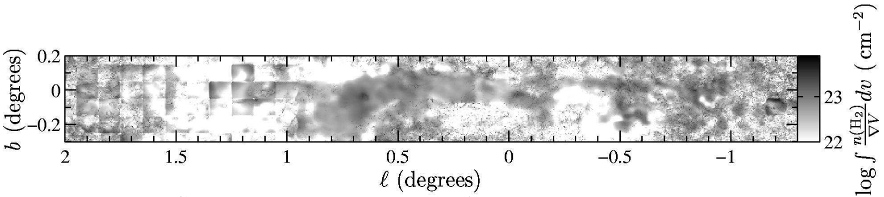

Figure 1. Greyscale representation of molecular column density in the Galactic Center Region, from an LVG model using AST/RO survey data (Martin et al. 2003).

CO, indicating that even the $J = 4$ state is in LTE most places; in contrast, the CO $J = 7 \rightarrow 6$ emission is spatially confined to far smaller regions. Applying an LVG model to these data together with data from the Bell Labs 7-m (Bally et al. 1988) yields maps of gas density and temperature as a function of position and velocity for the entire region. Kinetic temperature is found to decrease from relatively high values (> 70 K) at cloud edges to lower values (< 50 K) in the interiors. Typical pressures in the Galactic Center gas are $n(\mathrm{H}_2) \cdot T_{kinetic} \sim 10^{5.2}\,\mathrm{K\,cm^{-3}}$.

Above is a map of molecular hydrogen column density. It is often assumed that molecular hydrogen column density is proportional to the brightness of the $J = 1 \rightarrow 0$ CO line. The column densities estimated using AST/RO data deviate in places *by two orders of magnitude* from this simple assumption. These discrepancies are caused by variations in excitation and optical depth.

Galactic Center gas that Binney et al. (1991) identify as being on x_2 orbits has a density near $10^{3.5}\,\mathrm{cm^{-3}}$, which renders it only marginally stable against gravitational coagulation into one or two giant clouds (Elmegreen 1994). This suggests a relaxation oscillator mechanism for star bursts, where in-flowing gas accumulates in a ring at 300 pc radius for approximately 400 million years, until the critical density is reached, and the resulting instability leads to the sudden deposition of $10^7 \mathrm{M}_\odot$ of gas onto the Galactic Center.

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Antarctic Cosmic Ray Astronomy

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Abstract. Cosmic ray observations related to Antarctica commenced in the austral summer of 1947-48 from sub-Antarctic Heard and Macquarie Islands and from the HMAS Wyatt Earp. Muon telescope observations from Mawson station, Antarctica, followed from 1955. The International Geophysical Year was the impetus for the installation of a number of neutron monitors around Antarctica, observing the lowest energy cosmic rays accessible by ground based instruments. In 1971 a new observatory was built at Mawson including the only underground muon telescope system at polar latitudes in either hemisphere. Over more than half a century, cosmic ray astronomy has been undertaken from Antarctica and its surrounding regions and these observations have been critical to our growing understanding of the heliosphere.

1. Introduction

Cosmic rays are fully ionized relativistic particles arriving outside the earth from beyond the solar system. On rare occasions the sun can be a source of cosmic rays. At the lowest energies (1–50 GeV) neutron monitors are employed to detect the radiation but these instruments have no directional capability. The viewing cone is defined by the particle trajectories through the geomagnetic field that can reach the atmosphere above the monitor. At higher energies (∼10–1000 GeV) highly penetrating muons are produced in the atmospheric interaction and these may be detected by standard charged particle detectors arranged in multi-tray coincidence systems above or below ground. These muon telescopes effectively record the arrival direction of the initial cosmic ray above the atmosphere. For a discussion of the general properties of cosmic rays and their detection see Duldig (1994). The deflections experienced by cosmic rays traversing the heliomagnetic field can be used to tell us about the field's structures and its interactions with the local interstellar medium. The Antarctic platform provides a unique opportunity to study cosmic rays of low energy due to proximity to the magnetic pole and arrival directions not accessible from other places on earth.

2. Observations and Results

In the late 1940's Geoff Fenton began developing Geiger counters. He investigated the mid-latitude E-W effect from Hobart confirming the southern hemisphere showed the same effect as the north. Geiger counter telescopes and ionisation chambers were operated on the ship HMAS Wyatt Earp in the southern ocean and on the sub-Antarctic Heard and Macquarie Islands by groups from Melbourne and Tasmania Universities. Around 1950 Melbourne University withdrew from the cosmic ray observations in the sub-Antarctic. Muon telescopes were installed at Mawson in 1955, one year after the station opened and neutron monitors followed at several Antarctic stations in time for the IGY.

A large ground level enhancement (GLE) was observed in May 1960 with the global neutron monitor network. This resulted from acceleration of protons to cosmic ray energies associated with a flare on the Sun. The flare site was magnetically well connected to the earth and the Mawson observation of the response proved the existence of the Parker spiral field long before the in-situ measurement of the field by spacecraft (McCracken 1962). The discovery of the co-rotational anisotropy and its spectrum relied heavily on global observations and the Antarctic observations were critical to understanding the process.

In 1971 a new observatory was constructed at Mawson that includes the only underground muon observatory at polar latitudes. The underground telescopes were instrumental in the discovery of isotropic intensity waves by Jacklyn, Duldig & Pomerantz (1987). In a landmark study (Bieber & Chen 1991; Chen & Bieber 1993) used polar neutron monitors to derive cosmic ray gradients and mean free paths in the heliosphere. This work was extended by Hall, Duldig & Humble (1997) to higher energies by incorporating the muon telescopes' observations from Mawson and other sites. Nagashima, Fujimoto & Jacklyn (1998) challenged conventional wisdom with a new interpretation of the sidereal anisotropy response observed. Further work employing Mawson and other muon telescope observations by Hall et al (1999) elucidated the structure more precisely.

3. Summary

The Antarctic region has been critical to understanding the cosmic ray flux at earth. Over half a century of instrumental development and observations have led to a deepening understanding of the heliosphere. Now cosmic ray measurements are providing promising input into space weather prediction. The future of Antarctic cosmic ray astronomy seems to be as bright as ever.

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IceCube: A Kilometer-Scale Neutrino Observatory at the South Pole

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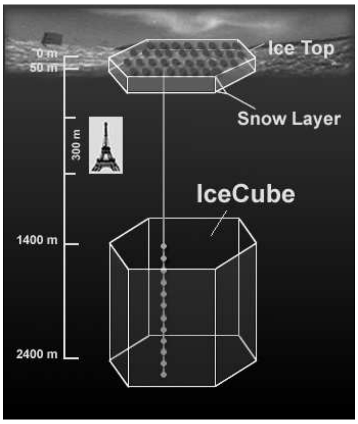
Abstract. Solving the century-old puzzle of how and where cosmic rays are accelerated mostly drives the design of high-energy neutrino telescopes. It calls, along with a diversity of science goals reaching particle physics, astrophysics and cosmology, for the construction of a kilometer-scale neutrino detector. This led to the IceCube concept to transform a kilometer cube of transparent Antarctic Ice, one mile below the South Pole, into a neutrino telescope.

