Working Paper WP20a XXX SCAR Agenda 5.7

Scientific Committee on Antarctic Research

Astronomy & Astrophysics from Antarctica (AAA)

Proposal to establish the AAA Scientific Research Programme

VERSION: 15 May 2008

Expected Duration: 2008 – 2012

Estimated SCAR funding: $US60,000

Programme Summary

Astrophysical observations require minimum interference from the Earth's atmosphere: low thermal background, low absorption, and high angular resolution. The moderate "launch costs" for Antarctic plateau observatories make them an extremely attractive alternative to space.

Astronomy from the Antarctic came of age in the last decade with a cosmological result of major significance. Balloon-borne millimetre observations of the cosmic microwave background from the first BOOMERANG flight led directly to the discovery of the zero-curvature Universe. Submillimetre astronomy has also prospered in the Antarctic: the South Pole Telescope is expected to probe the nature of "dark energy", the biggest constituent of a "flat" Universe. Optical and infrared astronomy can define the "equation of state" of the Universe, probe the interior structures of stars (including the sun) using time-domain astrophysics, and search for new planetary systems, while particle astronomy answers fundamental questions about the nature of the Universe.

Astronomy & Astrophysics from Antarctica will facilitate international astronomical programs in Antarctica. These programs are aimed at understanding the overarching ecological processes in the Universe, from the birth of stars and of planetary systems around other stars, to the return of heavy-element enriched materials to the interstellar medium, and the formation of new molecular clouds.

Astronomy & Astrophysics from Antarctica will add value by fostering international collaboration in order to permit goals to be achieved that are beyond those of single national programs. Some themes for AAA will be site-testing and validation (including potential new sites in the Arctic), organization of scientific goals that involve a multi-wavelength approach and hence multiple facilities, creation of a roadmap for major facilities, and stimulation of international cooperation in the development of these facilities. Cross-disciplinary links outside astronomy will also be forged.

A strong AAA program will also strengthen the accomplishments of SCAR, which exists to promote frontier science driven coordination and collaboration. SCAR can enhance the scientific value of Antarctic astronomy by moving to establish the AAA Scientific Research Programme at this time. The benefits of coordination and international collaboration will be keenly felt.

Once established, AAA will seek endorsement from the International Astronomical Union to have its launch recognized as an activity of the International Year of Astronomy in 2009.

1. The objectives of the programme

Broadly stated, the objectives of *Astronomy & 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.

To achieve this, *Astronomy & Astrophysics from Antarctica* will:

- Coordinate site-testing experiments to ensure that results obtained from different sites are directly comparable and well understood,
- Build a data base of site-testing data that is accessible to all researchers,
- Increase the level of coordination and cooperation between astronomers, atmospheric physicists, space physicists and meteorologists,
- Extend existing Antarctic site-testing and feasibility studies to potential Arctic sites; for example, in Greenland and Canada,
- Define and prioritise current scientific goals,
- Create a roadmap for development of major astronomical facilities in Antarctica,
- Stimulate international cooperation on major new astronomical facilities in Antarctica.

