INFRARED ASTRONOMY AT THE SOUTH POLE:

A Report to the OIR Panel of the Decadal Committee for Astronomy and Astrophysics

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SUMMARY

The mission of CARA, the Center for Astrophysical Research in Antarctica, is to explore and exploit the unique conditions at the geographic South Pole and to lay the foundation for an ongoing national observatory. A small prototype user-facility instrument has demonstrated that very sensitive imaging in the thermal infrared can be routinely performed at the South Pole. The site should be further developed with a larger, more sensitive telescope. The Antarctic Infrared Observatory (AIRO), a 2-meter infrared telescope optimized for wide-field imaging, queue observing, and standardized data processing, will provide a productive and reliable resource for the astronomical community through the coming decade.

Because the mean annual temperature is -50 C, the thermal background at the South Pole in the 2.4-5 micron spectral range is 20-50 times smaller than that at temperate sites. This enormous advantage in thermal background translates directly into increased observing speed. A small, inexpensive telescope at the South Pole can outperform larger telescopes at other sites for studies requiring wide-field imaging. Such studies in the thermal infrared can give important new insights into the evolution of stars and galaxies and the physics of the interstellar medium. AIRO's capabilities will complement ground-based 8-m telescopes, SOFIA, SIRTF, and NGST.

RESPONSES TO PANEL QUESTIONS

1. What are the existing facilities at South Pole?

South Pole Observatory Infrastructure:

Since 1991 CARA, a NSF Science and Technology Center, has supported South Pole research in infrared, submillimeter, and millimeter astronomy. Infrastructure developed through 1998 includes a 60-cm infrared telescope, a 1.7-m submillimeter telescope, a 2-m millimeter wave cosmic background telescope, and two laboratory buildings. These facilities operate continuously all year round.

IR Facilities: Abu/SPIREX:

We have taken the initial steps to exploit the South Pole's unique thermal background advantage in the infrared. We have: (1) established a year-round observatory at the South Pole; (2) measured the basic characteristics of the site; and (3) learned how to make telescopes and instruments work in the polar environment. We have deployed a state-of-the-art InSb camera (Abu) on the 60-cm aperture South Pole Infrared Explorer (SPIREX) telescope. This system has shown that because of the low ambient temperatures and dark infrared sky, the senstivities in the 2.4 to 5 micron spectral window surpass those attainable at any other ground-based site. Abu/SPIREX has completed its first long night of observing (March-September 1998). Some of these data, including the deepest L-band image ever taken, are shown in Appendix 1.

This year the facility is available to guest investigators from the general astronomical community via a collaboration with NOAO. The NOAO call for proposals generated 45 proposals, and the facility was oversubscribed by a factor of 6. A similar call in Australia resulted in 22 proposals. These programs span a wide variety of subjects, ranging from stellar astronomy to cosmology, clearly demonstrating the large demand for sensitive observations in the thermal infrared (Appendix 2).

Site Characterization:

One goal of CARA was to characterize the properties of the South Pole as an infrared observing site. Details of this site characterization are provided in Appendices 3 and 4. Briefly, compared with other ground-based infrared sites, the South Pole is much colder and much darker, but has only modest seeing (1.7 arcsec at 0.5 microns). The observed atmospheric structure at the South Pole, however, suggests that a simple tip-tilt system will improve the seeing dramatically.

2. What types of science will be addressed?

After the epoch of decoupling, the evolution of matter in the universe has been largely shaped by star-formation. The infrared spectrum from 2.4 to 5 microns provides a unique window on the star-forming Universe. In the continuum, this waveband probes the cooler material, such as evolved red stars, embedded protostars, and protoplanetary disks. Thermal infrared continuum measurements also trace dust in the vicinity of newly formed stars. In addition, the 2.4 to 5 micron band contains a number of astrophysically important spectral lines, most notably: (1) the 3.3 micron PAH feature, a probe of very small dust grains exposed to UV fields; (2) Brackett alpha, a tracer of ionized gas around hot OB stars that suffers very little from extinction; (3) the Q-branch H_2 lines at 2.42 microns, a unique, yet heretofore untapped, diagnostic of dense molecular gas.

