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TRANSFORMATIONS BETWEEN THE *JHK* IR SYSTEMS OF THE OBSERVATORIO ASTRONOMICO NACIONAL (OAN) AND THE SOUTH AFRICAN ASTRONOMICAL OBSERVATORY (SAAO)[1]

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RESUMEN

Un conjunto de estrellas estándar infrarrojas del Observatorio Astronómico Sud Africano (SAAO) (Carter 1990) se observan desde el Observatorio Astronómico Nacional (OAN) localizado en San Pedro Mártir (SPM) en el Norte de México. Se obtiene un conjunto de transformaciones lineales, para las cuales existe una ligera necesidad de un término de color el cual implica que ambos grupos de filtros tienen valores ligeramente diferentes para sus longitudes de onda efectivas. Se calculan valores para la extinción promedio en el OAN los cuales resultan mayores que los valores reportados por Carrasco et al. (1991); ésto se debe quizás a la ceniza y partículas depositadas en la atmósfera por recientes erupciones volcánicas. También se calculan transformaciones de color para el sistema IR homogéneo propuesto por Bessell & Brett (1988).

ABSTRACT

A set of infrared standard stars for the South African Astronomical Observatory (SAAO) (Carter 1990) are observed from the Observatorio Astronómico Nacional (OAN) located at San Pedro Mártir (SPM) in northern México. A number of linear transformation equations is obtained; in them, there is a slight need for a colour term which implies that both sets of filters have slightly different values for their effective wavelengths. Values for the OAN mean extinction coefficients are calculated. They are larger than the values reported in Carrasco et al. (1991); this might, however, be due to the ash and debris deposited on the atmosphere by recent volcanic eruptions. We also calculate a set of colour transformations to the homogeneous IR photometric system proposed by Bessell & Brett (1988).

Key words: **TECHNIQUES–PHOTOMETRIC**

1. INTRODUCTION

Due to the large number of IR systems in use at different astronomical observatories, it is imperative to work out a set of mathematical expressions that permit the transformation of magnitudes and colours from one system to another, so that direct comparison between results obtained at different sites is possible. A collaboration project between astronomical groups in Japan, South Africa and México prompted us to establish these transformations.

The basis for the IR work done at the OAN is outlined in the paper by Carrasco et al. (1991) in which a set of *JHK* primary standard stars for the OAN is established with a precision superior to 1% (see their Table 1).

In § 2 of this paper we describe our observations, the results are presented in § 3 and the conclusions are outlined in § 4.

2. THE OBSERVATIONS

The observations were obtained using the IR photometer (Roth et al. 1984) attached to the 2.1-m telescope at the OAN during four observing runs: Run 1 (24 Feb – 2 Mar 1991), Run 2 (26 Jun – 2 Jul 1991), Run 3 (12 May – 19 May 1992) and Run 4 (10 Nov – 14 Nov 1992). This equipment has a single InSb detector which permits IR photometry in the wavelength interval 1 to $\sim 5\mu$m.

[1] Based on observations collected at the Observatorio Astronómico Nacional, San Pedro Mártir, B.C., México.

We used the IR photometer with the $J(1.25\mu m)$, $H(1.65\mu m)$, $K(2.23\mu m)$ filter. In the IR, subtraction of the background radiation is of the utmost importance; the OAN IR system achieves this subtraction by means of a wobbling secondary which is a standard feature of the IR setup at this observing site.

There have been two attempts at establishing IR 'standard' systems for this observatory and this instrumental setup. The first by Tapia, Neri, & Roth (1986) and the second by Carrasco et al. (1991). In these papers the authors establish sets of standard stars which can be measured by other observers with the aim of obtaining extinction coefficients and zero points in order to transform from instrumental magnitudes to outside-the-atmosphere 'real' magnitudes. For full details as to how these 'standard' systems are established refer to the papers cited above.

Standard stars were observed following the Young (1974) recommendation trying to get low-altitude measurements around an airmass of the order ~2. If one assumes that the standard error of a measurement is proportional to some power 'p' of the airmass 'X', Young (1974) proves that his recommendation leads to the smallest error possible for the extinction coefficients.

In the reduction of our data, both systems, the Tapia et al. (1986) as well as the Carrasco et al. (1991) were used. The results obtained using one system agree well with those obtained using the other system.

