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Edited by

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ASTROPHYSICS FROM ANTARCTICA

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COVER ILLUSTRATION: THE SOUTH POLE TELESCOPE

The 10 m diameter South Pole Telecope (or SPT), seen under the light of the full Moon on a clear night, just before sunrise at the Pole. The SPT is located in the Dark Sector Laboratory (DSL) at the Amundsen–Scott South Station, 1 km away from the geographic South Pole.

The SPT is being used to observe the Cosmic Microwave Background Radiation, surveying a 2,500 square degree area of sky. The science objectives include searches for galaxy clusters using the Sunyaev Zel'dovic effect and making the highest angular resolution measurements of the CMB power spectrum. The results are being used to constrain models for Dark Energy and other cosmological parameters.

Photograph taken by Daniel Luong-Van in September 2010, wintering scientist for the SPT during 2010 and 2011. The picture was taken with a Canon 7D camera about 1.5 km away from the telescope in order to make the Moon and the SPT comparable in scale. It is interesting to note that the band of white is not cloud but is a mirage, being the reflection off the snow surface.

IAU SYMPOSIUM PROCEEDINGS SERIES

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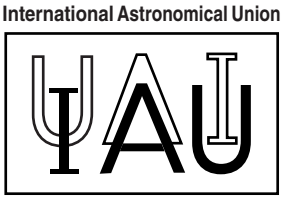

ASTROPHYSICS FROM ANTARCTICA

PROCEEDINGS OF THE 288th SYMPOSIUM OF THE INTERNATIONAL ASTRONOMICAL UNION HELD IN BEIJING, CHINA AUGUST 20–24, 2012

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Preface

Overview

The remarkable environment of Antarctica offers many advantages for astronomical observations. Over the past two decades this field of scientific endeavour has developed dramatically and Antarctic-based observatories now regularly contribute to front line astrophysical research, in particular in the measurement of the cosmic microwave background radiation. Scientific stations where astronomy is a major focus now exist at five locations on the Antarctic plateau, as well as on the Antarctic coast, and are operated as international facilities. This Symposium examined the contributions to astrophysics that Antarctic telescopes have made. It reviewed our understanding of the Antarctic environment, in particular that on the high Antarctic plateau. It considered the developments taking place across the continent. It also looked at the parallel opportunities offered by the Arctic environment. Finally, the Symposium examined the science that may be best addressed by future facilities on the Antarctic continent.

The Science

Over the past decade astronomy has matured as one of the fields of science that is being pursued in Antarctica, notably through high angular resolution studies of the cosmic microwave background, including the demonstration that the Universe is flat (de Bernardis *et al.* 2000), the first measurements of polarization of the CMB E–mode (Kovac *et al.* 2002), measurement of the kinematic and thermal SZ–effect in galaxy clusters (Staniszewski *et al.* 2009) and the demonstration that at high-l the background radiation is dominated by emission from dusty galaxies (Leuker *et al.* 2010). Several experiments are now being conducted, worldwide, to search for the B–modes of the CMB, with a large part of this effort taking place in Antarctica, using both ground-based and balloon-borne experiments. Over the same time period there have been science programs conducted in Antarctica from the optical to the sub-millimetre wavebands, and also a range of facilities constructed for high energy astrophysics, particularly for neutrino detection. These science achievements of astronomy in Antarctica have been summarised in the recent review of the field by Burton (2010).

The Stations

Concurrently, major infrastructure has been developed over the Antarctic plateau, undertaken by several different nations. The US have completed a major upgrade to the Amundsen–Scott South Pole station, as well as the construction of the first neutrino telescope (IceCube), in addition to an on-going CMB program. France and Italy have completed the building of the Concordia Station at Dome C, and have wintered personnel there since 2005. Dome A was first visited by humans that year and China has begun the construction of Kunlun station at the site. Dome Fuji station at Dome F has had personnel winter over for ice-core drilling, and astronomical site testing has recently been initiated there. Ridge A was first visited this very year, and a fully robotic telescope installed by the USA and Australia. Long durations balloons equipped with astronomical payloads are now being regularly launched from the US McMurdo station on the Antarctic coast with further extended missions under development.

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The Environment

Our understanding of the Antarctic environment as it pertains to the conduct of astronomical observations has improved dramatically over the past decade. Through the use of autonomous observatories at the South Pole, Dome C and Dome A, considerable quantitative information is now available on the properties and behaviour of the sky background and atmospheric transparency, as well as its stability over the high plateau. In particular, the special properties of the narrow surface boundary layer are being revealed. The median thickness of the boundary layer is now known to be less than 15 m thick in winter at the highest places on the plateau, and is often only half that height (e.g. Bonner *et al.* 2010). Further development of automated observatories at Dome A, Dome F and Ridge A is underway to expand this knowledge of the Antarctic environment. Test-bed astronomical facilities are also being operated at Domes A and C, prior to the completion of full infrastructure at these sites.