Despite its astrophyscial importance, this waveband has remained largely unexplored due to the high thermal background. In particular, wide-field imaging has proved especially challenging. Wide-field imaging: (1) is essential to understand global phenomena, because it provides large, statistically significant observational samples; (2) optimizes the chances for discovering new objects for follow-up study; (3) reveals the global environment surrounding a source and establishes how this environment shapes its properties; and (4) is important for monitoring studies when the objects of interest are distributed over wide areas.

A widefield infrared imager in the 2.4-5 micron waveband can address a broad range of astrophysical issues. A few examples include:

Protoplanetary Disks: Observations at millimeter wavelengths as well as observations with HST and ground-based infrared telescopes have demonstrated that circumstellar disks are common and perhaps universal consequences of star formation. Many of these objects may represent the first stages in the formation of planets. At optical wavelengths, these protoplanetary disks or “proplyds” can be seen as silhouettes against background nebulosity, but in the near-infrared they exhibit an excess and in the mid-infrared they can be seen directly in emission.

Models suggest that the spectral region near 3 μm may be particularly interesting. At this wavelength the emission comes predominantly from the optically thick, inner portions of the disk. Since the contrast between the disk and star increases at longer wavelengths but the contrast between the disk and background diffuse dust emission increases at shorter wavelengths, the 2.4 to 5 micron band may be optimal for their detection. A sensitive wide-field imager at 2.4 to 5 microns should detect large numbers of disks and answer fundamental questions about their frequency, distribution, and lifetime.

Detection of Embedded Objects: Deep images in L and M bands will discover virtually all the deeply embedded sources in nearby molecular clouds. Detecting these young stellar objects, protostars, and clusters will address many issues including the star and cluster formation rates and the efficiency of star formation within clouds.

PAH Probes of PDRs: Fluorescent 3.3 micron PAH emission is a remarkably sensitive probe of material exposed to UV radiation. AIRO studies of PAH emission will improve the angular resolution by an order of magnitude over that attained by the usual PDR tracers, the far infrared fine structure transitions of oxygen and carbon. In addition to illuminating the large-scale structure of molecular clouds in unprecedented detail, the PAH emission will provide a backlight which can reveal silhouetted small, dense clumps within the cloud cores.

AGB Stars and Their Impact on Stellar Evolution: Because the spectra of many dust enshrouded AGB stars peak between 2 and 5 microns, L and M band images are vital if we are to determine their luminosities, mass-loss rates, and chemical states. For example, deep images of star clusters in the LMC and SMC can give for the first time a sample of AGB stars near the end of their lives with known ages, metallicities, and both AGB and main-sequence masses. This will provide strong constraints on evolutionary models.

3. What is the best direction for further development during the coming decade?

We believe that the next step in infrared astronomy from the South Pole is to build AIRO (Antarctic Infrared Observatory), a wide-field 2.4 to 5 micron imaging telescope. Because AIRO's science mission focuses on large fields of view, a smaller aperture is preferable . Fortunately, the extremely low background at the South Pole allows even a modest 2-meter aperture to achieve sensitivities comparable to 8-meter telescopes at more temperate sites. To maximize the areal coverage on the sky, AIRO will be equipped with a large-format InSb camera. Using up-to-date, but mature technology, AIRO can be deployed to the Pole during the first years of the coming decade at only modest cost. AIRO will be optimized for efficient, relentless observing of large fields of view.

The current Abu/SPIREX project prototypes all of the key elements of such a facility. AIRO data will be readily available to the world astronomical community through queue observing; the data will be processed and archived via an efficient and automated pipeline which produces calibrated images ready for scientific analysis; and key-project databases will be promptly available to the entire community via the Internet. We presently anticipate that the observing time will be split approximately equally between key projects and general-observing proposals selected through the NOAO time allocation process.

As a general-purpose facility, AIRO can address a wide range of astrophysical topics, as demonstrated by the variety of the Abu/SPIREX proposals. These span such diverse topics as cosmology, extragalactic astronomy, stellar evolution, supernovae, planetary nebulae, protoplanetary disks, star formation, and the interstellar medium. AIRO will benefit from broad community involvement, and from the flexibility to field new instruments tailored to study novel, unanticipated research topics.

