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The History of Antarctic Astronomy

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Abstract

After performing a literature review using numerous papers relating to the developments of Antarctic astronomy over the last century, it became apparent that the astronomy undertaken on the ice can be separated into three specific areas. They are astrogeology, high energy particle physics and photon astrophysics. It is also clear that the majority of astronomy related research, with a few exceptions, has been located at either the South Pole or Mawson Station. This is due to the extremely favourable atmospheric conditions which are discussed during the review.

1.1 The early stages

The first documented astronomical observations south of the Antarctic Circle were made in 1772, on board the ships ‘Discovery’ and ‘Resolution’. Navel officer William Bayley was the appointed astronomer on this voyage lead by Captain James Cook, which crossed the Antarctic Circle three times while circumnavigating Antarctica. The purpose of acquiring these astronomical measurements was not to increase their knowledge of the behaviour of astronomical bodies, but instead to establish positional accuracy for the creation of charts of their discoveries and to improve astronomical navigation. Their equipment consisted of several differently designed compasses, a Hadley sextant, accurate chronometers, an astronomical quadrant as well as a Dollond refractor and a Bird reflector which were used for stellar and lunar observations (Andrewes 1996).

Figure 1: An example of an astronomical quadrant (http://www.math.nus.edu.sg/aslaksen/pictures/gunters.jpg).

Following this voyage and throughout the 19th century, several expeditions were undertaken to the Antarctic, however there is little evidence to reveal the progression of scientific astronomical understanding. One reason for this lack of astronomical advancement is that our current Antarctic astronomy fields of research were simply non-existent or not advanced at that time to make Antarctic observations plausible. Another reason is manufacturing and transporting equipment that was robust enough to survive the journey and the adverse Antarctic conditions would have been a feat in it’s self.

2.1 Antarctic astrogeology

The Australasian Antarctic Expedition (1911-1914) was lead by Sir Douglas Mawson with the intention of examining the coastal region between west Terra Nova and Gauss (Mawson 1915). A transit telescope was located at Cape Denison base camp, with the aim of measuring star transit times across the meridian to accurately ascertain the longitude of Cape Denison. In spite of this it is apparent that no astronomy was done with the telescope.

Several field trips were executed during this expedition and on one such occasion about 33km from the base camp and at an elevation of 900m on December 5, 1912, the field group (Frank Bickerton, Leslie Whetter, Alfred Hodgeman) discovered a partially buried black object (13 x 7 cm) in the snow (Bayly and Stillwell 1923). This was the first meteorite to be discovered in Antarctica and hence the first significant astronomical observation.

The next significant astronomical discovery (1961) was made in the Lazarev region with Russian geologists exposing and collecting numerous meteorites (Tolstikov 1961; Ravick & Revnov 1965). Only after 1969 when Japanese geologists had instituted a meteorite search program, founded on glaciological and geological evidence, was the astrogeological importance of Antarctica realised. Due to the diversity of meteorites uncovered in the Yamato location (hypersthene achrondites, type III carbonaceous, enstatite chondrites, bronzite chondrite (Nagata 1975)), it was unlikely that they amassed here by chance. This pushed theories of how meteorites falling onto Antarctica could be transported by the movement of ice sheets allowing aggregation in certain regions (Yoshida et al. 1971; Shima & Shima 1973).

3 High energy particle astrophysics

In this section the progression of high energy particle astrophysics and the equipment required for undertaking this type of science is discussed. It appears from the literature that there have been two major places where this work has been done, Mawson Station and at the South Pole.

3.1 Mawson Station

The first “modern” Antarctic astronomical research was performed by Australian scientists from the Physics Department at the University of Melbourne (Law 2000). The Australian National Antarctic Research Expeditions (ANARE) was set in motion in 1947, and included three of the UoM cosmic ray experiments. Two of these were deployed to the sub-Antarctic islands of Heard and Macquarie, with the third being based on the ship Wyatt Earp. Although data was not physically collected on the actual continent, it was the first astronomical experiment designed specifically for advancing Antarctic astronomical understanding.

Australia’s first Antarctic station (Mawson Station) was inaugurated in 1954 with the completion of the cosmic ray observatory in 1955. During this year two muon telescopes were built and shipped to Mawson Station for installation (Parsons 2000). The astrophysics experiments performed here were the first conducted on the continent and activated the birth of the Mawson cosmic ray program. The cosmic ray hut was constructed specifically for housing these telescopes, each of which consisted of three trays of Geiger counters. These early telescopes demanded high maintenance and often experienced faults, one of which spoiled the measurements obtained of the great solar flare (23 February 1956). A 12-counter neutron monitor was taken to Mawson in late 1956 and over the years has proved valuable for recording numerous solar flares.