We adopt as definitive the results obtained using the Carrasco et al. standard system because of its high internal precision and also because of the fact that they obtain their own extinction coefficients which, at least in principle, seems a better procedure than adopting average extinction coefficients as Tapia et al. (1986) do.

In optical photometry it is customary to obtain extinction coefficients and zero points by means of fitting a straight line to the points on the observed minus real magnitudes versus airmass diagram; this method is widely used and known as the Bouguer method. In IR photometry this method, although not quite correct, is also widely used.

In the early days of IR photometry, Johnson (1965*a*) realized that the atmospheric extinction for the IR in the airmass interval $0.0 \leq X \leq 1.0$ did not follow a linear relation, thus he recommended several ways of circumventing this problem. Following: *i)* A "square root law". *ii)* A linear interpolation to a negative value of the airmass, in order to compensate for the curvature of the extinction relation with airmass or, *iii)* A linear interpolation to zero airmass and then increasing the result (making it fainter) by a correction term equal to 15% – 30% of 'E' which represents the extinction coefficient obtained between airmass values of 1 and 2.

The application of these methods is difficult since deciding how far into the negative airmass values one must go or choosing the appropriate correction fraction for 'E' between 15% and 30% is not a straightforward task.

Observers seemed to forget about these problems and continued following the Bouguer method for IR photometry until Manduca & Bell (1979) showed, by means of a theoretical model for the terrestrial atmosphere, that not considering the non-linear nature of the extinction curve between 0 and 1 airmasses could lead to severe underestimation of the extinction values, which, in turn, led to stellar magnitudes that could be ~ 0.2 magnitudes too faint. Manduca & Bell (1979) pointed out the problem; they, however, did not offer a practical solution to it.

Young (1989) suggests using an equation of the following type, known as a Padé approximant:

$$\Delta m = \frac{(AX^2 + BX + C)}{X + X_0}$$

where A, B and C are constants derived from the fit to the data, X represents the airmass and X_0 is a free parameter whose value is set by "reasonable guesses". Application of this formula, even using rough guesses for X_0 allows substantially better extinction corrections than the usual assumption of a linear Bouguer curve (for full details see Young 1989).

Reduction of our data following both the Bouguer method and the Padé approximant, produces results that coincide within the observational errors. This fact and the need of 'guessing' a value for X_0 when using the Padé approximant led us to adopt the Bouguer reduction method for our data as a more direct and straightforward procedure.

Although the non-linear extinction effects do not affect our reductions significantly, it is necessary to mention that they may play an important role through the values used for the standard stars, which were taken directly from the Tapia et al. (1986) and the Carrasco et al. (1991) papers. In both papers there is no indication that allowance has been made for non-linear effects, and further personal communication confirmed the fact that the Bouguer method was used for the reduction of the data leading to the values for the standard stars in both papers. It could be argued, as noted by Manduca & Bell (1979), that the magnitude values for the standard stars suffer from severe underestimation of the extinction values and therefore the reported figures are fainter than they would have been, had the non-linear effects been taken into account.

