

INTRINSIC COLORS OF STARS IN THE NEAR-INFRARED

JORGE R. DUCATI, CLAUDIO M. BEVILACQUA, SANDRO B. REMBOLD, AND DAIANA RIBEIRO

Departamento de Astronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil; ducati@if.ufrgs.br; erex@if.ufrgs.br; rembold@if.ufrgs.br; claiana@if.ufrgs.br

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ABSTRACT

Intrinsic infrared colors of stars in the Johnson 11 color system are derived. The database is a list of 3946 stars with observations in *UBVRIJHKLMN*, of all spectral types and luminosity classes, including carbon, T Tauri, and Wolf-Rayet stars. Intrinsic colors were derived from the zero-reddening curve that can be defined in the bluer side of temperature versus observed color diagrams. In a sample of stars of the same spectral type, the bluest stars are considered to have an observed color very near their intrinsic color. The comparison with former derivations from Johnson and Koornneef presents significant differences: new *M* and *N* colors, for all spectral types, are bluer than published values, the differences being more important for giants and supergiants; the amplitude of color values in these new results is wider.

Subject headings: infrared: stars — stars: fundamental parameters — techniques: photometric

1. INTRODUCTION

The intrinsic colors of stars have been derived mainly for the visible part of the spectrum (Schmidt-Kaler 1982 for *UBV*; Philip & Egret 1980 for *uwby*). In the infrared the first derivation was that of Johnson (1966), followed by those of Lee (1970), Frogel et al. (1978), Whittet & van Breda (1980), Koornneef (1983b), Bessell & Brett (1988), Bouchet, Manfroid, & Schmider (1991), and Wegner (1994). Johnson's pioneering work was based on the assumption that there is no interstellar reddening out to distances of up to 100 pc from the Sun. The intrinsic colors of dwarfs and giants were the average of the observed colors, separated by spectral type; for supergiants he used a method similar to that of Kron (1958), which introduced corrections for interstellar reddening. Johnson's tables are still the most widely used, in spite of results obtained much later. Results from Koornneef (1983a, 1983b) were derived using blackbody models and do not differ significantly from Johnson's. Other works, even though representing improvements for certain classes of stars, do not cover all spectral types and are based on samples of limited size. Since the compilation of the catalog of Ducati (1993), a much larger amount of data has become available, allowing direct, statistically significant derivation of infrared intrinsic colors. In this paper, we first discuss the quality of our database in terms of homogeneity of published observations and validity of averaging. Next, we present the method, discussing its limitations. Finally, results are discussed and compared with earlier derivations.

2. DATA

The NASA infrared catalogs (CIO catalogs; Gezari et al. 1993), obtained from both ground and space observations, are the most comprehensive set of near- to far-infrared data on astronomical objects. Despite its near completeness in terms of literature search, the catalog lacks some additional information that would make it more useful, such as spectral types, *UBVRI* photometry, and galactic coordinates. In addition, the same object frequently has several identifications or even differences in coordinates. Using the CIO catalogs as sources for the near-infrared data, a catalog of *UBVRIJHKLMN* photometry of stars was compiled by

Ducati (1993), containing infrared and subsidiary information for 3946 objects. Extensive information on how this catalog was compiled is available (Ducati 1993), but the main constraints were as follows: the bulk of *J* to *N* data came from Gezari et al. (1993) and its updates; this comprises observational data from hundreds of references, which makes a case-by-case study of the observational, instrumental, and reducing techniques used in each paper very difficult and almost prevents an accurate standardization. Our first step was to fix narrow limits in the *JHKLMN* passbands, consistent with those defined by Johnson (1966). Attention was given to the beamwidth used in the observations, information given in the CIO catalogs. This is important because many observations concern stars embedded in nebulae (viz., in the region of Orion Nebula), implying that the field around the star also radiates in the infrared; different apertures give different contributions from the nebula to the measured infrared magnitude. In these cases we discarded all observations except those with the smallest diaphragm.

Even with these filters, our preliminary sample included many stars with multiple observations; averaging procedures are described in § 2.1. This does not concern the *R* and *I* colors in the Johnson system, which were extracted from the lists of Lanz (1986), Hoffleit & Jaschek (1982), and Hoffleit, Saladyga, & Wlasuk (1983) and from the SIMBAD database and for which no averaging was done. Identifications of carbon and T Tauri stars were made possible by the catalogs in Lang (1992), the infrared data coming from Gezari et al. (1993).

2.1. Averaging Procedures

We begin with a general consideration: the original purpose of compiling a catalog is to form a database that is larger than any of the many sources used. In merging data from several sources, it is unavoidable and in fact desirable that stars common to more than one source exist. The data from these common stars must be averaged, if possible; in fact, a catalog will be useful if averaging is indeed possible, because then all the data will be expressed in the same system. With this philosophy in mind, we took the steps described below.

The fact that many stars have been observed several times implies that, if some averaging has to be made, preliminary testing has to legitimate it. Averaging astronomical results from different observers can only be done after careful verification of data homogeneity, including whether the published results were reduced to the same photometric system. This problem was approached by comparing published infrared observations of the same stars made by different authors. Many papers did not mention whether their published observational data were reduced to some standard system, such as that of Johnson. As a first verification, we selected a sample of stars for which multiple observations from many papers were available. An inspection showed that the photometric indices J to N were in general very close. This strongly suggests that the papers in general contained data already reduced to the Johnson system, because if those papers had published their observations as instrumental magnitudes, or even in some other photo-

metric system, the closeness we found in this first comparison would not have occurred.

As a more quantitative approach to our study of the possibility of making averages, we took those papers which contributed more significantly to the compilation of the catalog, in terms of number of stars. We plotted, by sets of two papers and for the colors $JHKL MN$, the photometric indices for the common stars. The comparisons, expressed by the correlation parameters, give an indication on how far the photometry is from the standard Johnson 11 color system. Figures 1 and 2 illustrate some of these correlations. We see that the correlations, besides being linear, in most cases show a very small dispersion. This clearly indicates that, in the original papers, the data were very close to the Johnson system. Differences between papers tend to fall within observational errors. We conclude that it is valid to average observations of every color for each star with several observations. For example, in Figure 1a, we show