Mawson Station saw the installation of two high zenith angle muon telescopes in 1968, facing north and south respectively at 76 degrees (Jacklyn 2000). In 1971 a new cosmic ray observatory was constructed by directing a vertical shaft into the ground to a depth of 40 mwe (metres of water equivalent) in order to reduce the amount of low energy particles reaching the detector. An underground muon telescope was positioned at the bottom of the shaft and the building above it housed the high zenith angle telescopes and the neutron telescope. The combination of the data collected by these telescopes showed an astonishing solar modulation in 1982 (Jacklyn, Dulding and Pomerantz 1987), which occurred during a large cosmic ray decrease. No detections of these ‘isotropic intensity waves’ have been recorded since and therefore remains an enigma to scientists.

Figure 2: Mawson Station (www.aad.gov.au/default.asp?casid=28933).

3.2 Developments resulting from the International Geophysical Year

The International Geophysical Year took place from July 1957 to December 1958 with the aim of achieving multi-national scientific collaboration on geophysical aspects. 46 member states were involved right from the beginning, with a further 21 countries joining before the end. A suggestion was made by the US to place a cosmic ray detector at McMurdo, and Martin Pomerantz was assigned the task of coordinating this project (Pomerantz 2004). The detector was installed at McMurdo in 1959. Following this, a second detector was installed at the South Pole in 1964.

During that same year (1964) stellar and solar observations were made from the South Pole with a 3.5’’ telescope. Analysis of these data prompted Arne Wyller to compose a report which was published in 1970. He concluded that the seeing conditions at the South Pole were outstanding for optical astronomy, and that future attention should be directed towards this field (Indermuehle 2005).

3.3 The South Pole

The GASP (Gamma Astronomy at the South Pole) telescope was installed at the South Pole in 1994-97. It comprises six 1m mirrors with the purpose of detecting Cherenkov radiation produced by the interaction of gamma rays with the upper atmosphere (Indermuehle 2005). This piece of equipment was unsuccessful as it did not fulfil its aim of detecting celestial sources of gamma rays.

In order to measure cosmic ray air showers with energies near 10^{14} eV, large collecting area detectors are required. The flux from these events is too low to be measured by short duration scientific balloon flights or expensive satellites with relatively small collecting areas. Thus the large area detector SPASE (South Pole Air Shower Experiment) was built on the Antarctic Plateau near the Amundsen-Scott South Pole Station. With an altitude of about 3000 m, the constant zenith angle of the circumpolar sources, and having AMANDA (Antarctic Muon And Neutrino Discovery Array) below it, all combined to make this an ideal location. SPASE operated for the 10 years following 1987 under the direction of Alan Watson and Martin Pomerantz. The instrument consisted of 16 scintillation detectors distributed over a 6200 m^2 area (Indermuehle 2005). The purpose of this experiment was to identify cosmic sources of gamma ray emission, however no sources were found, and the particles events that were detected had an isotropic distribution across the sky.

The construction of AMANDA started in the early 1990's and as it became available for scientific work, SPASE was used to survey the position of AMANDA modules. AMANDA was composed of 23 strings which penetrated to depths between 1000m and 2350 m (IceCube Collaboration, 2001). Each string contained, on average, 30 optical modules or photomultiplier tubes (PMTs). In 1994 construction started on SPASE-2, with the goal of working in conjunction with AMANDA. This new instrument consisted of 120 scintillator modules distributed across an area of about 16 000 m^2 and had the ability to measure cosmic rays in the 10^{14} to 10^{16} eV range.

Figure 3: An AMANDA optical module being lowered into the drill hole (IceCube Collaboration, 2001).

Figure 4: An aerial view of the SPASE-2 array, December 1995 (http://www.bartol.udel.edu/spase/).

The SPASE-2/AMANDA relationship consisted of SPASE measuring the number of charged particles in the shower reaching the Earth's surface, while AMANDA detected the amount of high energy muons penetrating into the icecap. The aim of this experiment was to deduce the composition of cosmic rays and thus improve understanding on the sources of these particles. The SPASE project finished in 2004, but the detector is being incorporated as a surface part of IceCube (http://www.bartol.udel.edu/spase/).