AIRO will be an international partnership between the US and Australia, continuing a collaboration first forged within CARA. The Abu/SPIREX project has attracted participation by a strong team which will provide the base for the development of AIRO. This effort currently includes collaborators from Boston University, Goddard Spaceflight Center, NOAO, Mt. Stromolo Observatory, Ohio State University, Rochester Institute of Technology, the University of Chicago, the University of New South Wales, and the Universities Space Research Association. The breadth of this collaboration is another indication of the growing interest in Antarctic infrared astronomy.

4. How should plans for Antarctic facilities be integrated into an overall plan for infrared astronomy during the next decade?

Because AIRO will be optimized for wide-field surveys in the relatively unexplored 2.4 to 5 micron band, it will play a complementary role to large ground-based telescopes. Because of their superlative angular resolution, the larger telescopes will be in heavy demand for detailed studies of individual sources. AIRO will also complement airborne and space missions such as SOFIA, SIRTF, and NGST.

AIRO's imaging surveys and global studies will result in a host of questions requiring follow-up studies at higher angular resolution by larger aperture telescopes. They will also provide information about the astrophysical environments of the compact sources and so give clues about their evolution. AIRO can also provide a unique ground-based, low-background environment to test equipment designed for space missions such as NGST (see Appendix 5).

5. What are the scientific advantages relative to facilities at other sites both on the ground and in space?

The scientific advantages of the AIRO instrument are:

(1) The large field of view and excellent sensitivity of AIRO are optimally suited for deep, wide-field surveys and global studies at 2.4-5 micron thermal infrared wavelengths. With its unique thermal advantage, AIRO can be much more effective at wide-field imaging than telescopes at more temperate sites.

(2) Observations with AIRO will discover targets and establish the global context for investigations by larger telescopes at higher angular and spectral resolution.

(3) AIRO will be cost-effective and flexible. For example, upgrades to new detector technologies or additional polarimetric, spectroscopic, or mid-infrared capabilities can be implemented rapidly and relatively cheaply.

Infrared telescopes which will operate in the coming decade include Gemini, SIRTF, and SOFIA. AIRO's capability for wide-field imaging and monitoring will free these facilities to concentrate on their primary missions.

The Gemini telescopes and their instruments are optimized for the highest possible angular resolution over small fields of view, and this capability will be in heavy demand. For wide-field imaging and surveys, AIRO will achieve similar sensitivities. The cost of the building the AIRO telescope and camera will be of the same order as the cost of developing instruments for Gemini, but they can be used full time.

SIRTF will be a general-purpose observatory optimized for extremely deep imaging over narrow fields of view at wavelengths spanning the entire range from 3.5 to 200 microns. It will have a finite lifetime, no spectral imaging capabilities at the shortest wavelengths, no provisions for polarimetry, and no pixels smaller than 1.2 arcseconds.

SOFIA and AIRO will have comparable sensitivities in the 2.4-5 micron spectral range, since they have similar apertures, temperatures, and emissivities. However, SOFIA's primary mission is to observe wavelengths which cannot be seen from the ground.

Among programs now in the planning stage, NGST will have unsurpassed sensitivity at near infrared wavelengths, but will not fly before the latter part of the decade. AIRO will be an excellent precursor experiment which can explore some of the types of science which can be done with NGST, identify targets for follow-up study, and provide a testbed for NGST technology (see the letter from M. Greenhouse in Appendix 5.

A numerical comparison of sensitivities of background-limited telescopes at the South Pole, Mauna Kea, and space is given in Table 1.

6. What are the most significant technological (or other) hurdles to further development?

There are no significant hurdles.

AIRO requires no new technologies. Existing techniques yield exceptional results on the Antarctic plateau because the uniquely cold temperatures result in skies 20-50 times darker than at other ground-based sites.

The observatory and the infrastructure are already in place at the South Pole. In fact, the major modernization of the South Pole Station begun this past year will significantly improve the infrastructure. Given the US commitment to the South Pole base, the cost of operating AIRO will be similar to other ground-based observatories. Community access can be guaranteed using the approach pioneered by NOAO's Abu/SPIREX guest observer program.

