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# The South Pole Near-Infrared Sky Brightness

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**ABSTRACT.** We report our finding that the South Pole is the darkest known Earth-based site for near-infrared astronomical observations. For this reason it has great potential for the most sensitive surveys of distant or faint objects. We find that the south polar sky background is substantially darker in the standard near-infrared $J$, $H$, and $K$ filters, and in an optimized $K_{\rm DARK}$ filter centered at 2.36 $\mu$m. In particular, the $K_{\rm DARK}$ background at the South Pole is only $162 \pm 67$ $\mu$Jy arcsec$^{-2}$ at the zenith. This is consistent with the results described in an accompanying paper by Ashley et al. (1996, PASP, 108, 721) and is comparable to the sky brightness measured by high-altitude balloon at 2.4 $\mu$m (Matsumoto et al. 1994, PASP, 106, 1217).

## 1. INTRODUCTION

Observations in the near infrared allow astronomers to probe for distant or faint objects like primeval galaxies and brown dwarfs. The sensitivity of such deep imaging surveys from ground-based telescopes is severely limited by OH airglow and the thermal emission of the atmosphere and telescope. At the best temperate latitude sites these components together produce a background of around 13 mag arcsec$^{-2}$ (4000 $\mu$Jy arcsec$^{-2}$) at the zenith (Wainscoat and Cowie 1992) in the $K$ band, which is centered at 2.2 $\mu$m. At these sites, where the temperature sometimes falls to as low as a few degrees below freezing, thermal emission from the telescope contributes a significant portion of the total $K$-band background. The background brightness drops dramatically if the telescope is moved to the South Pole, where the ambient temperature usually stays below 210 K during the austral winter.

## 2. THE SOUTH POLE INFRARED EXPLORER (SPIREX) EXPERIMENT

Motivated by the potential of the polar coldness and other observational advantages (such as the unique continuous 24-hr sky coverage and potentially good seeing), we built the SPIREX 60-cm telescope and put it at the United States Amundsen–Scott South Pole Station in 1993 December. We designed the telescope to have an emissivity of less than 5%. We also installed the Near-Infrared Grism Spectrometer and Imager (GRIM) (Hereld et al. 1990). GRIM is cooled to 74 K by liquid nitrogen. GRIM's sensor is a NICMOS-2 focal-plane array built by Rockwell International Science Center. Its 128×128 HgCdTe detectors are sensitive between 1 and 2.5 $\mu$m. GRIM has a set of cold slits and a grism for low-resolution spectroscopy, a selection of broad- and narrow-band filters for order sorting and imaging, and three different camera lenses. With the $f$/10 beam of the SPIREX telescope, the available imaging scales are 1, 2, and 4 arcsec per pixel. The SPIREX system saw first light at the Pole in early 1994 February. With SPIREX, we will exploit the advantages of the site to carry out deep imaging surveys.

## 3. RESULTS

From the second week of 1994 April to the last week of 1994 August, when the Sun remained more than a few degrees below the horizon, we sampled the background flux in each of several filters. For most of the measurements we used our $K_{\rm DARK}$ filter. It is optimized to see the thermal portion of the $K$ band where OH airglow is thought to be absent. It has a half-max bandpass between 2.29 and 2.43 $\mu$m. Calibration was performed using standard stars (Elias et al. 1982), and was consistent with calibration previously done while testing GRIM at the Apache Point Observatory in New Mexico. In April and August, when the Sun was closest to the horizon, the background was measurably brighter toward the Sun. We pointed the telescope in the opposite direction for those measurements. The background did not appear to depend on azimuth direction during the months of May, June, and July. Figure 1 shows a representative skydip. Neither the presence of visible auroras nor of the moon affected the measured brightness appreciably. The extracted sky emission, summarized in Table 1, changes from one skydip to the next, over a time scale of an hour. The right ascension (RA) defines the azimuthal direction of the scan.