The Astronomy

Astrophysics has now been conducted in Antarctica in the optical, infrared, terahertz (or far-infrared) and sub-millimetre portions of the spectrum with a variety of small-scale facilities, undertaking studies mostly of stars, gas and dust in the Galaxy. Telescopes such as the 60 cm infrared SPIREX and the 1.7 m sub-millimetre AST/RO have demonstrated the ability to undertake new science in these bands in Antarctica. Of particular note is the recent demonstration of the opportunity for time series investigations in the optical domain with an extremely high cadence and duty cycle (the CSTAR experiment; Yang *et al.* 2010) at Dome A, and at Dome C for precision photometry to be undertaken (sIRAIT; Strassmeier *et al.* 2008) and the monitoring of exoplanet transits (ASTEP-South; Crouzet *et al.* 2010). Thermal infrared large scale repeated surveys, such as proposed for the PLT (Dome C) and KDUST (Dome A) telescopes, would also greatly benefit from Antarctic atmospheric conditions.

The Role of the IAU

The IAU has a special role in furthering the development of astronomy in Antarctica because of the unique political situation on the continent. No country owns Antarctica. International collaboration and co-ordination is the modus operandi for Antarctic science. This is facilitated through SCAR, a fellow ICSU body with the IAU with specific interests for Antarctic science. IAU recently affiliated with SCAR, the ninth scientific union to do so. Astronomy is not, however, a "traditional" Antarctic science. It faces particular difficulty in attracting funding for infrastructure as a result of many national funding arrangements. The IAU can play an important role in furthering astronomy in Antarctica through supporting the holding of a Symposium in the field, so giving recognition to both the maturing of the field as well as to the science potential it offers.

Chinese Plans for Antarctica

China, the host country for the IAU's XXVIII GA in 2012, also has a special interest in the development of astronomy in Antarctica at its newly established Kunlun station, following the first human visit to the site by China in just 2005. The first astronomical experiments are now taking place there during the construction phase of the station. Under the Chinese government's 12^{th} 5-year plan two major facilities would operate at

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Dome A when the station is completed: for the optical / infrared the 2.5 m KDUST telescope and for the THz waveband the 5 m DATE5 telescope.

Opportunities in the Arctic

The Arctic regions also offer several sites with comparable characteristics to Antarctica, notably in Greenland and in Ellesmere Island in Canada. These are high ($> 2,500$ m), dry locations on the summits of large islands located in the Arctic Ocean. Several sites are now under investigation there regarding their suitability for astronomical observations. Sub-orbital programs are also being planned for the Arctic regions, so as to achieve the full-sky coverage needed for large-scale polarization surveys of the CMBR. The science opportunities presented by Arctic observatories was also a theme at the meeting.

Looking to the Future

"Astrophysics from Antarctica" examined all the above themes. The Symposium reviewed our current understanding of the Antarctic environment as it pertains to astronomical observations. It looked at the major achievements of astrophysics in Antarctica to date, in particular with the CMB, but also in high energy astrophysics (neutrinos), radio astronomy (sub-millimetre and THz) and optical/IR astronomy. The Symposium also examined international developments in Antarctica, in particular at the high plateau stations, and the science themes that are emerging for them. In turn, these have many common needs for infrastructure, as well as in challenges that need to be met. To facilitate their furtherance, the Symposium also overviewed this international endeavour, including both the science programs being conducted through national Antarctic programs and the facilities being built or considered for their pursuit. Large international projects are increasingly driving developments in astronomy, and Antarctica and its method of government provides a locale where a "World Observatory" might be built. A particular focus was given to where Antarctic facilities can best contribute to addressing the big science questions posed for astronomy in many national reviews. The Symposium ended by seeking a vision for the future development of international facilities on the continent.

This Volume presents the papers delivered on all these subject matters at IAU Symposium 288, "Astrophysics from Antarctica", held in the China National Convention Center in Beijing from 20–24 August, 2012.

Michael Burton and Xiangqun Cui,
Co-chairs SOC, IAU Symposium 288
Sydney & Nanjing, November 1, 2012

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The Symposium website, at www.phys.unsw.edu.au/IAUS288, was supported by the School of Physics at the University of New South Wales in Australia.

Participants at IAU Symposium 288, "Astrophysics from Antarctica", held from 20–24 August 2012, in the China National Convention Center in Beijing's Olympic Park, as part the the XXVIII General Assembly of the International Astronomical Union.