The principal advantages of an Antarctic infrared telescope are: (1) low temperatures and dark skies, (2) modest cost and high flexibility, (3) optimal site for wide-field imaging, and (4) continuous access to the sky for long periods of time. AIRO can be an accessible, affordable, flexible, and ongoing national resource through the coming decade.

Table 1: 2-5 μm Point-Source and Survey Sensitivities for Antarctic, Temperate-Latitude, and Space Telescopes

Site	Mirror Diameter	Pixel Width	λ	Sky Brightness		Efficiency	Bandwidth	electrons/s pix	Photometry Area	NEFD (1 σ, 1 s, 1 field)		Array Size	FOV	Fields/deg^2	Survey Rate	Time to Limit (1 field, 5σ)	Survey Limit
		arcsec	μm	Jy/arcsec^2	$\frac{\text{photons}}{\text{s m}^2\text{ arcsec}^2\text{ neper}}$		Δλ/λ		#Pixels	Jy	mag	pixels$^{1/2}$	arcmin		Hours/deg^2	$\frac{\text{minutes}}{\text{field}}$	magnitudes (1 deg^2, 5 σ)
Mauna Kea	8	0.05	2.1	3.0E-03	4.5E+04	0.4	0.17	3.9E+02	16.0	1.5E-06	21.5	1024	0.9	4944	24.0	0.3	21.3
South Pole	2	0.25	2.4	1.5E-04	2.3E+03	0.4	0.08	1.4E+01	16.0	9.9E-06	19.5	1024	4.3	198	24.0	7.3	21.0
Space	8	0.05	2.2	1.0E-06	1.5E+01	0.4	0.17	1.3E-01	16.0	2.8E-08	25.9	1024	0.9	4944	24.0	0.3	25.7
Space	0.5	1	2.2	1.0E-06	1.5E+01	0.4	0.17	2.0E-01	16.0	8.9E-06	19.6	1024	17.1	12	0.22	1.1	20.1
Mauna Kea	8	0.05	3.6	3	4.5E+07	0.4	0.17	3.9E+05	16.0	4.8E-05	16.9	1024	0.9	4944	24.0	0.3	16.7
South Pole	2	0.25	3.6	0.15	2.3E+06	0.4	0.17	3.0E+04	16.0	2.2E-04	15.3	1024	4.3	198	24.0	7.3	16.8
Space	8	0.05	3.6	2.0E-06	3.0E+01	0.4	0.17	2.6E-01	16.0	3.9E-08	24.6	1024	0.9	4944	24.0	0.3	24.4
Space	0.5	1	3.6	2.0E-06	3.0E+01	0.4	0.17	4.0E-01	16.0	1.3E-05	18.4	1024	17.1	12	0.22	1.0	18.9
Mauna Kea	8	0.05	4.8	8.0E+01	1.2E+09	0.4	0.03	1.8E+06	16.0	5.9E-04	13.5	1024	0.9	4944	24.0	0.3	13.3
South Pole	2	0.25	4.8	1.1E+00	1.7E+07	0.4	0.08	1.1E+05	16.0	8.4E-04	13.2	1024	4.3	198	24.0	7.3	14.7
Space	8	0.05	4.8	1.0E-05	1.5E+02	0.4	0.17	1.3E+00	16.0	8.8E-08	23.1	1024	0.9	4944	24.0	0.3	22.9
Space	0.5	1	4.8	1.0E-05	1.5E+02	0.4	0.17	2.0E+00	16.0	2.8E-05	16.8	1024	17.1	12	0.22	1.1	17.4

Relative sensitivities of background-limited telescopes at the South Pole, mid-latitude ground-based sites, and space for point sources and for survey-mode observing. Columns 11 and 12 give point-source sensitivities for a single pointing. Column 18 gives the point-source limit which could be reached after surveying one square degree for the time specified in Column 16. The time assumed for the smaller space telescope is that needed to complete an all-sky survey in one year. All limits were computed on the basis of total on-source exposure time. The sky brightnesses for the ground-based telescopes were taken from the references cited in Appendix 3 and the NSFCAM manual for the IRTF at Mauna Kea. The background assumed for the space telescopes is zodiacal light at 1 AU.