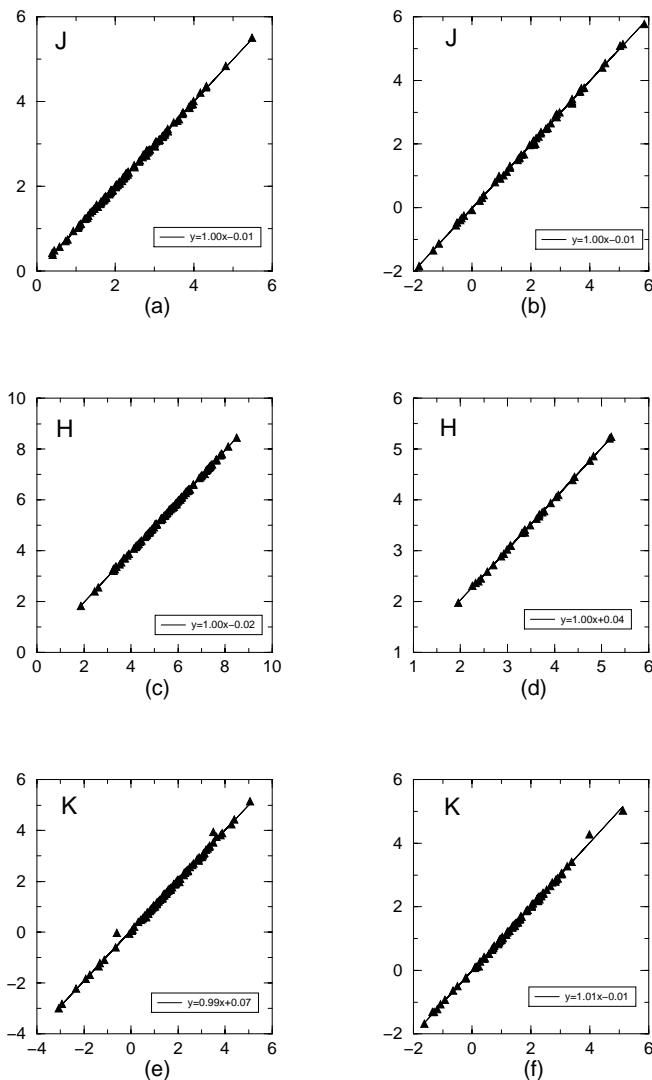


FIG. 1.—Correlation of data for (a) Carter (1990) vs. Glass (1974), (b) Engels et al. (1981) vs. Johnson et al. (1966), (c) Thé, Wesselius, & Janssen (1986) vs. Whittet & van Breda (1980), (d) Carter (1990) vs. Allen & Cragg (1983), (e) Selby et al. (1988) vs. Johnson et al. (1966), and (f) Glass (1974) vs. Johnson et al. (1966).

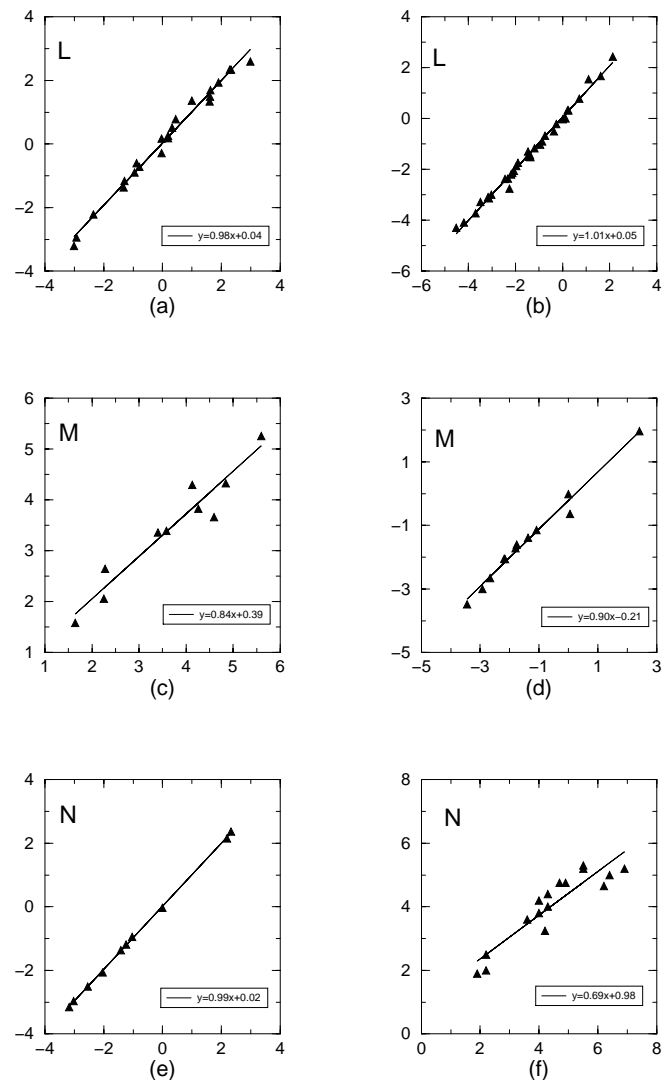


FIG. 2.—Correlation of data for (a) Catchpole et al. (1979) vs. Gillett, Merrill, & Stein (1971), (b) Gehrz & Woolf (1971) vs. Johnson et al. (1966), (c) Thé et al. (1986) vs. Gehrz, Hackwell, & Jones (1974), (d) Sinton & Titterton (1984) vs. Gehrz & Woolf (1971), (e) Tokunaga (1984) vs. Gehrz et al. (1974), and (f) Rydgren, Strom, & Strom (1976) vs. Cohen (1974).

the comparison between the J color of Carter (1990) and Glass (1974), for which we found 119 common stars. The correlation is very close to unity, and the dispersion of data is of the order of photometric errors. This shows that both papers deal with data expressed in photometric systems which are very close, making averaging possible. Information supplied in Figures 1 and 2 and its captions support these conclusions. Obviously, many pairs of papers have a 100% correlation, since they are part of series of publications from the same research group, using the same instruments and reduction methods. This makes merging a direct operation.

2.2. Expected Errors in JHKLMN Photometry

An important question concerns the error associated with a near-infrared observation. We know that UBV magnitudes have an internal error of about 0.01 to 0.02 mag. We analyzed our data looking for stars whose final infrared colors were the result of averaging. The standard deviations of these averages were also averaged for each of the $JHKLMN$ colors and for spectral types divided into OB, AF, and GKM groups of normal stars, as well as for Wolf-Rayet, carbon, and T Tauri stars. Table 1 shows these averaged standard deviations. The distribution of the standard deviations for color J is shown in Figure 3 to be strongly concentrated toward values near zero. Sterken & de Loore (1982) have calculated expected photometric errors for $JHKLM$ of Wolf-Rayet stars, finding standard deviations of the observed colors smaller than our values. Carter (1990) estimates an accuracy of 0.02 mag for J , H , and K and 0.05 mag for L , independent of spectral types.

The results in Table 1 show a clear trend, in the sense that the precision of infrared photometry is better for shorter wavelengths. For example, J photometry has an accuracy (for OB stars) comparable to UBV ; precision deteriorates toward N and for later spectral types. This is expected, because it is well known that photometry toward $10\ \mu\text{m}$ meets instrumental difficulties. Moreover, diversity of luminosity classes and evolutionary stages for late stars tends to increase the dispersion for those classes. We note that the size of each subsample is not relevant to the dispersion value. For example, K photometry provides data for 699 stars in the GKM group. Nevertheless, the dispersion is greater for those stars than that for OB and AF stars, derived from smaller samples. Also, we note that the great-

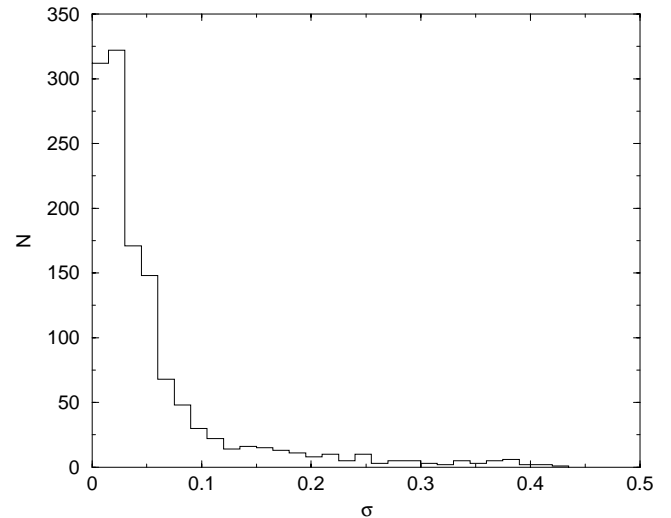


FIG. 3.—Histogram of standard deviations of J color

est dispersion, 0.187 in N photometry for GKM stars, was derived from 62 stars; however, this is greater than the dispersion in M for AF stars, which was derived from fewer stars ($\bar{\sigma} = 0.134$, from 57 stars).

