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Astronomy in Antarctica

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Preface

Astronomy in Antarctica
Special Session 3, IAU General Assembly XXVII
Rio de Janeiro, Brazil, August 6-7 2009

This was a 2-day meeting held during the XXVIIth International Astronomical Union General Assembly in Rio de Janeiro in 2009.

Antarctica offers a range of remarkable conditions that provide a superlative environment for observational astronomy from visible to millimetre wavebands, as well as for high energy astrophysics experiments. This meeting discussed the current state of Antarctic astronomy, with winter-time facilities now operating at both the South Pole and Dome C on the high plateau, and activity underway at Domes A and F. The status of facilities at these sites was reviewed at the meeting and new science results presented, including from the International Polar Year of 2007/08.

Scientific Rationale

Antarctica provides unique conditions for a wide range of astronomical observations. The cold, dry air above the high Antarctic plateau provides the best ground-based conditions for many observations at thermal infrared and sub-millimetre wavelengths. The stable air, low levels of high-altitude turbulence and narrow boundary layer over the summits of the plateau provide for superb seeing in the optical. The circumpolar wind provides suitable conditions for long duration balloon flights. The vast quantities of pure ice, on a stable platform, provide unsurpassed conditions for neutrino telescopes. The high geomagnetic latitude provides unique conditions for cosmic ray detection.

Over the past decade Antarctica has seen a wide range of experiments designed to exploit these conditions for a variety of astronomical observations. Extensive site testing on the plateau has established the great potential for observational astronomy from optical to millimetre wavelengths. At the South Pole there have been infrared (SPIREX), submillimetre (e.g. AST/RO, Viper) and several CMBR (e.g. Python, DASI, ACBAR) telescopes operating. Particle physics experiments, particularly cosmic ray air shower arrays (e.g. SPASE) and neutrino telescopes (AMANDA), have been developed. Coastal stations, such as McMurdo, have hosted long-duration balloon flights, such as the BOOMERANG CMBR experiment. The high plateau site of Dome C has now completed its third season of winter-time operations, with the first site-testing experiments deployed there demonstrating superb optical seeing conditions. The first expedition ever to Dome A, the summit of the Antarctic plateau, was undertaken in 2005. Initial investigations have also been undertaken regarding the suitability of Dome F for future astronomical observations.

At the 2,900m US Amundsen-Scott South Pole station there are now two major facilities for astrophysics. These are the cubic kilometre collecting volume IceCube neutrino telescope, and the 10m South Pole Telescope, to probe dark energy through for SZ measurements of distant galaxy clusters. For the French-Italian 3,200m Concordia Station at Dome C, the 80cm IRAIT mid-IR telescope is under construction, and a design study completed for the 2.4m optical/IR PILOT telescope. China conducted the first traverse to 4,200m Dome A, the highest point on the Antarctic plateau, and returned there in 2008 in the PANDA program of the International Polar Year. At the Japanese base of

Fuji at the 3,800m Dome F the first investigations on the suitability of this site for astronomical observations have begun.

International involvement in these experiments is high. International collaboration in Antarctica has been productive and effective, with both SCAR (the Scientific Committee for Antarctic Research) and the IAU sponsoring sub-committees to foster developments in astrophysical research there. This meeting will further all these objectives.

Conference Programme

The meeting took place over 1.5 days, and followed the format of the successful meetings held during the IAU General Assemblies in Sydney and Prague.

The first day reviewed the experiments of the past few years. Speakers from the major facilities were invited to report on their achievements. Highlights from the science conducted in the infrared, sub-millimetre, CMBR and particle astrophysics were presented. The opening session also provided an introduction to the field of Antarctic astronomy for the non-specialist, as well as the role of astronomy in SCAR.

The second day featured discussion on plans for the development of the high plateau stations and the astronomical facilities they might provide in the near future.

Day 1, August 6, 2009:

- Session 1: An Overview of Astronomy in Antarctica
  - Astronomy in Antarctica: an overview *by Michael Burton*
  - The SCAR 'Astronomy & Astrophysics from Antarctica' Scientific Research Program *by John Storey*
- Session 2: The South Pole
  - BICEP: a cosmic microwave background telescope at the South Pole *by Yuki Takahashi*
  - The 10m South Pole Telescope *by John Carlstrom*
  - IceCube neutrino observatory at the South Pole *by Kirill Filimonov*
  - Observing the Universe from the South Pole *by Vladimir Papitashvili*
- Session 3: Dome C
  - ARENA, a roadmap for astronomy at Concordia Station (Dome C) *by Nicolas Epchtein and given by Hans Zinnecker*
  - Future plans for Dome C *by Vincent Coudé du Foresto*
  - The LUCAS program: detecting vegetation and traces of life in the Earthshine *by Danielle Briot*
- Session 4: Dome A
  - CSTAR and future plans for Dome A *Xiangqun Cui*
  - The PLATO observatory: robotic astronomy from the Antarctic plateau *by Michael Ashley*

Day 2, August 7, 2009:

- Session 5: Dome F
  - Solar cycles and supernovae embedded in a Dome F ice core *by Yuko Motizuki*
  - Plans for Dome F *by Takashi Ichikawa*
- Session 6: Other Sites
  - Site testing activities on the Greenland Ice Cap *by Michael Andersen*
  - The Stratospheric Terahertz Observatory (STO) *by Gordon Stacey*
- Session 7: Visions for Antarctic Astronomy
  - Science for the Antarctic plateau: what should we do? *by Hans Zinnecker*

- Session 8: Business Meeting
  - Matters for Discussion
  - Election of Chair for Working Group
  - The SCAR Scientific Research Program

Most of the talks given at this meeting can be downloaded from the IAU Working Group for Antarctic Astronomy website, at URL http://www.phys.unsw.edu.au/jacara/iau.

Michael Burton, Chair SOC
Sydney, Australia, October 31, 2009

Scientific Organising Committee

Michael Burton (Chair, Australia)
Carlos Abia (Spain)
John Carlstrom (USA)
Vincent Coudé du Foresto (France)
Xiangqun Cui (China)
Sebastián Gurovich (Argentina)
Takashi Ichikawa (Japan)
James Lloyd (USA)
Mark McCaughrean (UK)
Gino Tosti (Italy)
Hans Zinnecker (Germany)

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Astronomy in Antarctica in 2009

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Abstract. This article summarises the subject matter of Special Session 3 at IAU General Assembly XXVII in Rio de Janeiro, Brazil, which took place on August 6-7, 2009. In it, we overview the state of Astronomy in Antarctica as it is in 2009. Significant astronomical activity is now taking place at four stations on the Antarctic plateau (South Pole, Domes A, C & F), as well as at the coastal station of McMurdo.

Keywords. Antarctica, Telescopes, Site Testing, Instrumentation.

1. Overview

As is now well known (e.g., Storey (2005)), Antarctica offers remarkable conditions for a range of astronomical observations across both the photon and the particle spectrum. This is especially so on the summits of the Antarctic plateau on account of the extremely cold, dry and stable atmosphere. The conditions enable measurements from optical to sub-millimetre wavelengths that would have greater sensitivity and/or sharper imaging quality than measurements made with equivalent facilities at temperate-latitude sites, as well as opening new windows for regular ground-based viewing in the mid-IR and THz spectral regimes. Furthermore, the pure ice provides a novel detector for the capture and detection of particles, in particular neutrinos. At coastal locations the circumpolar vortex provides opportunities for long duration balloon flights that might last several weeks. The ice flow off the plateau also concentrates meteorites that have fallen over the continent into a few locations where they can be readily collected. In the following section we briefly review some of the astronomy ventures taking place over Antarctica. International collaboration is an integral part of these activities at each of the locations. Astronomy is now also established within SCAR – the equivalent body to the IAU for Antarctic science – as a formal research program. Lack of space precludes referencing in this article; however further information on the activities mentioned below is to be found in the accompanying articles in this Journal.

2. Antarctic Stations conducting Astronomy

2.1. *South Pole: the US Amundsen-Scott Station*

The South Pole Station dates back to the IGY of 1957-58, with astronomical activity pioneered there by the late Martin Pomerantz beginning in 1979. The establishment of the "Dark Sector" in 1994 set the scene for what is a major Observatory today. Four astronomical experiments are currently funded; the AMANDA and IceCube neutrino observatories (the latter will comprise of a cubic kilometre detector 2 km beneath the ice surface), the 10m South Pole Telescope (SPT) measuring the SZ-effect in galaxy clusters to probe the equation of state for dark energy, and BICEP measuring the polarization of the cosmic microwave background emission in order to search for gravity waves from the inflation of the Universe.