Whereas it has been realized for many decades that the case for neutrino astronomy is compelling (Gaisser, Halzen & Stanev 1995), the real challenge has been to develop a reliable, expandable and affordable detector technology to build the kilometer-scale telescopes required. Conceptually, the technique is simple. In the case of a high-energy muon neutrino, for instance, the neutrino interacts with a hydrogen or oxygen nucleus in deep ocean water and produces a muon travelling in nearly the same direction as the neutrino. The blue Cerenkov light emitted along the muon's kilometer-long trajectory is detected by strings of photomultiplier tubes deployed at depth shielded from cosmic radiation. Although IceCube can identify the secondaries produced by neutrinos of all flavors, muons with interaction lengths exceeding 10 km at the highest energies can be collected far outside the detector and therefore the ν_μ effective detector volume far exceeds the volume instrumented.

Elsewhere in these proceedings we have presented the case for kilometer-scale neutrino observatories (Halzen 2003). The first first-generation telescope, AMANDA II, is approaching an integrated flux sensitivity to TeV–EeV neutrinos of $\sim 0.05\,\mathrm{km}^2$ year. The instrument is sensitive to neutrino fluxes roughly equal to those emitted by the observed TeV gamma ray sources. It is too early to conclude whether first generation telescopes will discover sources of cosmic neutrinos, or whether it takes kilometer-scale observatories to see neutrinos associated with the enigmatic cosmic rays as anticipated by theoretical estimates. We do already know that it will take much larger detectors such as IceCube to study any sources that AMANDA II may discover.

IceCube (Wissing 2003) will consist of 80 kilometer-length strings, each instrumented with 60 10-inch photomultipliers spaced by 17 m. The deepest module is 2.4 km below the surface. The strings are arranged at the apexes of equilateral triangles 125 m on a side. The instrumented (not effective!) detector volume is a cubic kilometer. A surface air shower detector, IceTop, consisting of 160 Auger-style Cerenkov detectors deployed over $1\,\mathrm{km}^2$ above IceCube, augments the deep-ice component by providing a tool for calibration, background rejection and air-shower physics, as illustrated in the figure.



The transmission of analogue photomultiplier signals from the deep ice to the surface, used in AMANDA, has been abandoned. The photomultiplier signals will be captured and digitized inside the optical module. The digitized signals are given a global time stamp with a precision of $< 10\,\mathrm{ns}$ and transmitted to the surface. The digital messages are sent to a string processor, a global event trigger and an event builder.

Construction of the detector is expected to commence in the Austral summer of 2004/2005 and continue for 6 years, possibly less. The growing detector will take data during construction, with each string coming online within days of deployment. The data streams of IceCube, and AMANDA II, embedded inside IceCube, will be merged off-line using GPS time stamps.

IceCube will offer great advantages over AMANDA II beyond its larger size: it will have a higher efficiency and superior angular resolution in reconstructing tracks, map showers from electron- and tau-neutrinos (events where both the production and decay of a τ produced by a ν_τ can be identified) and, most importantly, measure neutrino energy. Simulations, backed by AMANDA data, indicate that the direction of muons can be determined with sub-degree accuracy and their energy measured to better than 30% in the logarithm of the energy. The direction of showers will be reconstructed to better than 10° above 10 TeV and the response in energy is linear and better than 20%. Energy resolution is critical because, once one establishes that the energy exceeds 1 PeV, there is no atmospheric muon or neutrino background in a kilometer-square detector and full sky coverage of the telescope is achieved. The background counting rate of IceCube signals is expected to be less than 0.5 kHz per optical sensor. In this low background environment, IceCube can detect the excess of anti-ν_e events from a galactic supernova.

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Beyond Dome C

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Abstract. A well-focused research program over the past decade has shown that the South Pole has many remarkable characteristics that are particularly favorable for astronomy. These include the very cold, dry atmosphere and the vanishingly small free-air turbulence. Dome C, site of the new French/Italian station Concordia, has all of these attributes plus the added advantage of very low ground-level wind speeds. Higher on the plateau, locations such as the 4200 m high Dome A may well represent the ultimate ground based astronomical observing sites.

The exceptional conditions that make the Antarctic plateau so attractive to astronomers are well known. It is very cold (temperatures can drop below $-80\,^{\circ}$C) and reasonably high (Dome A is at 4200 m), leading to extremely low levels of precipitable water vapor and thermal emission from the sky.

What is less well know is that the ground-level wind speeds are also very low (2.8 m.s^{-1} average at Dome C) and that these winds remain low throughout the entire atmospheric column. This results in a very low turbulence, and that remaining turbulence is confined to a low (100 m scale) boundary layer.

The South Pole is now firmly established as one of the world's premier observing sites (Storey et al. 2002). Over the next few years, Concordia station is set to take its place as an equally attractive draw card for astronomers, as major facilities are constructed to complement those at South Pole.

However, it is natural to ask: what lies beyond? Almost 1 km higher than Dome C, Dome A can be expected to have essentially zero wind for much of the time and to have precipitable water vapor levels that can drop below 50 microns. These conditions would make possible a wide variety of experiments that are currently only possible from balloons, high-altitude aircraft, or space.

At the present time there is no infrastructure at Dome A, nor any well-defined plans to establish any. It is likely that any observatory to be placed there would be a robotic facility, serviced annually from the South Pole or a coastal station such as Davis. Adaptive-optics aside, modern astronomical instruments are vastly more complicated than the telescopes they are attached to. In a benign environment, such as exists at Dome A, it is reasonable to expect that a robotic telescope would be no more demanding to operate than any existing large-scale instrument at a conventional site.

With little turbulence and very low wind speeds, requirements for adaptive optics are dramatically simplified. It is likely that even large optical/IR telescopes would need only a simple tip-tilt or low order AO system, using just a single natural guide star.

The first step in the exploration of Dome A is to go there. It is remarkable that what is potentially the best astronomical site on earth has never been visited (although a Chinese traverse team have come close). An initial expedition should install an Automated Weather Station, plus additional micro-power instruments to measure cloud cover and boundary-layer turbulence.

The next step would be the installation of a comprehensive site-testing facility similar to the AASTINO (Lawrence et al. 2003). Running autonomously for a full year and communicating with the world via Iridium satellite, an AASTINO at Dome A would not only fully characterize the site but would also represent a prototype of the type of autonomous astronomical observatory that might ultimately be installed there.