Appendix 1

Abu/SPIREX Images

Placing a large-format 2.4-5 micron camera at the South Pole allows small telescopes at the South Pole to outperform larger telescopes at temperate sites. The darker sky reduces the background flux dramatically, and allows the use of larger bandwidths without saturating the detector. Using the 60 cm SPIREX telescope with the Abu camera, during the winter winter of 1998, we detected L=13.5 mag (S/N=10 in 1 hour). For comparison, the same camera used on the Kitt Peak 4-m could detect only L=8 mag (S/N=10 in 1 hour) with a field of view approximately 20 times smaller than SPIREX/Abu.

The following images of the star-forming regions 30 Doradus in the Large Magellanic Cloud and NGC 6334 inside our own Galaxy were taken with the CARA SPIREX (South Pole InfraRed EXplorer) telescope using NOAO's Aladdin array-based Abu camera. Data were processed by the Abu data pipeline team, at NOAO and the Rochester Institute of Technology. Composites were produced by K. Michael Merrill, NOAO.

NGC 6334:

Within the color composite, blue is an image taken through a narrow-band 3.28 micron filter that isolates emission from PAH grains; green through a broad L-band filter; and red through a narrow-band 4.05 micron Brackett-alpha filter. Exposure times were about 1 hour for the L-band, 2 hours for the 3.28 micron (PAH), and 30 minutes for the Brackett-alpha data. Note that the brightest stars are saturated in this stretch and so appear white.

30 Doradus:

Within the color composite, red is an L-band image taken with Abu/SPIREX. Green and blue are, respectively, K-band and H-band images made by Darren DePoy at Cerro Tololo Interamerican Observatories. With a total integration time of 9.25 hours, this L-band image is the most sensitive ever obtained from the ground.

Appendix 2

NOAO Approved Programs (March - October 1999)

PI	*Institution*	*Prop. ID*	*Site*	*Tel.*	*Hrs.*	*Proposal Title*
Allen, Lori	Harvard-Smith. Center for Astrophy.	1999A-0532	SP	SPIREX	24	Deep L-band Imaging of the L1688 Young Cluster
Bania, Thomas	Boston University	1999A-0514	SP	SPIREX	35	Dust Emission from High Galactic Latitude Translucent Molecular Clouds
Clemens, Dan	Boston University	1999A-0509	SP	SPIREX	40	L and M band survey of southern star-forming small Bok globules
Davidge, Timothy	Herzberg Institute of Astrophysics	1999A-0515	SP	SPIREX	46	A 3 - 5 micron Photometric Survey of Globular Clusters
Frogel, Jay	Ohio State University	1999A-0517	SP	SPIREX	65	A Search for Mass Losing Variables in Galactic Globular Clusters
Jackson, James	Boston University	1999A-0504	SP	SPIREX	72	PDRs in a Variety of UV Fields: Abu Observations of NGC 6334
Jackson, James	Boston University	1999A-0525	SP	SPIREX	114	Photodissociation Regions at the Galactic Center
Jeffries, Rob	Keele University	1999A-0528	SP	SPIREX	65	The lifetimes of circumstellar disks in young solar-type stars
Jones, Lauren	University of Florida	1999A-0533	SP	SPIREX	22	Brackett Alpha Imaging of NGC 300
Kastner, Joel	Massachusetts Institute of Technology	1999A-0506	SP	SPIREX	25	A Q-branch H_2 Imaging Survey of Southern Planetary Nebulae
Kastner, Joel	Massachusetts Institute of Technology	1999A-0523	SP	SPIREX	26	Mass-Losing Red Giants in the Galactic Bulge: Filling in the Blanks with ABU
Kenyon, Scott	Harvard-Smith. Center for Astrophy.	1999A-0519	SP	SPIREX	20	Three Micron Observations of Young Stars in the Chamaeleon I Dark Cloud: Frequency of Circumstellar Disks