TABLE 1

MAGNITUDES OF THE STARS OBSERVED IN THE OAN AND THE CARTER (SAAO) SYSTEMS

Stars	J_{RN}	σ J	H_{RN}	σ H	K_{RN}	σ K	J_{Car}	H_{Car}	K_{Car}	N
BS 0003	2.85	0.02	2.33	0.02	2.18	0.02	2.879	2.280	2.202	5
BS 0033	3.92	0.03	3.70	0.04	3.56	0.04	3.966	3.672	3.647	5
BS 0117	2.88	0.03	2.13	0.02	1.87	0.02	2.901	2.052	1.895	5
BS 0188	0.44	0.02	−0.04	0.02	−0.21	0.02	0.401	−0.138	−0.224	6
BS 0334	1.62	0.02	1.05	0.02	0.90	0.02	1.622	0.985	0.886	4
BS 0434	2.48	0.02	1.76	0.02	1.53	0.02	2.490	1.689	1.562	3
BS 0489	2.14	0.02	1.45	0.02	1.24	0.02	2.173	1.382	1.266	4
BS 0539	1.92	0.02	1.38	0.02	1.20	0.02	1.933	1.314	1.224	5
BS 0585	1.16	0.02	0.38	0.02	0.09	0.02	1.125	0.263	0.105	3
BS 1552	3.97	0.04	4.07	0.04	4.13	0.04	4.033	4.084	4.145	3
BS 1654	0.77	0.02	0.06	0.02	−0.19	0.02	0.736	−0.067	−0.204	3
BS 1698	2.58	0.03	2.03	0.02	1.80	0.02	2.586	1.954	1.851	3
BS 1865	2.05	0.02	1.95	0.02	1.81	0.02	2.040	1.894	1.858	7
BS 1983	2.69	0.03	2.49	0.02	2.35	0.02	2.701	2.438	2.411	6
BS 2085	3.08	0.03	2.96	0.03	2.84	0.03	3.104	2.926	2.907	4
BS 2227	1.88	0.02	1.26	0.02	1.05	0.02	1.866	1.162	1.050	3
BS 2421	1.87	0.02	1.92	0.02	1.81	0.02	1.884	1.840	1.847	3
BS 2429	2.26	0.02	1.77	0.02	1.59	0.02	2.256	1.714	1.618	5
BS 2451	3.30	0.03	3.39	0.03	3.34	0.03	3.339	3.369	3.399	4
BS 2546	3.79	0.04	3.08	0.03	2.85	0.03	3.850	3.052	2.887	6
BS 2574	1.64	0.02	0.86	0.02	0.66	0.02	1.620	0.796	0.672	4
BS 2693	0.80	0.02	0.57	0.02	0.38	0.02	0.784	0.482	0.399	4
BS 2701	3.20	0.03	2.64	0.03	2.49	0.02	3.212	2.605	2.530	6
BS 2854	1.87	0.02	1.09	0.02	0.86	0.02	1.863	1.024	0.892	6
BS 2882	5.45	0.05	5.18	0.04	5.04	0.05	5.548	5.206	5.157	5
BS 2970	2.24	0.02	1.78	0.02	1.59	0.02	2.268	1.704	1.626	5
BS 2993	1.77	0.02	0.98	0.02	0.73	0.02	1.774	0.910	0.749	5
BS 3045	1.54	0.02	1.10	0.02	0.87	0.02	1.550	1.008	0.902	6
BS 3113	4.30	0.04	4.22	0.04	4.10	0.04	4.344	4.232	4.205	6
BS 3131	4.34	0.04	4.34	0.04	4.23	0.04	4.400	4.335	4.326	3
BS 3314	3.86	0.04	3.91	0.04	3.88	0.04	3.917	3.920	3.924	4
BS 3484	2.77	0.03	2.38	0.02	2.18	0.02	2.818	2.319	2.242	3
BS 3842	3.90	0.04	3.48	0.03	3.34	0.03	3.972	3.482	3.405	3
BS 3871	3.67	0.04	3.32	0.03	3.17	0.03	3.709	3.311	3.234	5
BS 3903	2.56	0.03	2.19	0.02	1.99	0.02	2.608	2.108	2.028	5
BS 3982	1.51	0.02	1.64	0.02	1.57	0.02	1.521	1.557	1.586	5
BS 3994	1.99	0.02	1.50	0.02	1.37	0.02	2.008	1.494	1.404	5
BS 4357	2.30	0.02	2.29	0.02	2.24	0.02	2.333	2.255	2.246	5
BS 4695	2.92	0.03	2.30	0.02	2.19	0.02	2.990	2.292	2.194	4
BS 5249	4.24	0.04	4.41	0.04	4.37	0.04	4.322	4.426	4.482	5
BS 5287	1.40	0.02	0.85	0.02	0.66	0.02	1.410	0.772	0.684	5
BS 5288	0.45	0.02	−0.08	0.02	−0.26	0.02	0.388	−0.178	−0.260	3
BS 5315	1.91	0.02	1.18	0.02	0.97	0.02	1.913	1.118	1.004	3
BS 5412	5.51	0.04	5.59	0.05	5.55	0.05	5.623	5.635	5.651	3
BS 5444	2.99	0.03	2.24	0.02	2.04	0.02	3.036	2.200	2.052	4
BS 5457	5.06	0.04	4.87	0.04	4.75	0.05	5.166	4.901	4.858	3
BS 5471	4.31	0.04	4.45	0.04	4.42	0.04	4.388	4.468	4.520	3
BS 5487	3.11	0.03	2.95	0.03	2.85	0.03	3.130	2.916	2.890	5
BS 5531	2.48	0.02	2.46	0.03	2.36	0.02	2.484	2.412	2.397	3
BS 5685	2.77	0.03	2.84	0.03	2.77	0.03	2.772	2.802	2.830	4

