Astronomy within Antarctica

The past and the present

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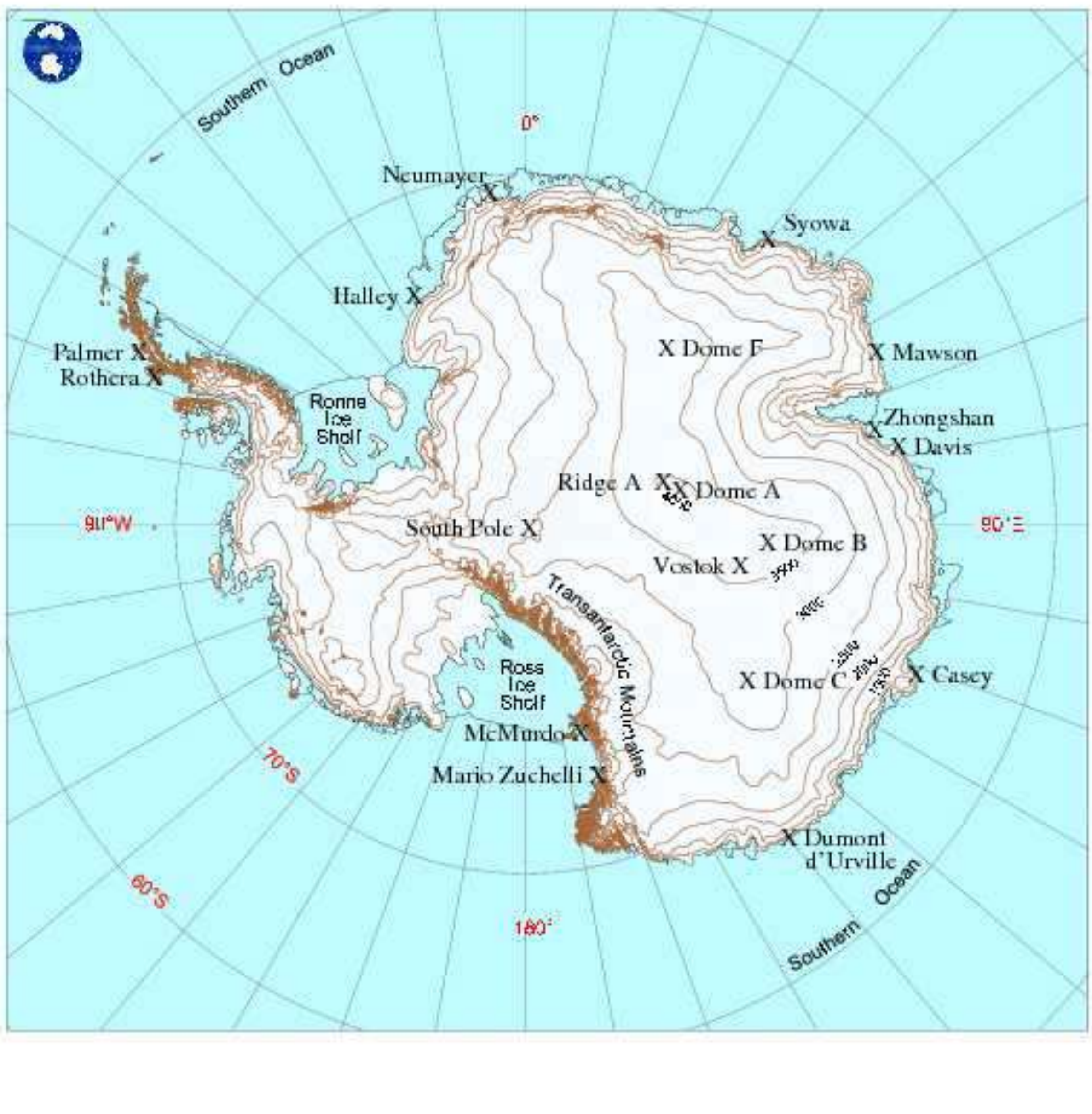

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Abstract

Early astronomy activities were not practiced until the 1950s, however today the activities are undergoing at four plateau sites: the Amundsen-Scott South Pole Station, Concordia Station at Dome A, Kunlun Station at Dome A and Fuji Station at Dome F, in addition to the long duration ballooning from the coastal station of McMurdo, at stations run by the USA, France / Italy, China, Japan and the USA respectively (Indermuehle *et al.* 2004). All these programs are operating with great difficulties due to natural environment and technology limitations; however the temptation of the ideal astronomical laboratory has always been the driving force to astronomers to overcome the difficulties.