3. DERIVATION OF INTRINSIC COLORS

We are dealing with a $V-\lambda$ catalog. Given the rather large amount of data available, it is possible to make a direct approach to the problem of deriving intrinsic colors. We have several hundred points corresponding to stars, with a large range of distances and to a large range of reddenings. It is therefore natural that the nearest stars will show little, if any, reddening. Given a group of stars with the same spectral type and luminosity class, those with the smallest $V-\lambda$ tend to have a near-zero reddening. For a range of spectral types, it is possible to draw an envelope within which reddening is close to zero, giving the intrinsic color of each spectral type. Diagrams of temperature-color indices were constructed for the $RIJHKLMN$ colors, for each spectral type, and for luminosity classes V, III, and I; for Wolf-Rayet, carbon, and T Tauri stars we used spectral classes instead of temperature. Temperatures for normal stars were taken from Allen (1973), where a fit was made to provide information for intermediate spectral types. For the other three classes, the spectral sequences as given by Jaschek & Jaschek (1987) and Kaler (1989) were used. Next, we investigated the question of the size of the gap between the least reddened stars and the envelope that is the locus of zero reddening. This question can be addressed by considerations about the mean distance between stars of the same luminosity class. Densities of various star populations, as given by Mihalas & Binney (1981), can be used to show that, in this region of the Galaxy, the mean distance between dwarfs is about 2.1 pc and that, for giants and supergiants, it is about 14.3 pc. Given that those distances are small for reddening effects and that our sample tends to be complete toward brighter and less reddened stars, we took the envelope line as the zero-reddening curve, corresponding to the intrinsic colors. The final envelopes were drawn from best-fit polynomials or more complex functions; from A to colder stars the temperature scale was expanded, because the correlation between temperature and color indices becomes steeper.

TABLE 1
ERRORS IN $JHKLMN$ PHOTOMETRY

Star Type	J	H	K	L	M	N
O, B	0.045	0.046	0.061	0.062	0.115	0.105
	387	359	464	351	129	38
A, F	0.033	0.032	0.036	0.064	0.134	0.123
	273	201	315	154	57	18
G, K, M ...	0.058	0.062	0.063	0.079	0.110	0.187
	624	485	699	427	137	62
WN, WC...	0.070	0.068	0.079	0.116	0.121	0.158
	26	33	51	27	23	12
Carbon	0.211	0.166	0.162	0.130	0.159	0.298
	87	82	91	61	27	6
T Tauri	0.156	0.167	0.150	0.248	0.464	0.252
	27	42	40	59	19	2

NOTE.—For each type, the first row shows the mean standard deviation $\bar{\sigma}$ and the second shows the number of stars.

4. RESULTS

Diagrams of temperature-color indices are shown in Figures 4, 5, 6, and 7. Figures 8, 9, and 10 present spectral class-color indices diagrams for Wolf-Rayet, T Tauri, and carbon stars.

For these stars, in general, only upper limits can be derived from the data; actual intrinsic colors are probably bluer than the bluest stars in all classes. For T Tauri stars, we note that the scatter in the colors is smaller for late spectral types; this is expected, because late types are less