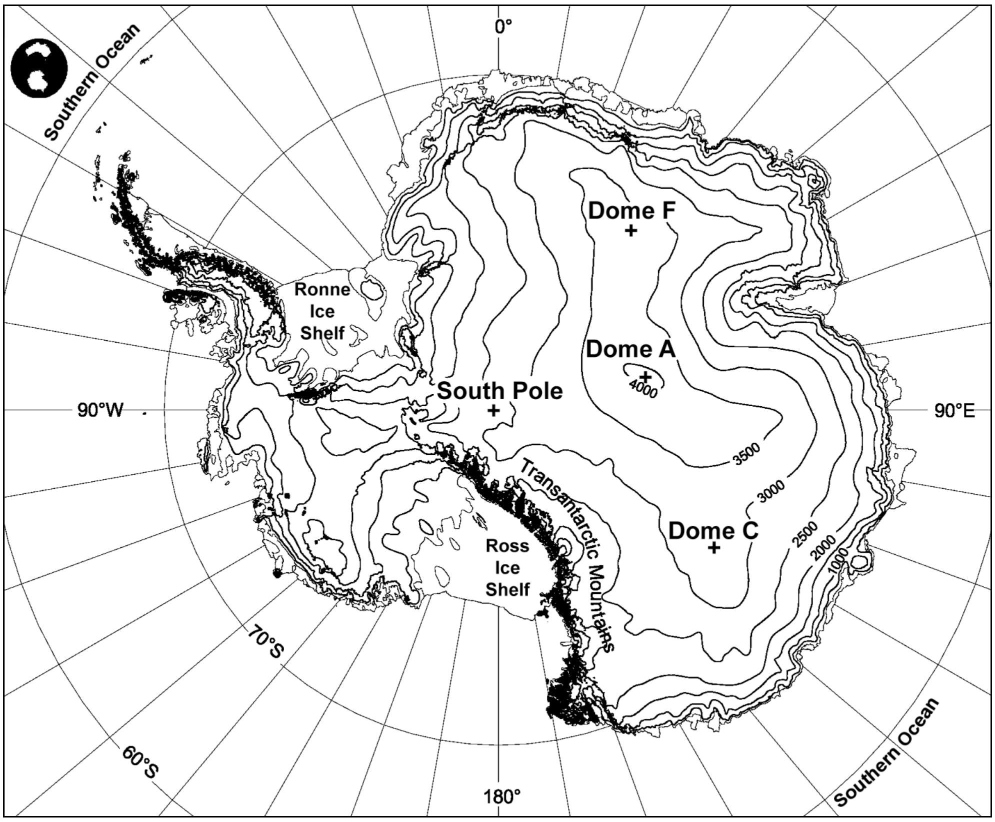
2. Scientific background

Over the next decade, the world will invest several billion dollars in new ground-based astronomical telescopes. Astronomical telescopes must be placed at the best possible sites if they are to achieve their full scientific potential. The earth's atmosphere places limitations—sometimes extremely severe ones—on the sensitivity, spatial resolution and wavelength coverage of all telescopes, particularly in the optical, infrared, terahertz and submillimetre parts of the spectrum. This is why some observations can only be carried out from space, despite the enormous cost.

The high Antarctic plateau, with an elevation that ranges from 2830m at South Pole to 4039m at its highest point, Dome A, has been found to offer unique and impressive advantages for astronomy over temperate sites. The atmospheric transmission from optical to millimetre wavelengths is unsurpassed. Because the sky is both extremely transparent and exceptionally cold, the infrared sky brightness (which sets an ultimate limit to the sensitivity of infrared observations) is correspondingly reduced—at some wavelengths by up to a factor of 100 over even the best temperate sites. In addition, the absence of a high-altitude jet stream combines with an exceptionally stable middle atmosphere to offer remarkably good image quality, compromised only by a very thin turbulent layer just above the ground.

A small prototype telescope, SPIREX, was deployed to the South Pole to demonstrate that such sensitivity gains could be realised in practice (Hereld 1994, Fowler *et al.* 1998). The success of this experiment was remarkable, and included the production of a map at 3.5 microns that was the deepest ever obtained at that time by any telescope. SPIREX was just 60 cm in diameter, and competed in an era of 8 and 10 metre diameter telescopes in Hawaii and Chile.

The Antarctic Submillimetre Telescope and Remote Observatory (AST/RO) made pioneering observations from the South Pole at sub-mm wavelengths for over a decade, beginning in 1995. Although again only of modest size (1.7 meters), AST/RO achieved many notable successes, including the first detection of neutral carbon in the Magellanic Clouds – our nearest galactic neighbours (Stark et al 1997). As SPIREX did in the infrared, so has AST/RO demonstrated beyond doubt that the unique characteristics of the Antarctic atmosphere can be used to great advantage for astronomy.



Map of Antarctica, showing the high plateau "dome" stations.
Basic map courtesy the Australian Antarctic Data Centre.

Some of the first scientific studies in Antarctica were of cosmic rays. Since 1956, neutron and muon detectors have operated at Mawson Station on the coast, and have later been joined by other such facilities.

Taking advantage of the vast volume of pure ice at the South Pole, the AMANDA (Antarctic Muon and Neutrino Detector Array) project has operated now for a decade (Halzen 1998). Consisting of hundreds of photomultiplier tubes lowered into bore holes in the ice, AMANDA detects the Cerenkov radiation of relativistic muons created when neutrinos interact with matter. Although the neutrino flux from the sun alone is around 10^{11} particles/cm^2/sec at the earth, their interaction with matter is so weak and infrequent that only a 100 or so neutrino events are detected each year by AMANDA.

A further important characteristic of Antarctica the presence of the circumpolar vortex. A high-altitude balloon launched from an appropriate site, such as McMurdo, travels around the continent at roughly constant latitude before over-flying the launch site some two weeks later. In this way astronomers can achieve hundreds of hours of data from a single flight, receive constant solar illumination on the solar panels, and have a better-than-average chance of recovering the payload intact. The BOOMERanG experiment, a collaboration between Italian and US teams, has demonstrated the benefits that such long integrations can have in cosmological studies (de Bernadis *et al.* 2000).

Data from the first long-duration flight of BOOMERanG in 1998 produced the stunning result that the Universe appears to be geometrically “flat”. This was later confirmed (in 2003) by the space mission, WMAP. One of the major implications of this result is that the matter we see around us (stars, gas, dust etc.) makes up less than 10% of the Universe. The vast majority of the Universe consists of something we currently know almost nothing about.

These pioneering facilities are just a few of the extensive suite of experiments that have been conducted in Antarctica by astronomers over the past few decades. (For a more detailed review, see Storey 2005.) However, they serve to illustrate the importance of Antarctica. Astronomy is now becoming highly international, as major facilities are planned that require resources beyond those of a single nation. SCAR has an important role to play here, in facilitating international agreements that will lead to the deployment of cutting-edge Antarctic observatories.