This review presents a general introduction of Antarctic astronomy, and discusses the advantages and disadvantages of conducting astronomy in Antarctica. At last, the review will summerise the achivements of the past astronomy researches, and looks at the future of astronomy in Antarctica.

1 Introduction

1.1 General information on Antarctica

Antarctica is the fifth largest continent in terms of area, the surface area being approximately 14 million square kilometres, which is almost twice the surface area of Australia. Up to 98% of Antarctica is covered by a thick layer of ice and on average, has the average highest elevation of all the continents in the world. Antarctica is also the only continent without permanent population.

Antarctica continent is surrounded by a circumpolar current and variety of marine life. Both the geographic South Pole and geomagnetic Pole (not to be confused with the south magnetic Pole) are located in Antarctic plateau.

Although Antarctica is considered to be one of the windiest places on Earth, the snow storms, fierce blizzards and strong gusts are more common around the coast than in the centre of the continent. There are no high mountain peaks and shallow slopes on the plateau, and most of the astronomy sites are built at local peak points which are the highest points within local proximity.

1.2 Past and Present astronomical sites

Most of the Antarctic observing sites are in the Australian Antarctic Territory.

Amundsen-Scott South Pole Station: the United States Government built the astronomical instruments after the relocation of the Amundsen Station in 1975, the first optical research started in 1979. Solar telescope test started since 1978-1979 summer, and the South Pole Optical Telescope (SPOT-1) was installed in 1983-1984 summer, which was reinstalled in 1984-1985 summer as APOT-2, an offset telescope was built in 1086-1987 summer to replace SPOT-2. Lidar and Cerenkov telescope (GASP) was installed in 1989-1990 summer (southpolestation.com), and the current South Pole

Telescope (SPT) was operated in 2007, it has been focusing on microwave frequency range between 70 and 300 GHz (Carlstrom J.E. et al. 2009).

Dome Circe or Charlie (Dome C): It was a site of ice core built by the US Naval Support Force in 1970s. In the year 2005, a French-Italian team started operating a series of activities including the European Project for Ice Coring in Antarctica (EPICA). Storey (2009) described dome C as the best site on Earth for optical/infrared astronomy. Since 2005, the French and Italian astronomers have been operating cooperatively all year round from station Concordia. One of the first projects was a robotic observatory called AASTINO (Automated Astrophysical Site-Testing International Observatory) built by the University of New South Wales (UNSW) (Storey 2009, Australian Science).

Dome Fuji (Dome F), or Valkyrie Dome or Valkyrjedomen: The station was established by Japan in 1995, the same year deep ice core drilling was conducted.

Dome Argus (Dome A): The Chinese National Antarctic Research Expeditions (CHINARE) located the highest point (so-called Dome A) of the ice sheet and set up an automatic weather station. The Polar Research Institute of China then set up a robotic observatory PLATO (PLATeau Observatory) on Dome A in 2008. PLATO has done projects on searching for transit of planets and supernovae. Dome A is with maximum elevation of 4093 metres, and the lowest average wind speed on Earth (Storey 2009, Australian Science)

In addition to the permanent sites, astronomers have carried out scientific ballooning since 1970, which was part of sounding rocket development project by the University of Tokyo (Japan Aerospace Exploration Agency 2008).

2 Advantages of carrying out Astronomy activities in Antarctica

2.4 Atmospheric stability:

Astronomers often ask each other about the seeing, a term that describes sharpness or clarity of an image, which is crucial for optical and infrared telescopes. The main factor drives the quality of the image is our atmosphere. Generally when light comes through different layers and different temperatures of the atmosphere, which is full of active turbulent areas, the wavefront of the light can be distorted. However, less distortion occurs in the Antarctica plateau because it has a very stable atmosphere. The continent is protected by high altitude winds, and the lack of day/night cycle which ensured a stable middle and lower atmosphere. To overcome 90% of major turbulence which is concentrated at 20m above ground, astronomers usually build telescopes on a tower (Storey 2009, Australian Science).

In 2006, Eric Aristidi charted 85% cloud-free skies above Dome C, highlights the ideal observing condition of the site. A high percentage of cloud-free days per year have been recorded by other stations with difficulties, for instance 74% clear skies were recorded at Dome C in 2001 and 90% clear skies were recorded at AASTINO in 2003 which were measured by Ashley et al and Lawrence *et al* (2004b) respectively. However, obtaining consecutive measurements at these stations is often frustrated by weather condition and lack of satellite coverage.