TABLE 1 (CONTINUED)

Stars	J_{RN}	σJ	H_{RN}	σH	K_{RN}	σ K	J_{Car}	H_{Car}	K_{Car}	N
BS 5787	2.18	0.02	1.67	0.02	1.49	0.02	2.194	1.598	1.520	3
BS 5993	3.95	0.04	4.04	0.04	4.02	0.04	4.017	4.045	4.090	4
BS 6136	2.94	0.03	2.24	0.02	2.00	0.02	2.954	2.186	2.046	4
BS 6147	2.78	0.03	2.35	0.02	2.20	0.02	2.794	2.321	2.244	4
BS 6241	0.48	0.02	–0.09	0.02	–0.27	0.02	0.440	–0.183	–0.273	5
BS 6371	3.55	0.04	3.15	0.03	2.98	0.03	3.596	3.109	3.038	2
BS 6378	2.27	0.03	2.29	0.03	2.22	0.02	2.284	2.251	2.248	3
BS 6380	2.56	0.03	2.43	0.02	2.28	0.02	2.584	2.380	2.343	4
BS 6630	1.28	0.02	0.73	0.02	0.50	0.02	1.282	0.625	0.518	5
BS 6698	1.73	0.02	1.31	0.02	1.10	0.02	1.732	1.211	1.126	3
BS 6736	5.70	0.05	5.72	0.05	5.65	0.05	5.796	5.766	5.771	4
BS 6746	1.33	0.02	0.82	0.02	0.66	0.02	1.310	0.732	0.660	4
BS 8075	4.02	0.04	4.05	0.04	3.96	0.04	4.066	4.036	4.042	3
BS 8167	2.79	0.03	2.39	0.02	2.23	0.02	2.812	2.330	2.250	5
BS 8278	3.18	0.03	3.08	0.03	2.99	0.03	3.203	3.059	3.043	4
BS 8414	1.46	0.02	1.08	0.02	0.93	0.02	1.464	1.014	0.928	3
BS 8431	4.33	0.04	4.34	0.04	4.25	0.04	4.384	4.351	4.349	4
BS 8499	2.59	0.03	2.17	0.02	1.99	0.02	2.622	2.110	2.030	3
BS 8551	2.97	0.03	2.43	0.02	2.25	0.02	3.008	2.380	2.299	3
BS 8556	2.35	0.02	1.88	0.02	1.68	0.02	2.354	1.797	1.715	3
BS 8576	4.23	0.04	4.27	0.04	4.20	0.04	4.274	4.270	4.273	3
BS 8709	3.06	0.03	3.09	0.03	3.01	0.03	3.114	3.067	3.053	4
BS 8728	1.06	0.02	1.09	0.02	0.97	0.02	1.054	1.010	0.999	3
BS 8812	1.72	0.02	1.12	0.02	0.95	0.02	1.719	1.054	0.956	3
BS 8892	2.11	0.02	1.51	0.02	1.35	0.02	2.108	1.452	1.370	5
BS 9016	4.47	0.05	4.52	0.05	4.45	0.04	4.566	4.550	4.540	3
HD 130163	6.72	0.05	6.77	0.06	6.67	0.05	6.852	6.841	6.824	2
HD 205772	7.63	0.05	7.60	0.06	7.50	0.06	7.779	7.685	7.663	3
HD 38921	7.43	0.05	7.46	0.05	7.40	0.06	7.579	7.544	7.551	3
HD 75223	7.18	0.05	7.22	0.05	7.10	0.06	7.312	7.286	7.271	4
Y 1181	5.75	0.05	5.28	0.05	4.97	0.05	5.864	5.285	5.071	2
Y 3501	5.60	0.05	5.00	0.04	4.67	0.05	5.710	5.010	4.770	3
Y 5117	3.89	0.04	3.26	0.03	3.01	0.03	3.954	3.223	3.067	3
Y 5817	5.24	0.04	4.72	0.05	4.42	0.04	5.335	4.732	4.527	3

Artificially fainter magnitude values for the standard stars, lead to fainter magnitudes for the 'real' magnitudes of the problem objects. Since the original data used for producing the Tapia et al. (1986) or the Carrasco et al. (1991) sets of standard stars are not available, it is not possible to reobtain their magnitudes corrected for the non-linear effects mentioned above. We feel that as long as our calculated magnitudes are consistently obtained with respect to a set of standard star values the transformations which are established between the OAN system and that of the SAAO are valid.