IceCube is a neutrino telescope which is currently under construction at the South Pole. Similarly to AMANDA, IceCube consists of PMT's attached to strings which are deployed into the ice to depths of 2450 m (IceCube Collaboration, 2001). The first IceCube String was lowered in 2005, with a further eight in 2006 and 13 more in 2007. This experiment aims to detect high energy neutrinos by detecting the interactions that they have with atoms of ice. It is currently estimated that when IceCube is completed it will detect approximately 1000 events each day (http://www.bartol.udel.edu/spase/). IceCube looks for neutrinos coming through the Earth from the north thus eliminating most of the unwanted neutrinos formed by cosmic ray interactions. Statistical ananlysis is undertaken on the results to determine where extraterrestrial sources are located.

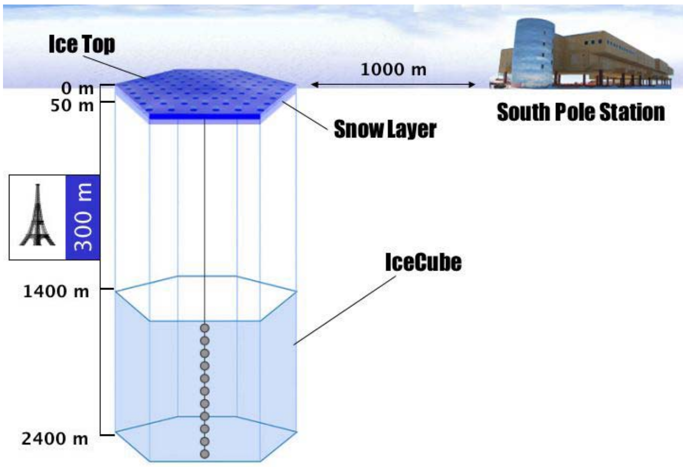

Figure 5: IceCube (www.astro.wisc.edu/~heroux/index.html).

The RICE experiment consists 20 radio antenna deployed with in a 4000 m^3 volume in the IceCube array. Its purpose is to detect the Cherenkov radiation produced from the interaction of neutrinos in the ice cap (Besson 2007).

ANITA (Antarctic Impulse Transit Antenna) is a radio telescope that detects high energy cosmic ray neutrinos from aboard a scientific balloon flying above Antarctica. It was launched in December 2006 and flew at an altitude of 37 km, from which it had the ability to scan 1.5 km^2 of ice (Gorham 2007).

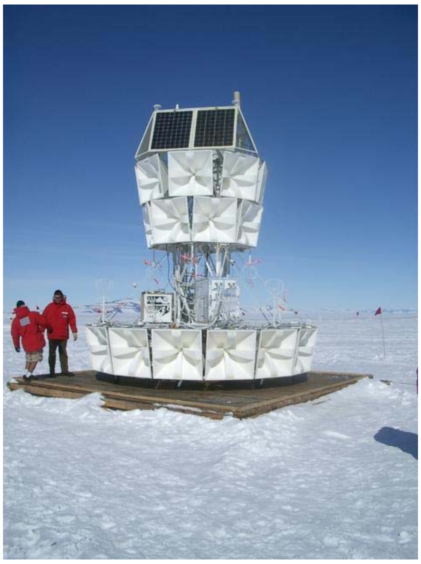

Figure 6: The ANITA instrument ready for launch on 15 December 2006 (http://www.phys.hawaii.edu/~anita/web/science.html).

The Antarctic icecap has proved invaluable for scientific research in the high energy particle physics domain. All four of the detectors, AMANDA, IceCube, ANITA and RICE use the solid, dense, transparent and large-volumed nature of the icecap as a target to detect neutrinos. All these systems strive to measure the Cherenkov radiation produced by the interactions of neutrinos with sub-atomic matter within the ice. AMANDA and IceCube are designed to detect penetrating muons whereas RICE and

ANITA are optimized for detecting compact electromagnetic cascades. As neutrinos are unaffected by magnetic fields and absorption by dust, by tracking the path of origin scientist can derive where and what caused them.

4 Photon astronomy

This chapter presents the four bands of photon astronomy that are undertaken in Antarctica. These are the optical, infrared, submillimetre and microwave windows.

