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A SET OF PHOTOMETRIC NEAR–INFRARED STANDARD STARS OBSERVED AT SAN PEDRO MARTIR

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RESUMEN

Se presenta una lista de 24 estrellas patrón brillantes para el sistema fotomêtrico *JHKL'M* del Observatorio Astronómico Nacional en San Pedro Mártir, México. Este es el resultado del análisis de las estrellas patrón observadas como parte de varios proyectos en 110 noches fotométricas. Se usó un fotómetro con un detector de InSb en el telescopio de 2.1-m. Se hace también una comparación con otras listas similares provenientes de otros observatorios para obtener transformaciones con nuestro sistema fotométrico.

ABSTRACT

A set of 24 *JHKL'M* bright standard stars in use at the Observatorio Astronómico Nacional in San Pedro Mártir, México, is presented. This is the result of an analysis of the standard stars observed during 110 photometric nights dedicated to several projects, with an InSb-based photometer on the 2.1-m telescope. A comparison is made with similar published lists from other observatories resulting in a set of transformation equations to and from our photometric system.

Key words: INFRARED – PHOTOMETRY

I. INTRODUCTION

Although near and mid-infrared photometry has been obtained for more than two decades, only in recent years and motivated by higher accuracy observations, has the astronomical community started to publish their lists of self-consistent standard stars that complete the definition of their photometric systems. In this way, it is also possible to determine accurate transformations to and from several sets of photometric observations made at different observatories with slightly different equipment (especially filters from different batches).

For many years the observations of bright stars by Johnson *et al.* (1966) served as primary standards for practically all near-infrared photometric observations. Two principal drawbacks of these observations are that their data on individual stars are of insufficient accuracy, and that they did not include measurements in the *H* filter, since this band was not defined in the original Johnson system. For the southern skies, Glass (1974) provided a large list of stars with more accurate *JHKL* photometry obtained from the South African Astronomical Observatory (SAAO). At present, more accurate observations yield more reliable sets of standard stars as observed with the most important infrared systems; these include the Anglo-Australian Observatory (AAO; Allen and Cragg 1983), Mount Stromlo and Siding Spring Observatories (Jones and Hyland 1982), the European Southern Observatory (ESO; Engels *et al.* 1981; Koornneef 1983) and the California Institute of Technology/Cerro Tololo Interamerican Observatory system (CIT/CTIO; Elias *et al.* 1982). Most of these include only the *JHK* and *L* (3.5 μm) bands and only Allen and Cragg (19830 and Sinton and Tittemore (1984) included the more sensitive *L'* band centered at 3.8 μm; the latter authors also provided the best set of standard stars for the *M* band with an InSb detector at the Mauna Kea Observatory (MKO) in Hawaii.

The present work summarizes the analysis of all standard stars observed during 110 full or partial nights with photometric sky quality, most of them dedicated to other programs, from 1982 May 10 to 1985 June 5. The infrared equipment has been described by Roth *et al.* (1984), though some minor improvements have been incorporated since.

II. ANALYSIS

A list of twenty-four stars, many of them equatorial, was compiled from the works by Engels *et al.* (1981), Johnson *et al.* (1966), Allen and Cragg (1983) and Elias *et al.* (1982) when systematic near-infrared observations were started at the Observatorio Astronómico Nacional in San Pedro Mártir, Baja California, México (cf. Tapia *et al.* 1984). The initial average extinction coefficients were those measured at La Silla (Engels *et al.* 1981) where atmospheric conditions similar to our Observatory have been reported.