A number of standard stars in the SAAO system (Carter 1990) in the following declination range $-46 \leq \delta \leq +28$ were observed on several occasions. BS 5457 at $\delta \sim -46$ is the southernmost star observed by us.

3. RESULTS

Table 1 shows the results of our observations. Column 1 gives the name of the stars. Columns 2, 3, 4, 5, 6 and 7 show the values for the average *JHK* magnitudes and their average standard deviations in the OAN system (Carrasco et al. 1991). Columns 8, 9 and 10 give the values in the Carter (1990) system and, finally, column 11 gives the number of different individual observations taken for each star.

For the reduction of data we prefer to work out zero points and extinction coefficients for each night rather than using average values. We observe groups of standard stars at different airmasses periodically in order to establish whether drastic changes of the extinction coefficients occur through the night.

The average extinction coefficients we obtain for OAN in the time period February 1991 – November 1992 are as follows:

$$a_J = 0.24\pm0.03 \text{ mag/airmass} \ ,$$

$$a_H = 0.11\pm0.04 \text{ mag/airmass} \ ,$$

and

$$a_K = 0.11\pm0.04 \text{ mag/airmass} \ .$$

These values are larger than those reported in Carrasco et al. (1991) (a_J = 0.0918, a_H = 0.0315, a_K = 0.0449 mag/airmass); at present we do not have an explanation as to why this is so; however, we speculate that this might be due to the ash and debris deposited in the atmosphere by the eruptions of Mt. Pinatubo on 1991 April–June and Mt. Unzen on 1991 June 3rd.

The Carrasco et al. (1991) results represent an average over 170 photometric nights distributed in the period 1984–89. In this time period no major volcanic eruptions were reported, except for that of the Mauna Loa during 1984 which sent ash and debris into the atmosphere to an altitude of approximately 7 miles. The low volcanic activity reported in this time interval may explain the low values for the extinction coefficients obtained by Carrasco et al.

The large difference obtained for the extinction coefficients between Carrasco et al. and our observations make us rather sceptical of using average extinction coefficients. As stated above we prefer, and recommend to other observers, to determine zero points and extinction coefficients independently every night.

Figures 1, 2 and 3 show graphs for our *J*, *H* and *K* values versus the Carter's *J*, *H* and *K* magnitudes. In all three cases a very tight linear relation is seen. A least squares fit for each case produces the following results:

$$J_{RN} = 0.046\ (\pm\ 0.007) + 0.974\ (\pm\ 0.002) J_{Car} \ ,$$

$$H_{RN} = 0.105\ (\pm\ 0.009) + 0.975\ (\pm\ 0.003) H_{Car} \ ,$$

and

$$K_{RN} = 0.005\ (\pm\ 0.007) + 0.978\ (\pm\ 0.002) K_{Car} \ .$$

In order to study whether the transformations between the OAN and the SAAO have a colour term, plots for $J_{Car}-J_{RN}$, $H_{Car}-H_{RN}$ and $K_{Car}-K_{RN}$ versus $(J-K)_{RN}$ are presented in Figures 4, 5 and 6. These figures indicate a broad distribution of points in the colour range $-0.10 \leq (J-K)_{RN} \leq +1.10$ with breadth $\sim$ 0.2 mag, which tends to mask a slight dependence with colour. A least squares fit to the points on each graph produces the following results:

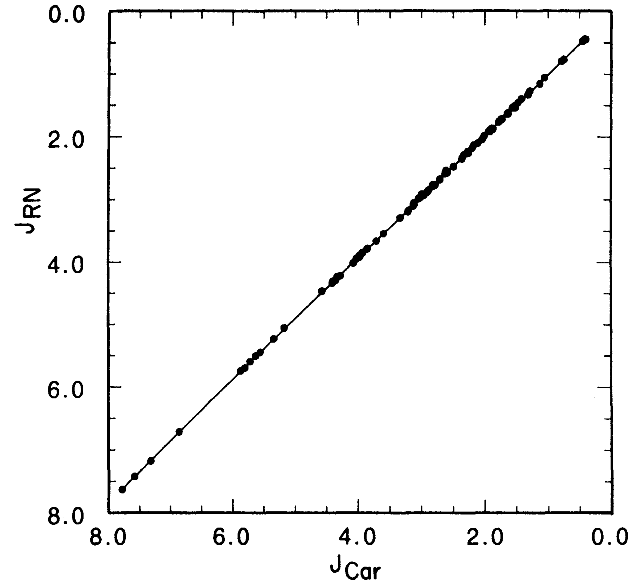

Fig. 1. Graph of J_{RN} versus J_{Car}. Note the tight linear relationship between the variables.