A preliminary instrument suite to deploy to Dome A might include:

- an acoustic radar, to measure boundary-layer turbulence,
- a MASS (Multi-Aperture Scintillation Sensor), to measure the distribution of turbulence throughout the atmosphere,
- a mid-infrared spectrometer, to measure sky brightness and opacity from 3-30 micron,
- a sub-millimeter Fourier Transform Spectrometer to measure sky brightness and opacity,
- a near-infrared photometer, to measure sky brightness in the 2.35 micron "cosmological window".

Plans are already underway to include an exploration of the astronomical potential of Dome A as part of the International Polar Year of 2007. Regardless of what is discovered there, the well-established advantages of South Pole and Concordia Station will inevitably lead to a continued rapid expansion in the astronomical activities at those existing sites.

Ultimately, however, Dome A may prove to be simply irresistible.

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ACMSA: Antarctic Centre for Millimetre and Sub-millimetre Astrophysics

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Abstract.
A Working Group has been created to study the feasibility of ACMSA: Antarctic Center for Millimetric and Sub-millimetric Astrophysics, an international facility based at Dome Concordia (Dome C).

Tests made over the last ten years show that the Antarctic Plateau, an elevated and extended area, characterized by thin, dry and stable atmosphere, is the most convenient place for ground based observations of the sky at mm and sub-mm wavelengths. Better conditions can be found only in space.

Facilities for mm- sub-mm astronomy on the Antarctic Plateau have been so far available only at the Amundsen Scott base at South Pole, but are insufficient to satisfy the international community needs. To complement South Pole, a group of astrophysicists from Europe, Australia and USA (Olmi 2003) recently suggested the creation of a new mm and sub-mm facility at Dome C, ACMSA (the Antarctic Centre for Millimetric and Sub-millimetric Astrophysics). Here the expected observing conditions are even better that at South Pole. The French – Italian Dome Concordia base will soon become operational all year round.

To prepare a proposal for ACMSA a Working Group (WG) has been formed. The aim is a scientific and technical case which will: i) investigate how selected astrophysical and cosmological questions can be converted into coherent frontier science at sub-mm wavelengths, ii) propose facilities and experiments, iii) review existing facilities and experiments on the Antarctic Plateau and elsewhere, iv) study the state of the art technology available and the use of robotized systems and v)make cost evaluations. The WG will: a) inform the scientific community at large, b) look for collaborations, c) search for links with national and international organizations (French – Italian Concordia Program, European Polar Board, SCAR, IAU Antarctic Working Group, ESO, NSF etc.)

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The Case for a 30m Diameter Submillimeter Telescope on the Antarctic Plateau

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Abstract. A large single-dish submillimeter-wave telescope equipped with a focal plane array containing $\sim 10^4$ bolometers and costing about \$120M could locate most protogalaxies in the southern sky within a year of operation.

Many of the telescopes planned for the next few decades are designed to observe high-redshift galaxies in the process of formation (NRC 2001). These instruments, such as the James Webb Space Telescope (JWST), the Overwhelmingly Large Telescope (OWL), and the Atacama Large Millimeter Array (ALMA), will have sufficient sensitivity and resolution to observe detailed structure within protogalaxies; they will not, however, have sufficient field of view to survey large areas of sky and discover objects to study. Consider, for example, the ALMA. As seen in Figure 1, protogalaxies typically have a flux density at $\lambda 450\mu$m which is $\lesssim 10$ mJy. The ALMA can detect such a source in 3 minutes of observing time. That's really fast. The size of an ALMA map, however, is $\sim 2 \times 10^{-5}$ square degree, so to survey a square degree at this sensitivity would require ~ 100 days. If the ALMA were dedicated to a sky survey for ten years, it would be able to cover about 10^{-3} of the entire sky.

A 30-m submillimeter-wave telescope operating on the Antarctic Plateau with a focal-plane array of bolometers would be able to survey the southernmost $\frac{1}{3}$, of the sky in a year. Observatory sites on the Antarctic Plateau have exceptional submillimeter-wave sky transparency and stability (Chamberlin 2001, Peterson et al. 2003). Technological progress in submillimeter-wave detectors will make possible focal-plane arrays containing many thousands of bolometers. A 10-meter class single-dish telescope designed for such arrays and located at the South Pole has been approved, and construction is expected to begin this year (Stark 2003). Looking ahead, a 30-meter class telescope could be made sufficiently accurate for submillimeter and far-infrared work through a modest application of active surface techniques. A basic design similar to the IRAM 30-m could be combined with crude active control of the primary mirror panel alignment for a total cost of $\sim$ \$120M. The $2''$ to $5''$ beam size of such a telescope would be well-coupled to protogalaxies. With a field of view $\sim 10^{-1}$ square degree in size, this instrument could survey the entire sky south of $\delta \approx -25°$ with 1 mJy sensitivity in a year. Almost all protogalaxies and protostellar cores would be found, and could be distinguished on the basis of $\lambda 350\mu$m to $\lambda 450\mu$m color. The resulting catalog would be a treasure trove of objects for high-resolution study with the giant telescopes to come.

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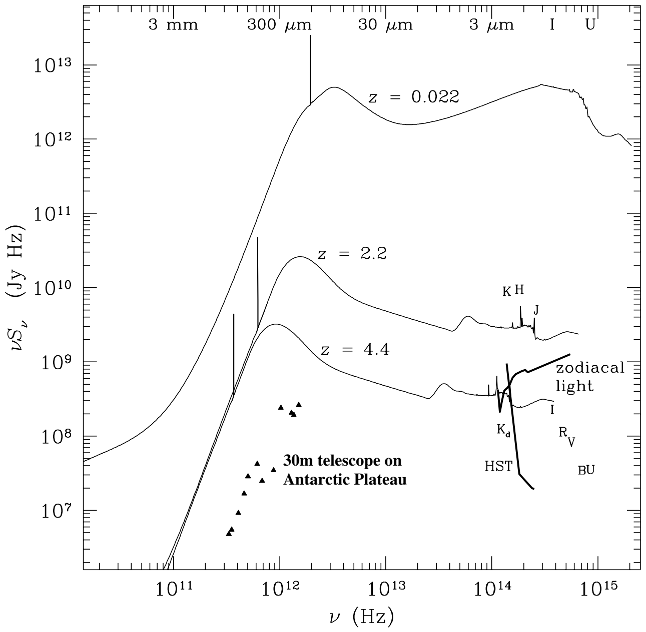

Figure 1. Normal galaxies at low and high redshift. The broad-band galaxy spectrum labeled $z = 0.022$ has the luminosity and spectrum of M99, a normal L^* spiral. The spectra labeled $z = 2.2$ and $z = 4.4$ are models of the initial star burst in such a galaxy at two possible eras, evolved in a standard CDM model (Katz 1992) with $h_{75} = 1$ and $\Omega = 1$. The 158μm C^+ line is shown to scale; other lines are suppressed. The points KHJIRVBU are 1% of the sky brightness in a square arcsecond at Mauna Kea (CFHT Observer's Handbook). The point K_d is 1% of the sky brightness in a square arcsecond at the South Pole at $\lambda 2.3\mu$m. The curve labeled HST is the limiting sensitivity of the NICMOS on the Hubble Space Telescope. The triangles show the continuum sensitivity in one hour of a 30 meter Antarctic telescope in the submillimeter-wave atmospheric windows (Stark 1997).

