

AD-A061 020

AIR FORCE GEOPHYSICS LAB HANSCOM AFB MASS
CALIBRATION OF THE HI STAR SENSORS.(U)
JUL 78 S D PRICE, R G WALKER

F/G 17/5

UNCLASSIFIED

AFGL-TR-78-0172

NL

1 OF 1
AD
A061 020



END
DATE
FILMED
2-79

DDC

AD A061020

DDC FILE COPY

AFGL-TR-78-0172
INSTRUMENTATION PAPERS, NO. 288

(12) LEVEL II
NW



Calibration of the HI STAR Sensors

STEPHAN D. PRICE
RUSSELL G. WALKER

3 July 1978



Approved for public release; distribution unlimited.

OPTICAL PHYSICS DIVISION PROJECT 7670
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

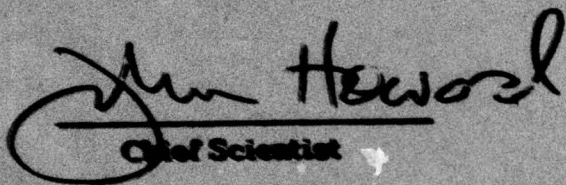


78 10 26 032

This report has been reviewed by the ESD Information Office (OI) and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER


Chief Scientist

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the National Technical Information Service.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-78-0172, AFGL-IP-268	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) CALIBRATION OF THE HI STAR SENSORS.	5. TYPE OF REPORT & PERIOD COVERED Scientific. Interim.	
7. AUTHOR(s) Stephan D. Price Russell G. Walker	6. PERFORMING ORG. REPORT NUMBER IP No. 268	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Geophysics Laboratory (OPI) Hanscom AFB Massachusetts 01731	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 76700606	
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory (OPI) Hanscom AFB Massachusetts 01731	12. REPORT DATE 3 July 1978	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Instrumentation papers	13. NUMBER OF PAGES 30	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited. 1249p.	15. SECURITY CLASS. (of this report) Unclassified	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) B		
18. SUPPLEMENTARY NOTES * Present Address: NASA Ames Research Center, Moffett, CA 94035		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Problems exist in calibrating a cryogenically cooled infrared sensor system in the laboratory. Although there are limited laboratory facilities which attempt to simulate the actual operational environment, the sensor-tester interface has created difficulties for calibrating LWIR sensors in general. The procedures used to calibrate the AFGL infrared celestial survey experiments are described in detail. It was found that stars are reliable calibration sources which offer several advantages over laboratory references. The long		

DDC
RECEIVED
NOV 8 1978
B

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

409 578

78 10 26 032

LB

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. Abstract (Continued)

term stability of the sensor systems as well as linearity of the system are discussed.

RE: Classified references, distribution unlimited-
No change per Mr. B. Schurin, AFGL/OPI

ACCESSION for	
NTIS	White Section ☒
DDC	Bull Section ☐
UNANNOUNCED	☐
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
DATE	
SPECIAL	
A	

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Contents	
1. INTRODUCTION	5
2. APPROACH	7
3. RESULTS	13
4. CONCLUSIONS	24
REFERENCES	25
APPENDIX A	27

Illustrations	
1a. Comparison of the Measured versus Reference Star Magnitudes for a λ_e (4.2 μm) Channel	14
1b. Comparison of the Measured versus Reference Star Magnitudes for a Different λ_e (4.2 μm) Channel	14
2a. Comparison of the Measured versus Reference Star Magnitudes for the Most Sensitive λ_e (11.0 μm) Channel	15
2b. Comparison of the Measured versus Reference Star Magnitudes for a Different λ_e (11.0 μm) Channel	15
3. The Measured Minus Reference Star Magnitudes Plotted Against the Measured Magnitude at λ_e (4.2 μm) for all the Reference List Sources Observed During the AFGL Survey	20

Illustrations

- | | |
|---|----|
| 4. Comparison of the λ_e (11.0 μm) Measured Magnitudes and Their Respective Measured Minus Reference Magnitudes for all Reference List Sources Observed During the Survey | 21 |
| 5. Comparison Between the Measured and Measured Minus Reference Magnitudes at λ_e (19.8 μm) for all Sources in Common With the AFGL Catalog ¹ and the Reference List | 22 |

Tables

- | | |
|--|----|
| 1. Effective Wavelengths and Bandwidths for the Survey Sensors | 8 |
| 2. Comparison of the Calibration Parameters Obtained With Stellar References and Values Derived From Independent Sources | 16 |
| 3. Observed and Reference Magnitudes for Stars Commonly Used as Infrared Standards | 23 |

Calibration of the HI STAR Sensors

1. INTRODUCTION

The survey data compiled into the "AFGL Four Color Infrared Sky Survey" catalog¹ were calibrated against selected stars observed during the course of the scan and augmented, when necessary, with relative responsivities measured in the laboratory. The celestial sources used for calibration were chosen from a list, compiled at AFGL, of objects with infrared observations reported in the astronomical literature prior to mid 1974. Subjective judgement was used in selecting the most reliable sources and measurements from the list.

A detailed description of the experimental profile and instrumentation is given by Price and Walker¹ for the nine rocket flights on which survey data were obtained. Briefly, the survey used small (16.5 cm diameter) doubly folded Gregorian telescopes cooled to cryogenic temperatures. The focal plane of each telescope contained three linear staggered arrays of eight detectors each arranged in the cross scan direction and spectrally band limited with interference filters. The sensor scan resulted in sequential observations in the three spectral colors. The cross

(Received for publication 3 July 1978)

1. Price, S.D., and Walker, R.G. (1976) The AFGL Four Color Sky Survey: Catalog of Observations at 4.2, 11.0, 19.8 and 27.4 μ m, AFGL-TR-76-0205, Environmental Research Papers, No. 576.

scan field-of-view of adjacent detectors in a single color band overlapped at least optical one blur diameter.

The telescopes used for the first seven experiments were filtered for the 4, 11 and 20 micron spectral regions and used doped Germanium detectors. Silicon detectors were substituted for the last two experiments and a spectral band centered at 27 microns was used in place of the 4 micron color. The same sensor system was flown on the first six experiments and different telescope and/or focal plane was employed for the last three.

A linear regression with fixed unit slope of the observed system magnitudes against the reference magnitudes was performed for each of the 24 detectors on each flight. The preliminary calibrations on the first six experiments, which used the same sensor, indicated that data from the separate flights could safely be combined to improve the accuracy of the calculations. This sensor was also twice calibrated in the MARK 7 chamber at Arnold Engineering Development Center (AEDC). The first test² was performed before the survey experiments began and the second³ was done after the sixth flight. Inconsistencies in the data from the first test obviated the use of these results. The data from the second test indicates the presence of systematic errors in the aperture sizes assumed by AEDC for the blackbody integrating cavity. However, the excellent agreement between the second AEDC calibration and that obtained from the stars indicates that these errors were small.

There were an insufficient number of reference stars observed to reliably calibrate each of the detectors for each of the remaining three flights. The reference list for these flights was, therefore, augmented with the results reduced from the previous experiments. Even this was inadequate in some cases, especially for the 27 μ m color. For these channels, the relative responsivities of the detectors in each color measured in the laboratory for the focal plane alone had to be compared to the available celestial reference values. The internal consistency of the procedure was found to be good.

2. Hickey, R. F. (1971) Performance Evaluation of the SAMSO/Hughes HI STAR Sensor, AEDC-TR-71-63 (Classified Report).
3. Nutt, K. W. (1973) Performance Evaluation of the HI STAR Sensor Using a New Integrating Sphere Target Source, AEDC-TR-73-142 (Classified Report).

2. APPROACH

The voltage output of a linear system due to a spectral irradiance H_λ is given by

$$VR^{-1} = \int_0^\infty S_\lambda H_\lambda d\lambda \quad (1)$$

where S_λ is the system spectral response and R its responsivity in terms of volt/watt. These quantities are routinely measured in the laboratory for the focal plane assembly alone. Invariably, the laboratory calibration sources are chopped blackbodies of "known" temperature which flood the full field of the detectors. Thus, not only do optical and electronic transfer functions have to be adopted to convert the measured focal plane response to a system response, but also an equivalence must be assumed between the chopping and scanning frequencies and the illumination geometry of the laboratory sources and those of scanned point-like celestial sources. Sayre et al.⁴ have measured large variation in responsivity with illumination geometry for the types of detectors used for the AFGL survey.

The stars offer several advantages as infrared calibration sources. The entire system is calibrated during data taking with the actual point source scan geometry and with sources which, for the majority of cases, have spectral characteristics similar to that of the cataloged object. Variations in responsivity over the surface of a detector are averaged out as the stellar transit positions are not fixed. Further, for practical considerations, stars provide the only reliable calibration for spectral bands such as the 4 micron band. This filter has a two micron wide spectral leak of about 4 percent peak transmission at $14 \mu\text{m}$. Below 250°K the blackbody energy through this "red" leak is at least as great as the flux in the pass-band. Thus, small errors in the detailed knowledge of the transmission in this leak produce large errors in the correction terms required at these temperatures. Unfortunately, the AEDC^{2,3} calibrations used blackbodies with temperatures on the order of 250°K . The known, and measured, higher temperature of the reference stars reduce the amount of the red leak correction for these sources to less than one percent.

On the other hand, few stars have been measured with sufficient spectral detail in the infrared to allow an exact evaluation of the integral in Eq. (1). Just as for the laboratory sources, some assumptions are necessary concerning their spectral

4. Sayre, C., Arrington, D., Eisenman, W., and Merriam, J. (1976) Characteristics of Detectors Having Partially Illuminated Sensitive Areas, IRIS Meeting on Detectors.

distributions. Also, there are too few true astronomical photometric standard stars bright enough to reliably calibrate each of the detectors for each experiment, so measurements on stars of late spectral type, that is, cool, small amplitude and Mira type variable stars had to be included in the list of reference sources. The variability of these stars is much smaller in the infrared than the visual, often amounting to only 10 to 20 percent.

The spectral characteristics of a system may be expressed by the system unique parameters of effective wavelength, designated λ_e , and effective bandwidth, $\Delta\lambda_e$. These quantities are defined by

$$\lambda_e = \frac{\int_0^{\infty} \lambda S_{\lambda} d\lambda}{\int_0^{\infty} S_{\lambda} d\lambda} \quad (2a)$$

and

$$\Delta\lambda_e = \int_0^{\infty} S_{\lambda} d\lambda \quad (2b)$$

respectively. Table 1 lists these quantities for the instruments used for the AFGL Infrared Sky Survey.

Table 1. Effective Wavelength and Bandwidths for the Survey Sensors

Hi Star		Hi Star South	
λ_e (μm)	$\Delta\lambda_e$ (μm)	λ_e (μm)	$\Delta\lambda_e$ (μm)
4.16	1.50	11.11	5.67
11.00	5.14	19.63	5.99
19.80	5.59	27.43	3.44

Expanding the irradiance in Eq. (1) about the effective wavelength, we get⁵

$$H_{\lambda} = H_{\lambda_e} + \frac{dH}{d\lambda} \bigg|_{\lambda_e} (\lambda - \lambda_e) + \frac{1}{2} \frac{d^2H}{d\lambda^2} \bigg|_{\lambda_e} (\lambda - \lambda_e)^2 + \dots + \frac{1}{n!} \frac{d^n H}{d\lambda^n} \bigg|_{\lambda_e} (\lambda - \lambda_e)^n$$

thus

$$VR^{-1} = \left\{ H_{\lambda_e} + \frac{1}{2} \frac{d^2H}{d\lambda^2} \bigg|_{\lambda_e} f_2(\lambda_e) + \dots + \frac{1}{n!} \frac{d^n H}{d\lambda^n} \bigg|_{\lambda_e} f_n(\lambda_e) \right\} \int_0^{\infty} S_{\lambda} d\lambda \quad (3)$$

where

$$f_n(\lambda_e) = \int_0^{\infty} (\lambda - \lambda_e)^n S_{\lambda} d\lambda / \int_0^{\infty} S_{\lambda} d\lambda$$

and $f_1(\lambda_e) = 0$ from the definition of λ_e .