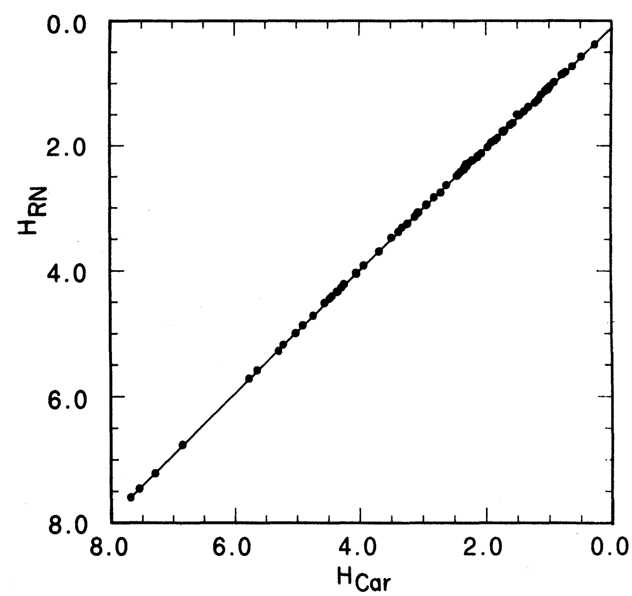

Fig. 2. Graph of H_{RN} versus H_{Car}. Note the tight linear relationship between the variables.

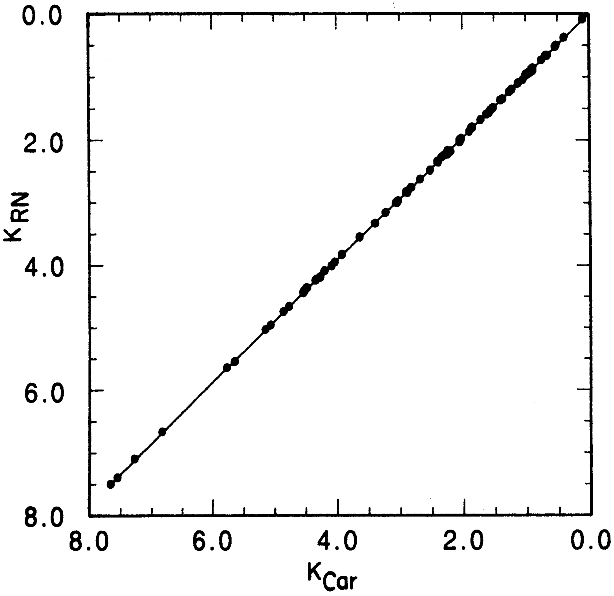

Fig. 3. Graph of K_{RN} versus K_{Car}. Note the tight linear relationship between the variables.

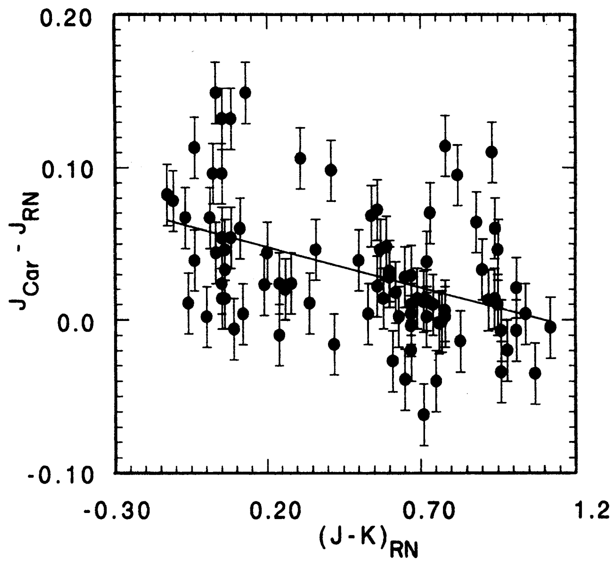

Fig. 4. Graph of $J_{Car}-J_{RN}$ versus $(J-K)_{RN}$. From the data points alone it is difficult to see whether there is a colour term. The solid line is a least squares fit to the data which reveals a mild colour dependence.