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Extremely Large Telescopes on the Antarctic plateau

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Abstract. The primary limitation to the performance of any large ground-based telescope is the atmospheric properties of its site, particularly the sky emission and the turbulence structure. There are several sites on the Antarctic plateau (South Pole, Dome C and Dome A) for which the increase in infrared sensitivity relative to a mid-latitude site should be as much as two orders of magnitude. The unique turbulent structure above Dome C indicates that an extremely large telescope equipped with only a natural guide star adaptive optics system should achieve equivalent resolution to a mid-latitude extremely large telescope with a multi-conjugate multi-laser guide star system.

Experimental data from a number of instruments, eg (Phillips et al. 1999), has shown that the winter time thermal sky emission above the South Pole station is as much as two orders of magnitude lower than found anywhere else on Earth. Additionally, data from radiosonde balloons measuring temperature and relative humidity have shown that the South Pole average winter time precipitable water vapor column density is 0.25 mm (Chamberlain et al. 2001). This is significantly lower than found at good quality mid-latitude sites such as Mauna Kea (1.6 mm average).

These factors result in a South Pole telescope being substantially more sensitive in the near to far-infrared than any other ground based telescope of the same size. The increased atmospheric transparency also results in a number of new windows opening up in the sub-millimetre and far-infrared.

There are several other sites on the Antarctic plateau that offer potentially superior sensitivity to even South Pole. These include the French/ Italian Dome C station at an elevation of 3250 m, and Dome A, the highest point on the plateau at an elevation of 4200 m. Atmospheric models for these high plateau sites have been developed based on temperature, pressure, and water vapor profiles inferred from South Pole aerological records, and high plateau Automatic Weather Station data. These models (giving atmospheric emission and transmission, and incorporating a telescope emission component) show that the relative increase in telescope sensitivity in going from South Pole to Dome A is largest in the near infrared, where a factor of 5-10 is expected. The benefits of a reduced atmospheric emission in the mid-infrared are somewhat offset by the significant contribution from telescope emission at these wavelengths. In the far-infrared and sub-millimetre, the lower water vapor expected at the higher sites results in a dramatic increase in atmospheric transparency compared with South Pole.

While the benefits of the South Pole low infrared sky background are well recognized, and the unique atmospheric turbulence profile (the majority of turbulence is confined within the lowest 300 m) is potentially beneficial for some applications, the ground level seeing is relatively poor (1.8 arcsec in the visible) compared with quality mid-latitude sites. However, the local topography of the high plateau sites (both Dome A and Dome C lie on high points of the plateau) indicates that the turbulence within the ground level inversion layer should be lower in magnitude than observed at the South Pole due to the absence of katabatic winds. The integrated ground level seeing during summer at Dome C was shown to be a median of 1.2 arcsec (Aristidi et al. 2003). The boundary layer turbulence is observed to drop below the detection threshold for a sonic radar instrument operating throughout winter of 2003, representing a contribution to the total seeing of less than 0.2 arcsec (Travouillon et al, in preparation 2003).

These results are used to define upper and lower bounds to the refractive index structure function profile for Dome C assuming that the contribution from the free-atmosphere to the total turbulence is the same as found at the South Pole. These profiles give an isoplanatic angle of greater than 10 arcsec, which is significantly larger than found at other sites (typically 2 arcsec at Mauna Kea). Additionally, the lack of strong winds observed throughout the Dome C atmosphere result in an atmospheric coherence time than is much longer than found elsewhere. These two factors (isoplanatic angle and coherence time) represent a serious limitation to the performance of any adaptive optics system on an extremely large telescope, and drive the need for multi-conjugate systems with many deformable mirrors and laser guide stars at mid-latitude sites.

An error budget for a 30 m telescope at Dome C has been calculated and compared with that specified for the 30 m CELT situated at Mauna Kea. The Dome C telescope, equipped with a single natural guide star system should achieve a wavefront error of 180-250 nm rms. This is equivalent to a multi-conjugate, multi-laser guide star system operating with a Mauna Kea atmosphere, and is a significant improvement over the single low order adaptive optics error of 500 nm rms. It should be noted that the turbulence profiles modeled here represent a conservative estimate of the isoplanatic angle at Dome C. It will be at least another two years until the atmospheric profile throughout winter is confirmed.

The improvements in sensitivity and resolution achievable by locating an extremely large telescope at Dome C rather than a mid-latitude site are so substantial that they could compensate for any logistical disadvantage. Additionally, factors such as the very low ground wind speed, and the non-existent seismic activity are very important for mechanical and structural considerations.

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A Large Reflective Schmidt Telescope for Antarctica

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Abstract. We present a simple design for a 16 metre, wide-field, fixed-axis, all-reflective, low cost f/4 Schmidt telescope to take advantage of the unique advantages of Antarctica as an Optical/IR site.

1. Introduction

Antarctica offers compelling advantages for Optical/IR astronomy, over and above the well-recognized gains of high transparency and low background.

1. It offers the unique possibility of single natural guide star AO-corrected observations over large fields-of-view. As well as allowing AO-corrected observations over much more of the sky, this opens up a whole new field of genuinely wide-field imaging at high spatial resolution.

2. The low temperatures remove most of the difficulties of IR telescope and camera optimization, allowing simpler and more general purpose designs.

3. ELT designs and costs are driven primarily by engineering considerations. The low wind speeds and seismic activity in Antarctica dramatically reduce the engineering difficulties.

In general, Schmidt telescopes offer the best optical quality and efficiency, over the largest possible fields of view, with the smallest possible number of elements. The Chinese 4m LAMOST design (www.lamost.org) shows how to build a big Schmidt — the axis is fixed, the corrector lens is replaced with a deformable segmented plain mirror, which corrects for spherical aberration as well as directing the light onto the fixed segmented spherical primary. The design is cheap and scale able. The speed is limited by the tilt on the corrector, which takes it away from the ideal, classical Schmidt position.