TABLE 1

SAN PEDRO MARTIR PHOTOMETRIC STANDARDS

HR	R.A. (1950)	Dec. (1950)	*J*	*H*	*K*	*L'*	n_1	*M*	n_2	Spectral Type	*V*
0039	$00^h10^m39^s.5$	+ 14°54′22″	3.45	3.50	3.57	3.56	7	3.67	6	B2 IV	2.83
0718	02 25 30.0	+ 08 14 14	4.42	4.45	4.46	4.39	25	4.38	7	B9 III	4.28
1084	03 30 31.1	– 09 37 33	2.21	1.74	1.62	1.57	30	1.66	19	K2 V	3.73
1231	03 50 41.7	– 13 39 22	0.12	– 0.68	– 0.90	– 1.04	11	...	...	M1 III	2.95
1239	03 57 54.4	+ 12 21 02	3.67	3.67	3.69	3.62	14	...	...	B3 V +	3.47
										A4 IV	...
1318	04 12 00.8	– 10 22 53	3.04	2.34	2.27	2.22	6	...	...	K3 III	4.87
1698	05 10 40.5	+ 02 48 12	2.52	1.95	1.79	1.74	8	...	...	K3 III	4.46
1790	05 22 26.8	+ 06 18 22	2.11	2.20	2.29	2.33	24	2.36	8	B2 III	1.64
2943	07 36 39.5	+ 05 20 25	– 0.33	– 0.52	– 0.64	– 0.69	64	– 0.67	24	F5 V	0.38
3314	08 23 09.5	– 03 44 33	4.02	4.01	3.99	3.91	19	...		A0 V	3.90
3982	10 05 41.9	+ 12 12 40	1.53	1.54	1.55	1.59	10	1.61	6	B7 V	1.35
4689	12 17 20.6	– 00 23 23	3.80	3.75	3.76	3.75	17	3.75	3	A2 IV	3.89
5384	14 20 42.4	+ 01 28 05	5.14	4.77	4.71	4.60	14	4.64	5	G1 V	6.27
6228	16 43 25.7	+ 08 40 20	2.41	1.63	1.44	1.29	14	...	...	K5 III	5.15
6603	17 40 59.9	+ 04 35 19	0.95	0.40	0.26	0.09	16	...	...	K2 III	2.77
6698	17 56 16.3	– 09 46 15	1.73	1.23	1.11	1.03	27	1.19	19	K0 III	3.34
7001	18 35 15.4	+ 38 44 24	0.06	0.04	0.01	0.02	17	– 0.01	7	A0V	0.03
7525	19 43 53.0	+ 10 29 25	0.36	– 0.37	– 0.56	– 0.76	17	– 0.54	13	K3 II	2.72
7557	19 48 22.4	+ 08 44 26	0.44	0.31	0.25	0.22	24	0.20	17	A7 V	0.77
7615	19 54 25.6	+ 34 56 57	2.22	1.74	1.62	1.53	14	1.73	14	K0 III	3.89
8143	21 15 26.9	+ 39 11 05	3.90	3.85	3.83	3.72	14	3.76	6	B9 I	4.23
8430	22 04 41.9	+ 25 06 03	2.94	2.72	2.67	2.59	13	2.63	10	F5 V	3.76
8541	22 22 29.0	+ 49 13 22	4.35	4.30	4.29	4.23	6	4.25	4	B9 I	4.57
8781	23 02 16.3	+ 14 56 09	2.50	2.50	2.51	2.48	23	2.50	8	B9V	2.49