Lada, Elizabeth	University of Florida	1999A-0535	SP	SPIREX	93	L-Band Imaging Survey for Circumstellar Disks in Clusters
Merrill, Michael	National Optical Astronomy Ob.	1999A-0522	SP	SPIREX	6	Diffuse Emission at 3.28 microns at the Galactic Center
Pian, Elena	ITESRE-CNR	1999A-0524	SP	SPIREX	48	Infrared Counterparts of Gamma-Ray Bursts Detected by BeppoSAX
Sellgren, Kristen	Ohio State University	1999A-0541	SP	SPIREX	40	The spatial distribution of 3.3 micron emission in selected IRAS sources
Suntzeff, Nick	National Optical Astronomy Ob.	1999A-0521	SP	SPIREX	29	L-Band Photometry of Bright Supernovae
Van Loon, Jacco Th.	University of Amsterdam	1999A-0516	SP	SPIREX	35	Dust-enshrouded Asymptotic Giant Branch stars in clusters in the Magellanic Clouds
Weintraub, David	Vanderbilt University	1999A-0512	SP	SPIREX	52	Searching Inside the Elephant Trunks in the Eagle Nebula
Wright, Edward	University of California, Los Angeles	1999A-0503	SP	SPIREX	30	Unveiling the Cosmic Infrared Background at 3.5 Microns by Measuring the Stellar Content of the Southern DIRBE Cold Spot
Yusef-Zadeh, Farhad	Northwestern University	1999A-0531	SP	SPIREX	20	Br (alpha) Survey of the Galactic Center Region

[South Pole **] [** NOAO **] [** CTIO **] [** KPNO **] [** SCOPE **]**

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Appendix 3

Infrared Sky Brightness at the South Pole

The advantages of Antarctica for astronomy at infrared wavelengths stem directly from its dark skies, cold temperatures, stable atmosphere, and the ability to observe objects continuously and relentlessly throughout its long winter night. In the thermal infrared, the sky at the South Pole is darker than other good ground-based sites by as much as two orders of magnitude, dramatically reducing photon noise and minimizing the effects of changes in sky brightness. The variability of the sky emission is further reduced by the homogeneity of the atmosphere above the featureless polar plateau.

Dedicated site-testing instruments have documented the 1.25-14 µm sky brightness (Chamberlain et al. 1999, Phillips et al., 1999). Typical values of sky brightness during winter at the South Pole are 70-180 µJy/arcsec^2 at 2.4 µm, 0.12-0.19 Jy/arcsec^2 at 3.6 µm, 0.8-1.3 Jy/arcsec^2 at 4.8 µm, and ~30 Jy/arcsec^2 at 9 and 11 µm. The incidence of clear, dark, skies suitable for astronomical observations is of the order of 50%.

In the near and mid-infrared, the darkest atmospheric window lies between 2.3 and 2.45 µm. The sky brightness can fall below 70 µJy/arcsec^2, to values comparable to those measured from balloon altitudes (Ashley et al. 1996, Nguyen et al., 1996, Phillips et al. 1999). The agreement between the South Pole and balloon data strongly suggests that the residual emission in this window during the coldest and darkest observing conditions comes predominantly from airglow at altitudes above 38 km. No correlation is observed between 2.4 µm sky brightness and auroral activity.

Practical benefits are even greater at the longer wavelengths of the L and M bands, since at warmer sites the infrared arrays which have been developed for astronomical applications are rapidly saturated by the high thermal backgrounds. Furthermore, the benefits of reduced thermal flux are available over the full bandwidths of the atmospheric windows. The largest gains may come at 4.6-5.5 µm, where the observed fluxes appear to be more than 50 times smaller than at other sites and the extremely low values of atmospheric water vapor can help open the entire window for routine observations.

In the N band (8-13 µm), the sky brightness is lower by a factor of 3-10. The low sky fluxes and the homogeneity of the atmosphere also contribute to lower sky noise (Smith and Harper 1998). In the most transparent parts of the window, the fact that the strong temperature inversion at the South Pole makes the telescope colder than the mean atmospheric temperature is also significant, since it makes it easier to reach the limit set by the atmospheric emission. In this waveband, the gains realized for a specific type of measurement will depend in detail on the relative importance of sky brightness, telescope emissivity, temperature, and sky noise.