2.2. *Dome C: the French / Italian Concordia Station*

Concordia Station opened for winter operation in 2005. Noted for its ice core measurements of a column nearly 1 million years in depth, the principal astronomical activity so far has been site testing and instrument characterisation. It is clear that the surface boundary layer, for instance, is much narrower than at South Pole, and the average wind speed is lower. European interest in the station has been piqued through the European Union-funded ARENA network program, which has examined possible options for the site. Highest priority of these is a 2.5m class IR-optimised telescope (PILOT/PLT), a collaboration also including Australia. Interest in the sub-mm is also high, as are the prospects for long-time series measurements, CMBR experiments, solar astronomy and, in particular, an IR interferometer for studying exo-zodiacal emission.

2.3. *Dome A: the Chinese Kunlun Station*

The first humans only visited Dome A in 2005 with a Chinese traverse to the summit of the Antarctic plateau. No humans have yet wintered over at the site. During 2009 China began construction of a new station, Kunlun. The PLATO autonomous observatory operated through the winters of 2008 & 2009, gathering the first astronomical data from the site, as well as site testing data, including on the boundary layer and the atmospheric transparency in the sub-millimetre. These have shown that the boundary layer is exceedingly narrow (less than Dome C), and that the air is exceedingly dry. The Chinese Center for Antarctic Astronomy is now examining options for ambitious facilities, including a network of 0.5m telescopes, a 4m optical/IR telescope and a 15-30m sub-mm/THz telescope.

2.4. *Dome F: the Japanese Fuji Station*

The Japanese station at Dome Fuji has been used to collect ice cores (with one fascinating astronomical result reported by Motizuki at the meeting), and has operated through an Antarctic winter. No astronomical experiments have yet been conducted, but some site testing data has been obtained. The site would appear to offer comparable qualities to Domes A and C. The site testing program is being enhanced and there are plans for both optical/IR and sub-mm/THz facilities. Pilot studies for prototype facilities in these bands have commenced.

2.5. *McMurdo:the US Long Duration Balloon Facility (LDBF)*

Over the Antarctic summer season the circumpolar vortex provides an opportunity for long duration (several weeks) flights of balloons launched from coastal locations, providing the rational behind the LDBF at McMurdo station. Several astronomical experiments have been launched from here, perhaps the most notable being the BOOMERanG experiment which determined that the Universe was flat. In 2010-11 a 0.8m diameter THz spectral imaging telescope will be launched (STO – the Stratospheric Terahertz Observatory) with the aim of mapping large scale N^+ and C^+ emission over the southern Galactic plane.

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Astronomy and Astrophysics from Antarctica: a new SCAR Scientific Research Program

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Abstract. In July 2008 the IAU became a union member of the ICSU body SCAR—the Scientific Committee on Antarctic Research. At the same time, SCAR initiated a Planning Group to establish a Scientific Research Program in *Astronomy and Astrophysics from Antarctica.* Broadly stated, the objectives of Astronomy and Astrophysics from Antarctica are to coordinate astronomical activities in Antarctica in a way that ensures the best possible outcomes from international investment in Antarctic astronomy, and maximizes the opportunities for productive interaction with other disciplines.

Keywords. Antarctica, the Arctic, Site Testing

1. What is SCAR?

SCAR—the Scientific Committee on Antarctic Research—was established as an ICSU body in 1957 and held its first meeting in 1958. It currently has 31 Full Members (those countries with active scientific research programme in Antarctica), 4 Associate Members (those countries without an independent research programme as yet or which are planning a research programme in the future) and, with the recent addition of the IAU, 9 Union Members (those ICSU scientific unions that have an interest in Antarctic research). Like the IAU, SCAR and its divisions hold a number of meetings and conferences throughout the year. Every two years an Open Science Conference is held, similar in size and breadth to the IAU General Assemblies. More information on SCAR is available from the SCAR web site: http://www.scar.org/.

SCAR is organised into three Standing Scientific Groups. These are the:
- Standing Scientific Group on GeoSciences
- Standing Scientific Group on Life Sciences
- Standing Scientific Group on Physical Sciences

In addition, there are five Scientific Research Programmes (SRPs) whose focus is on international scientific coordination. Currently, these are:
- Antarctic Climate Evolution (ACE)
- Subglacial Antarctic Lake Environments (SALE)
- Evolution and Biodiversity in the Antarctic (EBA)
- Antarctica and the Global Climate System (AGCS)
- Interhemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research (ICESTAR)

At the end of 2009, ICESTAR will no longer be an SRP, making way for *Astronomy and Astrophysics from Antarctica* (AAA) as a new Scientific Research Program.

2. Astronomy and Astrophysics from Antarctica (AAA)

AAA has set for itself the following goals. To:

(*a*) Coordinate site-testing experiments to ensure that results obtained from different sites are directly comparable and well understood,

(*b*) Build a data base of site-testing data that is accessible to all researchers,

(*c*) Increase the level of coordination and cooperation between astronomers, atmospheric physicists, space physicists and meteorologists,

(*d*) Extend existing Antarctic site-testing and feasibility studies to potential Arctic sites; for example, in Greenland and Canada,

(*e*) Define and prioritise current scientific goals,

(*f*) Create a roadmap for development of major astronomical facilities in Antarctica,

(*g*) Stimulate international cooperation on major new astronomical facilities in Antarctica.

3. Data Archiving

Section III.1.c of the Antarctic Treaty (1959) states that "Scientific observations and results from Antarctica shall be exchanged and made freely available." To assist with meeting this requirement, SCAR has established the Standing Committee on Antarctic Data Management (SCADM). SCADM helps facilitate co-operation between scientists and nations with regard to scientific data, and advises on the development of the Antarctic Data Management System. AAA will work closely with SCADM to maximise the usefulness and accessibility of data collected by astronomers in Antarctica.

4. Structure of AAA

To achieve its goals, AAA will be structured as four themes:

- Site testing, validation and data archiving.
- Arctic site testing.
- Science goals.
- Major new facilities.

Each of these themes will be managed by a working group. Each working group has a chair and a vice-chair, and a variable number of members. All IAU members, and others, are warmly encouraged to join one or more of these working groups and to contribute to the success of the AAA program.

Acknowledgements

I thank the other members of the AAA SRP Planning Group for their assistance in putting the program together: Michael Andersen, Philip Anderson, Michael Burton, Xiangqun Cui, Nicolas Epchtein, Takashi Ichikawa, Albrecht Karle, James Lloyd, Silvia Masi & Lifan Wang

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BICEP: a cosmic microwave background polarization telescope at the South Pole

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Abstract.
BICEP was a telescope designed to probe the polarization of the cosmic microwave background (CMB) for the signature of gravitational waves produced during the epoch of inflation. The instrument was developed by a team of scientists from Caltech/JPL, UC Berkeley, and UC San Diego. It was installed at the South Pole in November 2005 and the CMB observations were conducted from February to November each year with one winter-over scientist responsible for operating and maintaining the instrument. Taking advantage of the excellent atmospheric conditions at the South Pole, we mapped 2% of the sky at 100 and 150 GHz. We completed 3 years of observations from 2006 to 2008, mapping the CMB polarization anisotropy at degree angular scales with unprecedented sensitivity. In 2010, a next generation instrument, BICEP2, will be installed on the existing telescope mount for an even deeper survey.

Keywords. Cosmic Microwave Background, Instrumentation: polarimeters, Gravitational Waves.

1. Introduction

BICEP was specifically designed to search for a signature of gravitational waves from inflation by studying the polarization of the CMB. The ultimate goal is to find direct evidence for inflation through gravitational waves that would have been generated during inflation. Those gravitational waves would have resulted in polarization of the CMB with a "B-mode" pattern. The resulting B-mode polarization anisotropy has an angular power spectrum that is expected to peak at around 2° angular scales, and whose magnitude allows us to constrain the inflationary energy scale.

2. Experiment Design

Because the potential signal is expected to be under a μK rms, the design priorities for BICEP were sensitivity and systematic error control. For maximum sensitivity, we chose the South Pole site because of its highly transparent and stable atmosphere. We observed in atmospheric transmission windows near the peak of the CMB blackbody spectrum, at two frequency bands (100 and 150 GHz) as a guard against potential foreground contamination.

The BICEP telescope has a modest aperture of 25 cm, leading to a beam size of $\sim 1°$, which is adequate to resolve the B-mode anisotropy at its peak. This small aperture allows for aggressive shielding of sidelobes as well as simple and effective implementation of calibration measurements. To measure CMB polarization, we difference pairs of polarization sensitive bolometers (PSBs), similar to those recently launched on the Planck space-based telescope. The telescope is a simple on-axis refractor with feedhorns coupling the radiation onto 49 pairs of PSBs.