The advantages of the Antarctic Plateau are sufficiently well demonstrated that a number of medium-scale astronomical facilities have already been built, including the SPT, a 10 metre diameter sub-millimetre telescope at the South Pole (Ruhl *et al.* 2004). Other projects, are under construction such as IceCube (Ahrens *et al.* 2004). IceCube will populate a cubic kilometer of ice with photomultipliers; its improved sensitivity will herald a new era of particle astrophysics. Still others projects are in the design phase; for example, the Australian/European PILOT (Pathfinder for an International Large Optical Telescope), a proposed 2.4 metre optical/IR telescope.

3. Programme rationale and justification

The objectives of the *Astronomy & Astrophysics from Antarctica* programme can be broken down into a set of sub-programmes, or themes:

A. Site testing, validation and data archiving. There remain many unanswered questions about Antarctic site conditions that are crucial to the design of large telescopes, including those using adaptive optics or interferometry. These questions concern cloud cover, sky brightness and transparency (including water vapour content), and in particular the nature and distribution of atmospheric turbulence. In answering these questions, important insights into atmospheric processes are revealed. These data can be used by atmospheric physicists to understand air-surface interaction including heat and momentum transfer, and chemical mixing. These poorly understood processes are a crucial component of General Circulation Models (GCM) and regional scale atmospheric models, and an enhanced understanding of such processes in polar regions are required to improve the accuracy of global climate prediction.

Achieving a set of well-calibrated data that allows quantitative comparison of different Antarctic sites is difficult – particularly when individual research groups, often using techniques and instruments developed in their own laboratories, make measurements at only one location. *Astronomy & Astrophysics from Antarctica* has a vital role to play here in coordinating international studies that allow comparative data to be taken at different

Antarctic locations, preferably using an agreed set of instrumentation. This opportunity of cross-site comparability will be extended to the atmospheric modelling community, as most of the likely sites for astronomy would also yield unique data sets for model validation.

Coordination of these activities with the atmospheric, meteorological and ionospheric communities is vital if the maximum value is to be gained from site-testing campaigns. Wherever possible campaigns should be planned from the outset as an interdisciplinary collaboration, minimizing wasteful duplication and with mechanisms in place to ensure that the data are equally useful not only to astronomers but to other Antarctic researchers as well.

Once these properly calibrated data on site characteristics have been obtained, they should be made freely available through a web-accessible archive.

B. Arctic site testing. Stimulated by the International Polar Year, investigation of potential Arctic sites is now getting underway. By working closely with existing Antarctic site-testing programs, lessons learned in Antarctica can be applied to the design of Arctic instruments. Use of robotic facilities, perhaps modeled on the AASTINO or PLATO (Lawrence et al. 2006) can greatly reduce the logistic requirements and minimize the environmental impact.

C. Science goals. "Antarctic astronomy" is not a special kind of astronomy – rather there exist certain astronomical problems for which Antarctica provides the most cost-effective (or perhaps only) platform from which to conduct the observations. The key to making informed decisions is a full understanding of the observing conditions in Antarctica. Helping to determine whether an observation should be conducted from an existing temperate observatory, from space, or from Antarctica, is therefore another important role for *Astronomy & Astrophysics from Antarctica*. Many of the most important questions in astronomy can most efficiently be addressed by a multi-wavelength approach. Ensuring the free flow of information during the planning stages of new astronomical experiments is vital to ensure the best outcomes, and closer links between SCAR and the IAU will be very helpful here.

D. Major new facilities. While each of the current sites on the Antarctic plateau has much to offer, it is already clear that some sites will be better at some wavelengths than others. Achieving the best astronomical outcomes requires international cooperation to allow facilities to be built where they will achieve the best science, with sharing of data between operators of complementary astronomical facilities at other Antarctic (and temperate) observatories.

Where no existing facility can do the job, the astronomical problem – if judged to be of sufficient importance – becomes the "science driver" for a new facility. Building the science case leads then to a set of science requirements that define the new telescope. The results from site-testing programs will determine where such a new telescope should be built. These detailed design studies often represent major international programs in their own right, taking many years to complete. *Astronomy & Astrophysics from Antarctica* will help coordinate these studies, and ensure that astronomers from all nations are able to contribute.

4. Methodology and preliminary implementation plan

The successful execution of each of the four themes requires a somewhat different approach. The preliminary implementation plan for each theme is detailed below:

A. Site testing. Meaningful progress in site testing can only be made if the measurements are well calibrated and directly comparable to measurements taken at other sites (both in Antarctica and elsewhere). Astronomical site testing has become vastly more sophisticated in recent years, stimulated by the construction of the billion-dollar "ALMA" array in Chile (for sub-mm astronomy) and plans to build billion-dollar Extremely Large Telescopes (ELTs) in Chile and elsewhere (for optical and infrared astronomy). Astronomical site testing is a highly multidisciplinary activity, bringing together atmospheric physicists, climate modelers and instrumentation experts. Key parameters that must be measured are the vertical distribution of atmospheric turbulence, sky brightness and transparency at all wavelengths, cloud cover and atmospheric water vapour content.