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Editorial

One hundred years ago, on a bright and clear day on December 5, 1912 three young explorers – Francis Bickerton, Alfred Hodgeman and Leslie Whetter – were traversing across the sastrugi in the coastal highlands of Adelie Land in Antarctica, dragging a sledge along behind them. They had just abandoned an 'air tractor' which they were using to pull their load on their journey of discovery, and were struggling across the rough surface. They saw ahead of them a shiny black object, partially buried in the snow. About the size of one's hand, they immediately recognised it to be a meteorite, for how else could it have got there, all alone on top of an immense visage of ice?! They picked it up for their collection and later study. Now known as the Adelie Land Meteorite, and displayed in the Australian Museum in Sydney, it was the first meteorite to be found in Antarctica, though it was to be another 11 years before this find was written up as a scientific paper (Bayly & Stillwell, 1923). It was the start of astronomy in Antarctica. However, it was to be almost half a century later before another meteorite was found. Indeed, it was not until 1969, when several different types of meteorites were found close together (Nagata, 1975), that it was realised that Antarctica provides a superb platform for finding meteorites on account of the great flows of the ice, gathering objects that fall upon them and taking them to blue-ice fields where the snow is ablated by the wind, leaving them easy to spot and so collect.

Astronomy in Antarctica has had a slow gestation. Cosmic ray studies were the first astronomical science programs, being instigated around the time of the International Geophysical Year (1956–57). It was not until 1979 that the first astronomical science was carrried out at the South Pole, using an optical telescope to measure oscillations in the interior of the Sun (Grec, Fossat & Pomerantz, 1980). This was followed by a variety of experiments at millimetre-wavelengths looking for interstellar dust and the cosmic microwave background radiation. It was not until the 1990's, with the instigation of CARA, the Center for Astrophysical Research in Antarctica, at the South Pole, that astronomy in Antarctica began to be undertaken in earnest†. Since then, the growth in the field has been rapid.

Today astronomical investigations are being carried out at five locations on the Antarctic plateau (South Pole, the ice Domes A, C and F, and at Ridge A), as well as long duration ballooning from McMurdo station on the coast. The images on the following pages provide a flavour of the activity at each of these sites. A rich variety of different types of astrophysics is now being being accomplished using data gathered in Antarctica.

The IAU recognised the potential for astronomy in Antarctica in 1991 at the XXI General Assembly in Buenos Aires, creating the 'Working Group for the Development of Astronomy in Antarctica', under the chair of Peter Gillingham. It was set up as an inter-divisional working group under Division IX (Optical/IR Techniques) and Division X (Radio Astronomy). Since then meetings on Astronomy in Antarctica have been held at the GA's in The Hague, Kyoto, Sydney, Prague and Rio de Janeiro‡. The size and context of these meetings has grown over time, with the last three being designed "Special Sessions", and their proceedings appearing in the IAU's *Highlights of Astronomy*.

† For a history of astronomy in Antarctica during these early years see Indermuehle, Burton & Maddison, 2005.

‡ See www.phys.unsw.edu.au/jacara/iau/.

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With the XXVIII GA in Beijing in 2012, widespread interest internationally in the prospects for astronomy in Antarctica, and with China beginning the construction of Kunlun Station at the highest point on the Antarctic plateau (Dome A), the time was ripe for the proponents of astronomy in Antarctica to seek to hold an IAU Symposium on this field, and so receive recognition from their peers of the maturity of this field of endeavour. The IAU agreed, and hence was born IAU Symposium 288, "Astrophysics from Antarctica"¶. In the pages ahead you will find papers written by the presenters at this Symposium describing a wide variety of activities in a vibrant field.

IAUS288 is the first, but it also may be the last, IAU Symposium devoted to the full subject matter of astronomy in Antarctica. For, having entered the mainstream, the results from Antarctic experiments will be reported more and more at discipline-specific meetings in the future, alongside results from the multitude of facilities that other domains of astronomy bring to the science.

We hope you enjoy reading these Proceedings!

