Publications of the Astronomical Society of the Pacific
108: 721–723, 1996 August

South Pole Observations of the Near-Infrared Sky Brightness

MICHAEL C. B. ASHLEY, MICHAEL G. BURTON, JOHN W. V. STOREY, AND JAMES P. LLOYD
Joint Australian Centre for Astrophysical Research in Antarctica (JACARA), School of Physics, University of New South Wales, Sydney 2052, Australia
Electronic mail: (mcba, mgb, jwvs, jpl)@newt.phys.unsw.edu.au

JOHN BALLY
Department of Atmospheric, Planetary and Astrophysical Sciences, University of Colorado, Boulder, Colorado 80309–0391
Electronic mail: bally@nebula.colorado.edu

JOHN W. BRIGGS AND DOYAL A. HARPER
University of Chicago, Yerkes Observatory, Williams Bay, Wisconsin 53191
Electronic mail: jwb@oddjob.uchicago.edu, al@oddjob.uchicago.edu

Received 1996 January 17; accepted 1996 April 30

ABSTRACT. To observe the faintest objects in the Universe astronomers require the darkest skies. In the infrared, sensitivities are limited by the thermal emission from the atmosphere and the telescope. By placing a telescope in Antarctica, and exploiting the reduced thermal emission and the natural absence of strong airglow emission between 2.3 and 2.5 μm, we can minimize the sky brightness. In this paper, and in an accompanying paper by Nguyen et al. (1996, PASP, 108, 718), we provide the first ground-based measurements of this "cosmological window." At 2.4 μm the sky flux can be as low as 50 μJy per square arcsecond, up to two orders of magnitude lower than the corresponding flux at temperate observatories. We also show that substantial reductions in the background can be achieved throughout the 2.9–4.1 μm region.

1. INTRODUCTION

The sensitivity of astronomical observations in the infrared is limited mainly by background emission from the Earth's atmosphere. This emission comes from rovibrational transitions of molecules such as H_2O and CO_2, from airglow (primarily due to OH radicals at altitudes of 80–100 km), and from auroral lines. By chance, there are no strong airglow or auroral lines in the 2.3–2.5 μm window (Lowe and Lytle 1973; Hoffman et al. 1974; Ito et al. 1976; Baker et al. 1977; Matsuura et al. 1994) which happens to correspond closely to the minimum in the flux density of the zodiacal emission. Even from the best-established observatories, however, this is only of academic interest since the thermal emission from the atmosphere and telescope is between 10^3 and 10^4 times greater. Only from an extremely cold ground-based site, a balloon-borne telescope, or a cooled telescope in space can the thermal background be reduced to levels comparable to the zodiacal light.

The Antarctic plateau, with typical wintertime temperatures of -60 °C, a precipitable water-vapor content of 100–300 μm and an altitude of 3000–4000 m, represents a unique location (Burton et al. 1994). Here, if the residual emission is sufficiently low, ground-based telescopes could not only achieve sensitivities which could make them competitive with space-based telescopes, but at 2.35 μm could offer one of the best possible windows on the early universe. We have therefore conducted a series of observations at the South Pole to verify the existence of this "cosmological window."

2. OUR EXPERIMENT

In January 1994 we installed an instrument at the US Amundsen–Scott South Pole Station to measure the sky brightness in the near infrared, and to search for possible airglow and auroral lines in the 2.3–2.5 μm region. The instrument was adapted from the infrared photometer–spectrometer (IRPS), used with the 4-m Anglo-Australian Telescope from 1980–1992. IRPS has a single-element InSb detector, an aperture wheel, and a filter wheel with broad-band filters (J, H, K, L', and M) and two CVFs (circular variable filters) covering the wavelength regions 1.4–2.5 and 2.9–4.2 μm at a resolution of 1%. The detector, optics, and filters are cooled to $\sim$65 K with solid nitrogen. With the addition of a rotatable external flat mirror, IRPS was converted into a stand-alone telescope with a field of view of 4° and a maximum aperture of 5.5 mm, able to observe from horizon to horizon along a fixed meridian. No chopping or beam switch is required, as the integrating preamplifier of IRPS (Barton and Allen 1980) allows a direct measure of flux. A full description of the instrument, and the modifications necessary for remote control and operation at ambient temperatures down to -80 °C, are given in Ashley et al. (1995, 1996).

