Antarctica as a Stepping stone to Space

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The high Antarctic plateau offers a unique observing environment that is in many ways intermediate between earth and space. In the infrared, for example, the sky brightness is typically 10 to 100 times darker than at "temperate" observatories. The sub-mm transmission is superior to that measured anywhere else on earth. However, perhaps the most important feature of Antarctica is the extraordinary stability of the upper atmosphere, which dramatically reduces scintillation and offers large gains in astrometric precision. In this presentation we will discuss the site-testing results to date, the science that can be best be done, and the technology demonstrators that can best be tested in Antarctica.

1. Introduction

The Antarctic plateau is the coldest and driest place on earth. The highest points are at elevations above 4,000 metres. The atmosphere above the plateau is extraordinarily stable, as there is no jet stream, very little wind, and – at the South Pole – no diurnal variation. There is nowhere else on earth that approximates a space environment better than does Antarctica.

2. What is known about site conditions

For many people, mention of Antarctica conjures up images of icebergs, blizzards and leopard seals. However, none of these things is present on the high Antarctic Plateau, where astronomical site-testing work has concentrated. Dome C, for example, enjoys lower average wind speeds than most – if not all – US cities. At South Pole, the wind speed averages around 6 m/s, and is remarkably constant for days at a time in both speed and direction.

Aurora, while spectacular, do not affect infrared or sub-mm observations.

Temperatures, of course, are extremely low. At South Pole the temperature can drop below –75C, while sites higher on the plateau can experience still lower temperatures.

2.1 Infrared sky brightness

Across the infrared spectrum, modern infrared array detectors are capable of background-limited performance (BLIP). The sensitivity of cameras and spectrometers at infrared wavelengths is therefore generally determined by the background flux, most of which comes from the atmosphere and the telescope mirrors themselves. On the Antarctic plateau the very low ambient temperatures result in low mirror temperatures, greatly reducing their emission – especially in the near-infrared. Additionally, the sky is both cold and dry, and both these factors result in a lower sky background flux.

Measurements of the near-infrared sky brightness by Ashley et al (1996) and Nguyen et al (1996) showed reductions in background flux of up to a factor of 100 relative to established, temperate-zone observatories such as Mauna Kea. A more comprehensive data set was taken by Phillips et al (1999). These data not only confirmed the earlier results, but also showed that the reductions in sky-brightness were substantial out to at least 5.5 microns.

The region around three microns is one of the two darkest places in the interstellar spectrum (the other is around 300 microns). At 2.4 microns, we find that on occasions the sky brightness can come within a factor of a few of the zodiacal light, as measured by rocket experiments.

In the mid-infrared, Smith & Harper (1998) showed reductions of over one order of magnitude in the sky brightness; a result that has since been confirmed by the more detailed measurements of Chamberlain et al (2000).

Finally, these gains have been demonstrated to be achievable in real astronomical observations, for example by the deep images obtained with the SPIREX telescope.

2.2 Submillimetre transparency and sky stability

Over a decade ago, Townes & Melnick (1990) analysed water vapour measurements from Vostok and predicted that far-infrared/sub-mm conditions the Antarctic Plateau would be extraordinarily good. The first measurements by Chamberlin, Lane & Stark (1997) confirmed that there was extremely good transmission at 492 GHz. These results have been extended to 860 GHz by Chamberlin (2001). More recently, Lay & Halverson (2001) have observed exceptionally low fluctuations in the microwave sky brightness.

2.3 Microthermal turbulence

Marks et al (1996), Marks et al (1999) and Marks (2002) were able to show, from a combination of tower and balloon-borne microthermal measurements, that the atmospheric turbulence above the Antarctic plateau is confined to a very thin boundary layer that extends to just a couple of hundred metres above the ice. More recent acoustic radar (SODAR) measurements (Travouillon et al, 2002) have detailed the extent and distribution of this boundary layer turbulence throughout the entire year.

2.4 Continuous observing

From the South Pole, every astronomical source outside the solar system moves around the sky at constant elevation and is, of course, continuously visible. This confers immense advantages to the study of time-varying phenomena, ranging from helioseismology to exo-planet searches.

For CMBR studies the constant elevation of any patch of sky allows integration over days or even months without need for correction of elevation-dependent ground-pickup or atmospheric emission.

At sites away from the South Pole, such as Dome C, sources suffer only a small diurnal elevation change and many remain circumpolar. The sun, moon and planets are variously observable at particular times of the year, although always at relatively low elevation.

The flip-side of this is that not all the sky is visible, and indeed the area of sky that can be seen is significantly smaller than at temperate locations. Partly compensating for this is that by sheer good fortune many of the most significant astronomical objects are well south of the equator – important examples include the Galactic Centre and the Magellanic Clouds,

3. The synergy between Antarctica and Space.

Antarctic observatories can play an important role in the development of space missions. This role is made up of the following main contributions: astronomical measurements before, during, and after the mission, and technology demonstrators.

3.1 Preliminary measurements

The unique observing conditions in Antarctica make it particularly well suited to carrying out preliminary surveys that can identify potential targets and weed out unsuitable sources.

3.2 Complementary measurements

In some cases it may be possible to perform some aspects of a proposed space mission from the ground, with little or no loss of capability. This enables the space craft to be designed to perform only those measurements that must be done from space. The result can be substantial cost savings, or a re-direction of effort into more mission-critical areas.

3.3 Follow-up measurements

Any successful mission creates more questions than it answers. Earth-based telescopes can follow up these questions immediately, while the next relevant space mission may be years away. This is a powerful argument for having capable Antarctic observatories in place and operating well before the launch of a space craft.

3.4 Technology demonstrators

Between now and the next-generation far-infrared/sub-mm space missions lies the need to develop and validate new technologies. As discussed above, there are many qualities of the high plateau Antarctic sites that render them uniquely suitable for this task. This is particularly so for interferometer experiments, where Antarctica can provide an attractive combination of a cold, stable environment, unlimited space, and a uniquely transparent and stable atmosphere.

4. Final thoughts

At first sight it may seem that the difficulties of building an observatory in Antarctica are a major obstacle. However, this is not the case. It is no harder than, but rather different to, building an observatory at a temperate site. The temperature range encountered throughout the year is about 60C, comparable to the range experienced in some inland US cities. The observatory must simply be designed for a "mean" temperature of around –50C, rather than +5C, and this is a simple matter of following good engineering practice.

While the difficulties of building a telescope in Antarctica may seem obvious, there are considerable logistical advantages. For example, the South Pole is currently the only observatory site in the world that is within a few hundred metres of a heavy-lift airport. (Concordia Station, now under construction at Dome C, will be the second.) Wind speeds on the Plateau are very low, and peak speeds for which structures need to be designed are also correspondingly low. Because the temperature never rises above zero, there is no liquid water and hence no re-freezing problems.

Digging a trench through snow is a lot easier than digging it through rock. Snow is a superb thermal insulator so, a few metres below the surface, the temperature remains remarkably constant year round. In such a trench could be placed interferometer delay lines and other critical optical components, obviating the need for elaborate temperature control systems (Lloyd et al 2002). This, combined with the absence of a high altitude jet stream, makes Antarctica a particularly attractive location for interferometer test-beds that will be needed for SIM, TPF and Darwin.

5. Acknowledgments

This work is supported by funding from the Australian Research Council, the Australian Antarctic Division, and receives generous logistic assistance from the NSF via the Center for Astrophysical Research in Antarctica.

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