Equation (4) may be written

$$VR^{-1} = H_{\lambda_e} \Delta\lambda_e (1 + \Delta H) \quad (4)$$

where ΔH is the color correction term which involves the second and higher order terms in the expansion. This is an exact expression equating the integrated in-band irradiance, and hence the system response, to the monochromatic irradiance at the effective wavelength of the spectral band of the system, H_{λ_e} , times the respective bandwidth through a proportionality constant ΔH , a color correction term. For the spectral bands used on the AFGL Survey, ΔH is about 0.25 for a λ^{-4} infrared spectral distribution and less for flatter variations with wavelength.

The photometry on the reference sources is in terms of magnitude, a logarithmic relationship between the stellar irradiance and that from a standard source. The adopted standard source is an AOV star at a distance of 10 parsecs (3.1×10^{19} cm). The infrared energy distribution from such a star can be accurately represented by a 10,000°K blackbody radiator which subtends 1.5697×10^{-16} steradians. The magnitude of a star at λ_e is defined by

5. Stromgren, B. (1937) Handbuch der Experimental Physik, ed. Wein and Harms, Leipzig: Akademische Verlags Gesellschaft M.B.H., 26:321.

$$m_s(\lambda_e) = -2.5 \log \left\{ \frac{H_{\lambda_e}(s)}{H_{\lambda_e}(AOV)} \right\} .$$

The observed system magnitude is defined as

$$m_o = -2.5 \log \left\{ \frac{\int_0^\infty H_\lambda(s) S_\lambda d\lambda}{\int_0^\infty H_\lambda(AOV) S_\lambda d\lambda} \right\} \quad (5)$$

which can be expressed in terms of the responsivity from Eq. (1) as

$$= -2.5 \log VR^{-1} + C_o . \quad (6)$$

Here C_o is the logarithm of the integrated zero point flux of the system and is uniquely determined for each color.

Employing the relationship given in Eq. (4), Eq. (5) can also be rewritten

$$m_o = -2.5 \log \left\{ \frac{H_{\lambda_e}(s) \Delta\lambda_e (1 + \Delta H(s))}{H_{\lambda_e}(AOV) \Delta\lambda_e (1 + \Delta H(AOV))} \right\}$$

$$m_o = -2.5 \log \left\{ \frac{H_{\lambda_e}(s)}{H_{\lambda_e}(AOV)} \right\} - 2.5 \log \left\{ \frac{1 + \Delta H(s)}{1 + \Delta H(AOV)} \right\} \quad (7)$$

$$m_o = m_s(\lambda_e) + C_1 . \quad (8)$$

Equating (6) and (8) and rearranging terms, we have

$$2.5 \log V = -m_s(\lambda_e) + 2.5 \log R + C_o - C_1 . \quad (9)$$

V is the measured variable, voltage, $m_s(\lambda_e)$ is the reference magnitude input, R is the sought for system responsivity, C_o is a known system value and C_1 is a constant which contains an unknown color correction term. Noting that

$$\begin{aligned}
C_0 - C_1 &= 2.5 \log \left\{ \int_0^\infty H_\lambda(\text{AOV}) S_\lambda d\lambda \right\} + 2.5 \log \left\{ \frac{1 + \Delta H(s)}{1 + \Delta H(\text{AOV})} \right\} \\
&= 2.5 \log \left[H_{\lambda_e}(\text{AOV}) \Delta \lambda_e (1 + \Delta H(\text{AOV})) \left\{ \frac{1 + \Delta H(s)}{1 + \Delta H(\text{AOV})} \right\} \right] \\
C_0 - C_1 &\simeq 2.5 \log \left\{ H_{\lambda_e}(\text{AOV}) \Delta \lambda_e \right\} + \Delta H(s) \\
&\quad \text{if } \Delta H(s) \leq 0.3 \quad . \quad (10)
\end{aligned}$$

Equation (9) may be rewritten in terms of the monochromatic zero point flux:

$$2.5 \log V = -m_s(\lambda_e) + 2.5 \log R + 2.5 \log \left\{ H_{\lambda_e}(\text{AOV}) \Delta \lambda_e \right\} + \Delta H(s) \quad . \quad (11)$$

A reference star with a known magnitude at λ_e can be used to determine the system responsivity to within a constant ΔH by means of Eq. (11). If the stars used in the calibration have similar infrared energy distributions, then their color correction terms are approximately the same and average calibration may be obtained to within a mean color correction value representative of the class of objects used. The star to star differences in color correction terms then introduces scatter into the calculations.

Almost all the reference stars are cool giant or supergiant stars with photospheric effective temperatures between 2000 and 3500°K. Many of these stars possess circumstellar emission which enhance the flux in the ten micron region by as much as a factor of three. For "oxygen" stars the emission feature is due to silicate grains. In "carbon" stars the enhancement is caused by silicon carbide plus an underlying continuum with characteristic temperatures on the order of 600°K. Detailed studies by Merrill⁶ and Forrest et al⁷ on a number of the objects in the reference list show that the infrared energy distributions for these stars are smooth and somewhat similar, and that over the spectral bands used for the survey the energy distributions are either proportional to λ^{-4} for the photospheric radiators or somewhat flatter if circumstellar emission is contained in the band. Thus, for the system bands ΔH varies from zero for an equal energy distribution to about 0.25 for λ^{-4} distribution. This implies that the approximation used in Eq. (10) is

6. Merrill, K.M. (1977) Infrared Observations of Late Type Stars, Invited Review Paper at I.A.V. Symposium No. 42.
7. Forrest, W.J., Gillett, F.C., and Stein, W.A. (1975) Circumstellar grain and the intrinsic polarization of starlight, Ap. J. 195:423.

valid for the reference list stars and the star to star color correction differences will be small second order terms.

It now remains to transfer the reference magnitudes from the astronomical literature to values at the system effective wavelengths. The λ_e (4.2 μm) reference magnitudes were obtained by either interpolating linearly in magnitude between published values at 3.5 μm and 5 μm or, if there is no 5 μm reference values reported, extrapolating the 2.2 μm and 3.5 μm reference values. This procedure is valid if the stellar spectral distribution obeys a power law in wavelength through this region, an applicable assumption for the reference list sources. A small systematic error amounting to a few percent for some of the stars may have been introduced due to CO absorption at 4.3 μm .

The various ground based photometric systems which reported stellar measurements in the 8 to 24 micron region have color bands with effective wavelengths at or very close to, that is, within 10 percent, the λ_e (11.0 μm) and λ_e (19.8 μm) system bands. The ground based measurements were adopted directly and errors due to mismatch in the effective wavelength and bandwidths between the ground based and our space borne systems were assumed to introduce random scatter into the calibration. The λ_e (27.4 μm) calibration references will be discussed separately.

The compiled list of reference sources is contained in Appendix A along with the adopted magnitudes at the system effective wavelengths. The maximum and minimum brightness which have been reported are also given. In most cases, the adopted magnitude is a simple mean of the brightness extrema.

Although known infrared variables were accepted as reference sources under penalty of increased scatter, stars known to vary by more than 0.75 magnitudes (a factor of two in brightness) were eliminated from the calibration. Beam size effects were at least partially accounted for by deleting all objects known, or measured by the survey, to be extended.

The reference sources used in the calibrations were further restricted to stars in the IRC.^{8,9} This was done to increase the probability that the reference source was indeed a star with no unusual infrared spectral properties or beam size effects.

A linear least squares regression with fixed unit slope of the observed magnitude, more precisely 2.5 times the logarithm of the observed voltage, against the reference magnitudes is calculated. The solution intercept at $m_s(\lambda_e) = 0$ leads directly to the system responsivity through Eq. (11).

8. Neugebauer, G., and Leighton, R.B. (1969) Two Micron Sky Survey, A Preliminary Catalog, NASA SP-3047.

9. Neugebauer, G. (1971) Unpublished extension to the IRC.

3. RESULTS

The sensors proved to be very stable. The response of the detectors to low temperature, evaporated thin film, infrared emitting sources pulsed during the experiment remained constant to within 10 percent even though the background varied by as much as a factor of five. Furthermore, the preliminary calibrations for the first six experiments which employed the same sensor system had remarkable homogeneity. This agreement is shown in Figures 1 and 2. The reference star magnitudes are plotted against observed magnitudes for two of the λ_e ($4.2 \mu\text{m}$) channels in Figures 1a and 1b, while Figures 2a and 2b are similar plots for two of the λ_e ($11.0 \mu\text{m}$) channels. The different symbols on these plots represent different flights. The data from the first six experiments were combined in order to improve the accuracy of the calculations. Note also that the reference sources extend over a factor of 100 (5 stellar magnitudes in the figure) in brightness.

An iterated linear least squares regression with fixed unit slope was calculated for each detector of the logarithm of the observed voltage against the reference magnitude by means of Eq. (11). The intercept of the solution leads directly to the system responsivity if an average value is adopted for the color correction term. The solutions for each channel were iterated by rejecting as many as five sources with the largest deviations exceeding twice the standard deviation of the previous solution. This was done in order to minimize the effects of any large deviations due to unknown beam size effects, a greater variability of the source than the reference values indicate, or large unknown measurement errors. Also, only measurements on reference sources which exceed a specified signal-to-noise ratio were included in order to minimize the measurement error.

Table 2 lists the least squares calibration parameters based on stellar references for the combined six experiment data compared to other calibration methods. The first column lists the channel number; channels 1 through 8 are filtered for λ_e ($11.0 \mu\text{m}$), the λ_e ($4.2 \mu\text{m}$) channels are 9 through 15 (channel 16 was inoperative) and channels 17 through 24 are λ_e ($19.8 \mu\text{m}$) colors. The number of reference star observations used in calibrating each channel after all rejections is listed in column 3. As expected, the number of reference sources available for calibration decreases with increasing wavelength. Indeed, there were hardly enough sources in the λ_e ($19.8 \mu\text{m}$) band to permit a meaningful regression calculation.

As a check on the linearity of the system, a separate regression was calculated with the slope as a free parameter. Column 3 gives the value of the derived slope and column 4 lists the root mean square deviation of the fixed unit slope. Over half the channels have slopes within one rms of unity while all but one channel are within two standard deviations. This argues strongly that the system response was indeed linear.

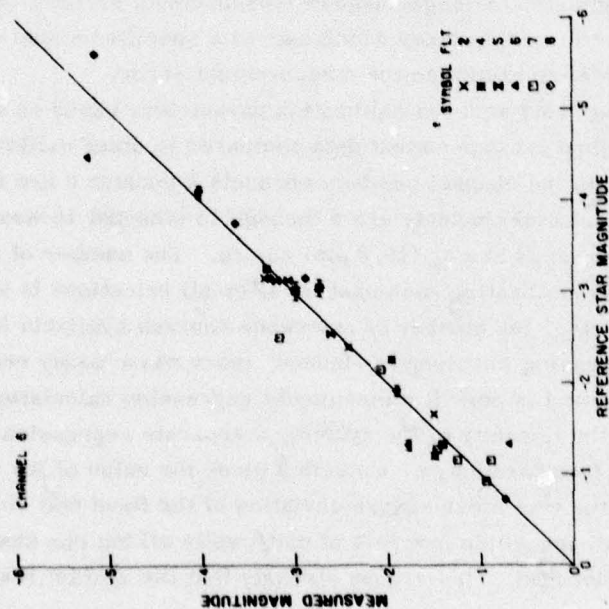


Figure 1a. Comparison of the Measured versus Reference Star Magnitudes for a λ_e (4.2 μm) Channel. The different symbols for the data points represent the preliminary calibrations for the individual experiments for the first six flights which used the same sensor system. The horizontal lines in the figure represent the range of values found for the reference source.