3. CALIBRATION

The CVF wavelength scales were calibrated using mercury lines from a fluorescent tube, and are accurate to within the resolution. The absolute sensitivity of IRPS was determined by observations of a blackbody at 0 and 60 °C in 1995 February, allowing us to derive the absolute sky brightness

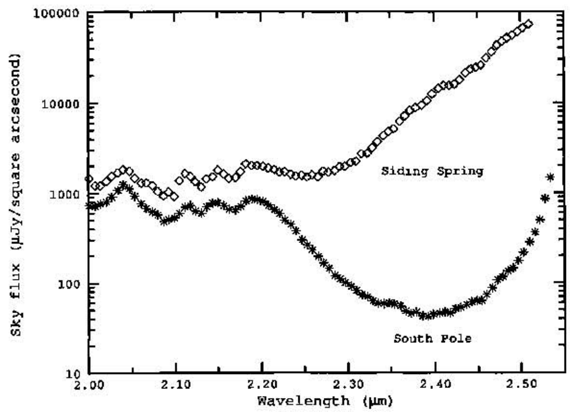

FIG. 1—A comparison of the measured sky brightness at the zenith between the South Pole and Siding Spring (Australia), for K band (2.0–2.4 μm). The South Pole data were obtained on 1994 May 31, when the ambient temperature was −62 °C; the Siding Spring data were obtained on 1993 December 9, at +10 °C.

in Janskys per square arcsecond. With an estimated maximum uncertainty of 1 °C in the blackbody temperature we can be confident of our absolute flux calibration to 10%.

Before taking IRPS to the South Pole, we used it to measure the sky brightness at Siding Spring Observatory in Australia.

4. RESULTS

Our Siding Spring data allow us to make a direct comparison of conditions at the two sites, as shown in Figs. 1 and 2. From 2.0 to 2.2 μm there is little difference between the sites, as the sky brightness is dominated by OH airglow. Beyond 2.2 μm the improved conditions at the South Pole become apparent. At about 2.3 μm the sky brightness at Siding Spring begins to rise steeply, as the contribution from thermal emission starts to dominate. The sky brightness at the South Pole is 20 times less than at Siding Spring at 2.3 μm, and does not begin to rise until about 2.45 μm. At this wavelength there is a difference of over two orders of magnitude in sky brightness between the sites.

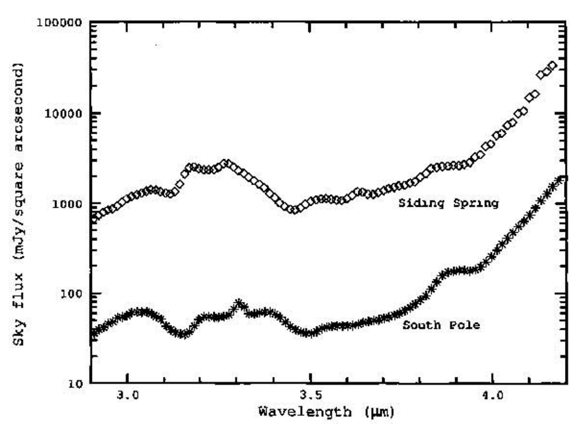

FIG. 2— A comparison of the sky brightness at the zenith between the South Pole and Siding Spring (Australia), for L band (2.9–4.1 μm). The South Pole data were obtained on 1994 June 2, when the ambient temperature was −66 °C; the Siding Spring data were obtained on 1993 December 9, at +10 °C.

Throughout the L band (2.9–4.1 μm) the sky brightness at the South Pole is a factor of between 20 and 40 lower than that at Siding Spring.

It should be noted that all the observations reported here have been obtained at the zenith. When observing away from the zenith, sky brightness generally increases due to the larger airmass being sampled.

As do all observatory sites, the South Pole experiences both good and bad weather. During four representative 24-hr periods when the sky was apparently clear, we recorded sky brightness levels at 2.3–2.4 μm ranging from 50 to 250 μJy per square arcsecond (17.7 to 16.0 magnitudes per square arcsecond) at the zenith, and for 3.5–3.6 μm we saw a range from 20 to 100 mJy per square arcsecond. At present it is not known whether these variations are due to fluctuations in atmospheric emission or due to thin clouds. We measured the sky flux to be 6000 μJy per square arcsecond between 2.3 and 2.4 μm at Siding Spring, some 120 times higher than that at the South Pole. For comparision with the observations reported by Nguyen et al. (1996) we rebinned our data to a 2.29–2.43 μm bandpass, corresponding to their K_{DARK} filter, and obtain 180±60 μJy per square arcsecond with a range of 60 to 320, in close agreement with their results of 162±67 μJy per square arcsecond with a range of 59–349. Over the entire K window (2.0–2.4 μm) we obtain a brightness of 580±90 μJy per square arcsecond at the South Pole (cf. ~500 μJy per square arcsecond from Nguyen et al. 1996).

While the minimum sky brightness we see between 2.3 and 2.4 μm is exceptionally low, it is still significantly higher than theoretical predictions (Lubin 1988; Harper 1989), and well above the fundamental limit due to the Zodiacal background (~1 μJy per square arcsecond). There are two likely sources for the increased emission we see: thermal emission from narrow saturated absorption lines, and residual airglow emission. Emission from astronomical sources, such as individual stars or the Galactic Plane, can be ruled out since the instrument pointed to the South Celestial Pole, well away from bright stars and the Galactic Plane. A star would have to have a K magnitude of −3.8 to equal our observed fluxes. If we pointed at the Galactic Center, the increase in sky brightness over our 4° beam would be no more than ~25 μJy per square arcsecond (estimated from balloon measurements made by Hayakawa et al. 1981), a factor of 2 less than the lowest figure we observed.