2. Proposed design

- LAMOST-style, horizontal axis, transit telescope. Can reach to equator and South Pole from Dome-C (75°S).
- 16m aperture, f/4, length 125m; Plate scale $300\mu m/''$ to match $0.1''$ seeing.
- Segmented flat corrector mirror: steerable and deformable at $100\mu m$ level.
- Primary mirror fixed, spherical, segmented, phased.
- Partial vignetting at very large and very small elevations.
- Raised on 10-30m high ice pyramids (not shown) to get above ground-level turbulence.
- Shack-Hartmann module determines corrector Schmidt deformations; also corrects for tracking errors, windshake, mechanical sag; also provides adaptive wave-

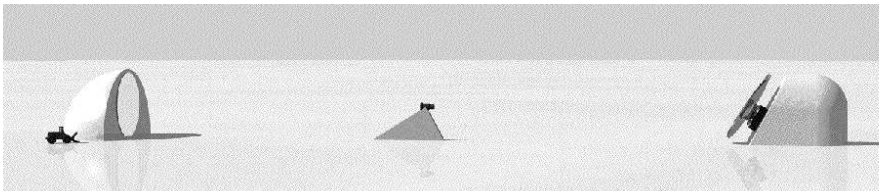

Figure 1. Proposed layout for 16m Antarctic reflective Schmidt telescope

front correction at up to 100Hz (fast enough for Antarctica).
- Focal stations: f/4 prime focus; and f/13, f/40 Cassegrain foci.
- IR uses baffles and Narcissus mirrors but no cold-stop. Increase in sky noise (over a perfect cold-stop) is few % at K_{dark} (2.3μm) and few tens of % at L (3.5μm).
- Can easily guide to R=14.2, can always find guide stars at Prime, and usually at Cassegrain $f/13$, and over $\sim$ 10% of the sky at $f/40$.
- Guesstimated cost at this stage (based on Hobby-Eberly, SALT, Keck) US$100M-200M vs ~US$500M for other 25m-class ELT's.

3. Focal stations and image quality

- $f/4$ Prime Focus MOS: curved field plate: 300μm/$''$, 0.2$''$ fwhm over 3°
- $f/4$ Prime Focus for imaging: flat-field, 0.05$''$/pixel, 0.06$''$ fwhm over 0.5°
- $f/13$ Cassegrain Focus: 0.015$''$/pixel, 0.025$''$ fwhm over 4.5$'$
- $f/40$ Cassegrain Focus: 0.005$''$/pixel, 0.015$''$ fwhm over 1.5$'$

4. Science Drivers

At Prime Focus, the $A\Omega$ (Collecting Area × Solid Angle) for this design is 1-2 orders of magnitude larger than existing or proposed telescopes. For all thermal IR work, it would also be an order of magnitude more sensitive than other 25m-class ELT's, or NGST. Science drivers would include:

Wide-field Optical/NIR imaging at 0.1$''$ fwhm: HDF-quality images over many square degrees. Complete evolution history of galaxies; LSS via lensing; stellar census in the Milky Way; stellar populations in nearby galaxies; in general, finding rare, faint objects.

Multiplexed fiber spectroscopy over 3° fields: combination of aperture and FOV unparalleled for virtually all multi-object spectroscopy.

At Cassegrain, the image quality is as good as NGST or other proposed ELT's in the IR, but offers the prospect of AO corrected optical imaging, and either way do this over $1.5' - 5'$ fields. Such a telescope could be expected to dominate 'deep fields' Optical/IR astronomy, high resolution optical astronomy, and all IR astronomy of faint objects.

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Adaptive Optics and Interferometry on the Antarctic Plateau

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Abstract. The unique properties of atmospheric turbulence in atmosphere above the Antarctic plateau offer some compelling advantages for astronomical adaptive optics and interferometry. The shallow nature of the turbulent layer at the South Pole results in low scintillation and large angular coherence (Marks et al. 1996, 1999; Lloyd, Oppenheimer, & Graham 2002; Lloyd et al. 2003). Recent wintertime SODAR measurements at Dome C indicate that similar conditions exist at Dome C, but that the turbulent layer is likely both weaker and shallower. This paper discusses the outcomes of such conditions on the atmospheric properties for astronomy. Particularly due to the low wind speed at Dome C, the atmospheric properties are highly favorable for adaptive optics and interferometry. The resulting long coherence time enables adaptive optics at visible wavelengths, and the large angular coherence results in a useful field of view as a result.

Estimating the turbulence parameters at Dome C

The possibility of "Super-Seeing" in the Antarctic was first suggested by Gillingham (1993). The smooth topography, suppressed diurnal cycle, and low wind speeds strongly suggest that the mechanisms that generate turbulence at mid-latitude sites might be absent, resulting in excellent seeing. Indeed, this has been verified to be the case at the South Pole (Marks et al. 1996, 1999) above the ≈ 200m boundary layer. The boundary layer at the South Pole has been extensively studied, and is well characterized by SODAR studies (Travouillon et al. 2002, 2003).

The relatively poor seeing at the South Pole results from the mixing of cold air in thermal contact with the radiatively cooling ice with warmer air from the free atmosphere. Above this layer, the atmosphere is very close to adiabatic, resulting in little optical turbulence, even in the presence of mechanical turbulence. Further, the absence of high velocity winds, such as created by subtropical jet-streams results in lower amplitude, and lower velocity turbulence. The turbulence strength and height in the boundary layer are driven by the ground layer wind speed. It is therefore likely that sites higher than the South Pole, which do not suffer from the same katabatic windspeeds would not suffer the same poor seeing. Indeed this appears to be verified by the preliminary results of wintertime SODAR observations at Dome C (Travouillon 2003).

For the purposes of exploring the potential scientific niches available at Dome C, a toy C_N^2 profile is useful. Mean wind speeds at Dome C are typically a factor of three lower than South Pole, and the boundary layer height is plausibly a factor of three lower. Applying these scaling factors to the South Pole model of

Lloyd et al. (2002) provides an estimate (though not necessarily quantitatively correct) of possible seeing and adaptive optics parameters at Dome C, using the definitions of Hardy (1998) are shown in Table 1. Such parameters would open “a new window” at Dome C for visible wavelength adaptive optics with substantial fields of view. The isoplanatic angle and focal anisoplanitism parameters require verification of the upper atmosphere turbulence properties, but the exceptionally long coherence time is an almost inevitable outcome of the low wind speeds.

Site	r_0	f_G	θ_0	NGS d_0 (10 km)	LGS d_0 (90 km)
Mauna Kea	20 cm	80 Hz	1.6”	0.7 m	2.9 m
South Pole	6 cm	35 Hz	34”	6.4 m	47 m
Dome C	20 cm	2.5 Hz	380”	62 m	514 m

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The Antarctic Planet Interferometer

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Abstract.
The Antarctic Planet Interferometer (API) is a concept for an infrared interferometer located at the best accessible site on Earth. Infrared interferometry is strongly effected by both the strength and vertical distribution of thermal and water vapor turbulence. The combination of low temperature, low wind speed, low elevation turbulence, and low precipitable water vapor make the Concordia base at Antarctic Dome C the best accessible site on Earth for infrared interferometry. The improvements in interferometer sensitivity with respect to other terrestrial sites are dramatic; an interferometer with two meter class telescopes could make unique infrared measurements of extra solar planets that might otherwise only be possible with a space-based interferometer.