3. Deployment and Observations

We integrated and tested the instrument from 2003 to 2005 and deployed it to the South Pole in November 2005 for 3 years of operation until December 2008. During the summer seasons, we performed careful calibration measurements to characterize the instrument and to ensure that systematic errors are subdominant to the noise level. Takahashi et al. (2009) describes the instrumental properties characterized, including the bolometer temporal response, PSB pair beam mismatch, far sidelobes, spectral bandpass, polarization orientations and polarization efficiency. For CMB observations, we chose the cleanest available 2% of sky where the dust emission is minimized at 150 GHz. We also observed polarized emission from the Galaxy, including that from mid-latitude dust.

4. Results

Bicep achieved mapping depth on the Galaxy similar to that expected by the Planck survey. Our maps of polarized emission from the Galactic plane are being used to calibrate the polarized response of Planck. In our CMB field, Bicep probes much deeper. Our E-mode spectrum is sample variance limited up to the first peak. Bicep has lowered the upper limits on the B-mode by an order of magnitude with only the first 2 years of data and aggressive cuts. From the analysis of these data, the tensor-to-scalar ratio has been constrained to $r < 0.73$ with 95% confidence (Chiang et al. 2009). Systematic errors are controlled to well below this limit, and the analysis of the full 3-year data is ongoing.

Figure 1. Bicep at the South Pole.

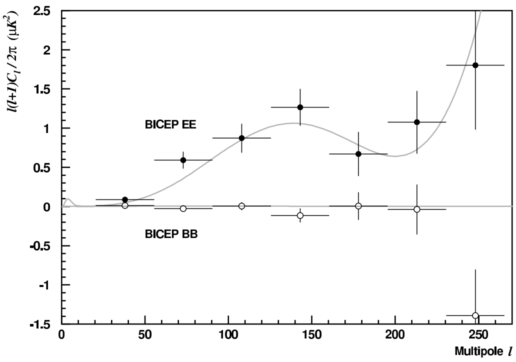

Figure 2. Two-year polarization spectra.

5. Future

Observations will continue in 2010 with Bicep2, which has a highly packed antenna-coupled transition-edge sensor bolometer array. With over 200 PSB pairs, mapping speed is expected to increase ~5 fold. Extrapolating from the achieved sensitivity of Bicep, Bicep2 can expect to reach the sensitivity necessary to begin probing physically interesting ranges of amplitudes for gravitational wave signal from inflation.

We acknowledge support by NSF Grant OPP-0230438 and the US Antarctic Program.

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IceCube neutrino observatory at the South Pole: recent results

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Abstract. The IceCube neutrino observatory, the largest particle detector in the world (1 km^3), is currently being built at the South Pole. IceCube looks down through the Earth to filter out lower-energy particles and uses optical sensors embedded deep in the ultra-clean Antarctic ice to detect high energy neutrinos via Cherenkov radiation from charged particles produced in neutrino interactions. A summary of selected recent results is presented.

Keywords. Neutrinos

The upper limit on the flux of high energy neutrinos from optically thin extra-galactic sources can be estimated using the measured flux of high energy (10^{18} eV) cosmic rays [Bahcall & Waxman 2001]. To detect the diffuse flux of neutrinos of $dN/dE_\nu \lesssim 5 \cdot 10^{-8} E_\nu^{-2}$ GeV^{-1}cm^{-2}s^{-1}sr^{-1} predicted in this way demands very large detector volumes. Both water and ice are naturally occurring optically transparent media for detection of neutrino interactions using Cherenkov radiation. When completed, IceCube will comprise 80 strings of 60 Digital Optical Modules (DOMs) each, deployed between depths of 1,450 m and 2,450 m in the clear ice below the Amundsen-Scott Station at the South Pole [Achterberg *et al.* 2006]. The typical inter-string separation is 125 m and the DOMs are vertically spaced by 17 m within each string. The detector geometry is optimized for detection of high-energy neutrinos ($E_\nu >$ TeV). In addition, 6 closely spaced (72 m) strings will form a core in the center of the IceCube array, reducing the energy threshold for a subset of the detector volume. On the surface, a pair of ice filled tanks containing two DOMs are placed close to each string to form the IceTop air shower array. The surface array will be used to measure cosmic ray composition and for calibration and background studies. At the time of this conference, IceCube is taking data with 59 strings. Here we concentrate mainly on the data taken with 40 strings during 2008.

1. Moon Shadow

As the Earth travels through the interstellar medium, the Moon blocks some cosmic rays from reaching the Earth. This results in a relative deficit of muons measured by IceCube from the direction of the Moon. The resulting deficit (Moon shadow) can be used to calibrate detector angular resolution and pointing accuracy. Figure 1 shows the distribution of reconstructed muons per 1.25° square bin, relative to the position of the Moon. A 5.2σ deficit is observed for the Moon bin. From this, we can conclude that IceCube has no systematic pointing error larger than the search bin, 1.25° [Boersma *et al.* 2009].

† http://icecube.wisc.edu

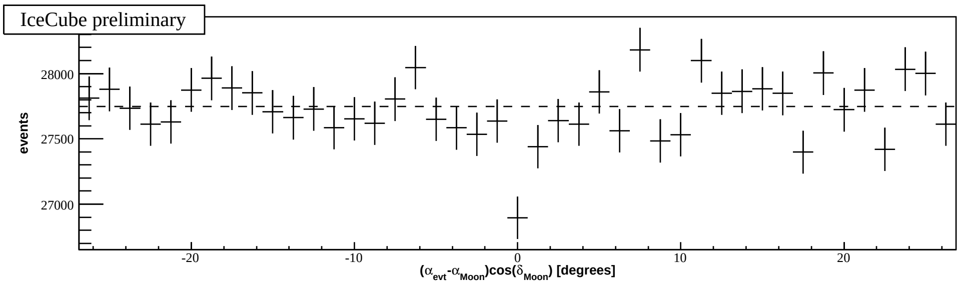

Figure 1. Number of events per 1.25° square bin, relative to the position of the Moon. The declination of the reconstructed track is within 0.625° bin from the declination of the Moon.

2. Point Source Search

One of the primary physics goals of IceCube is to identify point sources of astrophysical neutrinos. Six months of the IceCube 40-string dataset were unblinded for a point-source search. A maximum likelihood analysis, including an energy term to help separate a hard power-law spectrum from the softer backgrounds, was performed over the whole sky on a very fine grid, along with a list of 39 *a priori* source candidates. A sky map of directions of 17,777 events (6,796 up-going neutrino candidates and 10,981 high energy down-going muons – the backgrounds for the northern and southern sky searches, respectively) and their significance is presented in Figure 2. The most significant location in the all-sky

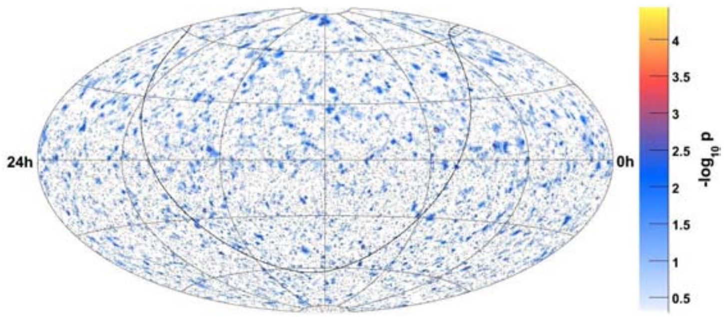

Figure 2. A sky map of the point source candidates (black dots) and their significance (color/shade intensity) in 175.5 days of IC40 data (IceCube preliminary).

search was at r.a. = 114.95°, dec = 15.35°, although an equal or greater significance shows up in 611 out of 1000 scrambled skymaps, meaning the post-trial p-value for the all-sky search is 61.1%. For the list of 39 pre-defined sources, the most significant source was PKS 1622-297 with a pre-trial p-value of 5.2%. Again from scrambling, the post-trial p-value for the source list was 61.8%. No evidence of a point source of high-energy neutrinos has been found with IceCube so far [Dumm *et al.* 2009]. Upcoming analyses of a larger dataset with the IC59 and larger configurations will yield much better sensitivity.