Atmospheric turbulence determines, amongst other things, the achievable image quality and spatial resolution of a telescope. The most basic atmospheric turbulence parameter is the "seeing". This term has a specific meaning in astronomy, being the apparent full-width-half-maximum angular diameter of a stellar image, and results from the total integrated atmospheric turbulence along a path from the star to the observer. However, with the development of adaptive optics and interferometric techniques that can partially compensate for the atmospheric turbulence, it now becomes crucial to measure **how** that turbulence is distributed throughout the atmosphere.

Fortunately for astronomy, turbulence does not have a uniform vertical distribution. Typically there will be an intense surface layer, a few narrow layers at altitudes 5–10 km, and a high-altitude (20 km) layer associated with the jet stream. It is the highest layers that have the greatest influence, largely determining the correctable field-of-view of an adaptive optics system (the "isoplanatic angle") and the ultimate photometric precision ("scintillation index").

In addition to the intensity of the turbulence, it is equally important to know how quickly the turbulence becomes uncorrelated with itself, a quantity called the "coherence time", or τ_0. In most atmospheric models, the turbulent structure at a particular height is considered to evolve fairly slowly. This "frozen screen" of refractive index variations is then blown across the field of view by the wind speed at that height. In principle, τ_0 can therefore be calculated from a knowledge of the wind speed and turbulence at each height, or it can be derived directly from the frequency components in the scintillation pattern. For a telescope equipped with adaptive optics, τ_0 has a direct effect on almost all of the important performance characteristics, including the required bandwidth of the feedback loops, the minimum intensity of the reference star, and the residual error in the image correction. For an interferometer, it directly affects the achievable signal-to-noise ratio on a given star and the achievable astrometric precision.

A number of techniques exist to measure turbulence profiles, each with its own advantages and disadvantages. The most direct way is to launch a series of meteorological balloons carrying (in addition to the normal pressure, temperature and humidity sensors) a pair of microthermal sensors capable of resolving millikelvin temperature fluctuations. While this technique gives a direct in-situ measurement, it requires the expenditure of a balloon and radiosonde package for each flight, and can only be carried out from a manned station.

A second way is to make use of the observed scintillation (intensity fluctuations imposed on the starlight by the intervening atmosphere) from a single or double star. Most such techniques require a relatively large telescope, and hence are only possible after a site has already been established as an astronomical observatory. However, both the SSS (Single-Star SCIDAR) and MASS (Multi-Aperture Scintillation Sensor) are able to operate with relative modest telescopes (just 80 mm diameter in the case of the MASS).

Exceptionally low levels of turbulence above Dome C were measured by Lawrence et al 2004, with a median free-atmosphere seeing of 0.27 arcseconds—a factor of 2–3 better than the best temperate sites. This provides a dramatic improvement in image quality over existing observatories. These results were confirmed the following year with balloon-borne microthermal measurements (Agabi et al 2006) that gave a median free-atmosphere seeing of 0.24 arcseconds.

Nevertheless, there is an omnipresent, intensely turbulent surface layer. Swain & Gallée (2006) have modelled this layer across the entire plateau and found major differences in its thickness from location to location, with one of the thinnest regions being at Dome A and Dome F. Only coordinated, multi-year studies at all sites, preferably with identical instruments, can provide the data needed for a meaningful comparison of potential observatory locations. These data will also be highly desirable to the atmospheric physics community for improving climate and regional scale parameterisation (sub-grid scale) schemes. As a return on this exchange, the expected improvement in the skill of such models *at the site* will allow enhanced forecasting of long term site climate and short term weather prediction.

The infrared sky brightness above the Antarctic plateau has been shown by a number of experiments—notably Phillips et al (1999) and Chamberlain et al (2000)—to be a factor of 20–100 lower than at temperate sites. This leads to a direct sensitivity gain of 4–10 over a comparable telescope at a temperate site and is itself sufficient to justify construction of medium-scale telescopes at Dome C and the South Pole. However, at the present time no infrared measurements have been made at Dome C except during the sun-lit summer (Walden et al 2005). One of the most remarkable results from this work is a measured atmospheric transmission at 11.6 microns of 99.8%, making this the clearest atmospheric window at any wavelength in the entire optical/infrared domain anywhere on Earth. Detailed information about the exact depth of the extremely dark “cosmological window” at 2.35 microns is important for the design of future cameras and spectrometers, while at longer infrared wavelengths uncertainties remain about the contribution of aerosols to the sky brightness. New, clever instruments are required to allow robust, robotic measurements to be made across the infrared.

At optical wavelengths, the sky above Antarctica can be expected to be brightened by aurorae, and to have longer periods of twilight than more equatorial sites. Studies of the available information on aurorae suggest that they will have little if any effect on most astronomical observations, while a detailed analysis of the overall sky brightness conditions (Kenyon and Storey 2006) highlights the complex nature of this question and emphasises the urgent need for greater collaboration between astronomers and Antarctic upper-air researchers.