Most of the Domes in Antarctica are built in low wind speed areas with the average wind speed around Dome C is 3m/s. By comparison, some traditional sites such as Mauna Loa (island of Jawai) and La Palma (Los Llanos de Aridane) both experience higher wind speed. The wind in Antarctica generally comes from one direction only meaning that engineers can build appropriate infrastructure. In addition there is a low variation in airmass in Antarctica, which is the length of the optical path length for light from a celestial body, through the Earth's atmosphere. This helps to make high precision photometry and wide-field imaging (Lawrence J. Ashley M. 2004a).

2.2 Temperature:

Antarctica is extremely cold, the average winter temperature varying between -60°C and -85°C, which reduces the radiation created by telescope and the atmosphere. The low temperature assists the telescope to *see* through its own infrared radiation which created by its own heat. The cold environment also stops water vapour by freezing it, this is really helpful because water vapour absorbs almost every wavelength (Storey 2009, Australian Science). Telescopes are designed to capture a variety of spectra, so reducing the water vapour will enhance the quality and the quality of the light that reaches the telescope.

2.3 Air condition:

Antarctic plateau is a desert, the typical precipitation water vapour levels of 250µm exist for much of the year and levels can fall below 100µm in places (Storey 2009; Lawrence 2004a), which was much lower than the average globally. The driest atmospheric conditions have been recorded by PLATO, which give Astronomers a better chance to explore the terahertz region (sub-millimetre wavelength), where not many observations have been done (Storey 2009, Australian Science).

2.4 Low seismic activity:

The absence of seismic activity in Antarctica is another important factor for astronomers to select sites (Storey 2009, Lawrence 2004a). Unlike some of very big observatories, such as Mauna Kea, Canary, and Chilean observatories; the Antarctica continent experiences low level seismic activities due to its geological advantage, the Antarctic plateau is a huge bedrock which is very stable. In this way, the additional cost of reinforcing building can be saved, and astronomers often ignore the vibrations of the ground (Ashley M. Burton M and Storey J. 2004).

2.5 Low level of Aerosols:

Many people have seen pictures of a solar halo, which is an optic phenomenon caused by light being scattered by small particles called aerosols. It can affect the brightness measurement of stars; however Antarctica Astronomy sites have up to 50 times less aerosols than traditional sites (Storey 2009, Australian Science). Observation requires great contrast ratios which also benefits from the low level scattering (Lawrence *et al* 2004a) as well.

2.6 Continuous observing:

Antarctica has very unique sky coverage due to the spinning motion of the Earth. The term called the circumpolar circles, which describe circles of skies around celestial poles. Then one above Antarctica is called south circumpolar circle, the sky within the circle will be seen most of the year, especially at the South Pole. This gives astronomers an opportunity to continue observing an object for a long period of time. For instance, extra-solar planets transits require continuous measurement in days, asteroseismology, large and small Magellanic Clouds (dwarf galaxies) can be well studied with long period of observing.

2.7 Low light pollution:

The use of artificial lights has a big impact on Astronomy especially at mid-latitude observatories. Fortunately the lack of human activities in Antarctica has preserved very dark skies for people to investigate.

2.8 Financial aspect:

Building up telescopes in Antarctica may seem to be expensive; however, it is more reasonably priced compare with launching satellites into space, the current cheapest option to ship down equipment down to Antarctica is around US $10 per kilogram, but it costs at least US$15,000 per kilogram to conduct projects in lower earth orbit (Storey 2009, Australian Science). The site conditions such as no dust, low level and stable direction wind, and clear skies also greatly reduce the telescope costs (Ashley M. Burton M and Storey J. 2004).

2.9 Contributions:

Since the exploration in Antarctica has only been relatively recent, any techonology in Antarctica is extremely modern and telescopes are no exception. The Dome C is several times larger than mid-latitude sites (Lawrence J. Ashley M. 2004a), and it also has 300 times faster mid-IR interferometer detector than that of at Mauna Kea (Lawrence J. Ashley M. 2004b). Since the land in Antarctica is not subject to the same restrictions that apply to the rest of the world, there is more freedom to build observatories in the best possible location for observing (Lawrence J. Ashley M. 2004a).

All the sites have been observed under environmental protocols and there have been no records of interaction with endangered (Lawrence J. Ashley M. 2004a).

AASTINO made the first winter measurements of the turbulence free atmosphere at Dome C (Storey 2009, Australian Science), the results will not only benefits astronomical observation but also other scientific fields, such as atmospheric study and climate study.

The distribution of galaxies of the early univer has been studied and measured by the South Pole 10-metre diameter submilimetre dish; this research has a big step forward in the field of astronomy.

There are many more achievements will not be mentioned here but they are equaly important to any other discoveries.

