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The Near-IR and Mid-IR Sky Background at the South Pole

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Abstract. At typical ground-based observatories, the thermal emission from the sky and the telescope in the near- to mid-IR far exceeds (by factors of 10^3 to 10^4) the natural background limit due to zodiacal emission and scattered sunlight. Furthermore, the fluctuations in the thermal emission limit the extent to which its effect can be subtracted. At the South Pole, we have the right ingredients for a superb near- to mid-IR (and sub-mm) site: its pressure altitude is comparable to Mauna Kea and Chilean sites, it has less precipitable water vapor, and it is much colder. It remains to quantify the improvement, to measure the temporal stability of the emission, and finally, to conduct observations of astronomical sources with a state-of-the-art instrument so as to unequivocally demonstrate the advantages. This paper summarizes the considerable progress that has been made towards these goals in the last three years.

1. Introduction

Since 1994 there has been a vigorous program at the US Amundsen-Scott South Pole Station to quantify the site conditions for infrared astronomy. Rapid progress has been made through the combined efforts of US and Australian astronomers. The antipodean interest comes from a desire to maintain the prominence of astronomy amongst Australia's sciences. This prominence is under threat, at least for optical and IR astronomy, from the growing number of 8-m class telescopes. A lack of suitable observing sites within Australia has lead to interest in joining overseas consortia to gain access to large telescopes. The realization that the antarctic plateau could contain the premier ground-based observing site has provided another avenue for securing a competitive advantage. Australia has a long history of Antarctic exploration and scientific study, largely from its coastal bases, and there is growing enthusiasm for combining astronomy with Antarctic research and moving up to the antarctic plateau—provided, of course, that the advantages are proven.

2. The Near-IR Sky at the South Pole

In the J and H windows, and in K up to 2.2μm, airglow emission exceeds the thermal emission from the sky, so there would appear to be little advantage in observing from the South Pole. However, the reduced water vapor content of the atmosphere produces windows that are wider and more stable, allowing better access to lines such as the molecular hydrogen Q-branch (2.4μm), and rarely observed lines such as [SiVI] (1.96μm) and [SiVII] (2.48μm) seen in high-excitation planetary nebulae. At the South Pole it is possible, although difficult, to observe right through the normally opaque region between the H and K windows.

From 2.27μm to 2.45μm (the $K_{\rm dark}$ band) there is a natural gap in the airglow distribution, where one may hope to reach the background level (Harper 1989). The existence of this "cosmological window" was confirmed during 1994 at the South Pole by two independent experiments under the auspices of the Center for Astrophysical Research in Antarctica (CARA): IRPS (Ashley et al 1995), developed by the University of New South Wales (UNSW), and the 60-cm SPIREX telescope and GRIM camera, from the University of Chicago. The results (Ashley et al 1996, Nguyen et al 1996) show that the window exists, and that the sky flux is between 20 and 100 times less than at temperate latitude sites. For reasons that are still unclear, the sky emission is a factor of ~ 5 above the original prediction (Harper 1989).

During June 1996, the SPIREX telescope observed the edge-on spiral galaxy NGC 5907, searching for near-infrared halo emission. In a total of 7.3 hours of observing (3.3 hours on source, 4 hours on sky) SPIREX was able to perform surface photometry to the extraordinarily deep limit of 25 mag arcsec^{-2} (Rauscher et al. 1997).

At longer wavelengths, 2.9–4.2μm, the IRPS showed a factor of 20–40 lower sky emission at the South Pole. This wavelength region has received relatively little scientific attention in the past due to the poor atmospheric transmission at typical observatories, and the large flux from the telescope and sky. The South Pole has the dual advantages of wider, more stable windows, and low background flux. This allows wider broad-band filters to be used without adding noise from the sky, and also allows longer integration times before the limit of detector saturation is reached. For these reasons, the gains in the L and M bands could surpass those in the 2.27–2.45μm window.