In the sub-millimetre, measurements at Dome C (Calisse et al 2004) suggest it has excellent atmospheric transparency. These measurements must be confirmed and extended to winter-time studies. However, atmospheric models suggest that Dome A will be the only location on earth from which routine measurements between 1 and 10 THz will be possible. Early results from the international PLATO experiment at Dome A indicate that this may indeed be the case, and create a compelling case for a detailed, quantitative study of the potential for terahertz astronomy from Antarctica.

Assessment of cloud cover above an astronomical observatory is normally a straightforward exercise, using existing satellite imagery. However, over Antarctica the contrast between the snow and higher layers of cloud is very low at all wavelengths, and in-situ measurements are required. Recently, Mosser & Aristidi (2007) report remarkable clear-sky statistics of 92% at Dome C throughout 2006 – significantly better than anywhere else on earth. Such estimates must be confirmed with quantitative measurements, and extended to Dome A, Dome F and the Arctic.

B. Arctic site testing.

At the current time, very little site testing has been carried out from the Arctic with astronomy in mind. However, the discovery that exceptionally favourable conditions exist at high plateau sites in Antarctica suggest that some Arctic sites may offer at least some of the same advantages. For example, Summit Station in Greenland is at almost the same elevation as Dome C, and at the same absolute latitude. In Canada, Ellesemere Island appears likely to be a favourable location.

Site testing in the Arctic is a logical extension of activities in Antarctica. The same techniques, instruments and data analysis can be used, although the funding agencies and institutions involved may have little overlap with their Antarctic counterparts. *Astronomy & Astrophysics from Antarctica* can provide a framework within which astronomers interested in one of the polar regions or the other can interact, sharing technical and scientific knowledge and thereby adding value to each other's programs.

Extending the Antarctic database of site testing information to cover Arctic results as well should be a straightforward enhancement.

C. Science goals.

Prioritization of scientific questions in astronomy, be they "big picture" questions like the nature of dark energy or more specific questions like the atmospheric composition of individual planets, is already carried out through vigorous debate at a number of astronomical forums – including IAU (International Astronomical Union) Symposia. There is no need for an additional forum to be created within the Antarctic community to duplicate this activity. However, a pressing need does exist for a greater level of communication to be established between the astronomers who have committed substantial effort into understanding the potential of Antarctica, and astronomers who have specialized in trying to answer specific particular astrophysics questions in astrophysics.

The role of *Astronomy & Astrophysics from Antarctica* is therefore to create opportunities for networking and collaboration between operators of Antarctic observatories (and planners of new facilities) and "mainstream" astronomers, ensuring that maximum scientific return is achieved by new and existing Antarctic astronomical facilities.

D. Major new facilities.

New, leading edge astronomical observatories now take many years to plan and typically cost between $100m and $1b. As these costs are often beyond the reach of individual nations, international consortia are usually created to allow contributions from several countries and to maximize the scientific return. A good example is the European Southern Observatory

(ESO), an intergovernmental organisation of 13 European states and an annual budget of €121m. Another international partnership is the Gemini Observatory, whose members are Argentina, Australia, Brazil, Canada, Chile, the United Kingdom and the United States.

For many years, astronomers have built their large facilities at the best available sites, rather than on their own soil. For example, all of ESO's telescopes are located in Chile. The Gemini consortium has one telescope in the USA (Hawaii), and one in Chile. The Pierre Auger Observatory, with members from 17 countries, is located in Argentina. The establishment of new observatories typically involves the negotiation of intergovernmental agreements – both for the funding for the construction and operation of facilities, and for the access arrangements to the site.

As Antarctic astronomy develops, it is clear that similar international processes will be required. Although issues of sovereignty are less clear in Antarctica, the need for logistic support dictates that agreements be negotiated between different agencies in the participating countries.

Astronomy & Astrophysics from Antarctica can play an important role in identifying which Antarctic station is best suited to a particular astronomical program, and then by providing site data and background information to brief the national agencies engaged in formal negotiation.

5. Programme management and governance

The *Astronomy & Astrophysics from Antarctica* SRP programme will be managed by a Steering Committee, with representatives from all spectral regions (optical, infrared, terahertz, sub-mm and mm), plus particle physics, atmospheric physics and scientific ballooning. The Steering Committee is also representative of a broad spread of nations conducting astronomical research from Antarctica, its ten members coming from eight different countries.

The inclusion of members from the Antarctic atmospheric physics and meteorology community in the Steering Committee will assist the formulation of protocols in data acquisition and archiving that allow for a freer flow of information between these disciplines and the astronomical community, thus minimizing wasteful duplication of effort.

Links with complementary non-Antarctic facilities and non-astronomical polar expert groups will be explored and possible synergies documented.

6. Deliverable outcomes, including public awareness

We aim to deliver:

- Quantitative assessments of the potential of each Antarctic plateau station to contribute to astronomy,
- Advances in the understanding of Antarctic meteorology, as it applies to astronomical observations,
- Improved coordination with atmospheric and ionospheric researchers,
- Papers in peer-reviewed journals,
- Properly archived data sets of site-testing data.

Results will be communicated at three levels: at the broad national and international policy level, to specialist instrumentation astronomers and engineers, and to the general public.