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The ARENA roadmap

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Abstract. We present the main achievements of the ARENA network and a set of recommendations for the development of astronomy and astrophysics at CONCORDIA (Dome C)

Keywords. Site Testing, Instrumentation: high angular resolution, Surveys, Sun: infrared, Stars: general, Cosmology:cosmic microwave background, Infrared: stars, Galaxies: high-redshift

1. The ARENA network

ARENA (*Antarctic Research, a European network for Astrophysics*) is an initiative to draw out a roadmap for the development of Astronomy and Astrophysics at the French Italian Station Concordia at Dome C sponsored by the European Commission. It gathers some 100 scientists, engineers and polar technicians from 7 countries (6 in Europe and Australia). The activity of the network covers the 4-year period 2006-2009 encompassing the International Polar Year (IPY, 2008-9).

Dome C is one of the highest loci in Antarctica, and CONCORDIA (see Figure 1) one of the rare stations run all year round inside the continent. Created mainly to undertake the deepest drilling of the ice cap down to 3,000 m, Dome C happens to offer also compelling conditions for astronomical observations in a wide range of frequencies and techniques.

In 2005, several laboratories in Europe were struck by the exceptional seeing conditions reported by an Australian team. The atmosphere above a thin boundary layer of some 30 m is free of turbulence and, thus, the seeing exceptionally good (300 mas) above this layer. Dome C appears as an extremely appealing site for the rapid build-up of the first multispectral international observatory in Antarctica.

Realizing the potential of Dome C, a successful proposal was submitted to the EC in 2005, which had the following goals, i) aggregate and give access to the site assessment data collected so far, ii) identify the most compelling science programmes, iii) propose a few case studies of instrumental devices compliant with the polar conditions, iv) evaluate the logistics requests to set up one or several astronomical facilities, v) stimulate the interest of the public (especially during the IPY).

The ultimate goal of the network is to raise strong arguments in favour of the creation of an International Observatory in the forthcoming decade at Dome C (the so called "ARENA roadmap"). A set of some 25 specific tasks led by experts were carried out and, later on, 6 working groups were set up to prepare independently their roadmaps in their respective areas. The latter are briefly described in the following section.

2. Working Groups achievements

Wide field optical/infrared surveys. Under a grant of the Australian government UNSW/AAO carried out in 2008 a phase A study for the PILOT project, a 2.5 m class

† on behalf of the ARENA consortium

Figure 1. The Concordia station in 2007: main buildings, the site testing instruments, and the Concordiastro towers *(courtesy E. Aristidi)*

telescope that would serve as a pathfinder for future larger telescopes equipped with a suite of focal imaging instruments from the visible to the far infrared. European and Australian astronomers came to a less ambitious project that would basically focus on the spectral range in which Antarctica brings an obvious advantage: the near thermal infrared and especially the 2.3-3.5 μm window hardly accessible from the ground. The PLT (*Polar Large telescope*) is a descoped version of PILOT. This project is considered as the most mature in its cost range and is fully supported for an immediate phase B study (2010-2013). In the meantime, IRAIT, an 80-cm IR dedicated telescope will provide rapidly (as of 2011) the first IR images and invaluable clues on the IR sky at Dome C.

Submillimetre-wave dish. Measurements of water vapour content definitely show that Dome C supersedes any other site in the THz regime and in particular in the 200 μm window. After ruling out a project to clone a 12 m ALMA antenna, configured for Antarctic conditions and installed shortly as a pathfinder, the working group eventually proposed a 25 m diameter dish (*the Antarctic Submillimetre Telescope*), envisioning a much more scientifically compelling project to exploit the 200-400 μm windows. It should rapidly enter a phase A study through a joint venture between Italy (INAF- IEE) and France (ThalesAleniaSpace, CEA, Saclay).

Optical/infrared interferometry. The ultimate goal of the interferometric community is to set up a kilometric array of optical/NIR telescopes. The Antarctic plateau with its immense flat areas and its unique atmospheric conditions would be the perfect location to install such an instrument (KEOPS project). The best pathway to this gigantic instrument is, however, still uncertain. Several pathdfinders have been proposed among which the Aladdin concept (a nulling interferometer to measure *"exozodis"*) is currently the most advanced, essentially by Observatoire de Paris, Nice and Liège Universities and AMOS. This instrument is described in more details by V. Coudé du Foresto elsewhere in this session.

Long time series. The basic advantage of polar sites is to provide long dark periods perfectly suited to the study of periodic variations of astronomical objects (sun, stars, planet transits). Several projects are underway, among them the most advanced is A–STEP, a 40 cm telescope aimed to measure planetary transits. This instrument led by Nice Observatory/UNSA is under construction at Dome C and should provide first images in 2010. Other more complex and robotic projects are proposed and supported by ARENA such as ICE-T (a twin telescope with an ultra precise photometer) at AIP/Germany, and SIAMOIS (an interferometer to measure oscillations of stars) at Paris Observatory.

Cosmic Microwave Background. Antarctic sites have a very stable atmosphere and allow long integration times of the same area of the sky. They are very appropriate to measure tiny flux variations in the millimetre wave range and Dome C is likely to be even more stable than the South Pole. A French-Italian consortium (APC University of Paris 7 and University of Roma, la Sapienza) is undertaking a project to measure the B polarization of the CMB using a bolometer and an interferometer (BRAIN/QUBIC). Dome C has an additional advantage being 15^o away from the pole in latitude. For polarization experiments it is actually crucial to measure the same polarization direction with different inclinations of the axis of the polarimeter.

High angular resolution imaging solar physics. Dome C is an outstanding site for high angular resolution especially during Summer. Simultaneously, the sky is coronal and the seeing is excellent. Antarctica is suitable for very high angular resolution imaging of the solar photosphere and corona. An instrument consisting of a solar interferometric imager (AFSIIC) is proposed, consisting of 3 telescopes of 70 cm on top of a tower of about 30 m.

More details on all this are given in the ARENA website (http://arena.unice.fr) and in the Proceedings of the 3 conferences organized by ARENA (Epchtein & Candidi, 2007), (Zinnecker *et al.,* 2008), and in particular(Spinoglio & Epchtein, 2010).

3. Conclusions and Recommendations

Dome C is the only place where one can expect to undertake outstanding programmes of astronomy in Antarctica in the next decade from the visible to the submillimetre range. The excecutive committeee of ARENA is preparing a series of recommendations in conclusion of the ARENA roadmap. Among them, it is recommended to create an astronomical observatory at Dome C with a stable structure, to proceed with the internationalization of the CONCORDIA station, to pursue the site assessment, open wide access to the site qualification data, and facilitate the comparison of site characteristics, to strongly support the currently on-going instruments (IRAIT, A-STEP, QUBIC), to seek funding and support for a couple of additional small instruments (ICE-T, SIAMOIS) to start phase B studies of PLT for a first light before 2020, and phase A studies for ALADDIN, AFSIIC and AST. It is also highly recommended that a strong cooperation be initiated between all the countries involved in astronomical developments on the Antarctic continent in order to define a global policy.

Acknowledgements

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The LUCAS program: detecting vegetation and traces of life in the Earthshine

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Abstract. The aim of the LUCAS program is to observe chlorophyll and atmospheric molecules in the Earthshine spectrum in order to prepare the detection of life in terrestrial extrasolar planets to be discovered. Actually, observations from Antarctica offer a unique possibility to study the variations of Earthshine spectrum during Earth rotation while various parts of Earth are facing the Moon. Special instrumentation for the LUCAS program was designed and put in the Concordia station in the Dome C. Observations are in progress.

Keywords. Astrobiology, Earth, Moon

1. Introduction

The detection of extrasolar planets has given a new impulse to the research of life in the Universe. In order to prepare the detection of life on Exo-Earths or SuperEarths located in the hability zone, when their images could be seen, we study the detection of terrestrial life, Earth being seen as a dot. Earthshine, which is located in the dark part of the Moon inside the crescent, corresponds to the Earth light backscattered by the non-sunlit Moon. Due to the lunar surface roughness, any place of the Earthshine reflects all the enlighted part of the Earth facing the Moon. So a spectrum of the Moon Earthshine directly gives the disk-averaged spectrum of the Earth, as could be seen extrasolar planets. In this spectrum we can see molecules in the planet atmosphere, like oxygen and ozone, which may be biologic markers, and also the chlorophyll spectrum due to the vegetation reflectivity. The chlorophyll spectrum presents a very typical sharp edge in the near-infrared, near 700 nm, the so-called Vegetation Red Edge (VRE). Since 2002, (see Arnold *et al.* (2002) and Woolf *et al.* (2002)), several studies detected the VRE from Earthshine observations (see a review of the results in Arnold 2008). Although the values of VRE are only a few percent, we found larger values when continents are facing the Moon and smaller values in case of an ocean (see Arnold *et al.* (2002) and Hamdani *et al.* (2006)). To detect the variation of the Earthshine as a function of the Earth landscapes facing the Moon, long observational times are necessary, so as to observe the rotating Earth. This is possible only in the case of observations from very high latitude places, and even more so when near the pole, during a total diurnal cycle (nycthemere).