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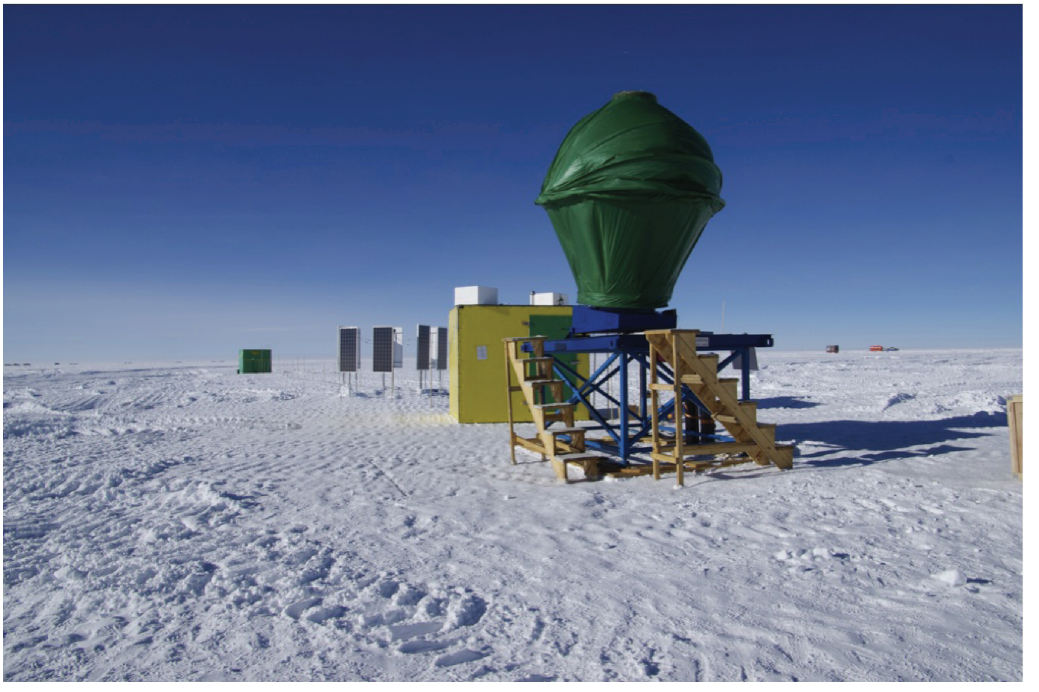
¶ www.phys.unsw.edu.au/IAUS288.

Top: The US Amundsen–Scott Station at the South Pole. Four CMB telescopes can be seen: SPT, BICEP, ACBAR and QUAD/DASI, with the IceCube neutrino telescope under the ice to left. An LC130 aircraft is taking off. Credit: Steffan Richter. Bottom: The French–Italian Concordia Sation at Dome C. Labelled are the cluster of experiments that make up the Concordiastro site testing program. The twin towers of the station are to the rear. Credit: Karim Agabi.



The 0.5 m AST3 optical telescope at the Chinese Kunlun station at Dome A. The yellow and green buildings behind are the Australian-built PLATO laboratory. Credit: NIAOT.

The Tohoku-DIMM placed on the mount for the AIRT 40 cm infrared telescope at the Japanese Dome Fuji Station at Dome F. Credit: Hirofumi Okita

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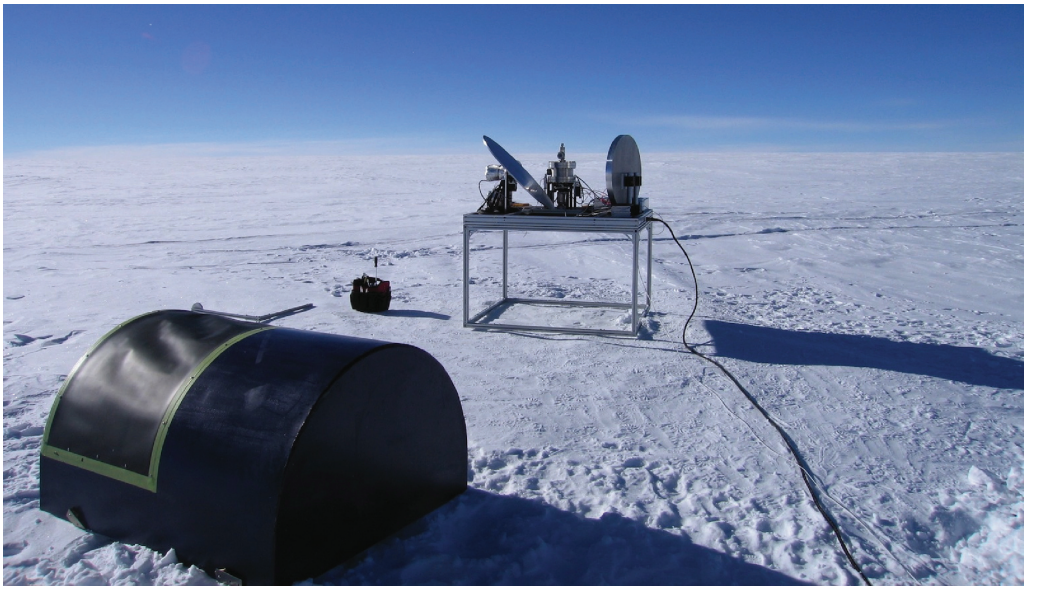
Launch of the 2 m BLAST THz telescope from the Long Duration Balloon Facility (LDBF) at McMurdo Station. The Mount Erebus volcano is in the background. Credit: Mark Halpern.



The 60 cm HEAT THz telescope deployed at the SCAR international station at Ridge A by the USA and Australia. Credit: Craig Kulesa.

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