7. Biennial milestones

By mid 2010

- Comparative site-testing data obtained from Dome C, Dome A, and Dome F, base-lined against South Pole data,
- Input provided to the ARENA final report, and to the PILOT design study,
- Site testing commenced at sites in Greenland and northern Canada.

By mid 2012

- Web based archive of site testing data from all sites fully publicly accessible,
- At least one major (>$50m) new international astronomical facility approved for construction, with approval based in part on *Astronomy & Astrophysics from Antarctica* recommendations,
- Roadmap in place for future astronomical facilities

Beyond 2012

- The *Astronomy & Astrophysics from Antarctica* SRP is proposed for a period of four years only in the first instance. If it is meeting all of its milestones at this time, including the successful coordination of major new astronomical facilities in Antarctica, a new proposal for its continued operation will be submitted.

8. Success factors

- Published results in refereed journals,
- Higher visibility both for SCAR and for Antarctic astronomy, as measured by increased numbers of positive media reports,
- Greater cooperation with atmospheric, meteorological and ionospheric researchers, as evidenced by increased numbers of interdisciplinary publications and cross-discipline citations,
- Systematic programs site-testing of Arctic sites established, with close links to new and existing Antarctic programs,
- *Astronomy & Astrophysics from Antarctica* results and recommendations used by builders and planners of major new astronomical facilities in Antarctica.

9. References cited

Agabi, A. et al. 2006, “First Whole Atmosphere Nighttime Seeing Measurements at Dome C, Antarctica”, *Pub. Astron. Soc. Pac.,* **118,** 344.

Ahrens, J. et al. 2004, “Status of the IceCube Neutrino Observatory”, *New Astronomy Reviews,* **48,** 519.

Calisse, P.G., Ashley, M.C.B., Burton, M.G., Phillips, M.A, Storey, J.W.V., Radford, S.J.E. & Peterson, J.B. 2004, “Submillimeter site testing at Dome C, Antarctica”, *Pub. Astron. Soc. Aust.,* **21,** 256.

Chamberlain, M.A., Ashley, M.C.B., Burton, M.G., Phillips, A., Storey, J.W.V. & Harper, D.A. 2000, “Mid-infrared observing conditions at the South Pole”, *Astrophys. J.,* **535,** 501.

De Bernadis, P. et al. 2000, “A Flat Universe from High-Resolution Maps of the Cosmic Microwave Background Radiation”, *Nature,* **404,** 955.

Fowler, A.M. et al. 1998, “ABU/SPIREX: The South Pole Thermal IR Experiment”, *SPIE,* **3354**, 1170.

Halzen, F. 1998. “The AMANDA neutrino telescope”, *New Astronomy Reviews,* **42,** 289.

Hereld. M. 1994, “SPIREX - near infrared astronomy from the South Pole”, *Experimental Astronomy,* **3,** 87.

Kenyon, S.L. & Storey, J.W.V. 2006, “A review of optical sky brightness and extinction at Dome C, Antarctica”, *Pub. Astron. Soc. Pac.,* **118,** 489.

Lawrence, J.S., Ashley, M.C.B., Tokovinin, A. & Travouillon, T. 2004a, “Exceptional astronomical seeing conditions above Dome C in Antarctica”, Nature, **431,** 278.

Lawrence, J.S. et al. 2006, “Site testing Dome A, Antarctica”, *Proc. SPIE,* **6267,** 62671L-1.

Mosser, B. & Aristidi, E. 2007, “Duty Cycle of Doppler Ground-based Asteroseismic Observations”, *Pub. Astron. Soc. Pac.,* **119**, 127.

Phillips, A., Burton, M.G., Ashley, M.C.B., Storey, J.W.V., Lloyd, J.P., Harper, D.A. & Bally, J. 1999, “The near-infrared sky emission at the South Pole in winter”, *Ap. J.,* **527,** 1009.

Ruhl, J. et al 2004, “The South Pole Telescope”, *Proc. SPIE,* **5498,** 11.

Stark, A.A., Bolatto, A.D., Chamberlin, R.A., Lane, A.P., Bania, T.M., Jackson, J.M. & Lo, K.-Y. 1997, “First Detection of 492 GHz [C I] Emission from the Large Magellanic Cloud”, *Astrophys J.,* **481,** 587.

Storey, J.W.V. 2005, “Astronomy from Antarctica”, *Antarctic Science,* **17**, 555.

Swain, M.R. & Gallée, H. 2006, “Antarctic Boundary Layer Seeing”, *Pub. Astron. Soc. Pac.,* **118,** 1190.

Walden, V.P, Town, M.S., Halter, B. & Storey, J.W.V. 2005, “First measurements of the infrared sky brightness at Dome C, Antarctica”, *Pub. Astron. Soc. Pac.,* **117,** 300.