Currently, the UNSW group is analyzing the more extensive data set collected by IRPS during the 1995 winter. IRPS was operational from 6 April until 18 September 1995 (5 days before sunrise). Beginning 17 May, a homogeneous data set was obtained every two hours, with 35% uptime. We have 900 such sets consisting of sky-dips from horizon to horizon passing through the zenith, in the J, H, K, and M broad-band filters, and a $K_{\rm dark}$ filter. There are also complete H, K (1.4–2.5μm) and extended L (2.9–4.2μm) spectra of the sky at $\sim 1\%$ resolution at the zenith and at an altitude of 13.5 degrees.

An unexpected result from the 1995 IRPS data has been our ability to construct a fairly complete all-sky map that can be compared with the 2.2μm map produced by the DIRBE instrument aboard the COBE satellite. This will allow an independent calibration of the IRPS fluxes.

We are also exploring correlations between the sky emission at various wavelengths, and with meteorological and ionospheric data. A major question to resolve is the source of the excess 2.27–2.45μm radiation. Two possibilities are faint airglow lines, and thermal emission from absorption lines. Airglow emission is proportional to airmass, since it is always optically thin. Thermal emission is optically thick in the cores of saturated absorption lines, and so will be relatively independent of airmass at these wavelengths. The IRPS data, in conjunction with a detailed atmospheric model, should be able to ascertain the relative importance of these contributions. If thermal emission is dominant, then it should be possible to obtain even lower 2.27–2.45μm emission at colder sites on the plateau.

As part of the AASTO experiment (Storey, this volume), UNSW has constructed a Near Infrared Sky Monitor (NISM) that will measure the sky emission in the 2.27–2.45μm window as a function of airmass. The NISM was successfully deployed at the South Pole in February 1997, and will later move to other plateau sites.

3. The Mid-IR Sky at the South Pole

In the N band (8–13μm) we expected to see gains of a factor of ~ 2.5 at the South Pole due to the lower temperature, and an additional factor of a few due to the lower water vapor. Reduction in aerosols and dust in the atmosphere could also help. An unknown quantity was the effect of wind-blown ice crystals, which could act as both a source of increased background and of decreased stability.

To test these conjectures, Craig Smith of the University College, UNSW, observed with his NIMPOL instrument at the South Pole during January 1996. NIMPOL (Smith et al 1994) is an imaging camera with a 128×128 Si:Ga array, a 1.6 degree beam on the sky, and N and Q (16–22μm) broadband filters and 8–14μm circular variable filter (CVF). The results (Smith and Harper 1997) exceeded all expectations: the 10.2–11.8μm region was 20–40 times darker than a mid-latitude site. The improvement in the Q band was a factor of 4.5. Even better results could be expected during winter due to the reduced temperature and lower water vapor.

NIMPOL also showed that the mid-IR sky emission at the South Pole is so stable that it approaches photon shot noise. This eliminates the need to chop, thereby gaining an additional factor of 50 to 100% in observing efficiency. During a period of ice haze, NIMPOL recorded a 16% increase in N band emission, with some sky noise below 2 Hz.

More site-testing data, extending out to 40μm are being obtained during the 1997 winter by the SPIRAC camera (and telescope) run by CARA and NASA/GSFC. Preliminary results (Casey 1997) confirm the low water vapor measurements measured previously in the sub-millimeter (< 0.25 mm precipitable H_2O).

Finally, the AASTO (Storey, this volume) is equipped with a Mid Infrared Sky Monitor (MISM) built by UNSW that will measure the sky emission using fixed filters and two CVFs covering the 4–14μm wavelength range.

4. Summary and the Future

In the last few years, the South Pole has become the world's most thoroughly site-tested near- and mid-IR site. The result: it is by far the best place we currently know of on Earth to put an observatory. In a few more years, the AASTO data should allow a comparison with other sites on the antarctic plateau.

While the site-testing data are very convincing, the astronomical community requires final proof in the form of images of science targets. There are plans to acquire these in the near-IR during 1998 with a state-of-the-art InSb array camera on the SPIREX telescope. The technology is challenging and the time-scale is short. The next step will be a telescope of modest aperture, perhaps 2.5-m, and yet capable of world-beating performance.

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