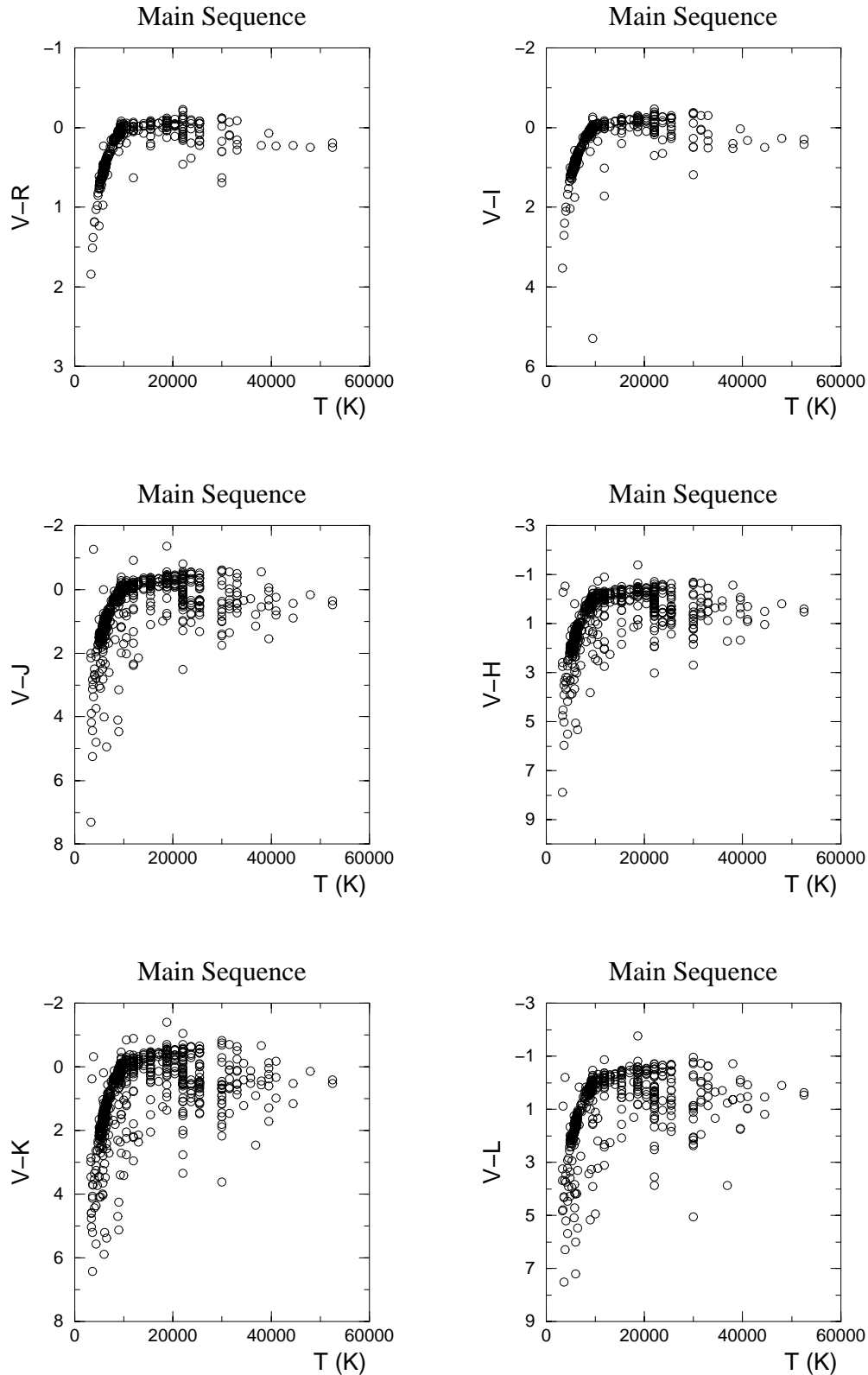


FIG. 4.—Temperature-color indices for main-sequence stars

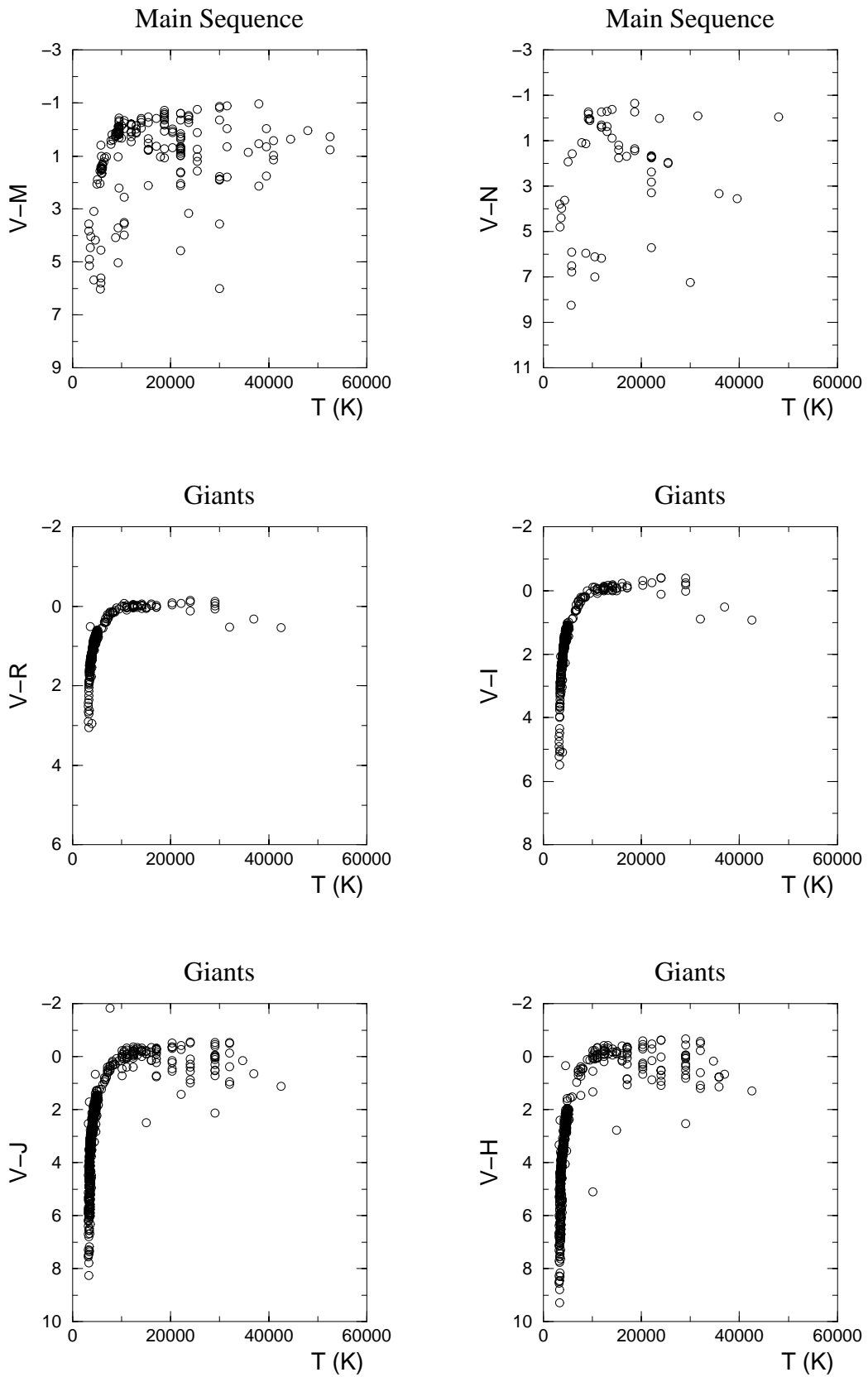


FIG. 5.—Same as Fig. 4, but for main-sequence and giant stars

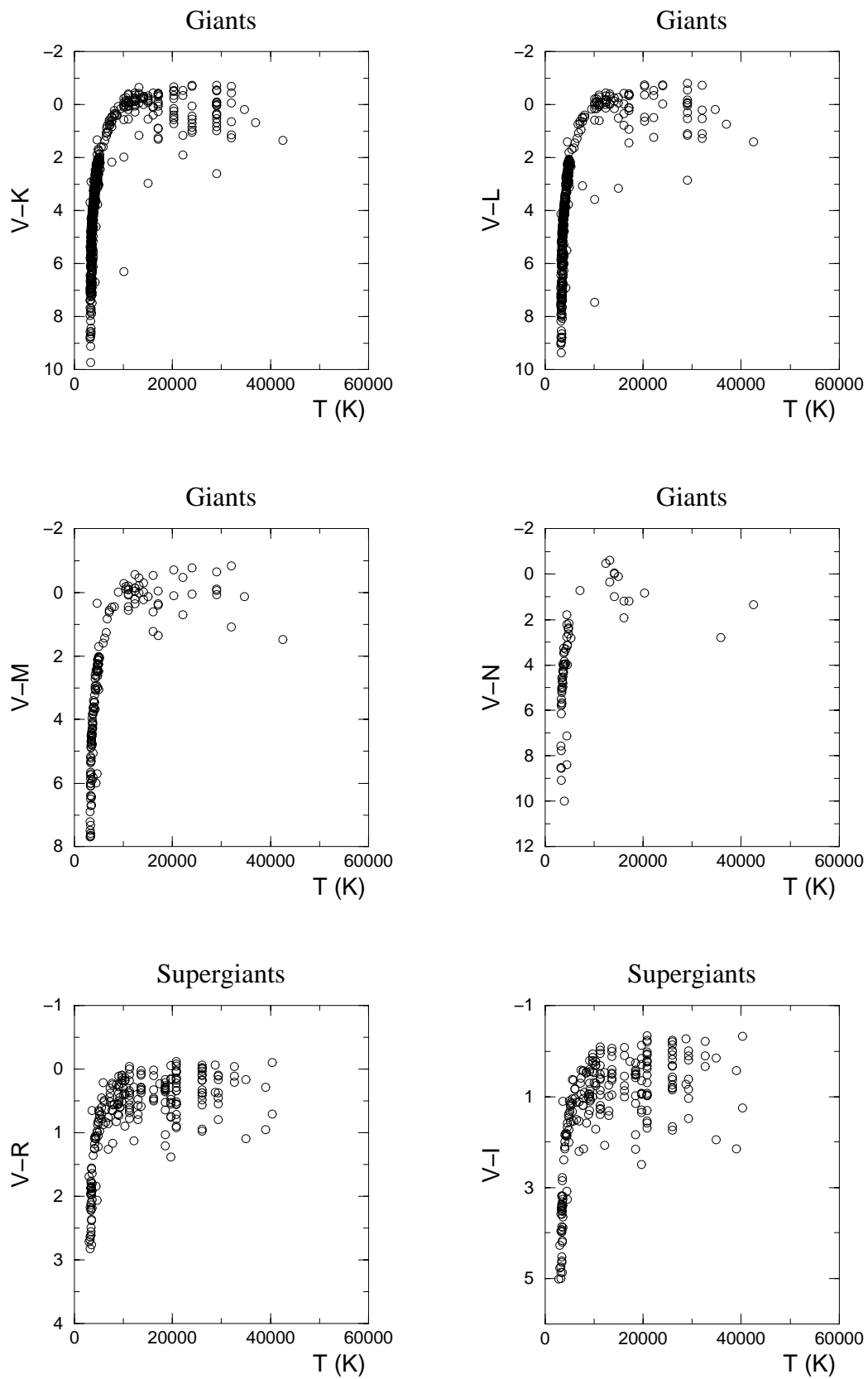