4.1 Optical

The first optical research program was situated at the South Pole and commenced in 1979. Directed by Eric Fossat and Gerard Grec (Observatoire de Nice), and Martin Pomerantz, 120 hours of uninterrupted solar observations were obtained. Analysis of these data enabled 80 solar harmonics, with periods raging between 3 and 8 mins to be detected (Indermuehle 2005). To increase angular resolution an array detector was added in the 1981/82 summer. Detection of these solar harmonic modes resulted in a discovery that the structure of the Sun’s convective zone at the equator differed from that near higher latitudes. It also gave rise to the present wisdom regarding solar temperature and composition, as well helioseismology.

Aside from the above mentioned work, most of the optical astronomy that has been done in Antarctica has been for the purpose of site testing. From 1984 to 1988 the 2’’ South Pole Telescope (SPOT) program was conducted by the University of Florida. During the southern summer measurements were taken in order to examine the visual seeing conditions, and during the winter long-period measurements were mad of variable stars. Unfortunately these data were affected by the presence of clouds which resulted in the observing time not surpassing that of observatories located at mid-latitudes. Another form of analysing visual seeing is through the use of differential image motion monitors (DIMMs). Star light is monitored through numerous adjacent apertures to determine the stability of the atmosphere. The HDIMM on the SPIREX telescope (Loewenstein et al. 1998) and the ADIMM used with the AASTO (Travouillon et al. 2003b) are two such experiments. A visual seeing value of approximately 1.5’’ was calculated for the Pole at ice-level, and although this is relatively bad, since the majority of it originates in the slender surface inversion layer, the future for adaptive optics correction is bright.

4.2 Infrared

The South Pole Infrared Explorer (SPIREX) is a 60cm telescope, which has been in operation since 1993. It observes in the 1-5 µm wavelength range and is located at the South Pole. The two different instruments used in conjunction with SPIREX were the GRism IMager (GRIM) from 1993 to 1997 (Hereld 1994); and following this the Adu camera until 1999 (Fowler et al. 1998). SPIREX was the only telescope in the world to continuously observe the week-long series of impacts of comet Shoemaker-Levy 9 colliding with Jupiter in July 1994. It logged 16 impacts in total. The SPIREX program completed its intended observations and was removed at the end of 1999.

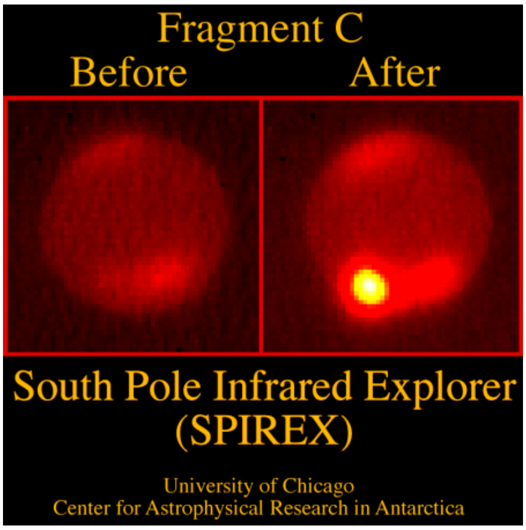

Figure 7: SPIREX infrared image of collision of Comet Shoemaker-Levy 9 with Jupiter (www2.jpl.nasa.gov/sl9/image31.html).

Some of the astronomical observations conducted during the winter cover areas such as: the interaction of stars, dust, and gas in active star-forming regions; the frequency of circumstellar disks in young clusters; the Galactic Center; and variable phenomena including a gamma-ray burster and an x-ray nova.

The fundamental scientific role intended for SPIREX was to image polycyclic aromatic hydrocarbons (PAHs) at 3.3 µm, tracers of photodissociation regions. These are the surfaces of molecular clouds excited by the far-UV radiation produced from young stars. Detecting PAHs in NGC 6334 (Burton et al. 2000), the Carina nebula (Brooks et al. 2000; Rathbourne et al. 2002), and wrapped around embedded protostellar objects resulted in the success of this project.

Another aim of the SPIREX program was to measure the infrared excess at 3.5 µm, from hot dust in the disks around pre-main sequence stars. This investigation revealed that disk emission at 3.5 µm was easier to detect that at the usual 2 µm band. Although SPIREX is of a relatively small size, at that time it had the deepest 3.5 µm image compared with any telescope.