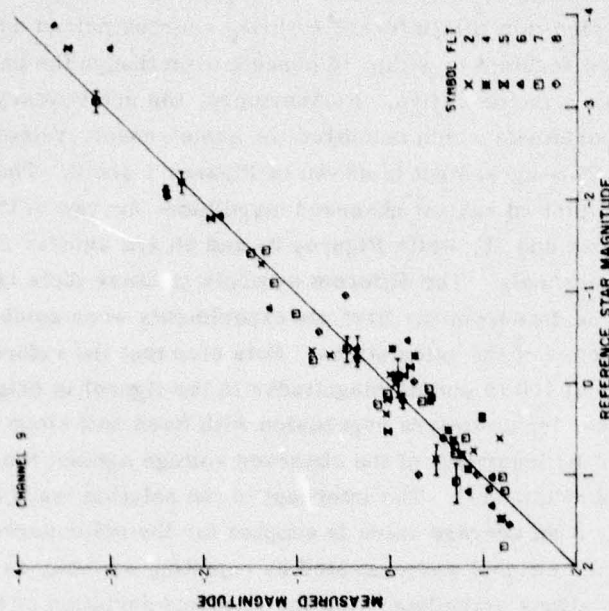


Figure 1b. Comparison of the Measured versus Reference Star Magnitudes for a Different λ_e (4.2 μm) Channel. The different symbols for the data points represent the preliminary calibrations for the individual experiments for the first six flights which used the same sensor system. The horizontal lines in the figure represent the range of values found for the reference source

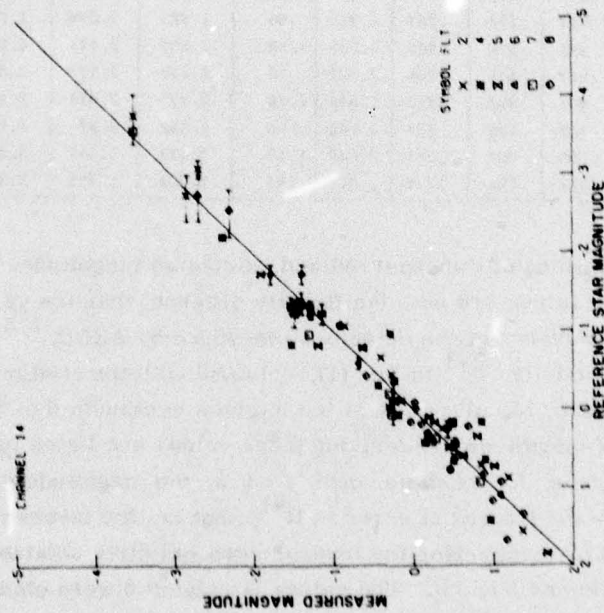


Figure 2a. Comparison of the Measured versus Reference Star Magnitudes for the Most Sensitive λ_e (11.0 μm) Channel. The different symbols for the data points represent the preliminary calibrations for the individual experiments for the first six flights which used the same sensor system. The horizontal lines in the figure represent the range of values found for the reference source

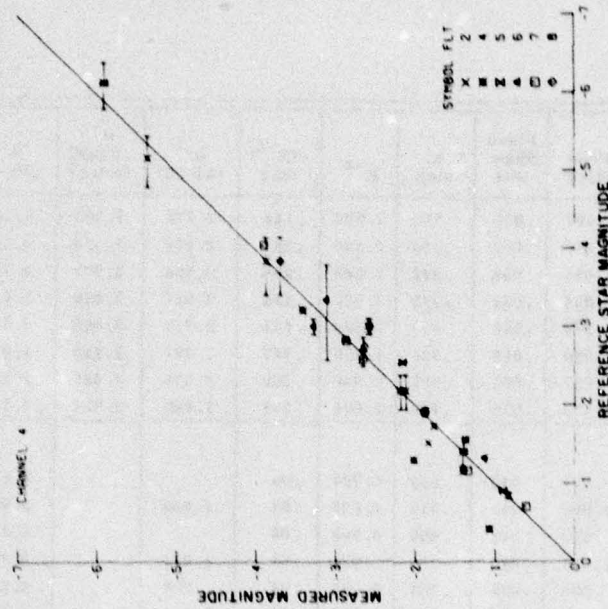


Figure 2b. Comparison of the Measured versus Reference Star Magnitudes for a Different λ_e (11.0 μm) Channel. The different symbols for the data points represent the preliminary calibrations for the individual experiments for the first six flights which used the same sensor system. The horizontal lines in the figure represent the range of values found for the reference source.

Table 2. Comparison of the Calibration Parameters Obtained With Stellar References and Values Derived From Independent Sources

Channel No. λ_e (11 μm)	No. of Stars	Free Slope	Fixed Slope rms	σ mag	R^{-1}	$\sigma(R^{-1})$ mag	R^{-1} (AEDC)	R^{-1} (AEDC Noise)	R^{-1} (Wake)	R^{-1} (Diode)
1	37	.897	.056	.315	2.988	.144	3.274	2.890	3.087	2.907
2	18	.959	.087	.294	5.294	.23	3.949	5.530	5.260	5.922
3	31	1.015	.094	.372	2.589	.216	3.098	2.993	2.71	2.065
4	25	1.034	.054	.329	3.976	.153	3.517	2.540	3.69	3.05
5	31	.973	.056	.294	2.632	.131	2.723	2.899	2.53	2.53
6	37	.990	.069	.354	1.820	.167	1.971	2.455	1.82	1.77
7	22	.887	.085	.363	2.020	.203	3.050	3.586	2.55	3.11
8	30	.805	.079	.430	2.074	.217	1.689	2.934	2.74	2.58
λ_e (4.2 μm)										
9	79	.877	.040	.359	5.797	.04			4.663	5.725
10	59	1.086	.043	.319	6.652	.04	1.958		3.996	4.117
11	41	.899	.063	.400	6.352	.06			3.176	6.808
12	71	1.005	.042	.350	5.924	.04	1.074		2.373	5.544
13	47	.996	.043	.294	4.055	.04	.793		4.244	7.332
14	72	1.019	.035	.288	4.573	.035	1.911		4.52	4.483
15	75	1.044	.044	.380	5.620	.04	1.132		3.85	3.698
λ_e (19.8 μm)										
17	8	.984	.093	.245	2.782	.45	2.212	2.538	2.646	2.807
18	7	1.042	.193	.287	1.715	.50	1.923	2.028	1.763	2.022
19	6	.553	.316	.443	3.325	1.30	2.857	2.471	4.381	3.26
20	6	.947	.151	.256	2.663	.70	2.447	2.710	2.313	2.43
21	4	.981	.290	.415	2.856	1.30	2.773	2.824	2.615	2.23
22	6	.762	.130	.357	1.792	.56	2.382	2.27	1.913	2.26
23	7	.600	.305	.531	2.626	1.19	2.422	2.649	4.32	2.79
24	9	.861	.094	.274	2.429	.43	2.054	1.867	1.72	2.47

The standard deviations of the observed and calculated magnitudes are given in column five. These values are not significantly different than the variations in responsivity over the surfaces of the detectors measured by AEDC.^{2,3}

The inverse responsivity, R^{-1} in Eq. (1), obtained with the stellar calibration references and normalized to unit power of ten is given in column 6 of Table 2 and the error, in terms of magnitude, in deriving these values are listed in column 7. For small values of error, for example, $\sigma(R^{-1}) < 0.3$, the magnitude error is approximately equal to the fractional error in R^{-1} , that is, the inverse responsivity is $R^{-1} (1 \pm \sigma(R^{-1}))$. For comparison the inverse responsivities obtained from AEDC tests³ are listed in columns 8 and 9. The values in column 8 were obtained by a linear least square fit of the measured voltage to a "known" irradiance from a point

source transitting a detector at the nominal survey rate. The source always transited the detectors at the same specified elevation so these values are not averaged over the detector's surface. The AEDC data^{3, 10} indicate that there may be a small systematic error of 5 to 15 percent in the adopted values of the blackbody aperture sizes. The standard deviations of the observations to the linear fit for the λ_e (11 μm) values in column 8 are between 6 and 36 percent and are comparable to the equivalent values of $\sigma(R^{-1})$ based on the stars. The λ_e (4.2 μm) AEDC data have large discrepancies which are certainly due to the red leak in this filter.

The inverse responsivities in column 9 were obtained at AEDC by measuring the mean square noise voltage as a function of a controlled, known background. The measurement errors are bound to be somewhat high as the measured voltage changes with the square root of the photon flux, making the measurement insensitive to changes in the input variable and restricting the measurements to only three or four points because of dynamic range considerations. Despite these factors, the two calibrations are within 30 percent of each other for all but three channels. Again, the red leak in the λ_e (4.2 μm) channel precluded meaningful measurements by this technique.

The last two columns contain relative inverse responsivities, scaled to the values obtained from the stars, derived from transient phenomena which fill the field-of-view of each detector and were observed on each flight. These values were included in order to evaluate possible independent measurement methods which could be used to derive the relative detector responses and to check possible geometry effects. Column 10 lists the relative inverse responsivities derived from observations made on the high altitude re-entry wake of the rocket sustainer. As this phenomenon was of significant angular extent, the desired information was derived by extending the system response toward dc by applying the inverse bilinear z transform of the electronic high pass filter to the data stream. The resulting spatial energy distributions were well represented by Gaussian profiles. The internal consistency of the resulting amplitudes were between 5 and 13 percent of the scaled mean. The amplitude, flux and width of this phenomena are observed to change from scan to scan over a period of nine seconds,¹¹ and a time dependence is expected during a single observation in the sense that the bottom detectors of the array observe excited air from a shock which was formed a fraction of a second more recently than the top ones. This effect cannot be large as the measured half widths are well within the measurement error for all channels on a single scan and no systematic variation is evident. The λ_e (11 μm) and λ_e (19.8 μm) inverse

10. Hiatt, J. (1975) ARPA/Perkin-Elmer MARK VII Sensor Test, AEDC-TR-75-50 (Classified Report).

11. Murdock, T. L., and Walker, R. G. (1975) Infrared Signatures of High Altitude Reentry Wakes, AFCRL-TR-75-0083 (Classified Report).

responsivities derived from the wake scale to within a maximum difference of 20 percent of the stellar calibrations. The λ_e (4.2 μm) discrepancies are probably due to the red leak and the basic nature of the phenomenon. The physics of these events have been discussed in more detail by Murdock and Walker.¹¹

The scaled inverse responsivities derived from the internal calibrators are given in column 11. Large scale geometry effects were anticipated due to the location of these sources on one side of the focal plane housing. These measurements were considered on the assumption that the internal scattering of the radiation within the focal plane housing would average these effects out. The internal consistencies of these pulses were also good, with typical deviations of 20 percent of the scaled mean value. These relative values are, for the most part, within 30 percent of those derived from the stars. Greater discrepancies exist for the λ_e (4.2 μm) again due, in part, to the red leak.

Once the calibrated inverse responsivities were derived, an in band irradiance or a magnitude was calculated for each observation by means of Eq. (1) or (6) respectively. The λ_e (4.2 μm) values were adjusted for the red leak by applying a correction term derived by assuming that the source had a blackbody distribution in this spectral region with a color temperature defined by the λ_e (11.0 μm) and λ_e (19.8 μm) observations. The correction term is accurate for temperatures greater than 400°K. Below this the λ_e (4.2 μm) measurements are very uncertain.

The calibration of the data from the last three flights were more difficult as each of these experiments used a different focal plane assembly and thus had to be calibrated individually. These experiments detected an insufficient number of reference stars on each detector to provide an adequate regression solution, so the reference list was augmented for each subsequent experiment with survey measurements in the mutually overlapping area from previous experiments. The calibration errors for these experiments were higher due to the larger uncertainties inherent in the previous survey measurements and the fewer total number of sources to calibrate against.

The small difference in wavelengths between the 11 μm and 20 μm shown in Table 1 were ignored in calibrating the southern hemisphere data. The λ_e (11.1 μm) and λ_e (19.6 μm) colors for the eighth experiment had a sufficient number of reference sources to calibrate each detector individually by the previously described technique.

The inverse responsivities for the λ_e (27.4) channels were derived by scaling the voltage responsivities measured at the Naval Electronics Laboratory Center (NELC)¹² for the focal plane assembly to the fluxes inferred from published data

12. Arrington, D. C., and Cisenman, W. L. (1973) Test Data for a 24-Element Array, 2600-15, NELC.

on GL2688, GL2495 = IRC + 30407, GL4114 = η Car and GL2390 = IRC + 10420 and a blackbody extrapolation to the asteroid Ceres based upon the color temperature defined by the λ_e (11.1 μ m) and λ_e (19.6 μ m) observations. The estimated calibration errors are between 30 and 50 percent.

The scaling factor obtained by this method agrees well with those derived from the λ_e (11.1 μ m) and λ_e (19.6 μ m) individual channels and is essentially the total system gain for each color. Unfortunately, these system gains were 4 to 4.5 times less than those calculated from the known optical gain¹³ of the telescope and the electronic amplification as measured in the laboratory. If the amplifier gains are applied to the detector noise values measured at NELC, the result is within 50 percent of that observed during the flight.