FIG. 6.—Same as Fig. 4, but for giant and supergiant stars

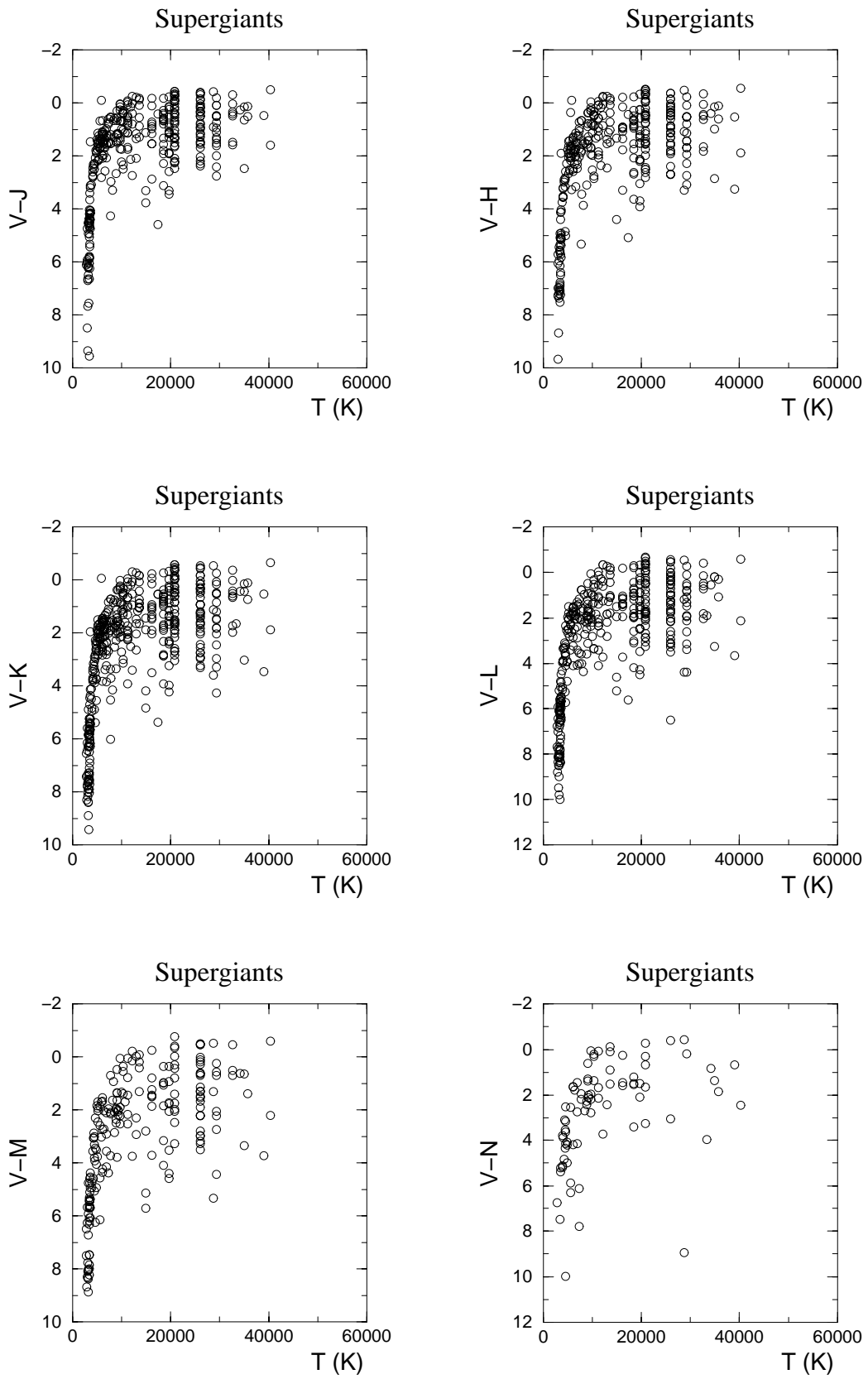


FIG. 7.—Same as Fig. 4, but for supergiant stars

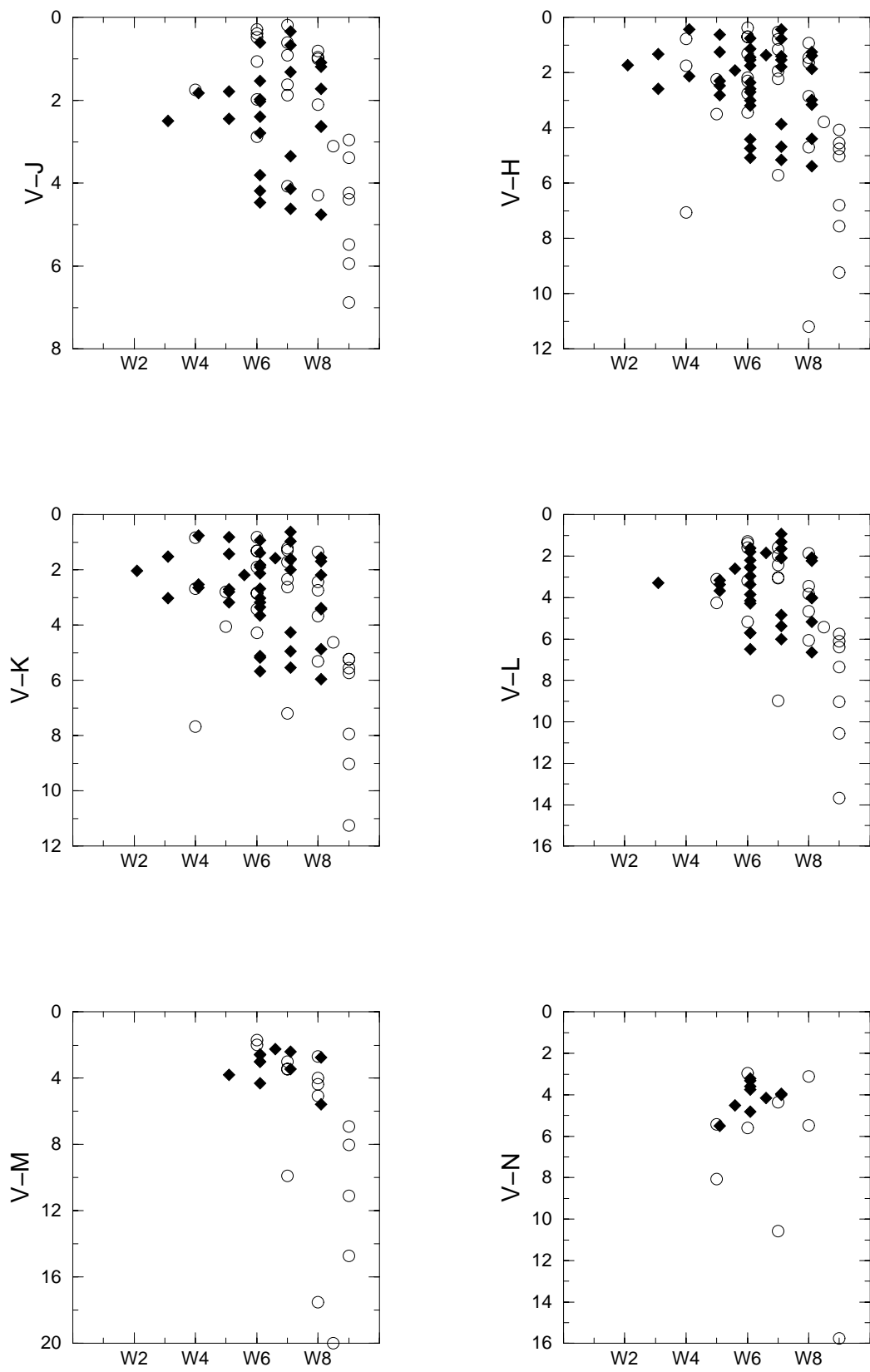


FIG. 8.—Spectral type-color indices for Wolf-Rayet stars. Diamonds denote WN stars; circles denote WC stars.