Unique Science from Earth; A Stepping Stone to Space

A number of spatial interferometry techniques are being developed for measurements of extra-solar planets including high-precision V^2, differential-phase, nulling, and astrometry. The unique properties of the Antarctic atmosphere at Dome C likely improve all of these techniques, compared to other terrestrial sites. Estimates for the performance gains for infrared interferometry at Dome C (Swain et al. 2003a) and at the South Pole (Lloyd et al. 2002, 2003) imply order of magnitude or better improvements are possible. These estimates are based on extensive site testing data including measurements of the turbulence profile (Marks et al. 1996, 1999; Marks 2002; Travouillon et al. 2003).

In addition to unique measurements of extra-solar planets, such as characterization of Jovian-class extra-solar planets in the habitable zone, an infrared Antarctic interferometer would be capable of other ambitious science programs (Swain et al. 2003a) such as:

- Distance scale - measurement of binary star orbits in LMC.
- Mass transfer in compact binary systems.
- YSO and proto-planetary disk formation.
- Active galactic nuclei.
- Accretion disk structure and evolution.

Recent observations with the Keck interferometer (Swain et al. 2003b) have marginally resolved what is likely infrared emission from the accretion disk in NGC 4151. Modest improvements in sensitivity and angular resolution, easily achievable with API, would allow measurements of the structure and evolution of the accretion disk in similar objects.

There are additional advantages of an Antarctic plateau location. The long night results in good instrument thermal stability. Most of the sources observed would be circumpolar, allowing extremely long, continuous observations not possible from other locations. These sources would also be excellent targets for interferometric synthesis imaging as they permit full rotation of the interferometer sampling function.

Further, because of similar science goals to projects such as DARWIN and TPF and a space-like environment (due to the extreme temperatures and remote location), the API, located at the Concordia base, could serve as a natural technology development test bed for these missions. When operating at 200 μm, API would also be an excellent prototype for the proposed SPECS mission (Leisawitz et al. 2000). In addition to producing unique and compelling science, an Antarctic infrared interferometer would serve as a precursor for future space-based interferometers.

Acknowledgments

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High Angular Resolution Mid-IR Astronomy at Concordia

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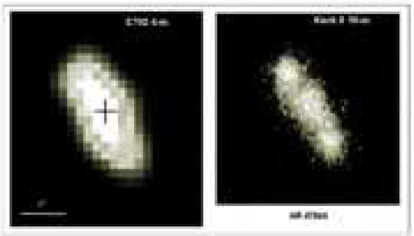
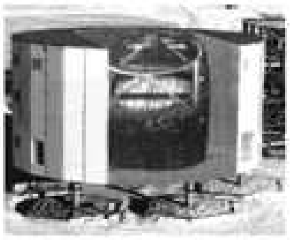
If we concentrate our attention on the study and the evolution of star forming processes rather than on the large scale structure, from the recent use of Large Telescopes in this context there are many examples of great interest. These include the study of the early phases of aggregation of matter (stellar and planet formation), and the late phases of disaggregation during stellar evolution. In Fig 1, a spectacular example is shown of a high resolution image of an edge–on circumstellar disk of a young star (HR4796A), with respect to previous less resolved information (C.Telesco et al, Proc SPIE 4834, 101, 2002). A recent hypothesis of a Large Infrared Telescope called GTA (Grande Telescopio Antartico) has been proposed to the PNRA (Italian Plan for Antarctic Researches). This will require the following characteristics: high angular resolution in the mid-IR domain (large aperture); very high sensitivity (mainly due to the cold, dry conditions of the site); extreme simplicity in design and operational modes. The telescope will be a survey instrument and will be used almost without human intervention. The project examines the construction of a third tower at Dome C with the telescope configured to work in quasi-drift-scan without moving the enclosure and with a limited tracking time. In Fig 1, a sketch of the tower hosting the telescope is shown (M.F-T. et al, Proc SPIE 4836, 165, 2002). A study will be developed to determine the optimum configurations for observing in different bands, from the optical to the sub-mm range, with a refurbishment of the telescope and instrumentation during the summer break.

We expect there to be great gains in sensitivity from the GTA with respect to the new class of Large Telescopes operating with similar angular resolution; more detailed studies can be accomplished by the large 'temperate' Telescopes by using more sophisticated instrumentation (spectrometers, polarimeters, coronographs etc.). Even more interesting could be the use of GTA in conjunction with the LBT or other facilities for ground-based interferometry, or with respect to the ultra-high sensitivity images expected from the future IR space missions-the GTA data will be of great help for addressing and analyzing both the space and the interferometric data. The GTA seems to be also an unavoidable step for future ELT projects.





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An AST/RO Survey of the Coalsack

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Abstract. Selected regions of the southern molecular cloud complex, the Coalsack are being imaged at sub-millimeter wavelengths using the Antarctic Sub-millimeter Telescope and Remote Observatory (AST/RO) located at the South Pole.

The Coalsack is one of the most prominent naked-eye features of the Southern sky, covering about 30 square degrees adjacent to the Southern Cross with 0.7-0.24 mag of extinction. Its proximity (about 180pc) make it an ideal candidate for studying the structure, composition and dynamics a large molecular cloud. Unlike other prominent dark clouds, the Coalsack has generally been thought to show no evidence of collapse leading to star formation. We have selected regions of the Coalsack to image at submillimeter wavelengths: this work is currently in progress. The AST/RO observations consist of a fully-sampled survey in the 230GHz CO(2-1) line over the entire extent of the Coalsack, together with smaller regions imaged in other CO isotopomers and the 461GHz CO(4-3) and 492GHz CI lines. We have already detected extended CO(4-3) emission at several locations. A preliminary LVG model for one position suggests that localized warm (25K) gas does exist in the Coalsack and that collapse leading to star formation, if not already occurring, may be imminent.

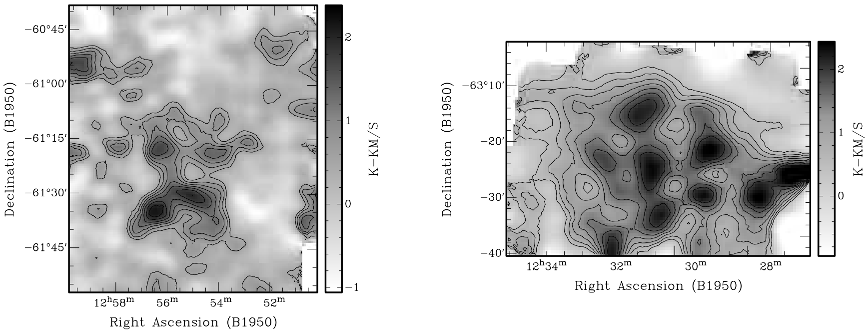

Figure 1. Two regions of the Coalsack imaged in the CO(4-3) line, shown with contours from 0.5 to 2.0 K km/s in 0.25 K km/s steps.