TABLE 2

PARAMETERS OF THE TRANSFORMATION EQUATIONS

			$K_{SPM} = \beta K + \gamma$			$(J-K)_{SPM} = \beta(J-K) + \gamma$			$(H-K)_{SPM} = \beta(H-K) + \gamma$			$L'_{SPM} = \beta L' + \gamma$		
Observatory	Ref.	N[a]	β	γ	rms[b]	β	γ	rms[b]	β	γ	rms[b]	β	γ	rms[b]
Cat. + Ton.[c]	1	21	1.005 ± .005	– 0.009 ± .013	.035	1.013 ± .029	– 0.008 ± .014	.045	...	...	...	...	...	...
ESO	2	14	1.007 ± .006	– 0.012 ± .016	.035	1.057 ± .023	– 0.021 ± 0.10	.028	1.045 ± .080	– 0.004 ± .007	.023	...	...	...
SAAO	3	6	1.010 ± .015	– 0.028 ± .032	.046	1.001 ± .032	0.034 ± .020	.027	0.983 ± .137	0.000 ± .015	.022	...	...	...
AAO	4	5	1.033 ± .015	– 0.103 ± .049	.031	0.974 ± .033	0.013 ± .018	.027	1.131 ± .071	0.004 ± .008	.012	...	...	...
CIT/CTIO	5	5	1.018 ± .013	– 0.038 ± .047	.022	1.138 ± .024	0.004 ± .006	.011	1.597 ± .178	– 0.014 ± .009	.015	...	...	...
AAO + CIT/CTIO transf.[d]	6	8	1.027 ± .009	– 0.079 ± .029	.026	0.983 ± .024	0.011 ± .009	.019	1.175 ± .078	0.002 ± .008	.017	...	...	...
MKO +	7	7	...	...	...	...	...	...	...	...	...	0.991	0.016	.016
AAO	4	...	...	...	...	...	...	...	...	...	...	± .004	± .013	...

a. Number of stars in common.
b. Uncertainty in a single measurement at one observatory.
c. Catalina and Tonantzintla.
d. Allen and Cragg's (1983) stars plus Elias *et al.*'s (1982) stars transformed to the AAO system.

References: 1) Johnson *et al.* 1966; 2) Engels *et al.* 1981; 3) Glass 1974; 4) Allen and Cragg 1983; 5) Elias *et al.* 1982; 6) Elias *et al.* 1983; 7) Sinton and Tittemore 1984.

For every night, the zero points for each filter were computed from the average of all standard stars observed. After approximately each year the residuals of all nights were computed and added to the previous values. Three iterations yielded a drastic decrement in the values of the residuals and at present they are considered to be similar to the intrinsic observational errors. Small changes in the adopted extinction coefficients were also made during this process.

Table 1 shows a list of the present values of the standard stars in the natural photometric system used in San Pedro Mártir (SPM). Here, the number of observations of each star in the *JHKL'* bands is given in the column labeled n_1 and for the *M* band, in the column labeled n_2. The standard deviations for a single measurement are 0.02 magnitudes or less for *JHKL'* when fifteen or more observations were available. As expected, the errors tend to be larger for fewer observations. For the *M* band, the deviations are twice as large as those for the shorter wavelengths.

Tests for systematic errors, depending on colour, brightness, air mass or date, were performed with negative

