THE ANTARCTIC PLATEAU: WHAT IT OFFERS AS A TESTBED FOR SPACE

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ABSTRACT

The Antarctic plateau is unlike anywhere else on earth. It is of course extremely cold and dry. However, what is not so well known is that it is also very high and that the atmosphere above the plateau is extremely calm, with very low wind speeds at all altitudes. This makes the plateau an ideal location for testing astronomical instrumentation and for exploring concepts that will later be flown in space. In addition, the plateau provides an ideal location for future telescopes – including interferometers and Extremely Large Telescopes – that could carry out some crucial aspects of the science presently being considered for space missions such as Darwin and TPF.

1. INTRODUCTION

Over the past decade the Antarctic plateau has received considerable attention from astronomers. The most established facility is the US NSF's Amundsen-Scott Station at the South Pole, although facilities also exist at Vostok (Russia) and at Dome Fuji (Japan). A very important new development is the construction of the French/Italian "Concordia'" station at Dome C. Conditions at South Pole are already known to be exceptionally favorable and, because of its 400-metre advantage in elevation, it is very likely that at Dome C they will be even better.

In this paper we further develop the ideas presented by Storey et al. [1], with a particular emphasis on planet-search programs.

2. EXCEPTIONAL SITE CONDITIONS

2.1 Infrared Sky Brightness

As expected from the extreme cold of the plateau (temperatures can drop below 190K) the infrared sky is extremely dark. In the near infrared, as much as two orders of magnitude reduction in sky brightness can be observed relative to temperate sites [2, 3, 4, 5, 6]. This reduction in sky emission stems not only from the direct effect of having a cold sky, but also from the fact that it is so dry. As a result, water vapour absorption is considerably reduced, and the atmospheric windows are wider and more stable, with observations becoming feasible at wavelengths inaccessible to other sites.

In the mid-infrared, a wavelength range of more relevance to the interferometer concepts of Darwin and TPF, the reduction in sky brightness is substantial (10 to 20 times lower than temperate sites). Winter-time data have so far only been acquired at the South Pole [6, 7]. However, preliminary summer-time data from Dome C [8] suggest that it is similar to, and perhaps significantly better than, South Pole.

This reduction in sky brightness translates directly into a sensitivity gain if the detectors are background limited (which is almost always the case). A given magnitude limit can therefore be reached in the same observing time with a significantly smaller telescope. This reduces the cost not only of the telescope but also of the entire instrument complement, as the telescope $A\Omega$ is preserved throughout the optical train.

2.2 Atmospheric stability

The first measurements of the seeing from the South Pole (see, for example Loewenstein et al [9]) found that it was relatively poor. However, it is known from microthermal studies [10] that almost all of the seeing degradation comes from the lowest couple of hundred metres of the atmosphere. Most of the high plateau lies within the polar vortex. As a result, the high-altitude jet-stream is expected to be completely absent. This has been confirmed by balloon measurements throughout the year from the South Pole [10] and by summer-time balloon flights from Dome C [11]. Because there are no high altitude winds, turbulence at high altitude is also expected to be dramatically reduced.

The absence of high-altitude turbulence is of profound importance [12]. Although the astronomical "seeing" depends only on the integrated turbulence throughout the atmosphere and is independent of the altitude at which it occurs, other image-quality parameters are heavily weighted by the higher altitude layers. These parameters include the isoplanatic angle, amount of scintillation, and the differential astrometric accuracy.

Low wind speed is also a crucial factor in that it determines the coherence time of an interferometer and the bandwidth requirements of an adaptive optics system.

These arguments have led Lloyd et al [13] to propose that an astrometric interferometer constructed on the Antarctic plateau could achieve precisions way beyond that obtainable elsewhere on the earth's surface. An interferometer of this type has a crucial complementary role to play to a space interferometery planet-finding mission, in that it can monitor the orbits of long-period (eg, Jupiter-orbit) planets over many years. This allows the effect of these planets to be removed from the space mission data, greatly improving the detection probability of shorter-period planets in the habitable zone.