The measured lower responsivity of the detectors was originally attributed to the illumination geometry effects observed by Sayre et al⁴ for parallel biased detectors such as the ones used for the survey. However, Arrington et al^{12, 14} noted that the detector responsivities decreased with increasing background flux. The NELC data^{12, 14} indicated that, if account is made for the "blue" spectral leak in the λ_e (27.4 μ m), the character of the responsivity decrease in each of the colors could be explained by a dilute 300°K background. This proved to be the case as an increase of the proper amount was observed in the detector response to the internal calibrators when the focal plane was optically sealed off from the rest of the sensor. This decrease in sensor sensitivity unfortunately about compensated for the anticipated increase due to the sensor modifications performed for the southern hemisphere experiments.

After the calibrations were applied to the individual survey experiments, multiple observations on a single object obtained from the different flights were combined in a simple mean. Comparisons between the resulting final survey magnitudes and reference source magnitudes for all objects common to both lists are shown in Figures 3, 4, and 5. In Figure 3 the difference between the λ_e (4.2 μ m) measured and reference magnitudes are plotted against the measured magnitudes. The vertical lines in this plot are the reported extreme on the reference sources. The same plot for the λ_e (11.0 μ m) color is shown in Figure 4. Here the crosses are magnitudes taken from the work of Hall¹⁵ who adopted a different set of reference values for many of the sources in common with the AFGL list. Finally, the same data for the λ_e (19.8 μ m) is shown in Figure 5.

13. HI STAR II PROGRAM (1974) Final Report, Hughes Aircraft Company, Report No. p74-288 (Classified Report).

14. Arrington, D. C., and Eisenman, W. L. (1974) Test Data for a 24-Element Array, 2610-17, Naval Electronics Research Laboratories.

15. Hall, R. T. (1974) A Catalog of 10- μ m Celestial Objects, SAMSO-TR-74-212.

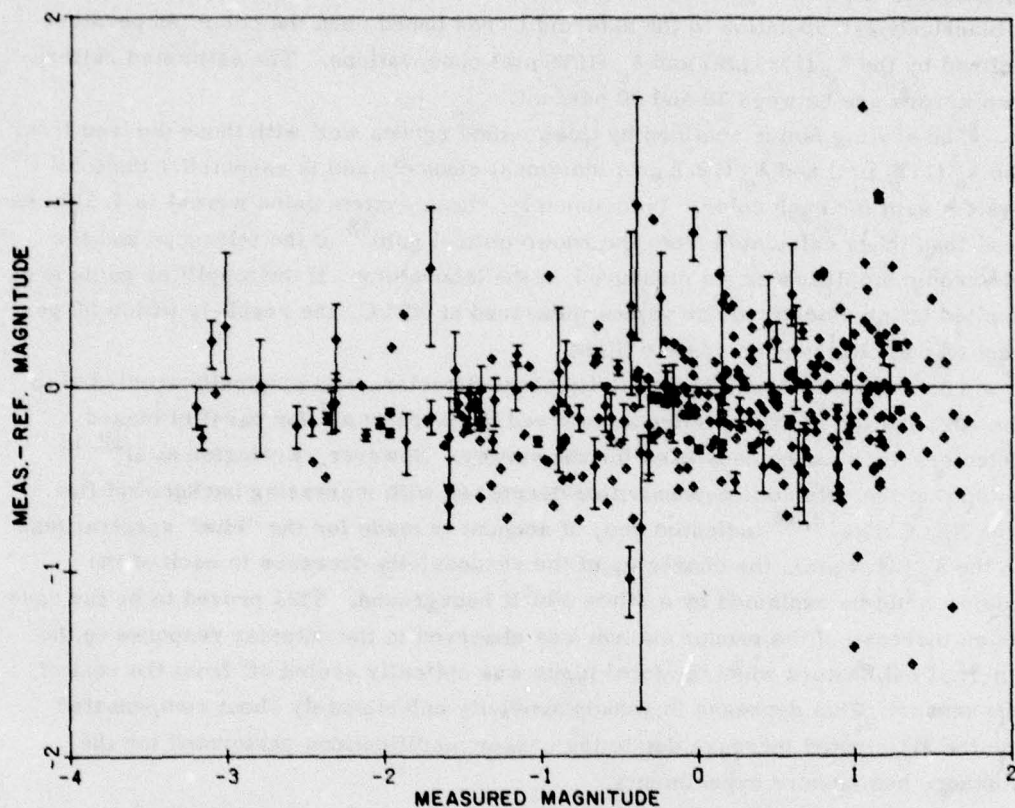


Figure 3. The Measured Minus Reference Star Magnitudes Plotted Against the Measured Magnitude at λ_e ($4.2 \mu\text{m}$) for all the Reference List Sources Observed During the AFGL Survey. The vertical lines represent the range of values reported in the astronomical literature while the symbol bisected by the line is the adopted mean reference value for this source

The AFGL survey is estimated to be statistically complete¹ down to magnitudes of $m(4.2 \mu\text{m}) \simeq +1.3$, $m(11.0 \mu\text{m}) \simeq -1.1$ and $m(19.8 \mu\text{m}) \simeq -3.1$. Below these levels the measurement error is a significant factor in calculating the observed magnitudes. This is evident in Figures 3, 4, and 5 where the difference between the measured and reference magnitudes become rather large for measured magnitudes fainter than the aforementioned limits. Also it may be noted that at the fainter magnitudes there is a tendency for the measured quantities to be brighter than the reference values. This can be explained by the fact that at these levels a positive measurement error added to the true observed voltage of the source will yield a brighter than correct measurement while a negative error will cause the observation to fall below the detection threshold and, therefore, eliminate it from

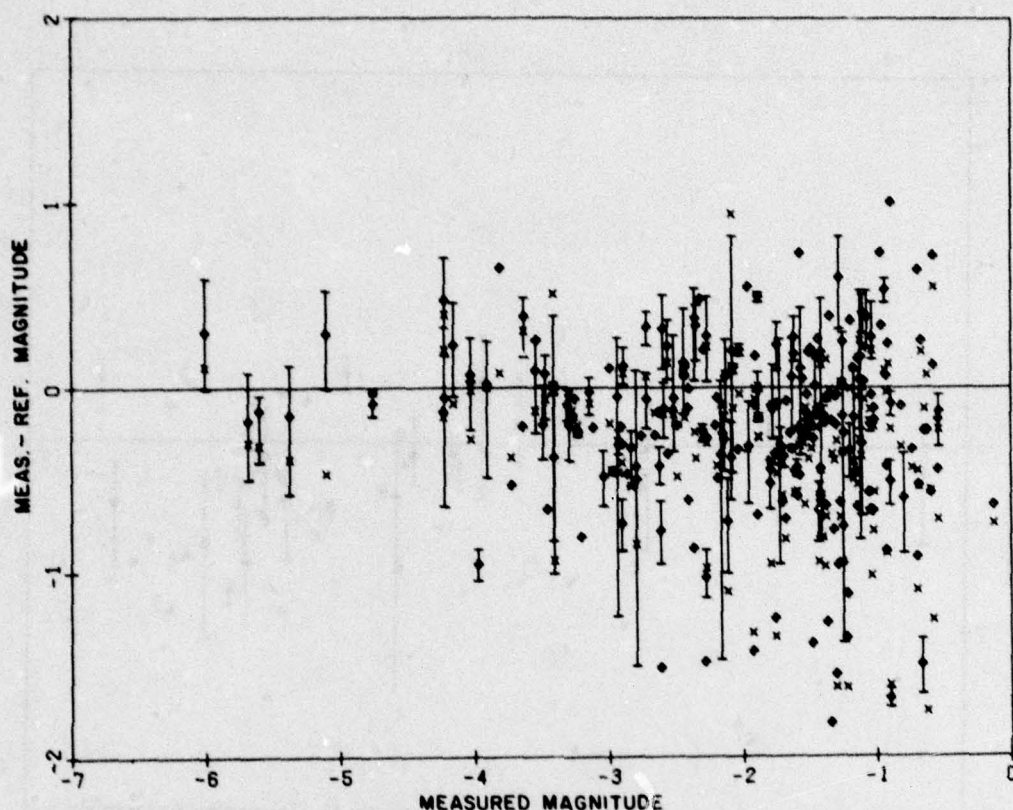


Figure 4. Comparison of the λ_e ($11.0 \mu\text{m}$) Measured Magnitudes and Their Respective Measured Minus Reference Magnitudes for all Reference List Sources Observed During the Survey. The points dotted with x's are reference magnitudes taken from the compilation of Hall.¹⁵ Note that for most of the variable stars the value adopted by Hall¹⁵ is different than that from the AFGL compilation. The other symbols have the same meaning as Figure 3

consideration. The threshold for a measurement to be included in the calibration was set to be equivalent to the limit of statistical completeness in each color, so this last effect should have been minimized in the calibration.

An indication of the accuracy of the calibration may be obtained from Table 3 which compares the observed magnitudes to the adopted standard magnitudes for 28 bright stars which are well measured in the infrared and are either known to be non-variable or have been used as infrared standard stars for various ground based photometric systems. As can be seen the two magnitudes agree within a few tenths of each other. For the stars in Table 3, the observed values in each color are, on the average, a tenth of a magnitude brighter than the standard magnitudes with root mean squared deviations of 0.2 magnitude about this mean difference.

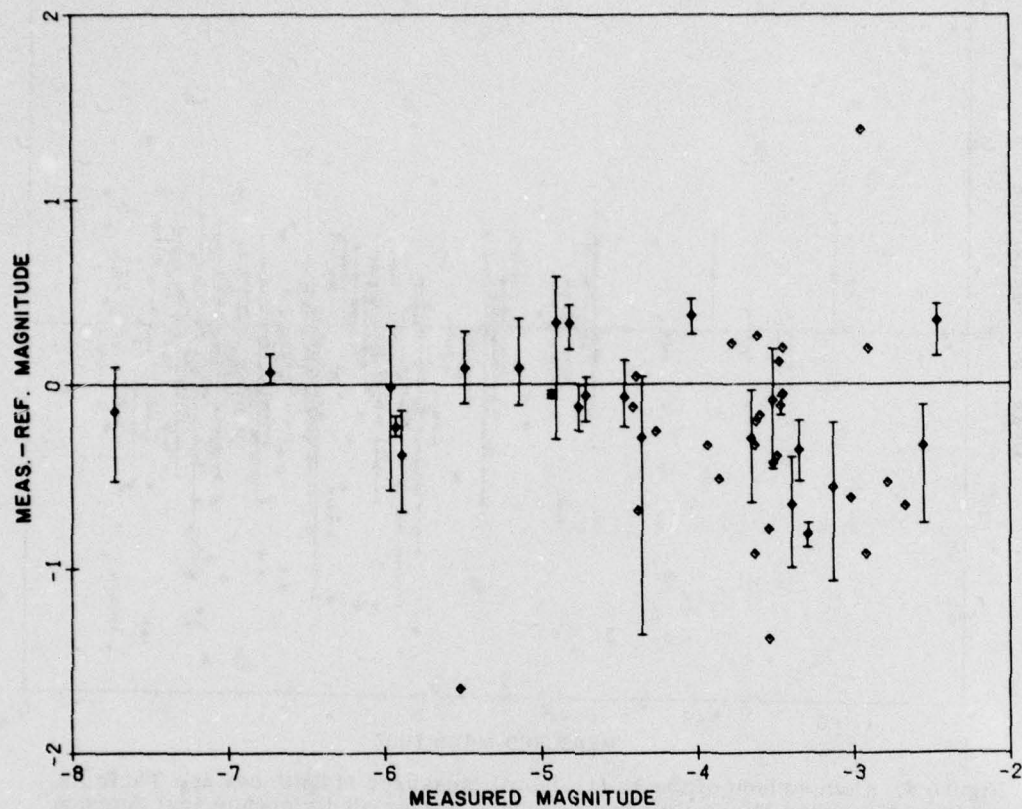


Figure 5. Comparison Between the Measured and Measured Minus Reference Magnitudes at λ_e (19.8 μm) for all Sources in Common With the AFGL Catalog¹ and the Reference List. Note the paucity of objects. The symbols have the same meaning as in Figure 3

Table 3. Observed and Reference Magnitudes for Stars Commonly Used as Infrared Standards