Other information about Earthshine can be found in the same volume (Briot, 2009).

2. Dedicated Instrumentation and the State of the Art

Concordia station at the Dome C offers such a possibility. After checking the darkness of the sky during Earthshine observations, the LUCAS *(LUmière Cendrée en Antarctique par Spectroscopie)* experiment was then imagined in 2006, installed in 2007, and the first observations planned for the southern winter of 2008. A dedicated instrumentation for Earthshine spectroscopic observations was designed and built at Haute Provence and Paris-Meudon observatories. It is made off a 20-cm diameter Schmidt-Cassegrain telescope that feeds a low resolution slit spectrograph. The spectrograph, based on a 300 grooves/mm reflecting grating, has a 500 to 900 nm spectral range and a resolution of about 100 at 700 nm. The camera is a KAF402ME-based CCD detector. Tests carried out at the Haute-Provence observatory validated the instrumentation: overall optical alignment focus, and data acquisition. Due to the extreme weather conditions in Antarctica, the full instrument (telescope, spectrograph and detector) is insulated to withstand the very low temperatures that prevail in the Concordia Station. The internal temperature of the instrument is regulated thanks to a set of PT100 temperature detectors and a heater that prevent the camera shutter to cool down to negative temperatures. During the 2008 campaign, we had some problems of shutter and heat insolation. The feedback we got from the first observing campaign in 2008 was very important to detect, analyze and correct instrumental problems due to extreme temperature and extreme physical conditions. Some important instrumental improvements were carried out for the 2009 winterover campaign: new thermalization, new impermeable box, high quality (military) connections, new dome, etc. These improvements, as well as the ingenuity of the winterover observers, were very efficient and we have obtained Moon spectra, Earthshine and enlightened Moon, during each observational sequence since 2009 June solstice, that is to say during each Moon cycle since the first or second day after the New Moon, up to the First Quarter. Continuous observations times spend up to 8 hours running. Obviously, so long an observational time of the Earthshine is impossible at low or moderate latitudes.

3. Conclusion

Actually, LUCAS is the first program with spectroscopic observations at Dome C. We obtain Earth vegetation spectra during several hours (up to 8 hours) and we will detect variations during Earth rotation, as it will be possible in the future for extrasolar planets. As such, it is also a test for the design and improvement of small instrumentation, data collecting and management of observations in Concordia's extremely cold environnement.

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The PLATO observatory: robotic astronomy from the Antarctic plateau

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Abstract. PLATO is a 6 tonne completely self-contained robotic observatory that provides its own heat, electricity, and satellite communications. It was deployed to Dome A in Antarctica in January 2008 by the Chinese expedition team, and is now in its second year of operation. PLATO is operating four 14.5cm optical telescopes with 1k×1k CCDs, a wide-field sky camera with a 2k×2k CCD and Sloan g, r, i filters, a fibre-fed spectrograph to measure the UV to near-IR sky spectrum, a 0.2m terahertz telescope, two sonic radars giving 1m resolution data on the boundary layer to a height of 180m, a 15m tower, meteorological sensors, and 8 web cameras. Beginning in 2010/11 PLATO will be upgraded to support a Multi Aperture Scintillation Sensor and three AST3 0.5m schmidt telescopes, with 10k×10k CCDs and 100TB/annum data requirements.

Keywords. Site Testing, Instrumentation: miscellaneous, Atmospheric Effects, Telescopes

1. Introduction

The potential of Antarctica, in particular the high plateau in the Antarctic interior, to provide the best astronomical observing sites on the Earth's surface has been widely discussed in the literature (see, e.g., Ashley *et al.* 2004). Dome C (3260m altitude) on the plateau shows a median seeing of 0.27 arcseconds above a 30m turbulent boundary layer (Lawrence *et al.* 2004). However, some of the best potential sites, such as Dome A, do not yet have the infrastructure to support people over the winter. To explore these sites, both for site-testing and for simple astronomical experiments, it is necessary to have a reliable source of power and internet connectivity. Hence PLATO.

PLATO, short for "plateau observatory", is a self-contained astronomical observatory designed to provide 1kW of electricity in order to run experiments with no human presence for up to a year before servicing (Lawrence *et al.* 2009). Electricity is generated by a combination of solar power and diesel engines running on Jet-A1 fuel. PLATO has "on-board" supervisor computers that provide internet access via Iridium modems, and allow many aspects of the facility to be controlled. For the convenience of instrument designers PLATO provides a thermally-insulated environment inside a 10-foot shipping container that can be temperature controlled, usually at least 50°C above the ambient temperature—which can fall to below −75°C in winter.

2. PLATO Performance

2.1. *Power system*

PLATO was installed at Dome A by the Chinese expedition team during January 2008, and ran for 204 days that year, stopping due to an exhaust leak from its engines in early August. At the time of writing (2009 November 9), PLATO has been running for 301 days continuously. Details of the engine system are given by Hengst *et al.* 2009.

2.2. *Iridium communications*

With two Iridium modems, PLATO can reliably transfer $\sim$ 30MB of data per day from Antarctica. The transfer occurs over an "ssh" socket connection, and uses a custom Perl script that copes efficiently with the partial transfer of large files, while simultaneously allowing bidirectional control of PLATO via a "bash" command-line interface. Iridium also provides reliable absolute time for the PLATO instruments, accurate to $\pm$20 ms.

2.3. *Scientific instruments*

The original PLATO instruments, and results from 2008, are described by Yang *et al.* 2009. The PreHEAT instrument showed spectacularly-high atmospheric transmission at a wavelength of 450 microns—a paper describing these results is in preparation.

During 2009, the instruments described in the abstract have been operating. All have worked well and returned data for much of the year. Three papers on CSTAR results are in preparation. Snodar (Bonner *et al.* 2009) has given excellent statistical information on the height of the atmospheric boundary layer, with 10 second or better time resolution, and 1m spatial resolution, throughout the year.

2.4. *Diagnostic information*

The data stream from PLATO includes health and status information such as bus voltages and engine temperatures. This information is available from a webpage updated every minute, with the data usually between 1 and 4 minutes old. Any anomalies with the data trigger the transmission of an SMS message to one or more mobile phones. In practice, PLATO can operate for weeks at a time with no need for outside intervention. Such intervention is usually only necessary to change instrument parameters or to work around sub-system failures. The redundant nature of much of PLATO's design has allowed us to continue operating despite the occasional electrical and mechanical problems.

There are 8 web-cameras of various types to monitor the sky conditions and instrument icing. One of the cameras is inside the Engine Module, and can assist with diagnosing engine problems such as the exhaust leak that stopped PLATO during 2008. This camera includes a microphone, to measure the engine RPM and general health.

3. Future Plans

PLATO is serviced each Austral summer by the Chinese expedition team organized by the Polar Research Institute of China. At a minimum, servicing involves replacing the six diesel engines, changing the lubricating oil, and filling the Jet-A1 fuel tank. The opportunity is also taken to maintain and upgrade the scientific experiments.

For 2010 we are adding a sub-millimeter Fourier Transform Spectrometer, and a lunar SHABAR to measure the contribution of the boundary layer to astronomical seeing.

Beyond 2010, we will need to replace PLATO's Engine Module with a higher-power version to support three 0.5-m Antarctic Schmidt Telescopes (AST3) under construction at NIAOT. There are also plans to install a Multi Aperture Scintillation Sensor to provide data on the free atmosphere contribution to the astronomical seeing.

4. Conclusions

The PLATO concept has proven its reliability through two successful periods of operation during 2008 and 2009. In practice, the lack of on-site people during winter has not been a major impediment, and has had some benefits: e.g., the instruments have to be designed from the outset for full automation, which tends to lead to greater reliability and longer uptimes.

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Supernovae and solar cycles embedded in a Dome F ice core

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Abstract. We have recently found signals of candidates for two historical supernovae and past solar cycles in a depth profile of nitrate ion concentrations in an ice core portion corresponding to the 10th and the 11th centuries. This ice core was drilled in 2001 at Dome Fuji (Dome F) station in Antarctica. We briefly review our findings and discuss why Dome F is appropriate for this study.