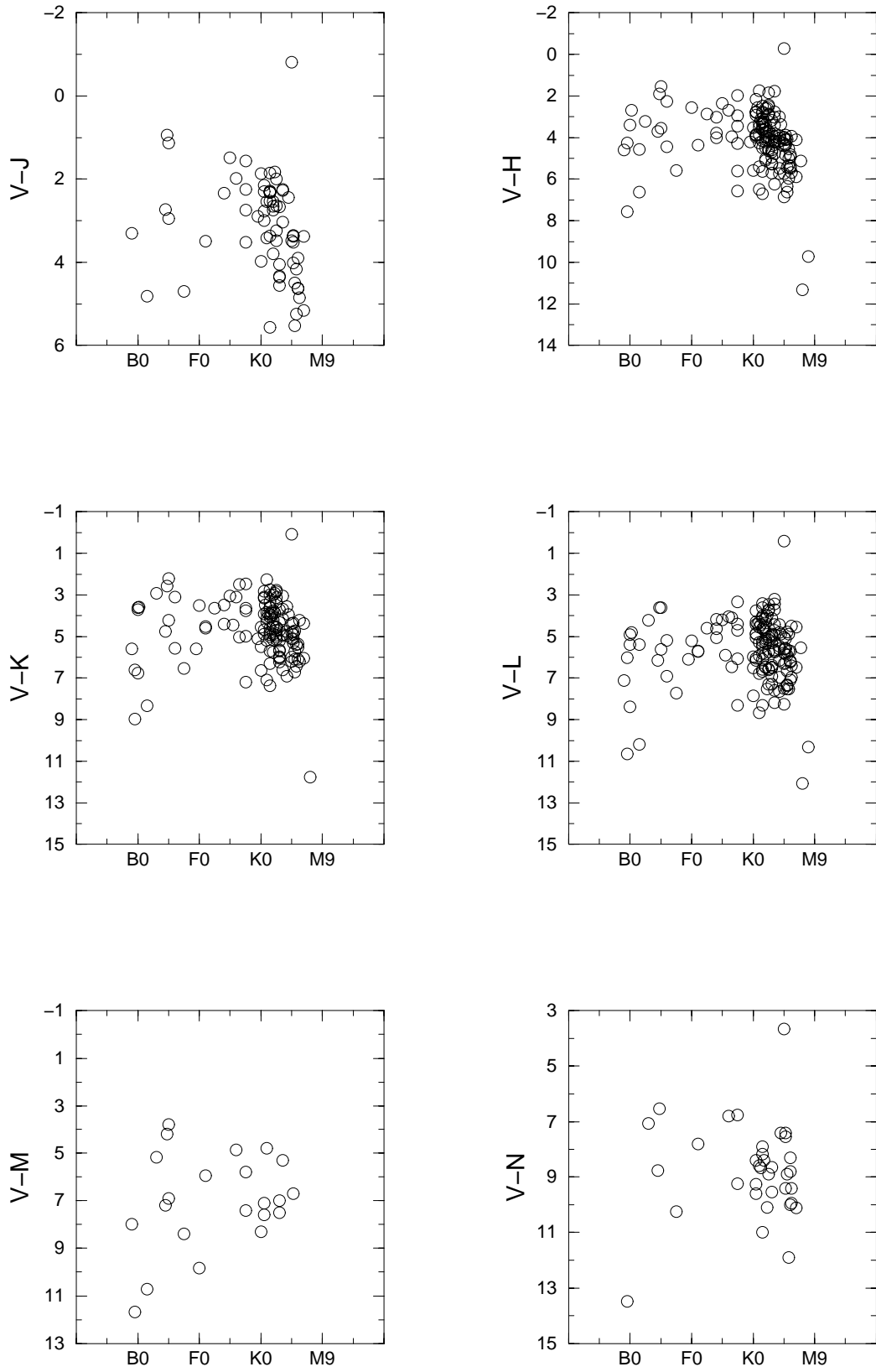


FIG. 9.—Same as Fig. 8, but for T Tauri stars

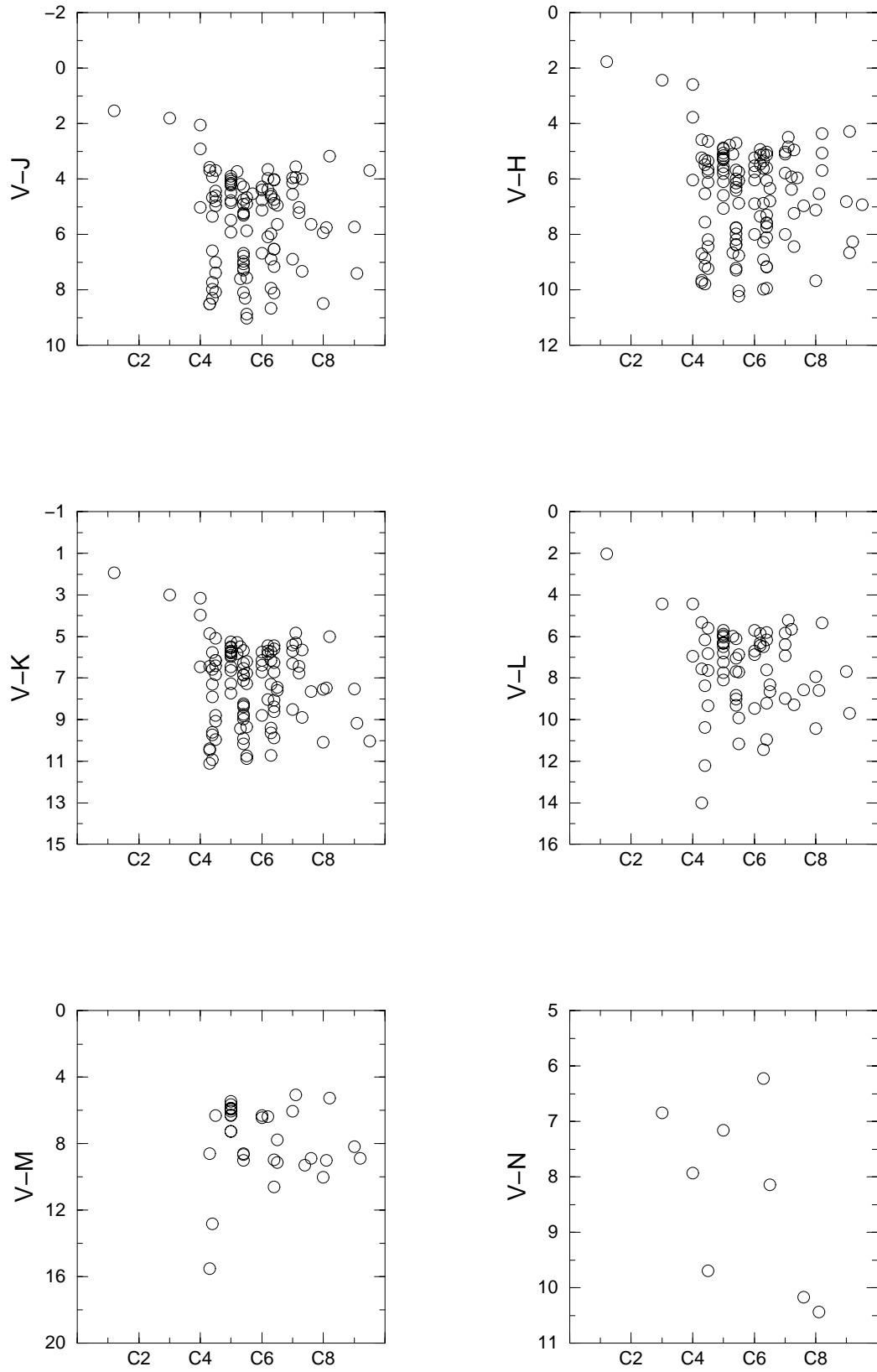


FIG. 10.—Same as Fig. 8, but for carbon stars

TABLE 2
NUMBER OF STARS IN EACH DIAGRAM

Diagram	I	III	V	Carbon	T Tauri	Wolf-Rayet
$(V-R)_0$	229	408	343
$(V-I)_0$	233	408	345
$(V-J)_0$	349	793	686	122	65	52
$(V-H)_0$	327	514	628	120	148	74
$(V-K)_0$	453	834	758	125	133	75
$(V-L)_0$	381	495	449	85	152	59
$(V-M)_0$	217	180	187	34	22	27
$(V-N)_0$	88	76	57	11	35	19

TABLE 3
INTRINSIC COLORS OF MAIN-SEQUENCE STARS

Spectral Type	$(V-R)_0$	$(V-I)_0$	$(V-J)_0$	$(V-H)_0$	$(V-K)_0$	$(V-L)_0$	$(V-M)_0$	$(V-N)_0$
B0	-0.22	-0.44	-0.80	-0.92	-0.97	-1.13	-1.00	...
B0.5	-0.20	-0.43	-0.77	-0.89	-0.95	-1.11	-0.99	...
B1	-0.18	-0.42	-0.73	-0.85	-0.93	-1.08	-0.96	...
B1.5	-0.17	-0.41	-0.70	-0.82	-0.91	-1.05	-0.94	...
B2	-0.15	-0.40	-0.67	-0.79	-0.89	-1.02	-0.92	...
B2.5	-0.14	-0.39	-0.64	-0.76	-0.86	-0.97	-0.88	-0.96
B3	-0.13	-0.38	-0.60	-0.72	-0.82	-0.92	-0.84	-0.91
B3.5	-0.12	-0.37	-0.58	-0.70	-0.80	-0.90	-0.82	-0.87
B4	-0.11	-0.35	-0.56	-0.68	-0.77	-0.86	-0.79	-0.84
B4.5	-0.11	-0.34	-0.54	-0.65	-0.74	-0.83	-0.76	-0.80
B5	-0.10	-0.33	-0.51	-0.62	-0.71	-0.78	-0.73	-0.75
B6	-0.09	-0.29	-0.46	-0.57	-0.64	-0.70	-0.65	-0.66
B7	-0.08	-0.26	-0.41	-0.51	-0.57	-0.61	-0.58	-0.58
B7.5	-0.08	-0.24	-0.39	-0.48	-0.54	-0.57	-0.54	-0.53
B8	-0.07	-0.22	-0.36	-0.45	-0.49	-0.52	-0.49	-0.48
B8.5	-0.07	-0.18	-0.31	-0.40	-0.43	-0.43	-0.42	-0.39