IRC	Name	m(4.2)		m(11.0)		m(19.8)	
		obs	std	obs	std	obs	std
40019	β And	-2.0	-1.8	-2.3	-2.1		
00018	α Cet	-2.0	-1.7	-1.9	-1.9		
40054	ρ Per	-2.5	-2.1	-2.5	-2.3		
-10055	γ Eri	-1.3	-0.8	-1.6	-1.4		
20087	α Tau	-3.2	-2.9	-3.2	-3.0		
30100	ι Aur	-1.0	-0.6	-1.7	-1.0		
50139	α Aur	-2.1	-1.9	-2.3	-2.0		
10100	α Ori	-	-4.4	-5.6	-5.5	-5.9	-5.7
-20084	17 Lep	0.5	0.55	-1.5	-1.4		
20144	μ Gem	-2.2	-2.2	-2.2	-2.1		
-20105	α CMa	-1.2	-1.3	-1.4	-1.3		
30194	β Gem	-1.4	-1.2	-1.4	-1.3		
-10217	α Hya	-1.5	-1.4	-1.2	-1.3		
40218	μ VMa	-0.6	-0.8	-1.6	-1.2		
10235	56 Leo	-1.1	-0.8	-1.4	-1.2		
	γ Cru			-3.4	-3.4	-3.5	-3.4
00226	δ Vir	-1.5	-1.3	-1.5	-1.5		
20270	α Boo	-3.1	-3.0	-3.3	-3.1	-3.5	-3.1
-30228	σ Lib	-1.5	-1.4	-2.1	-1.4	-2.8	-2.3
-30265	α Sco			-4.9	-4.7	-4.9	-4.9
40283	30g Her	-2.4	-2.2	-2.8	-2.7		
10324	α Her			-4.0	-4.1	-4.4	-4.4
	89 Her	1.1	1.2	-1.3	-1.2		
50274	γ Dra	-1.6	-1.3	-1.8	-1.7		
40322	α Lyr	-0.4	0.0	-0.6	0.0		
-20558	ν Sgr	0.9	1.4	-1.1	-1.3		
10439	γ Aql	-0.8	-0.3	-1.1	-1.1		
60325	μ Cep	-2.4	-2.2	-4.0	-4.1	-4.7	-4.7
30504	β Peg	-2.5	-2.3	-2.6	-2.7		

4. CONCLUSIONS

Several significant observations may be made from the results of the calibration procedures used at AFGL for its space borne cryogenically cooled sensors:

(1) The linear slope over two orders in magnitude for each detector obtained from the least squares regression of the system magnitudes against the reference values for the combined data from the first six flights, attest not only to the linearity and stability of the system but demonstrate that stellar references are good calibration sources provided enough of them are observed.

(2) Primary standards, that is sources with precisely known spectral energy distributions, are not required. Spectral uncertainties and amplitude errors for small amplitude variable stars add in a random fashion such that the average calibration is correct. If enough stellar references are observed over an adequate dynamic range, the error in calculating the system responsivity is smaller than the error in the regression fit. Further, the standard deviation of the observed and reference magnitude is of the same size as the measured variation in responsivity over the surface of a detector.

(3) Rather surprisingly, a good calibration was obtained from a least squares fit of the square of the observed noise voltage to a known background irradiance. Although, this procedure suffers from lack of sensitivity and, for practical reasons restricts the dynamic range of the independent variable, it may have value in calibrating some of the spectral colors proposed for future systems where few, if any, reliable laboratory or celestial sources are known with any accuracy.

In conclusion, it was found that the stars provided excellent reference sources to calibrate space borne sensors if a sufficient number of them are observed to permit a meaningful regression solution.

References

1. Price, S.D., and Walker, R.G. (1976) The AFGL Four Color Sky Survey: Catalog of Observations at 4.2, 11.0, 19.8 and 27.4 μ m, AFGL-TR-76-0205, Environmental Research Papers, No. 576.
2. Hickey, R.F. (1971) Performance Evaluation of the SAMSO/Hughes HI STAR Sensor, AEDC-TR-71-63 (Classified Report).
3. Nutt, K.W. (1973) Performance Evaluation of the HI STAR Sensor Using a New Integrating Sphere Target Source, AEDC-TR-73-142 (Classified Report).
4. Sayre, C., Arrington, D., Eisenman, W., and Merriam, J. (1976) Characteristics of Detectors Having Partially Illuminated Sensitive Areas, IRIS Meeting on Detectors.
5. Stromgren, B. (1937) Handbuch der Experimental Physik, ed. Wein and Hanms, Leipzig: Akademische Verlags Gesellschaft M.B.H., 26:321.
6. Merrill, K.M. (1977) Infrared Observations of Late Type Stars, Invited Review Paper at I.A.V. Symposium No. 42.
7. Forrest, W.J., Gillett, F.C., and Stein, W.A. (1975) Circumstellar grain and the intrinsic polarization of starlight, Ap. J. 195:423.
8. Neugebauer, G., and Leighton, R.B. (1969) Two Micron Sky Survey, A Preliminary Catalog, NASA SP-3047.
9. Neugebauer, G. (1971) Unpublished extension to the IRC.
10. Hiatt, J. (1975) ARPA/Perkin-Elmer MARK VII Sensor Test, AEDC-TR-75-50 (Classified Report).
11. Murdock, T.L., and Walker, R.G. (1975) Infrared Signatures of High Altitude Reentry Wakes, AFCRL-TR-75-0083 (Classified Report).
12. Arrington, D.C., and Cisenman, W.L. (1973) Test Data for a 24-Element Array, 2600-15, NELC.
13. HI STAR II PROGRAM (1974) Final Report, Hughes Aircraft Company, Report No. p74-238 (Classified Report).

14. Arrington, D. C., and Eisenman, W. L. (1974) Test Data for a 24-Element Array, 2610-17, Naval Electronics Research Laboratories.
15. Hall, R. T. (1974) A Catalog of 10- μ m Celestial Objects, SAMSO-TR-74-212.

Appendix A

The table in this appendix list the IRC source which comprised the reference star list used to calibrate the AFGL sensors. The first column lists the IRC number of the star while the second gives the star name, variable star or other designation. The maximum, mean and minimum magnitudes at λ_e ($4.2 \mu\text{m}$) adopted for this source is given in columns 3, 4 and 5, respectively. The respective λ_e ($11.0 \mu\text{m}$) values are listed in columns 6, 7 and 8 while columns 9, 10 and 11 give the λ_e ($19.8 \mu\text{m}$) magnitudes.

Note that in the name column, MUU and NUU were used to designate μ and ν in order to avoid possible confusion with variable star designations of MU and NU.

Table A1

ID	NAME	4.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
19	R OSC	1.51	1.51	1.51	.22	.22	.22			
30	CHI CFI	-1.36	-1.66	-1.66	-5.10	-5.63	-5.63	-5.39	-5.82	-6.01
39	ALF CFI	-1.70	-1.72	-1.74	-1.72	-1.87	-1.97	-1.68	-2.05	-2.30
67	12 IAU	2.91	2.91	2.91						
76	W OPI	-1.51	-1.51	-1.51	-1.72	-1.72	-1.74	-1.97	-1.97	-1.97
76	S OPI	-1.79	-1.79	-1.79	-1.60	-1.60	-1.60			
75	DEL OPI	2.89	2.89	2.89						
79	EPS OPI	2.14	2.14	2.14						
81	ZET OPI	2.33	2.33	2.33						
153	LOT MYA	.68	.68	.68						
217	SS VIR	.32	.32	.32	-.99	-.99	-.99			
321	BS 4817	.62	.62	.62						
323	CAM VIR	1.78	1.78	1.78						
324	RU VIR	-.33	-.33	-.33	-1.84	-1.96	-2.10			
376	DEL VIR	-1.23	-1.27	-1.31	-1.29	-1.47	-1.63	-2.35	-2.05	-2.05
380	SW VIR	-1.85	-1.89	-1.89	-3.10	-3.12	-3.13	-4.01	-4.01	-4.01
383	OS VIR	.55	.55	.55	-1.26	-1.26	-1.26			
385	3767	1.72	1.72	1.72	-1.54	-1.54	-1.54			
383	DEL OPH	-1.43	-1.43	-1.43	-.51	-.51	-.51	-1.77	-1.77	-1.77
382	EPS OPH	.93	.93	.93						
384	STG OPH	.86	.86	.86						
317	BET OPH	.08	.08	.08	1.60	1.00	1.00			
463	5043	.73	.73	.73	-2.40	-2.40	-2.40			
365	2176	-.54	-.54	-.54	-2.80	-2.80	-2.80			
377	AN AOL	2.52	2.52	2.52	1.90	1.90	1.90			
389		.48	.48	.48	-1.14	-1.28	-1.40			
399	UM AOL	1.46	1.46	1.46						
433	V376 AOL	.55	.55	.55	.13	-.50	-.90			
458	SR AOL	-.97	-.97	-.97	-2.40	-2.40	-2.40			
490		.04	.04	.04	-1.20	-1.20	-1.20			
479	OV AOL				-2.50	-2.50	-2.50			
507	BD-2-5597	.82	.82	.82						
509	GC 30492				-2.90	-2.90	-2.90			
513	ALF AOL	.95	.95	.95	.90	.90	.90			
517	35 PSC	2.16	2.16	2.16						
532	TX PSC	-.85	-.85	-.85	-1.20	-1.32	-1.37			
10011	GTY 3	-.65	-1.34	-1.96	-2.58	-3.42	-3.80	-4.61	-5.24	-5.49
10050	NMI IAU	-1.93	-2.35	-2.63	-3.58	-4.17	-4.55	-5.39	-5.58	-5.76
10084	CAM OPI	2.35	2.35	2.35	-1.45	-1.45	-1.45			
10102	ALF OPI	-4.29	-4.35	-4.42	-5.20	-5.48	-5.56	-5.65	-5.70	-5.76
10116		1.82	1.82	1.82						
10119	SN MON	1.57	1.57	1.57						
10121	BL OPI	.46	.46	.46	-.16	-.16	-.16			
10166	SV MON	1.08	1.08	1.08	-.27	-.27	-.27			
10154	R CMI	1.97	1.97	1.97	.97	.97	.97			
10162	27 CMI				1.12	1.12	1.12	1.37	1.37	1.37
10179	ALF CMI	-.69	-.69	-.69	-.86	-.86	-.86	-1.13	-1.13	-1.13
10171	U CMI	2.17	2.17	2.17	.78	.78	.78			
10184	O CMC	-1.09	-1.24	-1.35	-2.50	-2.54	-2.56	-2.82	-2.99	-3.15
10186	BET CMC	-.07	-.67	-.97	.51	.51	.51			
10189	27 CMC	.20	.20	.20						
10196	ZET MYA	.59	.59	.59						
10199	ST CMC	-.01	-.01	-.01	-.91	-.91	-.91			
10215	D LEO	-3.20	-3.35	-3.66	-7.40	-7.70	-8.93	-5.03	-5.23	-5.50
10716		-3.52	-4.14	-4.42	-7.36	-7.47	-7.70	-7.50	-8.63	-9.60

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

Table A1 (Cont.)