Keywords. Sun: general, Supernovae: individual (SN 1006, Crab Nebula)

1. Supernova and Solar Cycle Signals in Ice Cores

Ice cores are known to be rich in information regarding past climates, and the possibility that they record astronomical phenomena has also been discussed. Rood *et al.* (1979) were the first to suggest that nitrate ion (NO_3^-) concentration spikes observed in the depth profile of a South Pole ice core might correlate with the known historical supernovae: Tycho (AD 1572), Kepler (AD 1604) and SN 1181 (AD 1181). Their findings, however, were not supported by subsequent examinations by different groups using different ice cores (*e.g.*, Risbo *et al.* 1981; Herron 1982; Legrand & Kirchner 1990), and the results have remained controversial and confusing (Green & Stephenson 2004; Dreschhoff & Laird 2006).

Motizuki *et al.* (2009) presented a precision analysis of an ice core drilled in 2001 at Dome F station in Antarctica. It revealed highly significant three NO_3^- spikes dating from the 10th to the 11th century. Two of them were coincident with SN 1006 (AD 1006) and the Crab Nebula SN (AD 1054), within the uncertainty of their absolute dating based on known volcanic signals. They concluded that the coincidence had a confidence level much larger than 99%.

Moreover, by applying time-series analyses to the measured NO_3^- concentration variations, the authors discovered very clear evidence of an 11-year periodicity that can be explained by solar modulation. The 11-year periodicity was obtained with the 99.9 % confidence level by using the epoch-folding method, which has a clear mathematical basis. This was one of the first times that a distinct 11-year solar cycle has been observed for a period before the landmark studies of sunspots by Galileo Galilei with his telescope. See Motizuki *et al.* (2009) for details.

† This collaboration is organized by RIKEN, National Institute of Polar Research (NIPR), Shinshu University and National Institute for Environmental Studies (NIES) to perform ion concentration measurements of ice cores with high time resolution and to analyse the results, especially in relation to astronomical phenomena.

Table 1. Tritium concentration in snow corresponding to the deposition in 1966 reported in Antarctica. Extracted from Table 1 of Kamiyama *et al.* (1989).

Point	Tritium, TU
DC (Dome F)	4,200
South pole [Pit A]	2,800
Dome C	700
Halley Bay	620

2. Uniqueness of the Precipitation Environment at Dome F

Dome F is located at 77.2°S, 39.4°E, and its altitude of 3,810 m is the highest point in east central Antarctica. It is natural to wonder whether Dome F site is unique enough to catch such astronomical phenomena. The crucial point here is the degree of stratospheric components contained in ice cores, because both supernovae and solar activities can affect nitrogen oxide production in the stratosphere.

The uniqueness of the precipitation environment of Dome F has been shown from ionic and tritium measurements (Kamiyama, Ageta & Fujii 1989). First, the chemical composition there differs sharply from sea salts. Second, as is shown in Table 1, at Point 'DC' (the site of Dome F) the measured tritium content deposited in 1966 in relation to nuclear weapon tests was much larger than those observed at Dome C and Halley Bay, a coastal site. The tritium content was also observed to increase rapidly in the region above 3600m, where the effects of katabatic wind and the circumpolar vortexes become small. All results indicate that most of the ions in the snow at Dome F precipitate directly from the stratosphere, not from the troposphere (see *e.g.*, Kamiyama *et al.* 1989).

3. Future Prospects

The extension of our analyses to deeper and shallower depths is in progress. Our preliminary results suggest several other historical supernova candidate spikes in the past 2,000 years. Next we are planning to analyse another fresh Dome F core with more detailed core dating. As noted above, Dome F may be an appropriate place to investigate stratospheric or astronomical information. We also encourage the examination of our results by using ice cores recovered from other sites in Antarctica.

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Future plans for astronomy at Dome Fuji

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Abstract. In Antarctica the cold and dry air is expected to provide the best observing conditions on the Earth for astronomical observations from the infra-red to the sub-millimetre. To utilise these advantages of Antarctica, we have devised a plan to construct an astronomical observatory at Dome Fuji, which is located in inland Antarctica. For pilot research and site testing at Dome Fuji, we have developed 40 cm infrared and 30 cm THz telescopes, which are durable for the harsh environment of inland Antarctica. As our project for astronomical research at Dome Fuji is approved for the 3-year program of NIPR, we will start the site testing and pilot research for astronomy at Dome Fuji from 2010.

Keywords. Site Testing, Galaxies: evolution, Infrared: general, Submillimetre

1. Introduction

Antarctica is expected to provide the last windows open to space for ground-based astronomical observations. Especially, the highest regions of the Antarctic plateau above 3,000 m elevation are an attractive environment for observational astronomy. Due to the low temperature, thermal noise at infra-red wavelengths is much lower in Antarctica than other temperate sites. The dry atmosphere, with little water vapour, is more transparent from the infra-red to the sub-millimetre. At the summits of the plateau the wind speed is low and the atmosphere is stable, so that no violent storms and blizzards exist. Since the surface inversion layer is thin, we expect good seeing. As well as the South Pole, there are better sites for astronomy at several bases on the summits of the plateau, Dome C, Dome A, and Dome Fuji (also known as Dome F) (see Fig. 1). Astronomers in the world pay attention to these sites, which have extremely good conditions. In this context, a Japanese group has organized a consortium consisting of four universities (Tohoku, Tsukuba, Rikkyo, Nagoya) and two institutes (National Institute of Polar Research and National Astronomical Observatory) to promote astronomy at Dome Fuji.

2. Dome Fuji

Dome Fuji station is located at −77° 19' 01"S, 39° 42' 12"E; 1,000 km inland on the Antarctic Continent at 3,810 m above sea level (see Fig. 1), which is the second-highest summit of the Antarctic ice sheet. It was established in 1995 by NIPR for a deep ice drilling program and atmospheric observations. The year-round average temperature is about −54°C, and in winter the temperature falls as low as −80°C. Due to this low temperature, thermal noise at infra-red wavelengths is much lower in Antarctica than other sites. Although the site is on the border of the aurora oval, this is not a drawback for infrared and THz astronomy. In the 2006 summer we carried out monitoring observations of the atmospheric turbulence in the boundary layer (up to the altitude of 1,000 m) using a SODAR, and of transparency using a 220 GHz radiometer. However, it is in winter that the superior characteristics of Antarctica appear, so that it is necessary for us to examine turbulence and transparency then.

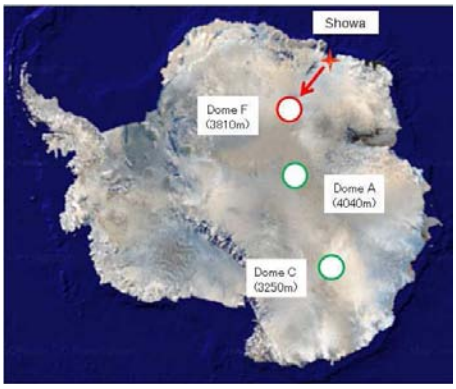

Figure 1. Dome Fuji and Syowa stations.

Figure 2. 40 cm infrared telescope at Rikubetsu, the coldest place in Japan

3. Science Goals

To enjoy the advantages in Antarctica, we are planning to construct 2m-class infrared and 10m-class THz telescopes. Thanks to the low background and high transmittance, a 2m-class telescope has the capability of 8m-class telescopes located at Mauna Kea in the near-/mid-infrared. An infrared survey observation in K-dark band at 2.4 μm will give the deepest and widest dataset for the high-z universe with reasonable cost and observation time. It will reach deeper than those of VISTA and UKIDSS by 1–2 mag. The THz telescope will target dusty galaxies at the high-z universe to study galaxy evolution in its early phase of star formation enshrouded in dust. The long polar night in winter is favourable for searching for variable objects with long periods, such as extra-solar planets in orbit in a habitable zone. The observation of molecules (e.g., CO, H_2O, CH_4) at the second eclipse will provide information on the exo-planet's atmosphere. To undertake such observations we are making near-/mid-infrared instruments for imaging and spectroscopy.

4. Future Plans

NIPR has planned the construction of a new permanent winter-over station with raised floors at Dome Fuji in the next 6-year program, because the old station was buried under snow. Astronomical facilities are also expected. Before the completion of the station, we will start astronomical site testing and pilot research (e.g., CO survey in Galactic plane, faint stellar halo of nearby galaxies, second eclipse of exoplanets) with small telescopes (Lundock & Ichikawa 2008; Murata et al. 2008) and site-testing equipments from 2010. In collaboration with an Australian group (Storey et al.), we will construct a PLATO observatory for Dome Fuji, which will enable us to make unmanned operation of the instruments before the winterover station is constructed.