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Helioseismology from South Pole: Past, Present and Future

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Abstract. The austral summer of 2002/03 marked the beginning of a new era for helioseismology from South Pole with the running of an experiment to seismically probe the solar atmosphere.

Helioseismology experiments conducted at South Pole over the period 1979 to 1995 provided several fundamental measurements of the properties of the solar interior including the internal sound speed and rotation profiles, and the sub-surface structure of a sunspot.

Today, thanks to these and other ground- and space-based helioseismology experiments, we have a good understanding of the overall properties of the solar interior. The Sun's atmosphere, however, is another story. This region of the Sun is not at all well understood (as evidenced by the lack of any reliable model). However, by observing the Sun at different heights in its atmosphere, and studying the behavior of the acoustic waves with frequencies above the acoustic cut-off frequency, it is possible to seismically map the properties of the atmosphere in an analogous way to that used for the interior (Jefferies 1998). Such maps will provide a strong constraint for any theoretical model of the atmosphere. The austral summer of 2002/03 saw the first multi-line observations at South Pole, with a double magneto-optical filter instrument being used to measure the velocity signals simultaneously in the photosphere and low chromosphere. These data have provided the first maps of sound-speed variations in the Sun's lower atmosphere. The next step is to tomographically map the 3-D structure of the Sun's atmosphere and to examine the coupling of this structure to both the local sub-surface structure and the magnetic field in the atmosphere. The goal being to better understand how and why the Sun varies and how the Sun drives space weather. The next generation of instrumentation has therefore been designed to provide both improved spatial resolution in the vertical direction (by observing more absorption lines in the atmosphere) and simultaneous measurement of the magnetic field at different heights in the atmosphere.

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CO 2–1 Mapping of WR16 with AST/RO

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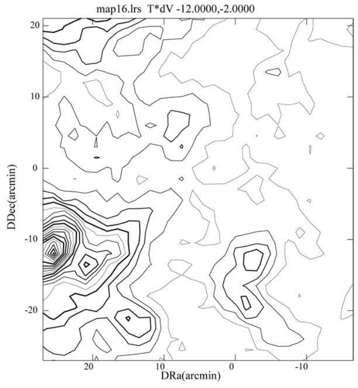
Abstract. Massive stars have profound effects on their surroundings, influencing them by their energetic stellar winds, and finally by supernova explosions. We present a CO 2–1 map of the surroundings of the Wolf-Rayet star WR16, taken with AST/RO at the South Pole, which shows some of these effects.

Marston et al. (1999) directly detected a cocoon of molecular gas in the CO 1–0 rotational line around the WN8 star WR16. They also presented evidence that that this material was in fact ejected from the star itself rather than being swept-up gas from the interstellar medium, but their study was limited by the relatively small extent of the CO map. We present an expanded map in CO 2–1 of the vicinity of WR16, on a square grid with 1.5′ spacing, with the star at the origin of the map. There is a small cavity around the star, consistent with that seen in the CO 1–0 map, surrounded by molecular material. At the outside of the map, there are a number of much brighter clumps, which might be fragments of a wind-blown shell from an earlier phase of the star's evolution.



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History of Astrophysics in Antarctica - A Brief Overview

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On examining the historical development of astrophysical science at the bottom of the world from the early 20th century until today we find three temporally overlapping eras of which each has a rather distinct beginning. These are the eras of Astrogeology, High Energy Astrophysics and Photon Astronomy.[15]

1. Astrogeological Era (from 1912)

In 1912, Mawson discovered the Adelie Land Meteorite. Russian geologists found several meteorites of unrelated morphological types in the Lazarev region in 1961, giving rise to the ablation zone theory. This was followed in 1969 by the first formal meteorite search programme. Thousands of meteorites have since been found in Antarctica, mostly from glacial ablation zones.

2. High Energy Era (from mid 1950's)

In 1955, the first Antarctic astrophysical project was initiated with a cosmic ray detector installed at McMurdo station. A detector was installed at the South Pole in 1964 and others were commissioned at several national research stations. Today, cosmic rays with energies above 50 TeV are recorded by *SPASE 2* which is situated on top of *AMANDA*. *AMANDA II* is scheduled to start operation in 2003 and by 2006, *IceCube*, a 1 km^3 detector, will open up the PeV energy region where the Universe is opaque to high energy γ-rays from beyond our galaxy.

3. Photon Astronomy Era (from 1970's)

Optical astronomy was first employed at the South Pole in 1964 for site testing. In 1979, a continuous 120 hours of solar observations allowed hundreds of solar eigenmodes to be discovered. Infrared and CMB measurements require the best atmospheric windows, and site testing since 1994 has demonstrated this is provided from the Antarctic plateau. In 1988, the first CMB measurement from Terra Nova Bay produced a map at an angular scale of 1.3°. In 1992, the CMB was imaged with better resolution by *Python*, a 0.75m telescope. It was replaced in 1997 by *Viper*, a 2.1m off-axis telescope, to be complemented in 1998 by DASI. The first flight of the *Boomerang* balloon in 1998 provided much improved angular resolution data for a CMB map published in late 2002. AST/RO, a 1.7m sub-mm telescope, has been mapping the Galactic plane in CI and CO since 1995. Between 1994 and 1999, *SPIREX* imaged the 2–5μm continuum and PAHs with the *Grim* and *Abu* cameras.

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[15] A full version of this paper will be submitted to *PASA*. The poster is on the SPS2 web site.

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CMB Observations from the Antarctic Plateau

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Abstract. CMB studies from the Antarctic Plateau are presented.

We used the unique properties of the Antarctic Plateau atmosphere for studies of the fine structures of the Cosmic Microwave Background (CMB):

a) Spectral distortions at decimetric wavelengths. In 1989/1991 we and LBL-Berkeley observed from South Pole (See reference group # 1).

b) Polarization at large angular scales. A correlation polarimeter, tested in Antarctica in 1994 and 1998, now at Testa Grigia (Italian Alps), is ready for observation at Dome C (See reference group # 2).

With IEN Galileo Ferraris (Turin) and IRA-CNR Arcetri we have developed low noise coherent detector systems and fabricated SIS mixers. We are preparing MASTER, a three band SIS system (94, 220 and 345 GHz), for studies of the Sunyaev Zeldovich effect (reference group #3).