REFERENCES

Ashley, M. C. B., Burton, M. G., Storey, J. W. V., Bally, J., Briggs, J. W., Harper, D. A., and Lloyd, J. P. 1996, P. A. S. P., **108**, 721

Appendix 3

Chamberlain, M., A., Ashley, M. C. B., Burton, M. G., Storey, J. W. V. 1999, in preparation

Nguyen, H. T., Rauscher, B. J., Harper, D. A., Loewenstein, R. F., Pernic, R. J., Severson, S. A., and Hereld, M. 1996, P. A. S. P., **109**, 718

Phillips, A., Burton, M. G., Ashley, M. C. B., Storey, J. W. V., Lloyd, J. P., Harper, D. A., and Bally, J. 1999, accepted for publication by Ap. J.

Smith, C. H. and Harper, D. A. 1998, P. A. S. P., **110**, 747

Appendix 4

ASTRONOMICAL SEEING AT THE SOUTH POLE

Summary

Both differential image motion observations and direct measurements of turbulence show that the seeing during the winter at the South Pole is approximately 1.7 arcseconds at visual wavelengths at a height of 12 meters above the snow surface. Assuming Kolmogarov turbulence, this implies seeing of approximately 1.2-1.1 arcseconds at thermal infrared wavelengths between 2.4 and 5 µm. Almost all of the turbulence causing the seeing is located in the lowest 200 meters of the atmosphere, where wind velocities are typically less than 7 meters/sec when the sky is clear. In these conditions, simple tip-tilt adaptive optics should allow 2-meter telescopes to achieve diffraction-limited imaging at 2.4-5 µm over large fields of view (Wild et al. 1998).

Differential Image Motion Measurements

Two telescopes made HDIMM (Hartmann Differential Image Motion Measurement) observations at a wavelength of 500 nm during the winter of 1995-96. The measurement technique is similar to the differential image motion method described by Sarazin and Roddier (1990), but employs multiple apertures to increase the amount of data which can be accumulated during a given measurement period (Bally et al. 1996).

The telescopes were the 60-cm SPIREX telescope (using a 48-aperture HDIMM mask) and a 28-cm Celestron telescope (using a 12-aperture HDIMM mask). The 28-cm telescope was attached to the side of the 60-cm telescope. They were mounted on a tower approximately 12 m above the snow surface.

A set of observations consisted of measurements of five stars, Alpha Centauri, Beta Centauri, Sirius, Alpha Eridani, and Alpha Carina. Each set took about 75 minutes. There were 28 sets of observations during the course of the winter, comprising a total of 274 individual stellar measurements (Loewenstein et al. 1998).

The differential-motion measurements yield a robust measure of the seeing. The two telescopes give similar values, with medians of 1.71 arcseconds for the 60-cm telescope and 1.64 arcseconds for the 28-cm telescope. Plotting the seeing data against wind speed and direction revealed no strong correlations.

The HDIMM data can also be analyzed to obtain the common-mode motion of the images. The common-mode motion is comprised of a component due to common-mode seeing and a component due to vibrations of the structure supporting the telescope. These results set upper limits on the separate contributions of the two components.

Appendix 4

The mean rms common-mode motion for the 60-cm telescope was 0.84 arcseconds. Power spectra of the motions show that most of the power is concentrated at frequencies below 5 Hz. The common-mode motion correlates weakly with wind speed, with higher values observed above 14.5 mph (the mean winter wind speed). There was no correlation with date of observation over the May-September duration of the experiment.

Microthermal Measurements

Direct measurements with microthermal sensors on a 27-m tower (Marks et al. 1996) and during 15 balloon flights (Marks et al. 1997) yielded results which are consistent with the HDIMM observations. In addition, the data show where the turbulence responsible for the seeing is located.

The mean value of the seeing calculated by integrating the balloon microthermal measurements from the surface to the maximum balloon altitude was 1.86 arcseconds. The data show that the turbulence causing the seeing is strongly concentrated in the lowest few hundred meters of the atomosphere, as expected from the altitude profiles of temperature and wind shear. The mean seeing above approximately 200 meters is 0.37 arcseconds. The balloon microthermal measurements were made and analyzed using techniques identical to those employed by Jean Vernin and his collaborators at a number of other astronomical sites, including Parenal in Chile. Above 200 meters, the Polar seeing is better than the seeing above Parenal.