IPC	NAME	4.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
10224	PT LEO	.52	.44	.37	.27	.22	.18	3.63	3.63	3.63
10226	ALF LEO	1.56	1.55	1.55	1.30	.65	-.04	1.78	1.78	1.78
10274	M LEO				-.26	-.39	-.50			
10236	VY LEO	-.27	-.27	-.27	-1.24	-1.24	-1.24			
10236	GC 15361	1.14	1.14	1.14	-.30	-.30	-.30			
10237	ZY LEO	1.31	1.31	1.31	1.01	1.01	1.01			
10243	QAF VIR	-.13	-.13	-.13	-.57	-.57	-.57			
10245	MUU VIR	-.11	-.11	-.11						
10256	R VIR	.10	.10	.10	.64	.64	.64			
10261	EPS VIR	.73	.73	.73						
10262	RT VIR							-3.42	-3.42	-3.42
10290	S SEP	.51	.51	.51	-.71	-.86	-1.00			
10294	ALF SER	.03	.03	.37	.51	.51	.51			
10295	LAM SER	3.00	2.98	2.96						
10317	29 HEP	1.02	1.02	1.02						
10315	KAP OPH	.52	.52	.52						
10318	PS 6787	.40	.40	.40						
10322		-.11	-.20	-.29	-1.66	-1.84	-2.00			
10324	ALF HEP	-3.58	-3.58	-3.58	-4.06	-4.06	-4.06	-4.44	-4.44	-4.44
10352	V454 OPH				-1.84	-1.84	-1.84			
10365	V111 OPH	-.39	-.97	-1.27	-2.40	-3.03	-3.40			
10366	X OPH	-1.47	-1.47	-1.47	-2.30	-2.55	-2.76	-3.10	-3.10	-3.10
10374					-1.50	-1.50	-1.50			
10386	V413 AOL	.52	.52	.52						
10401	V492 AOL	1.33	1.33	1.33						
10402	EPS AOL	1.43	1.43	1.43						
10401		-.19	-.19	-.19	-2.50	-2.50	-2.50			
10405	R AOL	-1.22	-1.37	-1.30	-2.30	-2.58	-2.87	-3.30	-3.35	-3.40
10407	VF44 AOL	.19	.19	.19						
10409	BD-13-6919	1.44	1.44	1.44	.50	.50	.50			
10421	5752	-.20	-.36	-.50	-4.20	-4.36	-4.50	-6.50	-6.50	-6.50
10431	MUU AOL	1.57	1.57	1.57						
10439	CAM AOL	-.32	-.32	-.32	-1.13	-1.13	-1.13	-1.12	-1.12	-1.12
10441	ALF AOL	.19	.19	.19	.26	.26	.26			
10444	PET AOL	1.55	1.55	1.55						
10474	THE DEL	2.12	2.12	2.12						
10444	UHI PEG				-2.60	-2.60	-2.60			
10503	EPS PEG				-2.30	-2.30	-2.30	-1.20	-1.20	-1.20
10510					-1.50	-1.50	-1.50			
10514	RS PEG				-1.20	-1.20	-1.20			
10527					-1.40	-1.40	-1.40			
10526	ALF PEG	2.36	2.36	2.36	2.18	2.18	2.18			
10527	R PEG	-.46	-.46	-.46	-.60	-1.61	-1.90	-2.30	-2.30	-2.30
20104	CHI PEG	.38	.38	.38						
20507	TV PSC	-.47	-.47	-.47						
20013	ZET AND	3.62	3.62	3.62						
20374	ALF ARI	-.69	-.69	-.69	-.77	-.79	-.80	-1.24	-1.24	-1.24
20051	RZ ARI	-1.33	-1.33	-1.33						
20063	ETA TAU	2.87	2.87	2.87						
20076	DEL TAU	1.01	1.01	1.01	-.40	-.40	-.40			
20087	ALF TAU	-2.82	-2.89	-2.95	-2.97	-2.99	-3.00	-3.00	-3.02	-3.04
20112	119 TAU	-1.04	-1.15	-1.30	-1.26	-1.30	-1.35			
20117	ZET TAU	2.51	2.51	2.51						
20121	Y TAU	-.38	-.38	-.38	-1.90	-1.92	-1.93	-1.78	-1.78	-1.78
20125	CHI1 ORI	2.69	2.69	2.69						

THIS PAGE IS BEST QUALITY PRACTICABLE
 FROM COPY FURNISHED TO DDC

Table A1 (Cont.)

IQC	NAME	4.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
20127	U OPI	-1.05	-1.32	-1.53	-2.82	-2.91	-3.00			
20134	TV GEM	.51	.51	.51	-1.27	-1.27	-1.27			
20135	WY GEM	1.72	1.58	1.46	1.46	1.21	1.00			
20136	BU GEM	.75	.75	.75	-.98	-.98	-.98			
20179	FTA GEM	-1.34	-1.44	-1.53	-1.74	-1.75	-1.76			
20184	FUI GEM	-2.16	-2.16	-2.16	-2.16	-2.16	-2.16	-2.32	-2.32	-2.32
20146	EX GEM	-1.43	-1.43	-1.43						
20154	CAJ GEM				2.19	2.19	2.19			
20163	41 GEM	1.70	1.70	1.70						
20169	ZET GEM	2.10	2.10	2.10	2.20	2.20	2.20			
20171	R GF4	1.60	1.60	1.60	.50	.50	.50			
20197	VV CMC	-.47	-.47	-.47	1.02	-2.12	-2.84	.36	.36	.36
20200	THE CMC	.59	.59	.59						
20206	X CMC	-.94	-.94	-.94	-.92	-.92	-.92			
20207	T CMC	.51	.51	.51	-.65	-.65	-.65			
20211	LAM LEO	.41	.41	.41						
20219	GAM1 LEO	-.79	-.79	-.79	-1.15	-1.15	-1.15	-1.24	-1.24	-1.24
20227	72 LEO	-.11	-.11	-.11	-.38	-.38	-.38			
20251	36 COM	.60	.60	.60						
20254	40 COM	-.22	-.22	-.22	-.62	-.62	-.62			
20257		1.54	1.54	1.54	1.10	1.10	1.10			
20263	UES 000	.18	.18	.18						
20267	FTA 000	1.28	1.28	1.28	-2.67	-2.67	-2.67			
20270	ALF 000	-3.04	-3.04	-3.04	-2.90	-3.09	-3.25	-3.10	-3.10	-3.10
20276	XI 000	2.45	2.45	2.45						
20281	WX SEP	1.30	1.07	.87	.90	-1.08	-1.70	-1.80	-2.22	-2.44
20282	TAUG SER	-1.17	-1.17	-1.17	-2.08	-2.08	-2.08			
20284	KAP SER	-.19	-.19	-.19						
20285	R SER	.07	.07	.07	-1.16	-1.16	-1.16			
20288	CS 5924	1.23	1.23	1.23						
20296	CAM HER	2.78	2.78	2.78						
20298	U HER	-.96	-1.02	-1.07	-2.30	-2.51	-2.60	-2.40	-2.74	-3.00
20326	16032				-2.50	-2.66	-2.80			
20329	HM HER	.74	.42	.18	-2.35	-2.38	-2.40	-4.33	-4.33	-4.33
20364	139 HER	.96	.96	.96						
20370		-.70	-2.81	-3.85	-1.69	-2.91	-3.50			
20392	HT 4-2	1.64	1.64	1.64						
20417	HT 4-1	2.19	2.19	2.19						
20419	HC 61	3.48	3.48	3.48						
20426	FLF SGE	2.46	2.46	2.46						
20427	PET SGE	1.94	1.94	1.94						
20433	DPI SGE	-1.07	-1.07	-1.07						
20434		.71	.71	.71						
20439	RD+22-7440	-.74	-.98	-1.09	-1.69	-1.86	-2.00			
20445	GAM SGE	-.45	-.45	-.45						
20481	U DEL	-.57	-.57	-.57	-1.74	-1.74	-1.74			
20505	I PEG	1.40	1.40	1.40						
20526	GC 30777				-.70	-.70	-.70			
20539	RS A714				-.30	-.36	-.30			
20557	PSI PEG	-.31	-.31	-.31						
30004	ALF AND				2.46	2.46	2.46	1.46	1.46	1.46
30014	DEL AND	-.05	-.05	-.05	-.01	-.01	-.01			
30021		1.07	1.05	1.03	-1.60	-1.88	-2.10			
30044	R T2T							-1.80	-1.80	-1.80
30058	RS 991	1.32	1.32	1.32						

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DQC

Table A1 (Cont.)

IRC	NAME	4.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
30368	ZET PER	2.66	2.66	2.66						
30373	DS 12A6	2.36	2.36	2.36						
30100	10T AMP	-.58	-.58	-.58	-.97	-.97	-.97			
30114	S AUR				-1.30	-1.30	-1.30			
30124	RS 1913	.50	.50	.50						
30120	RS 2018	.99	.99	.99						
30138		2.37	2.37	2.37						
30143	TU GEM	.21	.21	.21	-.99	-.99	-.99			
30190	ALF GEM	1.34	1.34	1.30	1.44	1.44	1.44			
30194	PET GEM	-1.16	-1.21	-1.26	-1.30	-1.32	-1.33	-1.24	-1.27	-1.30
30204	PHO2 CMC	-.07	-.07	-.07						
30209	ES CMC	-1.82	-1.83	-1.85	-2.95	-3.05	-3.13	-3.60	-3.60	-3.60
30210	PLF LY4	-.80	-.83	-.80						
30215	R L4T	-1.05	-1.26	-1.39	-2.50	-2.75	-2.83	-3.44	-3.44	-3.44
30219	FW L4T	-1.79	-2.73	-3.01	-4.20	-4.97	-5.40	-5.06	-5.13	-5.20
30220		1.24	1.29	1.29	-.17	-.17	-.17			
30230	NUU UNA	.09	.09	.09						
30246	DET COM	2.72	2.72	2.72						
30251	ES 5219	-.24	-.24	-.24						
30252	RY B00	-2.09	-2.24	-2.32	-3.30	-3.55	-3.65	-4.29	-4.29	-4.29
30259	FHO 900	.48	.48	.48						
30260	R B00	1.17	1.17	1.17	.42	.25	.10			
30261	RV P00	-.30	-.33	-.30	-1.56	-1.56	-1.56			
30262	RW B00	.36	.24	.32	-.81	-.89	-.96			
30263	W B00	.24	.23	.22	-.07	-.15	-.22			
30271	DEL 900	.88	.88	.88						
30272	S C23	-.81	-.93	-.98	-2.83	-2.99	-3.12	-2.94	-3.30	-3.50
30280	EOS C23	1.05	1.05	1.05						
30293	FU HEP	0.00	-.23	-.38	-.77	-1.37	-1.99	-1.89	-1.89	-1.89
30292		1.47	1.31	1.17	-.80	-.83	-.85			
30294	7ET HEP	1.06	1.06	1.06						
30363	DET LY3	2.20	2.20	2.20	-.86	-.86	-.86			
30370	PET CYG	-.09	-.09	-.09						
30374		.30	.30	.30	-2.30	-2.30	-2.30			
30376	YT CYG	1.43	1.43	1.43	.80	.80	.80			
30381		1.54	1.54	1.54						
30395	CHI CYG	-2.42	-2.80	-3.05	-3.42	-3.93	-4.16	-4.24	-4.40	-4.60
30401	ETA CYG	1.48	1.48	1.48						
30407	4FE 63	2.08	2.08	2.08	-.10	-.10	-.10			
30412		1.17	1.17	1.17						
30448	JO VIL	2.03	2.03	2.03						
30450	52 CYG	1.57	1.57	1.57						
30451	EPS CYG	-.05	-.05	-.05						
30464	UY CYG	1.07	1.07	1.07	-.50	-.50	-.50			
30477	7ET CYG	.93	.93	.93						
30481	TH DEG				-2.20	-2.23	-2.26	-3.05	-3.05	-3.05
30485	ICT DEG	2.59	2.59	2.59						
30499	ETA DEG				.50	.50	.50	.54	.54	.54
30504	PET DEG	-2.20	-2.27	-2.35	-2.32	-2.48	-2.62	-2.17	-2.41	-2.60
30509					-2.00	-2.00	-2.00			
30522	Z PEG	.92	.92	.92						
30604		.02	.02	.02	-2.40	-2.40	-2.40			
40006	VX AND	.41	.41	.41						
40009	R AND	-.43	-.97	-1.32	-2.60	-2.60	-2.60	-3.06	-3.43	-3.71
40011	AO AND	1.18	1.19	1.18	.25	.25	.25			

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDG

Table A1 (Cont.)