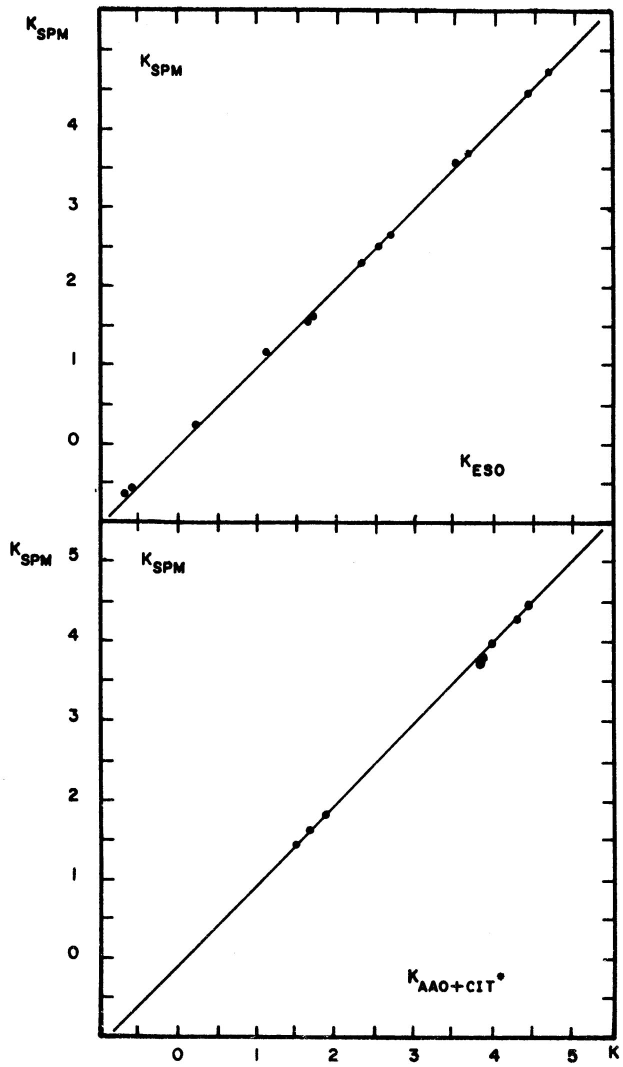

Fig. 1. (a) A plot of the *K* magnitudes of the standard stars measured in the SPM (this paper) and ESO (Engels *et al.* 1981) photometric systems. (b) Same as (a) but showing the *K* photometry from the AAO (Allen and Cragg 1983) and the CIT/CTIO (Elias *et al.* 1982) transformed to the AAO system (Elias *et al.* 1983). In both cases, the corresponding fit given in Table 2 is also drawn.

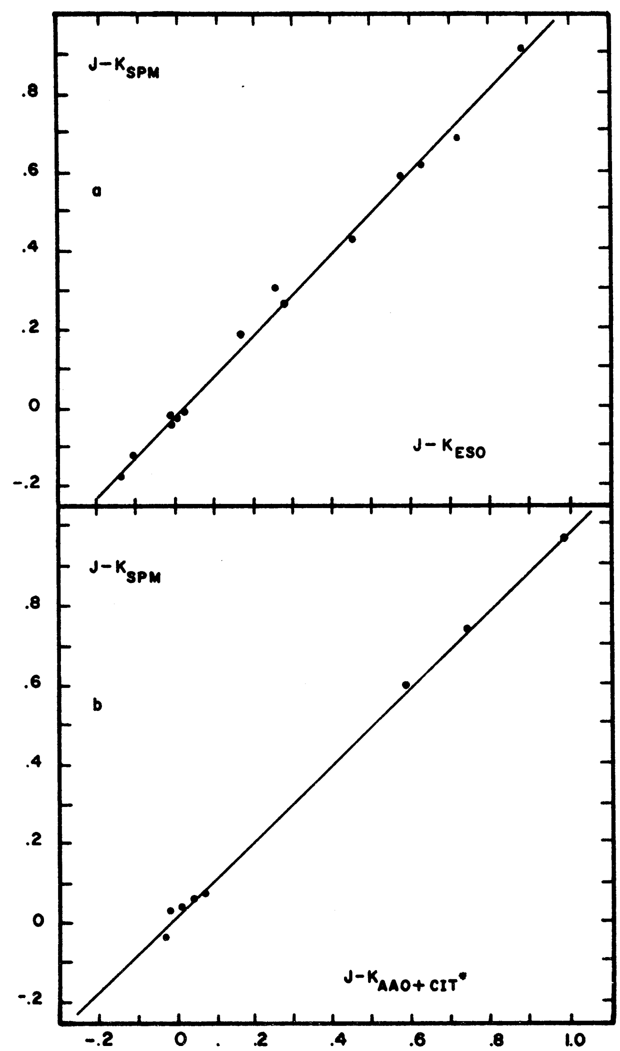

Fig. 2. (a) A plot of the *J-K* colour indices of the standard stars measured in the SPM (this paper) and ESO (Engels *et al.* 1981) photometric systems. (b) Same as (a) but showing the *J-K* colour indices from the AAO (Allen and Cragg 1983) and the CIT/CTIO (Elias *et al.* 1982) transformed to the AAO system (Elias *et al.* 1983). In both cases, the corresponding fit given in Table 2 is also drawn.

results within the quoted uncertainties. The final (and best) average atmospheric extinction coefficients are 0.09, 0.06, 0.11, 0.14 and 0.27 for the *J,H,K,L'* and *M* filters, respectively.