Not surprisingly, we found that the emission from the

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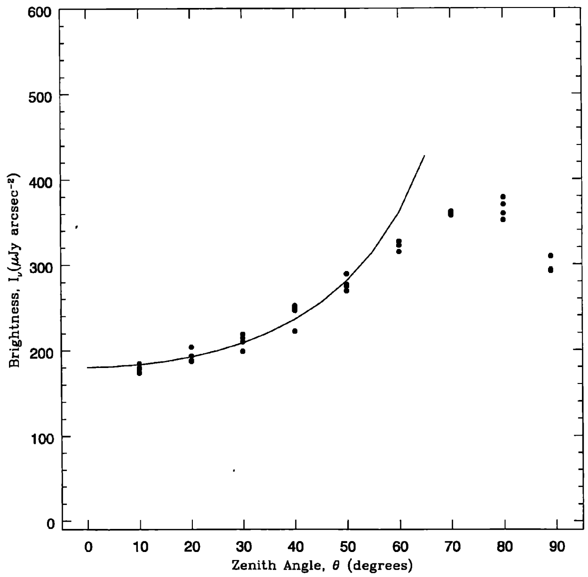


FIG. 1—Sky brightness vs. zenith angle. For each sequence of measurements, which we call a skydip, we varied the zenith angle of the telescope from nearly overhead to nearly horizon pointing. The background brightens in proportion to airmass to about 50° from the zenith, then rolls over within about 20° of the horizon. The rolloff can be attributed to absorption. We fit a portion of each skydip to a constant term plus the secant of the zenith angle (solid line). This form is meant to model a fixed telescope contribution and a separate sky-emission contribution that varies with airmass.

spider vanes, secondary obscuration, and edge of the primary contribute significantly to the flux in the $K_{DARK}$ band unless blocked by a cold pupil mask. Unblocked, the telescope contributes about the same flux as the sky at one airmass. With the cold pupil mask in place, we estimate that the emissivity of the telescope is less than 5%. The contribution from the telescope in this low-emissivity configuration is negligible compared to the background from the sky.

The sky brightness in the $K_{DARK}$ band was fairly consistent throughout the winter, giving an average and standard deviation of 162 ± 67 $\mu$Jy arcsec$^{-2}$ at the zenith. We compared this observation with a model of the background comprised of thermal emission from the telescope and from the atmosphere. In this model we assumed that the telescope is a 5% gray body at −60 °C. The emission from the atmosphere was calculated using an atmospheric transmission code (Traub and Stier 1976; Lubin 1988). The net result is a minimum background of 7 $\mu$Jy arcsec$^{-2}$ at the zenith. For comparison, the sky brightness from space at the south ecliptic pole is 6 $\mu$Jy arcsec$^{-2}$ (Hauser 1990). In Table 2 we compare our $K_{DARK}$ brightness measurement with measurements at different sites. The South Pole background is comparable to the result measured by balloon-borne instrument at 27 km altitude (Matsumoto et al. 1994). It is about four to five times brighter than the upper limit published by Hofmann et al. (1974) who also measured the OH airglow intensity from a high-altitude balloon.

From measurements using GRIM's spectroscopic mode at its intermediate resolving power ($\lambda/\Delta\lambda=230$), it is at least clear that the emission in excess of our model calculations is not concentrated in only a few lines.