Acknowledgements

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Site testing on the Greenland Ice Cap

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Abstract.
We present a site testing program initiated at the SUMMIT station on the Greenland Ice Cap. A DIMM was mounted in the SWISS tower, 39 m above the ice level, during a period of 3 weeks in the late Arctic summer 2008. Tracking Polaris, the DIMM obtained continuous seeing measurements. The campaign was hampered by poor weather and the measured seeing was fluctuating, suggesting that the boundary layer was very unstable. However, during short periods, the un-calibrated seeing went below 0.″5, indicating that the free atmosphere seeing above Greenland is not significantly different from what is found above the Antarctic plateau.

Keywords. Site Testing, Atmospheric Effects

1. Introduction

The Antarctic plateau has over the past 30 years been established as an observing platform of increasing importance (Indermuehle, Burton & Maddison (2005)). The key parameters which makes sites on the Antarctic plateau, such as Dome C, Dome F and Dome A, interesting, is the excellent seeing above a very thin boundary layer (Lawrence et al. (2004), Aristidi et al. (2009)), the cold environment and the extremely low precipitable water vapor. A limitation of Antarctic is that only about one third of the sky is visible. A similar site in the Northern hemisphere could complement the Antarctic plateau.

2. Greenland as an Astronomical Site

The only approximately similar site in the Northern hemisphere is the Greenland Ice Cap. Its area is 7 times smaller than Antarctica, but the altitude of summit, the highest point on the ice cap, is 3,221 m and thus almost identical to Dome-C. Because the scale height of the boundary layer under stable high pressure conditions is many orders of magnitude smaller than the extent of these ice caps, there is no reason to believe that the behavior of the boundary layer above the Greenland Ice Cap is fundamentally different from what is observed above the Antarctic plateau. There is thus reason to believe that one can get access to the free atmosphere from a tower of manageable height.

As compared to the Antarctic plateau, the Greenland Ice Cap is much more affected by external weather systems. However, Greenland has 56,000 inhabitants and an infrastructure which works year around, with daily connections between Kangerlussuaq international airport and Copenhagen on commercial airlines. There is also access by sea all year. In the summer season there is access to SUMMIT via USAF C-130 planes. In the winter season there is access with Twin-Otter planes and medical evacuations can be carried out, except for a few days a year when the temperature at SUMMIT drops below -55°C.

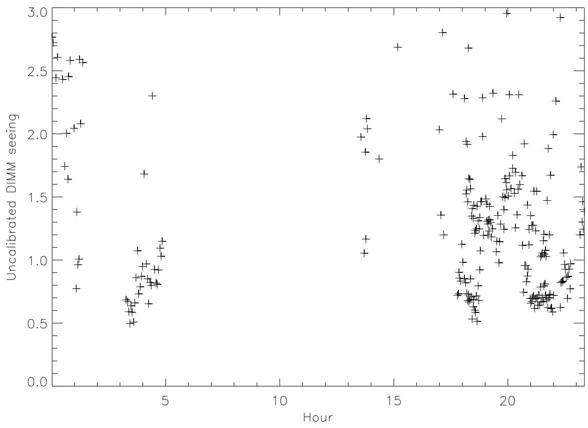

Figure 1. Uncalibrated seeing data for one day during the campaign. The measured differential image motion varies on short time scales, suggesting that the height of the boundary layer varied quite dramatically during these measurements.

3. A Tower-Mounted Seeing Monitor

The reference instrument for seeing measurement is the Differential Image Motion Monitor (DIMM) (Sarazin, M. & Roddier, F. (1990)). The challenge in characterizing sites on ice plateaus with a DIMM is that it must be located above the boundary layer, which has a completely dominant contribution to the seeing. The strategy which was identified as likely to be most successful for measuring the free atmosphere seeing above the Greenland Ice Cap at SUMMIT was therefore to place a DIMM, which can track Polaris, in the 50 m high Swiss tower. This DIMM is pointed to the celestial pole and brings the light from Polaris onto the axis of the DIMM telescope through the use of achromatic prisms. The achromatic prisms are mounted in a wheel which rotates at the siderial rate. The DIMM is foreseen to be able to operate fully autonomously.

4. First Seeing Measurements

During three weeks in August 2008, in the late Arctic summer, the DIMM was deployed in the Swiss tower, 39 m above the ice. Unfortunately the weather was not co-operative. There were clouds during most of the days and more or less continuous data could only be taken during some part of one day. The DIMM has not yet been cross-calibrated against another DIMM, so only un-calibrated seeing measurements are shown in Fig. 1. After calibration, the best seeing measurements are likely 10%-20% better, i.e. closer to $0\farcs4$. Permanent installation of the DIMM is intended from 2010 or 2011.

Acknowledgements

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Astronomy from the Antarctic Plateau: a global personal vision

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Abstract. The Antarctic Plateau (Dome C, also Dome A) is emerging as an especially good site for astronomical observations (high, dry, cold, no wind, good free seeing above a certain boundary layer). Over the last few years, several meetings and conferences took place to discuss potential astrophysical science cases for such exceptional atmospheric conditions. I summarise my personal conclusions from these discussions and present a global vision (roadmap) for Antarctic Astronomy for future optical, near-IR, thermal-IR, and far-IR/sub-mm observations. The need for international collaboration between Europe, Australia and China is stressed.

Keywords. Antarctica, Telescopes, Site Testing, Instrumentation.

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1. Introduction

The main advantages of the Antarctic Plateau ($\sim$3,200 m) for astronomy are the weather conditions. At Dome C it is cold, high, dry and the sky quite stable. There are few clouds, hardly any wind and there are few aurorae. There is excellent night-time seeing in the Antarctic winter (May – August) above a ground layer of some 30 m, with a median of about $\sim$0.3 arcsec in the visible. There are also 4 hours of excellent seeing on the ground during day-time afternoon in the Antarctic summer (Nov – Feb), especially in the thermal infrared (remember the FWHM of the seeing scales with the inverse 1/5 power of the wavelength) which allows us to make infrared astronomical observations in Antarctica in the summer-time, i.e. when the conditions are much less harsh than in the winter time and without building towers (cf. Zinnecker (2007)). The Italian 80 cm IRAIT telescope will be the first to prove the concept. Of course, optical observations require winter-time which in turn require telescopes on towers (except long-time series optical photometric observations, where the seeing is not critical).

Although Dome A and Dome F may be slightly better astronomical sites (see the contributions by X. Cui from China and T. Ichikawa from Japan, respectively, in this Special Session and Proceedings), as a matter of fact Dome C and its infrastructure, i.e. the French-Italian Concordia station, exist today and could be used (or even expanded) for optical/infrared/sub-mm astronomy, political problems notwithstanding.

2. How best to exploit the Antarctica Plateau for astronomy now

Astronomy in Antarctica is already going on at the Amundsen-Scott South Pole station. The South Pole 10 m radio/sub-mm telescope is installed and taking data and the BICEP 25 cm aperture is studying CMB polarisation anisotropy (J. Carlstrom; Y.D. Takahashi, these Proc.). This raises the question whether Dome C should also have a big radio antenna, to carry out sub-mm observations at 450 and 350 microns, and pushing for THz observations in the 200 microns window. This would be a very good idea considering the very low precipitable water vapour (PWV) values, often less than 0.25 mm. However, to be competitive a 25 m dish is needed (see the science case described by Minier (2008)) which would be very expensive and would stretch the current logistics at the Dome C Concordia station. In my view, this discourages going for such a Antarctic Submillimetre Telescope (AST) telescope at the present time; furthermore, there is a major push for Dome A which is claimed to be an even better sub-mm site than Dome C and where our Chinese colleagues plan to build a 15 m-class sub-mm–telescope. Finally, we should probably wait to see whether the 25 m CCAT (Cornell–Caltech Atacama Telescope, now under consideration) will be realised on a very high site (5,600 m) near Cerro Chajnantor or not.