B9	-0.06	-0.14	-0.26	-0.34	-0.33	-0.34	-0.34	-0.30
B9.5	-0.03	-0.11	-0.22	-0.29	-0.26	-0.27	-0.26	-0.22
A0	-0.01	-0.05	-0.16	-0.19	-0.17	-0.18	-0.18	-0.14
A1	0.01	-0.03	-0.11	-0.12	-0.11	-0.12	-0.13	-0.08
A2	0.03	-0.00	-0.07	-0.04	-0.05	-0.07	-0.08	-0.02
A3	0.05	0.02	-0.02	0.03	0.01	-0.01	-0.02	0.03
A4	0.07	0.07	0.03	0.11	0.08	0.05	-0.04	0.09
A5	0.10	0.12	0.09	0.19	0.15	0.12	0.10	0.16
A6	0.11	0.16	0.13	0.30	0.21	0.17	0.15	0.21
A7	0.13	0.19	0.18	0.32	0.27	0.23	0.20	0.26
A8	0.16	0.26	0.25	0.42	0.36	0.33	0.29	0.34
A9	0.18	0.31	0.31	0.49	0.44	0.41	0.36	0.41
F0	0.21	0.36	0.37	0.57	0.52	0.49	0.43	0.48
F1	0.23	0.40	0.43	0.64	0.58	0.57	0.49	0.54
F2	0.25	0.45	0.48	0.71	0.66	0.66	0.56	0.60
F5	0.33	0.57	0.67	0.93	0.89	0.90	0.77	0.80
F8	0.37	0.64	0.79	1.06	1.03	1.06	0.91	0.91
G0	0.41	0.70	0.87	1.15	1.14	1.18	1.01	1.01
G2	0.45	0.75	0.97	1.25	1.26	1.31	1.12	1.11
G3	0.45	0.76	0.98	1.27	1.28	1.33	1.14	1.13
G5	0.47	0.78	1.02	1.31	1.32	1.38	1.18	1.17
G8	0.52	0.85	1.14	1.44	1.47	1.55	1.34	1.30
K0	0.61	0.97	1.34	1.67	1.74	1.85	1.61	1.54
K1	0.67	1.05	1.46	1.80	1.89	2.02	1.78	1.68
K2	0.73	1.14	1.60	1.94	2.06	2.21	1.97	1.84
K3	0.80	1.25	1.73	2.09	2.23	2.40	2.17	2.01
K4	0.86	1.34	1.84	2.22	2.38	2.57	2.36	2.15
K5	0.97	1.54	2.04	2.46	2.66	2.87	2.71	2.44
K7	1.13	1.86	2.30	2.78	3.01	3.25	3.21	2.83
M0	1.26	2.15	2.49	3.04	3.29	3.54	3.65	3.16
M1	1.36	2.36	2.61	3.22	3.47	3.72	3.95	3.39
M2	1.46	2.62	2.74	3.42	3.67	3.92	4.31	3.66
M3	1.56	2.84	2.84	3.58	3.83	4.08	4.62	3.89
M4	1.65	3.07	2.93	3.74	3.98	4.22	4.93	4.11