We are participating in the following plans for observational facilities: i) proposal for a large sub-mm telescope at the South Pole, ii) Working Group for the Antarctic Center for Sub-millimetric Astronomy at Dome C (reference group #4).

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Earth as an Extrasolar Planet: South Pole Advantages

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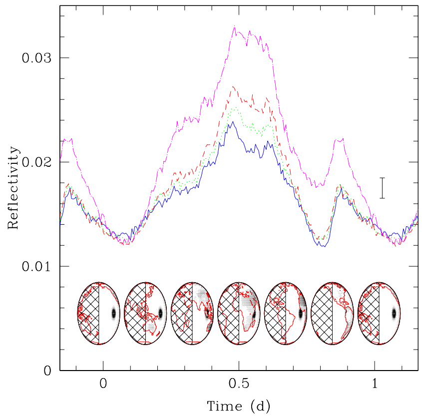
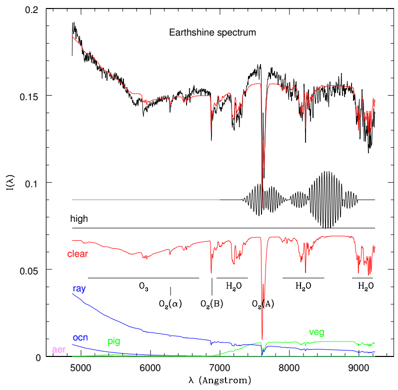
Abstract. We could observe the Earth as an extra-solar planet, viewing Earthshine on the dark side of the Moon, at the Pole, in winter.

A small telescope can measure H_2O, O_2, O_3, chlorophyll, air column density, clouds, continents, oceans, weather variations, and rotation period. This can be done only from the Pole, and in the coming few years of the lunar cycle, owing to the Earth-Moon-Sun geometry. The observations will validate analysis methods for the Terrestrial Planet Finder coronagraph.

Reflectivity variations (see model) will be strong; several-day observations are possible only at the Pole. Enhanced blue reflectivity from Rayleigh scattering gives the column abundance of molecules. Reflectivity from green land plants gives the "chlorophyll" feature. O_2 has 2 strong absorptions. Stratospheric O_3 gives the broad feature 0.6 μm. H_2O has 3 major bands. A primitive Earth might show CH_4 and CO_2 as well. Life on Earth produces abundant O_2, and no other known process competes except to produce relatively much smaller amounts. The strong O_2 bands are therefore good signs of the presence of plant life, along with the "chlorophyll" feature.





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The Explorer of Diffuse Galactic Emission (EDGE)

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1. Summary

The details of the formation of the first objects, stars and galaxies and their subsequent evolution remain a cosmological unknown. Few observational probes of these processes exist. The Cosmic Infrared Background (CIB) originates from this era and measurements of its anisotropy can provide information to test models of both galaxy evolution and the growth of primordial structure. Such measurements should provide a sensitive probe of the large-scale variation in protogalaxy density at redshifts, $z \sim 0.5$-3, while optical galaxy surveys provide complementary information at $z < 0.5$ and Lyman alpha absorption forest studies and Cosmic Microwave Background measurements add information at higher redshifts.

The Explorer of Diffuse Galactic Emission (EDGE) is a balloon-borne mission designed to measure the spatial fluctuations in the CIB from 200 μm to 1 mm on $6'$ to 3° scales with up to 2μK sensitivity/resolution element on an Antarctic Long Duration Balloon (LDB) flight. EDGE will employ an array of Frequency Selective Bolometers (Kowitt et al., 1996) to simultaneously measure spectral and spatial information with seven sky pixels each containing eight spectral bands. EDGE is designed to cover ~100 square degrees of the sky in a single ~10 day LDB flight to create a new observational constraint for large-scale structure formation theories.

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Compact Wide-Field Astronomical Telescopes for Dome C

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Abstract. We describe our project for a small and compact telescope, based on the TRT design, for wide–field observations from Dome C on the Antarctic Plateau, and discuss the main scientific goals.

The project is based on the 2–mirror, 3–reflection (TRT) Amoretti's design (Amoretti et al. 1989), where the primary acts both as the first and third reflecting surface. The main benefits of the TRT design are: the large corrected and unvignetted FOV, the flat focal plane allowing easy placing of large area detectors, easy baffling of straylight, minimum encumbrance (width/length close to unity), and easy instrument handling. Two 30 cm f/3 prototypes were realized in 1994 and 2002, and tested. In 2003 a new 45 cm f/5 TRT was realized based on Lemaitre's active optics techniques (Lemaitre 1996): the primary was obtained from a double–vase form substrate, polished spherically at rest, then in situ stressed by applying back to the mirror at 0.8 atm depressure. The secondary with a tulip form was polished under stress. The telescope was mounted in Tor Vergata, and tests are underway.

Our goal is to place on Dome C a mid–size TRT equipped with large area V–NIR detectors. The primary scientific objective, in the framework of the Spaceguard Foundation, is the search for potentially hazardous NEAs, especially at small solar elongations. The telescope can also be used for the search of extra-solar Jupiter–like planet transits, astroseismology and identification of GRBs.

Parts of this project were funded by CNR, ASI, PNRA and MIUR.

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FTS Opacity Measurements of the South Pole Submillimeter Sky

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Abstract. A sub-millimeter Fourier Transform Spectrometer (FTS) was used at the South Pole to acquire wide frequency span (300 GHz $< \nu <$ 2 THz) measurements of the atmospheric opacity, $\tau(\nu)$. Comparisons were made with other ongoing measurements to allow inference of typical wintertime observing statistics.

A sub-millimeter wavelength FTS of the Martin-Puplett type (Martin 1982) was deployed to the South Pole in 2001. In 2001 it was operated as frequently as operational constraints allowed to make measurements of $\tau(\nu)$. Comparisons were made with narrow bandwidth τ from the Antarctic Submillimeter Remote Telescope Observatory (AST/RO) near 806 GHz and broad bandwidth τ_{CMU} from the NRAO/CMU 860 GHz atmospheric radiometer (Peterson et al. 2003). Compared to the FTS and the AST/RO telescope, the uncorrected τ_{CMU} were offset but otherwise well correlated. The τ_{CMU} offset was likely caused by uncompensated antenna loss efficiency (Davis & Vanden Bout 1973, Calisse 2003). The observed correlation with the continuous τ_{CMU} record was used to extrapolate the FTS $\tau(\nu)$ to infer statistics for an entire annual cycle, see Chamberlin et al. (2003). The statistics from this extrapolation are probably characteristic of all years since South Pole wintertime sub-millimeter observing conditions are expected to have only a slight inter-annual variation (Chamberlin 2001). In the centers of the 1.3 THz and 1.5 THz windows our results indicate observing is possible about 50 days a year with $\tau < 2$ and about 20 days a year with $\tau < 1.75$.

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