$$J_{Car}-J_{RN} = 0.058(\pm 0.012)-0.053(\pm 0.021)(J-K)_{RN} \ ,$$

$$H_{Car}-H_{RN} = -0.004(\pm\ 0.009)-0.073(\pm 0.016)(J-K)_{RN} \ ,$$

and

$$K_{Car}-K_{RN} = 0.081(\pm 0.008)-0.062(\pm 0.014)(J-K)_{RN} \ .$$

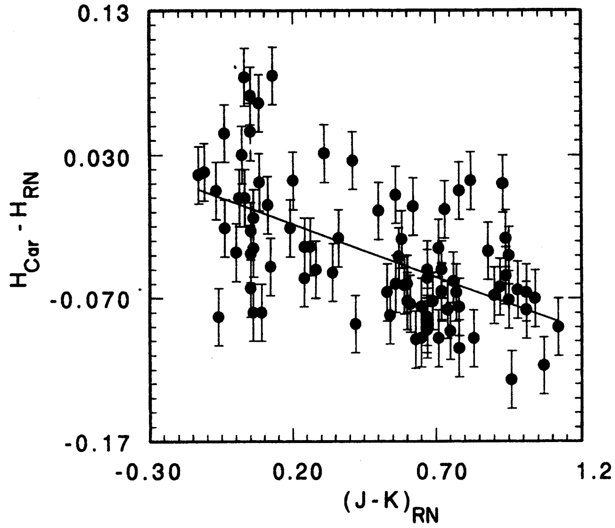

Fig. 5. Graph of $H_{Car}-H_{RN}$ versus $(J-K)_{RN}$. From the data points alone it is difficult to see whether there is a colour term. The solid line is a least squares fit to the data which reveals a mild colour dependence.

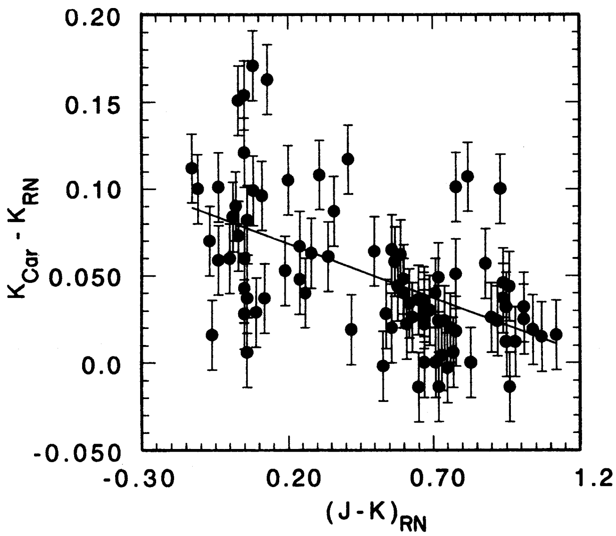

Fig. 6. Graph of $K_{Car}-K_{RN}$ versus $(J-K)_{RN}$. From the data points alone it is difficult to see whether there is a colour term. The solid line is a least squares fit to the data which reveals a mild colour dependence.

The colour terms, although small, imply a difference between the effective wavelengths of our filters (OAN) and those of the SAAO filters.

The effective wavelengths for the OAN *JHK* filters are given by Carrasco et al. (1991) as [λ_{eff}: J = 1.198 μm, H = 1.580 μm, K = 2.210 μm], comparing these values with those for the SAAO system which we calculated from the filter response curves published by Glass (1985) [λ_{eff}: J = 1.238 µm, H = 1.646 µm, K = 2.225 µm] we find that the shifts, defined as [Δ(Filter) = SAAO-OAN] are ΔJ = 0.040 µm, ΔH = 0.066 µm and ΔK = 0.015 µm; which correspond to $\sim 0.1^{*} J_{Bandwidth}$, $\sim 0.2^{*} H_{Bandwidth}$ and $\sim 0.03^{*} K_{Bandwidth}$.