III. COMPARISON WITH OTHER PHOTOMETRIC STANDARDS

Table 2 lists the results of fitting a straight line (simple linear regression) to the comparison between the SPM photometry and that from AAO, CIT/CTIO, SAAO,ESO and Johnson *et al.'s* for the respective common stars; Figures 1 and 2 show two examples of these. Only for the ESO (Engels *et al.* 1981), Johnson *et al.* (1966) and Koornneef (1983) lists were there a reasonable number of common entries with the present list. Only five stars could be used for the study of the AAO and CIT/CTIO systems, considered the most reliable; consequently and in spite of the rather poor statistics (notably in *H-K*), the mean residuals (rms) for these systems are somewhat smaller. In an attempt to increase the number of common stars, a transformation was made of the observations in the CIT/CTIO system into that of AAO by using the equations given by Elias *et al.* (1983). This procedure allowed the comparison of a total of eight stars measured in the AAO and SPM natural systems. The results are also given in Table 2 and shown in Figures 1 and 2. A number of other standards from these lists are being included for observation at our observatory.

IV. RECENT IMPROVEMENTS TO OUR INSTRUMENTATION

The following are the main changes which have been made to our infrared instrumentation since the compilation by Roth *et al.* (1984) was published.

(a) A new 0.5-mm diameter InSb detector from Cincinnati Electronics Corp. was installed in dewar 2 to be used mainly for CVF observations. No photometry from this system has been reported as yet.

(b) The optics of dewar 2 has been changed in order to have an aperture of $\sim$ 7 arcsec (FWHM).

(c) A new gold-coated dichroic was installed in the photometer shell after the present compilation of standard stars was made. The new detection limits obtained through measurements of faint sources with the 2.1-m telescope and a 12 arcsec diaphragm for a signal to noise ratio of three and one hour integration time are $17^{m}.7$, $16^{m}.8$ and $16^{m}.4$ for the *J,H* and *K* bands, respectively. This represents an improvement of up to $1^{m}.3$ (in *J*) over those quoted by Roth *et al.* (1984) in their Table 2.

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REFERENCES

Allen, D.A. and Cragg, T.A. 1983, *M.N.R.A.S.*, **203**, 777.
Elias, J.H., Frogel, J.A., Matthews, K., and Neugebauer, G. 1982, *A.J.*, **87**, 1029.
Elias, J.H., Frogel, J.A., Hyland, A.R., and Jones, T.J. 1983, *A.J.*, **88**, 1027.
Engels, D., Sherwood, W.A., Wamsteker, W., and Schultz, G.V. 1981, *Astr. and Ap. Suppl.*, **45**, 5.
Glass, I.S. 1974, *Mon. Not. Astr. Soc. South Africa*, **33**, 53.
Johnson, H.L., Mitchell, R.I., Iriarte, B., and Wisniewski, W.Z. 1966, *Comm. Lunar and Planet. Lab.*, **4**, 99.
Jones, T.J. and Hyland, A.R. 1982, *M.N.R.A.S.*, **200**, 509.
Koornneef, J. 1983, *Astr. and Ap. Suppl.*, **51**, 489.
Roth, M., Iriarte, A., Tapia, M., and Resêndiz, G. 1984, *Rev. Mexicana Astron. Astrof.*, **9**, 25.
Sinton, W.M. and Tittemore, W.C. 1984, *A.J.*, **89**, 1366.
Tapia, M., Roth, M., Costero, R., and Navarro, S. 1984, *Rev. Mexicana Astron. Astrof.*, **9**, 65.

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