Supporting information

1. Proposed chief officer and at least 3 other lead investigators

The following Steering Committee is proposed for the AAA SRP:

Michael Andersen (Denmark)
Philip Anderson (United Kingdom)
Michael Burton (Australia)
Nicolas Epchtein (France)
Takashi Ichikawa (Japan)
Albrecht Karle (USA)
James Lloyd (USA)
Sylvia Masi (Italy)
John Storey (Australia – Proposed Chief Officer)
Lifan Wang (China/USA)

Dr Michael Andersen is Associate Scientist at the Dark Cosmology Centre, Niels Bohr Institute, University of Copenhagen. He is the Project Scientist for site-testing at SUMMIT on Greenland. Andersen has previously held appointments at the Nordic Optical Telescope (Spain) and the Astrophysikalisches Institut Potsdam (Germany). He has a PhD in Astronomy from the University of Oulu (Finland).

Dr Philip Anderson is a senior scientist at the British Antarctic Survey. He has spent over five years running Antarctic atmospheric physics field equipment, specifically for boundary layer studies, including two over-winters at Halley research station running the TABLE and STABLE II boundary layer experiments. Present projects include theoretical work on stratified turbulence and wave/turbulence interaction and running the UK's polar autonomous Unmanned Aerial Vehicles (aUAVs); in 2007 this team, in collaboration with colleagues from the Technical University of Braunschweig, Germany, made the first successful aUAVs in Antarctica. Anderson has an honours degree in physics and a PhD in Environment Science from Lancaster University. He is on the committee of the International Society for Acoustic Remote Sensing, and was awarded the Polar Medal in 1996.

Prof Michael Burton is an astrophysicist at the University of New South Wales, where he is also Director of First Year Physics. He has been intimately involved with the development of astronomy in Antarctica for the past 15 years, and currently chairs the International Astronomical Union's working group for the Development of Antarctic Astronomy. He has held appointments at the Joint Astronomy Centre Hawaii, NASA Ames Research Center, the University of California, the Anglo Australian Observatory and the Dublin Institute for Advanced Study. His honours degree comes from the University of Cambridge and his PhD from the University of Edinburgh. He has been awarded the US Antarctic Service Medal. His scientific expertise is in the infrared and millimetre wave observation of molecular clouds and star forming regions. This has included the first infrared studies conducted from Antarctica.

Dr Nicolas Epchtein is *Directeur de Recherche* at the Centre National de la Recherche Scientifique (CNRS), the main French Research Agency. He graduated from the University of Paris 7 in 1970 and received his *Doctorat d'Etat* (habilitation) from this university in 1981. He has spent most of his career at Observatoire de Paris-Meudon (Space Department) (1973-1998), was appointed as Vice-President of Paris Observatory (1995-1997), then moved to the Observatoire de la Côte d'Azur (1998-2003). He is now at the University of Nice Sophia-

Antipolis (since 2004). Epchtein has been involved in several infrared astronomy ground and space programmes and was formerly PI of the Deep NIR Southern Sky Survey, DENIS, carried out at ESO Chile (1995-2000) in the framework of several programmes supported by the European Commisison during FP2 to FP4. He is presently coordinating ARENA, a European network of the FP6 whose aim is to draw out a road map for the development of Astronomy at Dome C.

Prof Takashi Ichikawa is Professor of Astronomy at Tohoku University, in Sendai, Japan. He is a member of the Japanese Antarctic Astronomy Consortium, and is the project leader for infrared astronomy at Dome F. Ichikawa has previously held appointments at Hitotsubashi University at Tokyo and the Kiso Observatory of the University of Tokyo at Nagano. Ichikawa has a PhD in astronomy from Kyoto University. He is PI of the MOIRCS Project of Subaru Telescope.

Prof Albrecht Karle is Professor of Physics at the University of Wisconsin-Madison. He received his PhD at the University of Munich based on research in the field of high energy gamma ray astronomy at the Max Planck Institute for Physics in Munich. He went to Madison in 1997, where he focused his research on neutrino astronomy with AMANDA and IceCube. He is presently Associate Director for Science and Instrumentation on IceCube, a large km-scale neutrino observatory currently under construction in the deep glacial ice at the South Pole. His primary scientific research is focused on the search for astrophysical point sources of high-energy neutrinos and on measurements on high-energy cosmic rays.

Prof James Lloyd is Assistant Professor of Astronomy at Cornell University. His current research focusses on the detection of extrasolar planets using infrared Doppler techniques and high-contrast adaptive optics. He has previously been a Fulbright Scholar at the University of California at Berkeley and a Millikan Fellow at the California Institute of Technology. He has wintered-over twice at Amundsen-Scott South Pole station, conducting astronomical observations with the SPIREX telescope.

Dr Silvia Masi is a researcher at the Department of Physics of the University of Rome *La Sapienza.* Her work is in the framework of Observational Cosmology, developing advanced instrumentation for precision measurements of the Cosmic Microwave Background (CMB). She is internationally recognized as an expert in balloon and satellite-borne instrumentation, space cryogenics, bolometric detectors and related electronics and optics. Masi has been a spokesperson for the BOOMERanG Antarctic balloon-borne experiment, and is now coordinating the OLIMPO experiment, a larger balloon-borne telescope for the measurement of the SZ effect in clusters of galaxies, and is deeply involved in its ideal continuation, the SAGACE satellite. She is involved in the Planck satellite of ESA (Planck Scientist for the HFI instrument) and is the PI of the BRAIN experiment, a European search for CMB polarization using bolometric interferometry from Dome C (Antarctica). She is a member of the Technical-Scientific Council of the Italian Space Agency (ASI) and is involved in the development with ASI of Long Duration Balloon facilities in Svalbard and in Malindi.