TABLE 1
Sky Brightness at One Airmass

| UT Date | RA | $I_\nu$ ($\mu$Jy arcsec$^{-2}$)[a] | Grade[b] | Comments[c] |
|---|---|---|---|---|
| Apr 15 | 13 | 136±8080 | B | clear, 213 K |
| Apr 19 | 13 | 10±43 | C | clear, 213 K |
| May 30 | 17 | 349±24 | A | clear, 217 K, aurora |
| May 30 | 5 | 75±34 | A | clear, 213 K, Moon |
| Jun 4 | 5 | 87±43 | C | overcast, 209 K |
| Jun 4 | 11 | 77±21 | C | overcast, 209 K |
| Jun 4 | 17 | 123±22 | B | scattered, 209 K |
| Jun 8 | 11 | 127±30 | A | scattered, 213 K |
| Jun 10 | 5 | 181±11 | A | clear, aurora |
| Jun 11 | 17 | 193± 7 | B | clear, aurora |
| Jun 11 | 11 | 59±17 | C | clear, becoming scattered |
| Jun 30 | 5 | 227±21 | A | clear, becoming scattered |
| Jun 30 | 5 | 154±30 | A | scattered, 213 K |
| Jun 30 | 11 | 105±80 | B | clear, 213 K |
| Jun 30 | 17 | 210±27 | A | clear, 207 K |
| Jun 30 | 23 | 210±18 | A | clear, 207 K |
| Jun 30 | 5 | 186±55 | B | clear, 207 K, aurora |
| Jun 30 | 11 | 98±95 | B | clear, 208 K |
| Jul 5 | 17 | 92±28 | C | clear, 203 K |
| Jul 5 | 17 | 90±28 | B | clear, 201 K |
| Aug 22 | 24 | 183±13 | B | clear zenith, hazy horizon, 216 K |
| Aug 22 | 24 | 109± 5 | B | clear zenith, hazy horizon, 213 K |

[a]The error in the fit is shown for each skydip. These are not included in the final error which represents the scatter over the entire season.

[b]We assigned grades to the skydips in order to remove measurements that might be difficult to interpret because of rapidly varying conditions or because of excess opacity. Flat or declining skydips were given a C grade. Skydips with a clear increase with airmass were give B and A grades. The average of the A and B grade measurements gives our quoted sky brightness of 162±67.

[c]These are mostly comments derived from the meteorological reports at the South Pole Station. They give a visibility indication and the ambient temperature.

Results from our brightness measurements in the $J$, $H$, and $K$ bands are collected in Table 3. The average of three skydips at each wavelength taken in June is presented. For rough comparison, the middle column shows typical sky-brightness data from a temperate site at one airmass.

## 4. CONCLUSIONS

Our measurements and those of Ashley et al. (1996) confirm that the $K_{DARK}$ sky is substantially darker at the South Pole than at any other known terrestrial site, and is comparable to sky brightness measured by a balloon-borne instrument at the altitude of 27 km. In addition, the $J$, $H$, and $K$

TABLE 2
$K_{DARK}$ Background at Different Sites

| Site | λ ($\mu$m) | Δλ ($\mu$m) | $I_\nu$ ($\mu$Jy arcsec$^{-2}$) | Comments |
|---|---|---|---|---|
| Mauna Kea | 2.22 | 0.39 | ~ 4000 | Wainscoat and Cowie 1992 |
| Mauna Kea | 2.11 | 0.35 | ~ 2700 | Wainscoat and Cowie 1992 |
| Balloon | 2.4 | 0.1 | < 26 | Hofmann et al. 1974 |
| Balloon | 2.38 | 0.08 | 130±19 | Matsumoto et al. 1994 |
| South Pole | 2.36 | 0.14 | 162±67 | This work |

TABLE 3
$J$, $H$, and $K$ Background

| Filter | $\lambda$ ($\mu$m) | $\Delta\lambda$ ($\mu$m) | Typical Site[a] $I_\nu$ ($\mu$Jy arcsec$^{-2}$) | South Pole $I_\nu$ ($\mu$Jy arcsec$^{-2}$) |
|---|---|---|---|---|
| $J$ | 1.25 | 0.30 | ~ 1500 | ~ 5002 |
| $H$ | 1.65 | 0.30 | ~ 4400 | ~ 1600 |
| $K$ | 2.20 | 0.40 | ~ 6700 | ~ 500 |

[a]These numbers come from *NOAO Infrared Array User Manual* (Probst 1989) and are meant to be representative. They are highly variable.

sky brightness is substantially darker there. This winter we will expand on our site testing program and begin our faint survey.

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