Acoustic radar measurements at the South Pole [14] have confirmed that the turbulent layer is very thin and that its thickness is directly proportional to the wind speed. At Dome C, where the wind is very low (zero for much of the time), it might therefore be expected that even this turbulent layer will vanish or become negligible for a substantial fraction of the time.

2.2 Disadvantages

There are of course some substantial challenges to constructing an observatory in Antarctica, and the site itself is not without disadvantages. Relative to a typical "temperate" site we see that there is:

- Increased cost of cold-rated construction,
- Increased logistics costs,
- Reduced sky coverage, and
- Reduced total amount of astronomical "dark" time.

These factors, all of which are readily quantifiable, must be weighed up against the advantages.

3. POTENTIAL SPACE-LIKE MISSIONS IN ANTARCTICA

There is a large amount of extra-solar planet science that can be conducted from Antarctica. In this section we look at a variety of programs that could take advantage of the unique atmospheric conditions to achieve sensitivities or precisions that are significantly better than achievable elsewhere on earth and, in some cases, rival what could be achieved from a medium-scale space mission.

3.1 Planetary eclipses

In order to prosecute a successful search for new planets via the transit method, it is essential that a vast number of stars are monitored with very high photometric precision. On the Antarctic plateau the greatly reduced scintillation leads immediately to a substantial improvement in photometric accuracy. A further gain in photometric precision comes from the reduction in diurnal elevation angle change that comes from being situated close to the Pole.

In addition, the large isoplanatic angle delivers consistent image quality and point-spread function across a much wider field than is otherwise achievable.

Finally, by taking advantage of the dramatically reduced infrared background, it becomes possible to observe in the 2.3 micron window, opening up the potential for studying very densely populated regions towards the Galactic Centre that would otherwise be invisible because of dust.

3.2 Interferometry

Because of the absence of high-altitude turbulence and the very slow wind speeds at all altitudes, the performance of an interferometer is dramatically improved. The Antarctic plateau is thus the best site on earth for the deployment of interferometers that are targeted at planet detection, such as the proposed Antarctic Planet Interferometer [15]. It is also worth mentioning the fact that vast areas of completely flat landscape are available, removing all restrictions on the physical placement of different baselines.

3.3 Wide field surveys

The absence of high altitude turbulence provides a much wider isoplanatic patch than can be achieved at a temperate site. Because there is only a single turbulent layer, multiconjugate adaptive optics is rendered unnecessary [16, 17], while the low wind speed leads to a long τ_0 and relaxes the bandwidth requirements demanded of the adaptive optics system.

3.4 Extremely Large Telescopes

In addition to the benefits already described for small telescopes and interferometers, it is possible to list some compelling advantages for locating an extremely large (30 – 100 metre) telescope on the plateau. These include:

- The very low wind speed at ground level, which simplifies both the mechanical design of the telescope and the structure of the telescope enclosure,
- The low wind speed at all altitudes, which increases τ_0 and therefore decreases the bandwidth required of the adaptive optics components,
- The vanishingly low seismic activity, eliminating the need for complicated protection mechanisms,
- A complete absence of dust (although small quantities of tiny ice crystals are often present), and

- The cleanest and least polluted atmosphere on earth, potentially offering major savings in mirror-surface maintenance.

4. CONCLUSION

The Antarctic plateau has a great synergy with space. Taking advantage of the uniquely favourable conditions at existing stations such as South Pole and Concordia, new Antarctic telescopes will be become important not only as technology demonstrators for planned space missions but, in some cases, significantly augment the science returns from the space mission. In the particular case of Darwin/TPF, Antarctica offers a remarkable test-bed for both the interferometer and coronagraph concepts. A mid-infrared interferometer would also have a vital role to play in performing target selection, complementary observations and follow up to the space mission.

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