Microthermal observations from a 27-m tower (Marks et al. 1996) indicate that the contribution of the lowest 27 meters of the boundary layer to the total seeing is approximately 0.6 arcseconds

Acoustic Backscatter Measurements

Acoustic backscatter (also called echosonde or SODAR) measurements also give information about the vertical distribution of turbulence. Measurements at the South Pole by Neff in 1993-94 (personal correspondence) confirm the result that most of the turbulence lies below an altitude of 200 m. During the summer of 1998-99, the University of New South Wales group installed an acoustic sounder in the AASTO (Automated Astrophysical Site Testing Observatory) at the South Pole. This instrument measures the altitude profile of turbulence, wind speed, and wind direction to a height of 300-600 m. It will continuously monitor the structure of the boundary-layer turbulence at the South Pole during the coming winter. After characterizing the seeing and sky brightness at the South Pole, the AASTO will be deployed to make similar measurements at other sites on the Antarctic Plateau.

Appendix 4

REFERENCES

Bally, J., Theil, D., Billawala, Y., Potter, D., Loewenstein, R. F., Mrozek, F., and Lloyd, J., 1996, Pub. Astron. Soc. of Australia, **13**, 22

Marks, R. D., Vernin, J., Azouit, M., Briggs, J. W., Burton, M. G., Ashley, M. C. B., and Manigault, J. F. 1998, "Antarctic Site Testing Microthermal Measurements of Surface Layer Seeing at the South Pole", Astron. Ap. Suppl., **118**, 385-390

Marks, R. D., Vernin, J., Azouit, M., Manigault, J. F., and Clevelin, C., "Measurements of Optical Seeing on the High Antarctic Plateau, 1998, Astron. Ap., accepted for publication

Loewenstein, R. F., Bero, C., Lloyd, J. P., Mrozek, F., Bally, J., and Thiel, D. 1998, in “Astrophysics in Antarctica”, A. S. P. Conference Series, **141**, 296, eds. Novak, G. and Landsberg, R. H.

Sarazin, M. and Roddier, F., 1990, Astron. Ap. Suppl., **227**, 294

Wild, W. J., Kibblewhite, E. J., and Harper, D. A., 1998, A. S. P. Conference Series, **141**, 303, eds. Novak, G. and Landsberg, R. H.

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Dr. Ian Gatley
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Rochester Institute of Technology
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13 October 1998

Dr. Gatley,

I am writing in support of your proposal to develop a plan for a new robotic infrared observatory at the south pole station. I'm sorry that NGST travel will prevent me from attending your presentation to the NSF next week. We see an opportunity for synergism between the Next Generation Space Telescope and your proposed observatory, and you may invite the NSF to contact me on this issue.

The NGST is pushing near- and mid-ir detector technology in the direction of larger array formats than have ever been flown before. For example, the baseline instrument configuration for NGST utilizes five 4096 x 4096 pixel InSb arrays and a 1024 x 1024 pixel Si:As array. In order to suppress power dissipation in the sensor chips and their front end electronics, these focal plane arrays are being optimized for the Zodiacal light limited background power conditions expected at the 1 AU orbit of NGST. As a consequence, these new arrays can not be used for broad-band imaging at typical high-background observatory sites such as Mauna Kea.

We anticipate that engineering grade detectors will be produced as the NGST flight detectors are developed. Past experience has shown that making prototype flight detectors available to the community for ground-based research is both scientifically productive and yields a depth of engineering understanding that could not be achieved through laboratory tests alone. The Stratospheric Observatory for Infrared Astronomy (SOFIA) is one low background observatory at which prototype NGST detectors could be used for imaging. However, a south pole observatory could bring unique capability and provide the community with an important alternative.

For example, a south pole wide field telescope (with natural seeing alone) could conduct deep imaging survey programs at spatial resolution and integration time far exceeding that achievable with SOFIA. Such an application is ideally suited to the large array formats we are developing for NGST. As a consequence, we feel that the community and the NGST Project would potentially benefit from development of a modern practical infrared observing capability at the south pole, and we support your advocacy for development of a detailed plan.

Sincerely,

Matthew Greenhouse
NGST Deputy Project Scientist