Leaving aside sub-mm telescopes, what should we do in optical and infrared astronomy? We have mentioned the advantages of the much reduced sky background in the thermal infrared regime (3 – 5 microns) compared to more temperate sites (factor ~ 30) due to the very cold atmosphere. There are several science cases for this part of the spectrum using a 2 – 3 m-class telescope (Burton (2005)), including molecular hydrogen surveys of the inner Galaxy, cool protostar and evolved star searches in the LMC/SMC and also Galactic star forming regions in the southern hemisphere (e.g. Carina, Vela, etc.). These would all benefit greatly from the increased spatial resolution with an Antarctic 2.5 m telescope, compared to Spitzer data obtained with a 85 cm telescope (factor 3 gain in angular resolution at 4 microns). Follow-up studies for NASA's soon-to-be-launched WISE (40 cm) near-to-thermal infrared all-sky survey telescope will also be an issue. It has been questioned whether all this would represent 'killer' science as opposed to fairly unique science. Perhaps the best use of a 2.5 m telescope (small enough to be affordable now but large enough to be a pathfinder for future large structures) may be to exploit the K_{dark} window (2.4 microns, Casali (2007)) where the reduced sky background allows us to really go deep (much below UKIDSS and VISTA) and carry out extra-galactic near-infrared surveys down to $K_{dark} = 25$ mag. to study distant galaxy populations at high redshifts. JWST will provide competition, but only in principle and not in practice, as the FOV of JWST/NIRCAM is 3.4×3.4 arcmin. while an Antarctic survey telescope would have 20×20 arcmin. or more, depending on the cost of IR-detectors.

3. Roadmap for a Dome C Astronomical Observatory

I consider a roadmap to be a temporal sequence of major milestones, with a beginning and an end. It should give realistic timescales to implement telescopes or instruments of increasing complexity. The beginning and first milestone would be to operate and obtain data with IRAIT as soon as possible (2010). The CAMISTIC bolometer camera on IRAIT will probe the quality of the site for sub-mm/THz (particularly for 200 microns) imaging observations. The second milestone should be an IR-optimised PLT–like telescope, if necessary with ground layer adaptive optics (first light in 5–10 years, 2015–2020). This should take advantage of the good Antarctic summer seeing and start operating in the day-time, doing 0.3 arcsec 2.5–5 microns imaging. At the same time, robotic optical telescopes like ICE–T could operate in the Antarctic winter, without towers (as the seeing is not critical for long-time series photometry). I would leave the lead for 2–4 m class optical telescope to our Chinese friends. The third milestone (in 10–15 years time) would be ALADDIN, the two-telescope thermal–IR interferometer; it would then still be in time to act as an exo-zodi precursor for DARWIN (the latter won't happen before 2025). The 4th major milestone (around 2030) could be a THz interferometer array (of the order of a dozen telescopes) complementing ALMA and SOFIA and being a pathfinder for a far-IR interferometer in space (ESA's future FIRI mission). The ultimate and 5th milestone that I see on the horizon (in the 2030-2040 time frame) would be an optical/IR kilometric array of 2 m class telescopes.

4. The need for international collaboration

Astronomy in Antarctica is expensive for any country trying to establish and maintain a permanent base on this remote continent. For example, the total operating costs of the Concordia station are 8 million Euro per year. Still, astronomy in Antarctica is much cheaper than ESA missions from space. Space projects are usually done in co-operation between several nations. Similarly, it would be too costly if every nation would want to build their own suite of telescopes in Antarctica. We have to share our resources. This means France and Italy will *invite* other European partners to participate in astronomy from Dome C. It also means that Dome C and Dome A should each concentrate and specialise on the best possible science doable from their respective sites. While Dome C might be best suited for near-infrared and thermal-infrared observations, Dome A (at 4,200 m) might be best for sub-mm and THz astronomy. Collaboration would reduce cost and help to exchange scientific, technical, and logistic experience. These and other issues could be discussed at an IAU symposium on Antarctic Astronomy during the next IAU General Assembly in 2012 in Beijing/China. By then, Chinese plans for Dome A will have firmed up, while Europe and Australia may have teamed up again at Dome C pursuing their common interests for a PLT-like telescope. The first IRAIT measurements and results at around that time would hopefully show that Dome C lives up to its expectation as the premier astronomical observing site on the planet.

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CSTAR and future plans for Dome A

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Abstract. The first set of Chinese Antarctic telescopes at Dome A is called CSTAR. It consists of four 14.5 cm wide-field telescopes and was installed at Dome A during the traverse of 2007/2008. CSTAR successfully operated for 135 days in 2008 and for more than 200 days in 2009. This paper briefly introduces recent developments in Chinese Antarctic astronomy and their international collaborative activities. It also describes future plans for Dome A, as the building of Kunlun Station began in January of this year.

Keywords. Antarctica, Telescopes, Site Testing.

1. Introduction

In 2004, a Chinese traverse team led by Yuansheng Li, the senior researcher of the Polar Research Institute of China (PRIC), reached Dome A, from Zhongshan Station. Shortly following this event, the first time humans had ever been to Dome A, Lifan Wang & Xiangqun Cui, with the collaboration of the LAMOST project, organised a workshop on "Wide Field Survey Telescopes at Dome C/A" in Beijing between 3 to 4 June of 2005. This workshop started Chinese astronomical activities and the international collaboration at Dome A. In June 28, 2005, organised by Jun Yan, Lifan Wang and Xiangqun Cui, a further meeting on "Antarctic Astronomy at Dome A" was held at Purple Mountain Observatory (PMO) in Nanjing. In November 2005, the meeting "Wide Field Astronomy on the Antarctic Plateau" was organised by Lifan Wang & Enrico Cappellaro in Padua, Italy. Through the efforts of Jun Yan, Xiangqun Cui, Longlong Feng & Lifan Wang, the Chinese astronomical community joined the PANDA project, which was a Chinese Key international program for the IPY between 2007 to 2010. A MoU between USNW–NAOC–PRIC was signed for collaborations on Antarctic astronomical research in December 2006. This includes the international collaboration on site testing of Dome A with Texas A & M University, USA, University of New South Wales, Australia, California Institute of Technology, USA, Solar Mobility, Australia, Thirty Meter Telescope Project, USA, University of Arizona, USA and the University of Chicago, USA. In addition to these activities, the Chinese Center for Antarctic Astronomy (CCAA) was established on December 24, 2006 in PMO, including the member institutes of Purple Mountain Observatory (PMO), Nanjing Institute of Astronomical Optics & Technology (NIAOT), National Astronomical Observatories (NAOC), Polar Research Institute of China (PRIC), Institute of High Energy Physics (IHEP), Shanghai Astronomical Observatory (SAO), Nanjing University, Tianjin Normal University and the Institute of Electronic Engineering.

Since then, in early 2007 building of the Chinese Small Telescope Array (CSTAR), which consists of 4×14.5 cm wide field telescopes, began in China, and the international

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collaboration on site survey instruments using the PLATO laboratory started. In the 2007/2008 traverse CSTAR and PLATO were successfully installed and operated (including the site survey instruments SNODAR, GATTINI, Sonics & Pre-HEAT) by Dr. Xu Zhou and Dr. Zhenxi Zhu. In the 2008/2009 traverse Dr. Xuefei Gong successfully maintained these instruments. The Chinese Kunlun Base Station at Dome A was also established. By January 27, 2009 236 square meters of the main building had been built for Kunlun Station. The complete building will be constructed next summer, during the 2009/2010 traverse.

2. CSTAR

CSTAR consists of four 14.5 cm small telescopes with a 20 sq deg FOV (4.5 x 4.5 degrees) and 1k x 1k frame transfer CCD for each, and with g, r, i filters and unfiltered respectively. The image quality is 90% of the light energy circled in 2 pixels. A fixed observing direction of the South Pole area was adopted for these pioneering observations.

The scientific purposes of CSTAR are to: (1) measure atmospheric extinction, (2) measure sky brightness, (3) search for variable stars, (4) search for transiting exo-planets and to (5) find bright SNe, Novae or afterglows of GRBs.

After 135 days observation with 20 seconds exposure time for each image, 271,041 good frames were obtained. Some results have been obtained from the data processing will be published soon.

See Cui, *et al.* (2008), Gong, *et al.* (2008), Kulesa, *et al.* (2008), Lawrence, *et al.* (2008), Lawrence, *et al.* (2008), Tothill, *et al.* (2008), Yang, *et al.* (2009) and Yuan, *et al.* (2008) for papers describing Chinese activities at Dome A.

3. Future Plans for Dome A

2008-2010:
- Continue site survey and astronomical observations
- Upgrade PLATO and CSTAR
- Develop and operate a Fourier Transform Spectrometer (FTS)
- Develop and operate $3 \times$ 50cm/70cm modified Schmidt telescopes (AST3)

2011-2015:
- Continue operation of FTS and AST3
- Develop and operate a 1m Optical/Infrared telescope
- Develop and operate a 5m Sub-mm/THz telescope

2012-2020:
- Develop and operate a 4m wide field Optical/Infrared telescope
- Develop and operate a 15m Sub-mm/THz telescope

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