Other authors have derived limits to the natural background flux at 2.4 μm from balloon-borne measurements. Hoffman et al. (1974) find an upper limit of 25 μJy per square arcsecond, whereas Matsumoto et al. (1994) find a considerably higher flux of 130 μJy per square arcsecond, which they speculate may arise from nonequilibrium emission from OH radicals. Our measurements lie between these two values. Detailed modeling, beyond the scope of this current work, is necessary to resolve the source of the excess emission. However, we note that our fluxes at 2.4 and 3.5 μm are consistent with emission from an atmosphere at −40 °C and emissivity 0.1. Our Siding Spring data are consistent with emission from an atmosphere at 10 °C and 0.1 emissivity.

We have also considered the possibility that IRPS itself is introducing unwanted signal. While the emissivities of the dewar window and scanning mirror have not been measured directly, the external optics were always colder than −55 °C. Even with a combined emissivity of 10% their contribution would be at most 10 μJy per square arcsecond at 2.4 μm. Additionally, the flatness of the spectrum in the 2.3–2.4 μm region argues against a thermal contribution from the instrument. A final concern was the possibility of a long-wavelength light leak through the CVF, which would contaminate the measurements at 2.3–2.4 μm. Tests with an additional short-pass filter in 1995 February showed that no such light leak was present.

5. CONCLUSIONS

From data presented here by us and Nguyen et al. (1996), it is clear that the Antarctic plateau offers major gains over observatories at temperate sites for infrared astronomy. At 2.35 μm a background-limited infrared camera would achieve sensitivities a factor of 10 better than a similar camera at Siding Spring Observatory. Furthermore, across the entire *L* band (2.9–4.1 μm), gains of a factor of 5 could be achieved. For some observations, sensitivity may be limited not by photon statistics but by the ability to flat field the detector. In this case, the advantage of antarctic telescopes would be even greater: up to a factor of 100, or 5 magnitudes at 2.35 μm.

To quantify this further, and to extend the wavelength coverage to 1–5 μm, IRPS is obtaining a more comprehensive data set at the South Pole during 1995 and 1996. It will then be redeployed to Mauna Kea Observatory to make a direct comparison with that site. To investigate additional locations on the Antarctic plateau, we are currently designing a suite of instruments for an automated observatory to measure the site characteristics from the ultraviolet to the millimeter (Storey et al. 1996).

We thank Bob Pernic and Bob Loewenstein of the University of Chicago, and John Barton and Frank Freeman of the Anglo-Australian Observatory for assistance. Special mention must be made of the late David Allen, who designed the original IRPS and who enthusiastically supported this project until his untimely death. This research was supported in part by the National Science Foundation under a cooperative agreement with the Center for Astrophysical Research in Antarctica (CARA), Grant No. NSF OPP 89-20223. CARA is a National Science Foundation Science and Technology Center. Support from the Australian Research Council and the Australian Department of Industry Science and Technology's Bilateral Program is gratefully acknowledged. Comments from an anonymous referee were helpful.

REFERENCES

Ashley, M. C. B., Burton, M. G., Lloyd, J. P., and Storey, J. W. V. 1995, Proc. SPIE, 2552, 33

Ashley, M. C. B., Brooks, P. W., and Lloyd, J. P. 1996, PASAu, 13, 17

Baker, K. D., Baker, D. J., Ulwick, J. C., and Stair, A. T., Jr. 1977, J. Geophys. Res., 82, 3518

Barton, J. R., and Allen, D. A. 1980, PASP, 92, 368

Burton, M. G., et al. 1994, PASAu, 11, 127

Harper, D. A. 1989, in Astrophysics in Antarctica, AIP Conf. Proc. No. 198, ed. M. Pomerantz (New York, AIP), p. 123

Hayakawa, S., Matsumoto, T., Murakami, H., Uyama, K., Thomas, J. A., and Yamagami, T. 1981, A&A, 100, 116

Hoffmann, W., Frey, A., and Lemke, D. 1974, Nature, 250, 636

Ito, K., Matsumoto, T., and Uyama, K. 1976, PASJ, 28, 427

Lowe, R. P., and Lytle, E. A. 1973, J. Appl. Opt., 12, 579

Lubin, D. 1988, Master's thesis, University of Chicago, Department of Astronomy and Astrophysics

Matsumoto, T., Matsuura, S., and Noda, M. 1994, PASP, 106, 1217.

Matsuura, S., Kawada, M., Matsuhara, H., Matsumoto, T., Noda, M., and Tanaka, M. 1994, PASP, 106, 770

Nguyen, H. T., Rauscher, B. J., Harper, D. A., Loewenstein, R. F., Mrozek, F., Pernic, R. J., Severson, S. A., and Hereld, M. 1996, PASP, 108, 718

Storey, J. W. V., Ashley, M. C. B., and Burton, M. G. 1996, PASAu, 35