TRC	NAME	4.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
40014					2.29	2.29	2.29	1.85	1.85	1.85
40019	BET AND	-1.81	-1.83	-1.86	-2.01	-2.07	-2.10	-1.93	-2.11	-2.26
40024	UPS AND	2.76	2.76	2.76						
40034	GEM AND	-2.84	-2.84	-2.84						
40037	W AND				-1.70	-1.70	-1.70			
40054	EMO PER	-2.05	-2.05	-2.05	-2.28	-2.29	-2.30	-2.37	-2.44	-2.50
40068	MUO PER	-.04	-.04	-.04	-.20	-.20	-.20			
40091	LK HALP111	-.23	-.23	-.23	-2.40	-2.40	-2.40	-3.70	-3.70	-3.70
40093	SA PER	1.09	1.09	1.09						
40105		1.90	1.90	1.90						
40109	FPS AUR	.94	.94	.94	1.05	1.05	1.05			
40144	BET AUR	1.86	1.86	1.86						
40156	12245	.79	.79	.79	-1.30	-1.30	-1.30			
40159	UW AUR	-.79	-.79	-.79	-2.15	-2.18	-2.20	-2.18	-2.18	-2.18
40195	31 LYN	.30	.30	.30						
40211	PS 3579	2.85	2.85	2.85						
40218	MUO UMA	-.78	-.81	-.85	-1.11	-1.16	-1.20			
40224	FST UMA	.26	.26	.26						
40233	U CVM	1.68	1.68	1.68	.35	.35	.35			
40244	P CVM	-.07	-.07	-.07	-1.29	-1.29	-1.29			
40253	RS 5299	-.46	-.46	-.46	-.38	-.38	-.38			
40271	EO CRB	.88	.88	.88	.44	.44	.44			
40273	V CRB	.96	.96	.96	-.85	-.85	-.85			
40275	Z HER	.46	.46	.46				-3.55	-3.55	-3.55
40278	TAH CRB	2.02	2.02	2.02						
40283	G HER	-2.12	-2.23	-2.33	-2.66	-2.72	-2.79	-2.80	-2.90	-3.00
40287	ETA HER	1.20	1.20	1.20						
40293	UW HER	1.20	1.20	1.20	-.70	-.70	-.70			
40321	T LYO	-.19	-.29	-.38	-.30	-1.10	-1.55	-1.35	-1.35	-1.35
40322	ALT LYO	-.01	-.01	-.01	-.03	-.03	-.03	-.08	-.08	-.08
40323	XY LYO	-.35	-.49	-.61	-.69	-1.01	-1.26			
40331	DEL2 LYO	-1.25	-1.25	-1.25	-1.66	-1.66	-1.66			
40334	P LYO	-2.08	-2.23	-2.39	-2.17	-2.46	-2.80	-2.62	-2.81	-2.90
40341	THE LYO	1.45	1.45	1.45						
40350	AA CYG	.46	.46	.46						
40397	BS CYG	1.26	1.26	1.26	.52	.52	.52			
40406	35 4077	.88	.88	.88						
40408	RT CYG	-.03	-.03	-.03	-2.40	-2.74	-2.90	-3.65	-3.65	-3.65
40409	EC CYG	-.20	-.22	-.25	-1.70	-2.89	-3.21	-3.87	-3.87	-3.87
40411	GAM CYG	.70	.67	.65	.80	.67	.56			
40415	KY CYG	-.71	-.71	-.71	-2.50	-2.50	-2.50			
40418	VW41 CYG	1.32	1.32	1.32						
40424	RW CYG	.11	.05	-.01	-2.50	-2.69	-2.80	-3.43	-3.43	-3.43
40427	MHC 349				-1.73	-1.73	-1.73	-2.71	-2.71	-2.71
40431	HC 2	.45	.39	.32	-1.80	-1.80	-1.80			
40432	CTI 13	1.25	.87	.59	1.00	.84	.70			
40434	HC 1	.30	.27	.24	-1.70	-1.70	-1.70			
40440	HC 6	2.00	2.00	2.00						
40441	V446 CYG				-1.30	-1.30	-1.30			
40442	DG CYG	.59	.59	.59	-.80	-.80	-.80			
40445	CIT 13	-.88	-.88	-.88	-1.88	-1.88	-1.88			
40448	NHL CYG	-2.35	-2.57	-2.76	-5.19	-5.51	-5.77	-6.74	-6.80	-6.90
40444	BS 8062	.59	.59	.59						
40468	YI CYG	.31	-.02	-.04	-.07	-.14	-.20	-.18	-.18	-.18
40469	61 CYG	1.59	1.53	1.49						

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

Table A1 (Cont.)

IRC	NAME	4.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
40481		.75	.69	.64	-1.20	-1.67	-2.00			
40489	VA60 CYG	1.38	.63	-.10	.79	-.37	-1.04			
40491	9V CYG	.12	.12	.12	-1.11	-1.11	-1.11			
40512	S LAC	1.78	1.78	1.78	1.05	1.05	1.05			
40540		-1.20	-1.20	-1.20	-3.80	-3.80	-3.80			
40545		1.14	1.14	1.14						
50030		.17	.17	.17						
50063	BD444-398	-1.35	-1.35	-1.35						
50062	XX PER	.73	.73	.73						
50072	THE PER	2.94	2.94	2.94						
50086	LOT PER	2.65	2.65	2.65						
50089	1.34	1.14	1.14	1.14						
50095	ALF PER	.53	.49	.44	.46	.30	.16	.58	.58	.58
50096	CIT 5	-1.55	-1.55	-1.55	-3.12	-3.22	-3.30	-3.35	-3.35	-3.35
50111	MUU PER	1.78	1.78	1.78						
50137		.26	.03	-.18	-1.62	-2.28	-2.90	-4.00	-4.00	-4.00
50139	ALF AJR	-1.83	-1.86	-1.99	-2.00	-2.00	-2.01	-1.98	-2.02	-2.05
50156	PT AJR	-1.19	-1.19	-1.19						
50164	PS11 AJR	.05	.05	.05	.13	.13	.13			
50180	Y LYA	-.52	-.59	-.86	-1.40	-1.69	-1.90			
50213	FMT UMA	.70	.71	.70						
50215	CAM UMA	2.56	2.56	2.56						
50219	Y CVN	-1.72	-1.71	-1.79	-1.95	-2.19	-2.39			
50222	IU CVN	-.37	-.37	-.37	-.50	-.50	-.50			
50226	V CVN	.51	.75	.70	-1.40	-1.47	-1.53			
50231	PT UMA	.14	.14	.14	.69	.69	.69			
50233	ETA UMA	1.31	1.31	1.31						
50266	ST MER	-.72	-.72	-.72	-1.70	-1.70	-1.70			
50268	X MER	-1.51	-1.55	-1.59	-2.95	-3.06	-3.18	-3.74	-3.74	-3.74
50273	OP MER	.14	-.09	-.28	-.74	-.74	-.74			
50274	CAM DOA	-1.29	-1.30	-1.30	-1.50	-1.66	-1.90			
50291	KAP CYG	1.64	1.64	1.64						
50294	CM CYG	-1.31	-1.34	-1.36	-2.57	-2.62	-2.70	-3.09	-3.09	-3.09
50301	P CYG	.19	.19	.19	-.90	-1.17	-1.30	-2.00	-2.00	-2.00
50308	DFL CYG	2.65	2.65	2.65						
50316	SV CYG	.91	.91	.91						
50324	U CYG	.43	.10	-.15	-1.40	-1.51	-1.61			
50337	ALF CYG	.80	.77	.74	.83	.78	.73	-.02	-.02	-.02
50338	V CYG	-1.39	-1.57	-1.72	-3.30	-3.64	-3.80	-3.88	-3.88	-3.88
50347	QZ CYG	.20	.23	.22	-1.32	-1.30	-1.30			
50351	AZ CYG	.71	.71	.71	-1.70	-1.70	-1.70	-2.76	-2.76	-2.76
50357		-.59	-.53	-.59	-1.76	-1.89	-2.00			
50362		1.13	1.13	1.13						
50385	FMO CYG	1.84	1.84	1.84						
50409	LW CYG	.69	.69	.69						
50417	PS 8421	.67	.67	.67						
50444	U LAC	.40	.34	.32	-1.00	-1.00	-1.00			
50452	PS 8726	.50	.50	.50						
50484	P CAS	-2.23	-2.35	-2.46	-4.10	-4.10	-4.10	-5.01	-5.15	-5.25
50501	V CAS	.10	.11	.10						
60704	BFT CAS	1.33	1.33	1.33	1.02	1.02	1.02	1.34	1.34	1.34
60805	DD463-3	1.01	1.01	1.01						
60809	T CAS	-1.45	-1.54	-1.63	-2.61	-2.79	-2.93	-3.45	-3.45	-3.45
60817	ALF CAS	-.02	-.02	-.02	-.61	-.61	-.61			
60919	ETA CAS	1.87	1.87	1.87	1.94	1.94	1.94			

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

Table A1 (Cont.)

IRC	NAME	4.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
60020	1,23	2.33	2.33	2.33						
60031	GAM CAS	2.88	2.88	2.88	.80	.80	.80			
60039	MS CAS	1.85	1.85	1.85						
60040	B7-61-219	2.11	2.11	2.11						
60046	PHI CAS	1.71	1.71	1.71	1.88	1.88	1.88			
60061		2.39	2.39	2.39						
60074	KK PER	1.58	1.58	1.58						
60078	BU PER	1.63	1.63	1.63						
60079	T PER	2.05	2.05	2.05						
60081	HD 14242	2.00	2.00	2.00						
60082	AN PER	1.85	1.71	1.58	.55	.55	.55			
60083	FZ PFZ	2.74	2.33	1.98	1.00	1.30	1.00			
60085	HD 14404	2.01	2.01	2.01						
60086	SU PER	1.15	1.15	.37	-.36	-.36	-.36			
60087	RS PER	.99	.99	.99						
60088	S PER	.26	.18	.10	-1.29	-2.37	-2.69	-3.01	-3.36	-3.62
60089	HD 14583	2.57	2.57	2.57						
60090	HD 14826	1.41	1.41	1.41						
60091		1.11	1.11	1.11	.47	.47	.47			
60092		-.23	-.23	-.23	-2.50	-2.50	-2.50			
60093	YZ PER	1.68	1.54	1.42	-.25	-.25	-.25			
60094	GP CAS	1.30	1.30	1.30						
60097	W PER	1.24	1.24	1.24	-1.25	-1.28	-1.30	-2.41	-2.48	-2.54
60098	ETA PER	-.19	-.19	-.19						
60100		1.34	1.34	1.34						
60106	1,31	1.58	1.58	1.58						
60110	IO PER	.22	.22	.22						
60111		1.40	1.40	1.40						
60117	PS 1009	.16	.16	.16						
60120	PS 1040	2.72	2.72	2.72						
60124	U CAM	.05	.05	.05						
60125	PS 1105	-.10	-.10	-.10						
60126	PS 1112	1.37	1.37	1.37						
60129		2.22	2.22	2.22						
60144		.17	.17	.17						
60150	TX CAM	.22	.22	.22	-1.00	-3.43	-4.12	-4.50	-4.50	-4.50
60179	F LYN	1.02	1.02	1.02	.04	.04	.04			
60208	ALF UMA	-.70	-.73	-.75	-.81	-.85	-.88	-.81	-.81	-.81
60213	Z UMA	.15	.13	.10	-.74	-.81	-.87			
60215	DY U-1A	2.33	2.27	2.21	.41	.29	.19			
60231	ICT DRA	.47	.47	.47						
60242	ETA DRA	.37	.37	.37						
60251	TY DRA				-1.70	-1.70	-1.70			
60255	T DRA	.81	.60	.43	-.69	-1.80	-2.20	-2.01	-2.01	-2.01
60294	UII CEP	2.09	2.69	2.09						
60298	ETA CEP	1.15	1.15	1.15						
60317	ALF CEP	1.80	1.80	1.80						
60317	PGC 5481	.36	.25	.15						
60317	SW CEP	1.10	1.10	1.10						
60325	NUU CEP	-2.17	-2.20	-2.23	-4.80	-4.10	-4.30	-4.52	-4.66	-4.76
60326	NUU CEP	2.63	2.63	2.63						
60333	VV CEP	-.24	-.39	-.52	-.72	-.72	-.72			
60334	HT 1-1	.61	.61	.61						
60336	HT 1-3	1.36	1.36	1.36						
60341	AZ CEP	1.82	1.82	1.82						

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC.

Table A1 (Cont.)