One may calculate the residuals for each expression as follows:

$$R_J = J_{RN} - 0.046 - 0.974 J_{Car} \ ,$$
$$R_H = H_{RN} - 0.105 - 0.975 H_{Car} \ ,$$
$$R_K = K_{RN} - 0.005 - 0.978 K_{Car} \ ,$$
$$R_{JCar-JRN} = (J_{Car} - J_{RN}) + 0.053 \ (J-K)_{RN} - 0.058 \ ,$$
$$R_{HCar-HRN} = (H_{Car} - H_{RN}) + 0.073 \ (J-K)_{RN} + 0.004 \ ,$$

and

$$R_{KCar-K_{RN}} = (K_{Car} - K_{RN}) + 0.062 \ (J-K)_{RN} - 0.081 \ ;$$

and also investigate their colour dependence by plotting them against $(J-K)_{RN}$.

The residuals for the magnitude versus magnitude transformations are all contained in the interval $-0.05 \leq$ residual $\leq +0.04$; whereas those for the difference of magnitude versus $(J-K)$-colour transformations lie in the interval $-0.1 \leq$ residual $\leq +0.1$.

This fact makes the transformation equations without the colour term better, since a larger number of points lies closer to the average expression. None of the residuals shows a dependence with $(J-K)_{RN}$ colour.

Bessell & Brett (1988) propose a homogeneous IR photometric system; if we assume that the SAAO system used by them is equivalent to that in Carter (1990), then the following are transformations between the OAN system and the homogeneous system proposed by Bessell & Brett:

$$(J-K)_{BB} = -0.047 + 1.027 J_{RN} - 1.022 K_{RN} \ ,$$
$$(H-K)_{BB} = -0.124 + 1.026 H_{RN} - 1.022 K_{RN} \ ,$$

and

$$(J-H)_{BB} = +0.056 + 1.027 J_{RN} - 1.026 H_{RN} \ .$$

4. CONCLUSIONS

A number of standard stars in the SAAO system has been observed by us using the IR photometer at the OAN. Our intention is to establish a set of transformation equations between the OAN and the SAAO *JHK* magnitudes, so that direct comparison between IR measurements obtained at these two observatories can be readily made.

The main conclusions of this work are as follows:

i) The transformation equations between our system and that from SAAO are linear.

ii) The transformations without a colour term are as follows:

$$J_{RN} = 0.046\ (\pm 0.007) + 0.974\ (\pm 0.002) J_{Car} \ ,$$
$$H_{RN} = 0.105\ (\pm 0.009) + 0.975\ (\pm 0.003)\ H_{Car} \ ,$$

and

$$K_{RN} = 0.005\ (\pm 0.007) + 0.978\ (\pm 0.002)\ K_{Car} \ .$$

iii) Those with a colour term are as follows:

$$J_{Car} - J_{RN} = 0.058(\pm 0.012) - 0.053\ (\pm 0.021)(J-K)_{RN} \ ,$$
$$H_{Car} - H_{RN} = -0.004(\pm 0.009) - 0.073\ (\pm 0.016)(J-K)_{RN} \ ,$$

and

$$K_{Car} - K_{RN} = 0.081(\pm 0.008) - 0.062\ (\pm 0.014)(J-K)_{RN} \ .$$

iv) The scatter of the observational points about the mean transformation line is tighter for the 'colour-less' set of equations; hence making this set better for transforming between one system and the other.

v) Both sets of transformations predict essentially the same SAAO value for a given OAN value plus a scatter of $\sim\ \pm 5\%$.

vi) The transformation residuals for different wavelengths do not depend on the value of the $J-K$ colour.

vii) The effective wavelengths of our filters seem to be slightly different to the effective wavelengths of the SAAO system filters. Where [Δ(Filter) = SAAO−OAN] ΔJ = 0.040 µm, ΔH = 0.066 µm and ΔK = 0.015 µm.

viii) A set of mean extinction coefficients for the OAN is obtained:

$$a_J = 0.24 \pm 0.03 \text{ mag/airmass} \ ,$$
$$a_H = 0.11 \pm 0.04 \text{ mag/airmass} \ ,$$

and

$$a_K = 0.11 \pm 0.04 \text{ mag/airmass} \ ;$$

although it is different from and much bigger than that reported by Carrasco et al. (1991). We speculate that this is due to the ash and debris recently deposited in the atmosphere by the eruptions of Mt. Pinatubo and Mt. Unzen.

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