3 Disadvantages of carrying out Astronomy activities in Antarctica

3.1 Sky coverage and duration:

Although Antarctica has continuous dark skies, the overall dark time is less than that of mid-latitude observatories. The total sky coverage (visible part of the sky) is less than mid-latitude areas

(Ashley *et al* 2004) due to the spin motion of the Earth, that means there are huge area of the sky will not be visible or too close to horizon to observe in Antarctica, such as Orion constellation, North star plaris and Canter constellation are not visible in Antarctica.

3.2 Limited access (maintenance):

Antarctica's extreme conditions make it really hard to access during the winter time. It is usually too cold for aircraft to land and take off safely, and the large sea ice area blocks the path of ships to their destinations in the winter (Storey 2009, Australian Science; Ashley *et al* 2004).

3.3 Long periods of twilight:

Astronomers are facing long periods of twilight in Antarctica in which the sky will not be dark enough for optical observations. However, this will not affect infrared spectrum observations and site testing can be conducted during this period of time.

3.4 Pollution (Moon light):

Light pollutions in mid-latitude area has resulted a difficulty for people to watch stars. Antarctica is facing the similar problems, but the source is the Moon, which reflacts huge mount of light from the Sun, this will result a low qaulity optical image.

3.5 Environmental and instrumental limitation:

High altitude and thinner atmosphere create difficulties in maintening telescopes. Exreme cold temperature and over heating can both damage the instruments, for instance thermal expansion of materials, such as grubb screws, which often become loose often by repeating vibrations and cause major instrumental problems. The life-span of cables, plastics and batteries is dramatically reduced in extremely cold temperatures. Overheating also has been brought to astronomers' concern, because serious problems can be results from over heating, such as fire and instrument failure. Some solutions have been given, such as using more flexible cables, lithium thinyl chloride batteries, and cold temperature resistant electronic devices (Ashley *et al* 2004).

Other problems that astronomers have to face are relative humidity, icing on the surface of telescopes, and engine exhausts increasing the amount of water molecules in the air creating observation difficulties.

3.6 Personnel aspects:

The time period for observing in Antarctica is restricted due to the seasonal conditions. Scientists including Astronomers and other support stuff have to choose a short working period during the summer which varies from a few weeks to a few months. Over winter stuff may spend a whole year in Antarctica, which includes 9 months of physical isolation from rest of the planet (Storey 2009, Australian Science).

Special engineering skills and necessary work experience are crucial for the repair of telescopes in the winter period, and it is a concern that such skills may not be readily available (Ashley M. Burton M and Storey J. 2004).

3.7 Anomolies:

Due to the selection of the site of the US Amundsen Scott South Pole, it experiences stronger a slightly average wind (6m/s) than other dome sites in Antarctica, it is because that other dome sites were built in low surface wind and less atmospheric turbulence areas (Ashley M. Burton M and Storey J. 2004).

Generally the Antarctica plateau experiences minor low level atmospheric activities, but there are some instances of rare local turbulence. In 2003, Dome C experienced winds up to speed 20m/s which was the highest wind speed recorded in Dome C in the last 23 years, but this only happens occasionally at all the dome sites (Ashley M. Burton M and Storey J. 2004) (Ashley M. Burton M and Storey J. 2004).

In addition to these problems the beautiful auroras that are experienced in Antarctica may cause minor impacts on the optical observing, because the it can generate extra light in the night sky; however some argue that the impact can be ignored (Ashley M. Burton M and Storey J. 2004).

4 The future/Conclusion

The Australian-European collaboration is planning to build a 2.5-metre in diameter optical/infrared telescope at Dome C, for which the design alone cost a one million dollars which was funded by Australian government. It may cost about $30 million to build. It is hoped that this telescope will be operating by 2015 (Storey 2009, Australian Science). The only site-testing has been done at Dome C and astronomers expect more work to be done examing long periods of atmosphere turbulence measurements, cloud activities, aurora and sub-mm transparency at 200μm (Ashley M. Burton M and Storey J. 2004).

At Dome A, the Chinese Astronomers have handed in a proposal, to build a 4-metre optical telescope, a trio of wide-field optical and a terahertz dish telescopes (AST3). Another goal at Dome A is to build an off-axis telescope the Large Antarctic Plateau Clear Aperture Telescope (LAPCAT). Building robotic telescopes has been emphasised because such telescopes require minimal staff and the additional initial cost can be recovered by extra observations and better reliability (Ashley *et al*. 2004).

Antarctica has provided us a natural laboratory for astronomers. The harsh environment will be overcome with advanced modern technology. Astronomers will able to perform their magic and plan for the future astronomical activities in Antarctica.

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