IRC	NAME	4.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
60344	ZET CEP	.16	.05	-.05	-.10	-.10	-.10			
60353	EM CEP	1.46	1.45	1.45	-1.20	-1.24	-1.30	-2.16	-2.16	-2.16
60356	DEL CEP	2.30	2.30	2.30	2.20	2.20	2.20			
60362	ST CEP	1.54	1.54	1.54	-1.00	-1.00	-1.00			
60361	2.25	1.02	1.02	1.02						
60362	M CEP	1.39	1.24	1.11	-1.70	-1.70	-1.70	-2.49	-2.49	-2.49
60367	2.78	1.88	1.88	1.88						
60374	2.79	.95	.95	.95						
60377		1.91	1.91	1.91						
60379	PS 8752	1.41	1.14	.87	1.62	.70	.43			
60389	V CAS	-.06	-.06	-.06	-1.33	-1.33	-1.33			
60410	W358 CAS	1.10	1.10	1.10						
60416	PS 8999	1.17	1.17	1.17						
60417	P2 CAS	.04	.03	.08	-2.70	-2.92	-3.10			
60424	V2 CAS	1.55	1.55	1.55	-1.20	-1.20	-1.20			
60429	EMO CAS	2.43	2.43	2.43	2.43	2.43	2.43			
60431	W7 CAS	.50	.32	.17	-.04	-.04	-.04			
70033		.92	.92	.92						
70016	SD74-46				-.10	-.10	-.10			
70026	S CAS				-1.10	-1.10	-1.10			
70046	PS 1155				-.55	-.55	-.55			
70066		-.26	-.26	-.26	-2.02	-2.17	-2.30			
70067	V CAM	.39	.39	.39						
70067	EMO UMA	-.48	-.48	-.48	-.40	-.40	-.40	-2.20	-2.20	-2.20
70117	VY UMA	.28	.31	-.69	-.39	-.39	-.39			
70107	LAM DRA	-.39	-.39	-.39	.38	.38	.38			
70116	RY DRA	-.59	-.59	-.59	-1.19	-1.31	-1.50			
70124	U UMI	.50	.49	.48	-.60	-.77	-.92			
70126	RR UMI	-.79	-.79	-.79	-1.08	-1.08	-1.08			
70136	P DRA	1.81	1.81	1.81	.44	.44	.44			
70150	DEL DRA	.74	.76	.76						
70158	SIG DRA	2.52	2.46	2.41						
70160	EPS DRA	1.56	1.56	1.56						
70168	T CEP	-2.17	-2.17	-2.17	-3.00	-3.12	-3.20	-3.60	-3.60	-3.60
70170					-1.10	-1.10	-1.10			
70171		.39	.39	.39						
80036	UX DRA	.22	.22	.22	-.41	-.41	-.41			
80048	S CEP	-1.42	-1.64	-1.85	-2.91	-3.01	-3.11			
-10002	33 PSC	2.15	2.15	2.15						
-10006	TOI GST	.82	.82	.82	-.44	-.44	-.44			
-10035	U CET	2.25	2.25	2.25	1.41	1.41	1.41			
-10041	2 FST	.35	.35	.35	-.84	-.84	-.84			
-10048	FPS FBI	1.43	1.43	1.40						
-10055	GAM FBI	-.82	-.82	-.82	-1.36	-1.36	-1.36			
-10064	OMT FBI	2.35	2.35	2.35						
-10080	P LEO	-.83	-.95	-1.06	-2.50	-2.52	-2.54	-2.06	-2.57	-2.92
-10085	DET ORI	.13	.13	.13	.03	.03	.03	-.52	-.55	-.57
-10093	M 42				-4.50	-4.50	-4.50	-5.00	-5.00	-5.00
-10098	KAP ORI	2.60	2.60	2.60						
-10169	PGC 1985	.19	-.11	-.35	.12	.12	.12	.13	.13	.13
-10194	FK MYA							-2.83	-2.83	-2.83
-10199	RV MYA				-.50	-.50	-.50			
-10217	ALF MYA	-1.22	-1.35	-1.46	-1.28	-1.28	-1.28			
-10242	U MYA	-1.10	-1.10	-1.10	-1.82	-1.82	-1.82			
-10253	DEL CRT	.77	.77	.77						

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDG

Table A1 (Cont.)

IRC	NAME	6.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
-10274	PSI VIR	-.17	-.17	-.17						
-10286	ALF VIR	1.53	1.53	1.53	1.78	1.78	1.78	-1.44	-1.44	-1.44
-10288	74 VIR	.05	.05	.05						
-10290	S VIR	-.11	-.22	-.33	-1.29	-1.46	-1.60			
-10390	KAP VIR	.92	.92	.92						
-10329					-.50	-.50	-.50			
-10339	V OPH	1.51	1.22	.99	.33	.19	.06			
-10343	ZET OPH	2.61	2.61	2.61						
-10344		.55	.55	.55						
-10376	XX OPH	2.45	2.42	2.39	1.27	1.27	1.27			
-10381		.99	.85	.66	-1.14	-1.25	-1.40			
-10395		.89	.89	.89						
-10396		-.23	-.23	-.23	-1.48	-1.71	-1.90			
-10401					-1.00	-1.00	-1.00			
-10414					-2.20	-2.20	-2.20			
-10415	FR SCT	2.05	1.79	1.58	.70	.70	.70			
-10419	3,49	1.79	1.79	1.79						
-10422	UY SCT	.21	.21	.21	-1.50	-2.03	-2.39			
-10434		1.45	1.45	1.45	-.50	-.50	-.50			
-10435	DD-14-5185	1.13	1.13	1.13						
-10440		2.33	2.33	2.33						
-10441	EX SCT	.71	.71	.71	-.10	-.10	-.10			
-10445		2.28	2.28	2.28						
-10450		.64	.64	.64	-1.30	-1.40	-1.50			
-10451	D SCT	1.42	1.42	1.42	.40	.40	.40			
-10457	S SCT	.43	.43	.43	-.42	-.81	-1.10			
-10479	RW SCT	.68	.68	.68						
-10483	12 AOL	2.41	2.41	2.41						
-10496	V AOL	-.36	-.36	-.36	-1.48	-1.48	-1.48			
-10497	M 16	1.28	1.28	1.28	.50	.50	.50			
-10497	M AOL	-.83	-1.03	-1.20	-2.93	-3.02	-3.10			
-10502		-.04	-.04	-.04	-2.40	-2.40	-2.40			
-10524	GY AOL	-.25	-.25	-.25	-2.40	-2.56	-2.70			
-10529		-.55	-.55	-.55	-3.20	-3.20	-3.20			
-10534	ALF1 CAP	1.71	1.71	1.71						
-10535	ALF2 CAP	1.21	1.21	1.21						
-10537	BET CAP	.81	.81	.81						
-10548	3 AQR	-.27	-.36	-.43	-.33	-.33	-.33			
-10557	MUR1 AQR	2.14	2.14	2.14						
-10565	BET AQR				.34	.34	.34	-.04	-.04	-.04
-10608	30 PSC	-.55	-.55	-.55	-.36	-.36	-.36			
-10609	M CET	1.61	1.61	1.61						
-20084	17 LEP	.55	.55	.55	-1.37	-1.37	-1.37	-2.27	-2.27	-2.27
-20105	ALF CMA	-1.27	-1.33	-1.38	-1.30	-1.32	-1.33	-1.47	-1.47	-1.47
-20112	OMT1 CMA	.10	.10	.10	-.23	-.23	-.23			
-20173	AK MYA							-2.48	-2.48	-2.48
-20184		.64	.64	.64	.88	.88	.88			
-20197		.65	.65	.65	-2.10	-2.10	-2.10	-5.50	-5.50	-5.50
-20210	MUR1 MYA	.19	.13	.19						
-20217	MUR1 MYA	.10	.13	.10						
-20218	V MYA	-2.07	-2.09	-2.12	-3.40	-4.02	-4.12	-4.31	-4.41	-4.50
-20222	P CRT	-1.55	-1.55	-1.55	-2.70	-2.70	-2.70			
-20233	EPS CRV	-.10	-.13	-.10						
-20240	BET CRV	.61	.61	.61	.97	.97	.97			
-20242	T CRV	1.58	1.58	1.58	.10	-.20	-.44			

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDG

Table A1 (Cont.)

IR#	NAME	4.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
-20249	G44 MYA	.70	.70	.70						
-20254	2 MYA	-2.97	-3.03	-3.20	-4.11	-4.39	-4.62	-4.51	-4.64	-4.76
-20266		.19	.19	.19	-.22	-.37	-.50			
-20275	BS 5568	2.66	2.63	2.24						
-20286	PS LTA	-.28	-.28	-.28	-1.69	-1.69	-1.69			
-20291	A2 LTB	1.94	1.94	1.94						
-20296	T4E LTA	1.37	1.37	1.37						
-20303	DEL SGO	2.87	2.87	2.87						
-20305	BFT1 SGO	2.73	2.73	2.73						
-20318	FHT DPM	2.22	2.22	2.22						
-20322		.75	.75	.75						
-20411	HFE 42443				-.20	-.20	-.20			
-20417	VE 2-45	-.58	-.62	-.56	-2.10	-2.20	-2.30			
-20421	GC 24547				-1.60	-1.60	-1.60			
-20423					-1.10	-1.10	-1.10			
-20424	1,232	-.72	-.87	-1.01	-3.10	-3.10	-3.10			
-20427					-1.40	-1.40	-1.40			
-20431	VX SGR	-1.62	-1.99	-2.32	-4.34	-4.76	-5.02	-5.43	-5.55	-5.60
-20434	AY SGR	2.66	2.49	2.40	-.32	-.51	-.68	-1.96	-1.96	-1.96
-20439					-2.00	-2.00	-2.00			
-20445		1.47	1.47	1.47						
-20451	14 SGR				-1.30	-1.30	-1.30			
-20451	14 SGR	1.47	1.47	1.47	-1.30	-1.30	-1.30			
-20454					-2.30	-2.30	-2.30			
-20464		1.72	1.72	1.72						
-20466	N 561A				-6.43	-6.43	-6.43			
-20526	YU1 SGR	-1.56	-1.56	-1.56	-1.68	-1.68	-1.68			
-20527	UY SGR				-1.90	-1.90	-1.90			
-20528	YU2 SGR	1.82	1.82	1.82						
-20530	X12 SGR	.78	.78	.78						
-20534	YU SGR	-.44	-.44	-.44	-1.90	-1.90	-1.90			
-20536	OMT SGR	1.39	1.39	1.39						
-20540		1.06	1.00	.95	-1.20	-1.67	-2.00			
-20542	PI SGR	1.67	1.67	1.67						
-20553	BS 7317	2.41	2.41	2.41						
-20554	V1042 SGR	.16	.16	.16						
-20558	UPS SGR	1.44	1.44	1.44	-.30	-1.29	-1.65			
-20568	30 SGR	.66	.66	.66	-.49	-.49	-.49			
-20596	RS CAP				-.80	-.80	-.80			
-20602	ZET CAP	1.68	1.68	1.68						
-20604	36 CAP	2.30	2.30	2.30						
-20642	R AGR	-2.27	-2.27	-2.27	-4.46	-4.46	-4.46	-3.00	-4.07	-4.40
-20675	DEL CMA	.16	.16	.16	-.06	-.06	-.06			
-30087	VY CMA	-3.06	-3.34	-3.74	-6.00	-6.31	-6.60	-7.20	-7.58	-7.82
-30182	BS 4532	-.29	-.29	-.29	-.50	-.50	-.50			
-30207	W MYA	-3.41	-3.83	-4.05	-4.80	-5.23	-5.50	-5.20	-5.51	-5.75
-30213	BT MYA	.51	.51	.51						
-30217		1.03	1.03	1.03	-.79	-.79	-.79			
-30219		-2.22	-2.22	-2.22	-4.07	-4.07	-4.07			
-30228	SIG LIB	-1.37	-1.44	-1.50	-1.11	-1.39	-1.62	-2.25	-2.25	-2.25
-30234	2 LUP	1.93	1.93	1.93						
-30260	SIG SGO	2.05	2.05	2.05	1.66	1.66	1.66			
-30265	ALF SGO	-3.98	-3.99	-4.00	-4.66	-4.67	-4.73	-4.86	-4.88	-4.90
-30282	AM SGO				-3.20	-3.20	-3.20			

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

Table A1 (Cont.)

IRC	NAME	4.2 MICRONS			11 MICRONS			19.8 MICRONS		
		MAX	MEAN	MIN	MAX	MEAN	MIN	MAX	MEAN	MIN
-30287	CO3C-13953				-1.10	-1.10	-1.10			
-30316					-1.80	-1.80	-1.80			
-30321	CAL CTR				-2.90	-2.90	-2.90			
-30326	KW SG8	.50	.60	.60	-1.90	-1.90	-1.90			
-30354	CO2C-14523				-1.10	-1.10	-1.10			
-30363	CO2C-12853				-1.10	-1.10	-1.10			
-30398		-.41	-.73	-.37	-3.10	-3.29	-3.50			
-30192F	2 GEN	-1.65	-1.65	-1.68	-1.32	-1.64	-1.88			
-30287F	ES 6392	1.32	1.32	1.32	-.84	-.84	-.84			
-40314F	V MIC	.71	.71	.71	-1.48	-1.48	-1.48	-3.70	-3.70	-3.70
-40325F	DEL2 GRU	-.90	-.90	-.90	-1.00	-1.00	-1.00			
-50001F	S HOB	-2.21	-2.21	-2.21	-3.50	-3.50	-3.50	-3.90	-3.90	-3.90

THIS PAGE IS BEST QUALITY PRACTICABLE
 FROM COPY FURNISHED TO DDG