4.3 Submillimetre

In 1984/85 a US-France collaboration used the 45 cm submillimetre, EMILIE (Emission Millimetrique) telescope, to measure galactic infrared emission. Due do the atmospheric measurements made in 1974, which revealed an atmospheric water content of less than that at Mauna Kea, (a prime infrared observatory) the South Pole was determined as an excellent site for pursuing infrared astronomy. The telescope was scanned (0.5 degree beam width) over the Galactic plane and detected emission at 900 µm near the Galactic centre. Dust emission from star-forming complexes in the southern Galactic plane was also detected in the 460 µm to 920 µm wavelength range (Indermuehle 2005). The results allowed an estimation of the infrared luminosities and temperature of these regions to be made. An improved version, EMILIE II, was used in 1986/87 to measure cosmic microwave background anisotropy. It was only after 10 years that the real fruit of the operation ripened.

Carbon is the most abundant heavy element and emits at 370 µm and 610 µm. Created through the stellar nuclear processes that occur in the interior of stars and delivered to the interstellar medium via supernovae and winds, it performs a vital role in astrophysical processes. Due to the presence of water vapour in the atmosphere causing opacity in the submillimetre band, Earth based carbon observations are challenging. However, at the South Pole these atmospheric challenges are minimal making it an ideal location for performing frequent carbon observations.

The Antarctic Submillimetre Telescope and Remote Observatory (AST/RO) is a 1.7 m telescope developed specifically for obtaining measurements of the dominant cooling lines from the dense interstellar gas near star formation regions (Lane & Stark 1997; Stark et al. 2001). The gas temperature and density can be determined by analysing these lines. The operation of AST/RO commenced in January 1995 and as a result is the longest working telescope to date, on the Antarctic plateau. AST/RO is used for both astronomy and aeronomy and operates throughout the winter in the 200 – 2000 µm range. Some of the AST/RO achievements cover the first detection of CI emission in the Magellanic Clouds (Two small irregular galaxies orbiting our Milky Way Galaxy), and a survey of CI and CO emissions from the HII region/molecular cloud complexes of Carina and NGC 6334. AST/RO is the most productive telescope built on Antarctica and only requires one winter-over astronomer to carry out the procedures.

Figure 8: The primary mirror of the AST/RO telescope (Jules Harnett 2004)

The Submillimetre Polarimeter for Antarctic Remote Observing (SPARO) was specifically built for use with the Viper telescope, and was installed from 2001 to 2003. Interstellar dust is polarized by the magnetic fields and through submillimetre dust emission, SPARO has been able to map the magnetic field through the inner several hundred parsecs of the Milky Way.

4.4 Microwave

Italian astronomers carried out an experiment in Terra Nova Bay in the 1980s to measure anisotropies in the CMBR (Cosmic microwave background radiation). They used a 1 m diameter flux collector which was sensitive to radiation from the 1.86 mm to 2.34 mm range. Simultaneously at the South Pole, American astronomers were using a 1 m^2 Bell Labs horn antenna for performing similar investigations.

The 'White Dish', a 1.4 m telescope with a waveguide operating at 90 GHz, produced the first significant results based on the measurements taken in the 1991 to 1993 period (Tucker et al. 1993).

COBRA (COsmic Microwave Background Radiation Anisotropy) built the 0.75 m Python telescope in 1992 which mapped the CMBR at 38, 42 and 90 GHz. The 2.1 m Viper telescope was installed in 1998 to extend the studies done with Python and to increase the quality of the data collected. DASI (Degree Angular Scale Interferometer) was a 13-element interferometric array which succeeded the Viper telescope and made the first detection of polarisation in the CMBR (Kovac et al. 2002; Leitch et al. 2002b). This result strengthen theoretical prediction about the generation of the CMBR. The DASI ended its caraer in 2003.

Figure 9: DASI telescope (cfcp.uchicago.edu/.../cosmicradiation/index.html).

The BOOMERanG (Balloon Observations Of Millimetric Extragalactic Radiation and Geophysics) experiment was launched from McMurdo Station and transported a 1.2 m microwave telescope to an altitude of 38 km. It was airborne for 10 days collecting data on the CMBR. When this data was analysed it appear inconsistent with other cosmological models due to topographical effects, but was consistent with a handful of cold dark matter models. The combination of this data with that from the South Pole produced evidence that the geometry of the Universe was flat (i.e. Non-accelerating).

5 Conclusion

This literature review presents some of the major astronomical developments that have taken place in Antarctica. From the early beginnings when the astronomy was used soley for navigation purposes, we have seen it advance to pursue the present day challenges of detecting huge cosmic events like gamma ray bursts. From the bottom of the world Antarctica has seen it all. The cosmological clock seems ceaseless, and one can only dream of the amazing and incomprehensive inventions and technology that will grace the ice continent in the coming cosmological hours.

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