Prof John Storey (proposed Chief Officer) is Professor of Physics at the University of New South Wales, in Sydney, Australia. He is PI on several site-testing projects in Antarctica, and is Project Leader for PILOT – Pathfinder for an International Large Optical Telescope. Storey has previously held appointments at the University of California at Berkeley, the Anglo-Australian Observatory, and the Max-Planck-Institut für extraterrestrische Physik in Garching. Storey has an honours degree in Physics from La Trobe University, and a PhD in

Chemistry from Monash University. He currently chairs the Astronomy and Astrophysics Expert Group of SCAR, is the International Astronomical Union's nominated observer on SCAR, and Program Leader for Astronomy within the Australian Antarctic Division. He has been awarded the Pawsey Medal by the Australian Academy of Science, and the US Antarctic Service Medal.

Prof Lifan Wang is the Director of the Chinese Center for Antarctic Astronomy, Purple Mountain Observatory, Nanjing, China and holds the Mitchell/Heep/Munnerlyn Career Enhancement Chair in Astronomy, as Associate Professor of Physics, Physics Department, Texas A&M University. He has previously held positions at Lawrence Berkeley National Laboratory, the University of Texas at Austin. Wang received his PhD, MS Astronomy, and BE from the University of Science & Technology of China. Wang initiated the program of spectropolarimetry at the McDonald Observatory through a Hubble Post-Doctoral Fellowship in 1995. This long-term program makes use of 10-meter class telescopes such as the ESO VLT and the Japanese Subaru telescopes, the program covers observations of supernova of all Types, but with the major focus on thermonuclear supernova explosions in recent years. This program led to some dramatic progresses in the understandings of the physics that led to supernova explosions. He also developed the Color-MAGnitude Intercept Calibration (CMAGIC) method for cosmological applications of Type Ia supernovae. Wang is participating in the supernova working groups of the SuperNova Acceleration Probe (SNAP), and the Large Synoptic Survey Telescope (LSST). Together with collaborators from China, Australia and the US, Wang is developing site survey and astronomical instruments to perform astronomical observations from the Antarctic Plateau.

2. Why SCAR support is needed

Understanding the site conditions at the potential observatory locations in Antarctica (and the Arctic) requires a coordinated, international approach. Detailed comparisons of the atmospheric transmission, turbulence profile and meteorological conditions at each site are needed, preferably conducted using identical instrumentation. Once opportunities for construction of major astronomical facilities are identified, funds must be raised by international consortia and the facilities built on the best sites. The level of commitment required usually goes beyond the capabilities of individual national programs, indicating a pressing need for an overarching body within SCAR to provide the coordination. As the peak body representing Antarctic research, SCAR is in a unique position to provide this coordination, focusing particularly on the international aspects and those benefiting from cross-disciplinary work.

3. Anticipated degree of national and international involvement

Several bodies already exist to coordinate national astronomical activities in Antarctica. These include the Chinese Center for Antarctic Astronomy, the Joint Australian Centre for Research in Antarctica (JACARA), the Japanese Antarctic Astronomy Consortium and the US Science Coordination Office for Astrophysical Research in Antarctica (SCOARA). Within Europe, the FP6-funded ARENA (Antarctic Research: a European Network for Astronomy) includes 21 institutions from 7 countries plus Australia. ARENA is chaired by Dr Nicolas Epchtein.

Internationally, the ICSU body IAU (International Astronomical Union), has applied to become a member of SCAR with Prof John Storey as its nominated observer. The IAU includes an inter-division Working Group: Encouraging the International Development of Antarctic Astronomy, chaired by Prof Michael Burton. This Working Group is sponsored by

Division IX (Optical & Infrared Techniques) and Division X (Radio Astronomy), illustrating the broad spectral range over which Antarctic sites can offer substantial benefit to astronomy. Close coordination between SCAR and the IAU will be essential for the future of Antarctic astronomy, with the formation of the *Astronomy & Astrophysics from Antarctica* SRP an important next step.

Data and meta-data archival for Antarctic science is already coordinated through the SCAR/COMNAP Joint Committee on Antarctic Data Management (JCADM). This group will guide *Astronomy & Astrophysics from Antarctica* to ensure that all site-testing data are managed and made available in accordance with the Antarctic Treaty.

4. Indicative budget for the first 4 years

A budget of US$15k per annum for the first four years is requested to cover travel expenses and costs related to organisation of the site-testing data bases. It is assumed that funding from host institutions will be used to supplement SCAR funding, allowing *Astronomy & Astrophysics from Antarctica* to achieve its goals within a modest cost envelope.

For each year of the four years we anticipate the following request from SCAR:

- Meeting of Steering Committee Executive: 5 people @ $2k each
- Software engineer: 1 month @ $80k/year