TABLE 4
INTRINSIC COLORS OF GIANT STARS

Spectral Type	$(V-R)_0$	$(V-I)_0$	$(V-J)_0$	$(V-H)_0$	$(V-K)_0$	$(V-L)_0$	$(V-M)_0$	$(V-N)_0$
G3	0.43	0.75	0.83	1.32	1.36	1.44	1.38	1.37
G3.5	0.44	0.77	0.86	1.35	1.40	1.47	1.42	1.40
G4	0.45	0.79	0.89	1.38	1.45	1.51	1.46	1.44
G5	0.48	0.83	0.94	1.44	1.53	1.58	1.53	1.51
G8	0.55	0.95	1.11	1.61	1.77	1.79	1.73	1.75
G9	0.57	0.99	1.17	1.66	1.85	1.88	1.82	1.83
G9.5	0.58	1.01	1.20	1.69	1.90	1.92	1.86	1.88
K0	0.60	1.03	1.23	1.72	1.94	1.97	1.90	1.92
K0.5	0.63	1.07	1.30	1.79	2.03	2.07	2.00	2.02
K1	0.66	1.12	1.37	1.87	2.12	2.17	2.09	2.11
K2	0.74	1.23	1.56	2.08	2.36	2.44	2.35	2.37
K2.5	0.80	1.30	1.69	2.23	2.52	2.62	2.52	2.54
K3	0.86	1.39	1.84	2.40	2.69	2.82	2.70	2.73
K3.5	0.91	1.49	1.99	2.73	2.86	3.01	2.88	2.91
K4	0.96	1.61	2.16	2.77	3.05	3.22	3.08	3.02
K5	0.99	1.67	2.25	2.87	3.14	3.33	3.18	3.21
M0	1.09	1.91	2.55	3.23	3.46	3.69	3.51	3.54
M0.5	1.13	1.98	2.64	3.33	3.55	3.79	3.61	3.64
M1	1.16	2.07	2.73	3.45	3.64	3.90	3.70	3.74
M2	1.27	2.32	2.99	3.76	3.89	4.18	3.96	4.00
M3	1.39	2.61	3.25	4.08	4.13	4.46	4.22	4.26
M4	1.58	3.04	3.58	4.49	4.42	4.79	4.52	4.56
M4.5	1.70	3.32	3.76	4.73	4.57	4.97	4.69	4.73
M5	1.85	3.67	3.95	4.98	4.73	5.15	4.86	4.90
M6	2.24	4.53	4.34	5.50	5.04	5.51	5.18	5.23

TABLE 5
INTRINSIC COLORS OF SUPERGIANT STARS

Spectral Type	$(V-R)_0$	$(V-I)_0$	$(V-J)_0$	$(V-H)_0$	$(V-K)_0$	$(V-L)_0$	$(V-M)_0$	$(V-N)_0$
O9	-0.19	-0.41	-0.57	-0.75	-0.84	-0.78	-0.99	-0.65
O9.5	-0.18	-0.39	-0.55	-0.73	-0.82	-0.75	-0.95	-0.63
B0	-0.17	-0.37	-0.53	-0.70	-0.78	-0.71	-0.90	-0.59
B0.5	-0.16	-0.35	-0.50	-0.66	-0.75	-0.67	-0.84	-0.55
B1	-0.15	-0.32	-0.47	-0.62	-0.70	-0.61	-0.77	-0.50
B1.5	-0.14	-0.30	-0.45	-0.59	-0.67	-0.58	-0.73	-0.47
B2	-0.14	-0.29	-0.43	-0.56	-0.63	-0.55	-0.68	-0.44
B3	-0.11	-0.25	-0.37	-0.49	-0.54	-0.45	-0.57	-0.35
B4	-0.09	-0.22	-0.33	-0.42	-0.48	-0.38	-0.48	-0.28
B5	-0.07	-0.19	-0.28	-0.34	-0.39	-0.30	-0.38	-0.19
B6	-0.06	-0.17	-0.24	-0.30	-0.34	-0.25	-0.32	-0.14
B7	-0.04	-0.14	-0.20	-0.24	-0.27	-0.18	-0.24	-0.06
B7.5	-0.03	-0.13	-0.17	-0.20	-0.22	-0.14	-0.19	-0.02
B8	-0.01	-0.10	-0.12	-0.14	-0.15	-0.07	-0.11	0.05
B9	0.02	-0.03	-0.04	-0.03	-0.02	0.06	0.03	0.19
B9.5	0.04	0.00	-0.01	0.01	0.03	0.11	0.08	0.23
A0	0.05	0.03	0.02	0.06	0.08	0.15	0.13	0.29
A1	0.08	0.08	0.09	0.14	0.18	0.25	0.23	0.39
A2	0.09	0.10	0.11	0.17	0.21	0.28	0.27	0.43
A5	0.13	0.18	0.20	0.29	0.35	0.41	0.41	0.57
F0	0.20	0.31	0.36	0.51	0.60	0.64	0.65	0.82
F2	0.24	0.37	0.44	0.62	0.73	0.77	0.77	0.95
F5	0.29	0.47	0.57	0.79	0.91	0.95	0.96	1.15
F8	0.43	0.70	0.87	1.17	1.34	1.35	1.36	1.58
G0	0.55	0.90	1.14	1.52	1.71	1.72	1.72	1.98
G2	0.65	1.06	1.35	1.80	1.99	2.01	1.99	2.28
G3	0.68	1.12	1.43	1.90	2.09	2.11	2.09	2.38
G3.5	0.70	1.16	1.47	1.95	2.15	2.17	2.14	2.44
G4	0.72	1.19	1.52	2.01	2.20	2.23	2.20	2.50
G5	0.77	1.26	1.61	2.13	2.32	2.35	2.31	2.63
G8	0.87	1.43	1.83	2.41	2.59	2.64	2.58	2.91
K0	0.95	1.59	2.01	2.64	2.80	2.87	2.79	3.14
K1	0.99	1.68	2.11	2.76	2.91	3.00	2.90	3.26
K2	1.03	1.76	2.20	2.87	3.01	3.12	3.01	3.38
K3	1.13	1.96	2.41	3.14	3.25	3.39	3.25	3.63
K3.5	1.16	2.04	2.50	3.25	3.34	3.50	3.35	3.74
K4	1.20	2.13	2.59	3.37	3.44	3.62	3.46	3.84
K5	1.27	2.27	2.74	3.55	3.59	3.80	3.62	4.01
M0	1.42	2.59	3.07	3.97	3.92	4.22	3.99	4.38
M0.5	1.46	2.68	3.16	4.08	4.01	4.33	4.09	4.48
M1	1.50	2.77	3.25	4.20	4.10	4.45	4.19	4.58
M1.5	1.54	2.87	3.35	4.32	4.19	4.57	4.29	4.69
M2	1.58	2.97	3.45	4.45	4.28	4.70	4.40	4.80
M2.5	1.70	3.24	3.73	4.79	4.53	5.04	4.69	5.07
M3	1.83	3.55	4.03	5.16	4.79	5.41	5.01	5.37
M3.5	1.95	3.86	4.32	5.53	5.03	5.77	5.31	5.65
M4	2.09	4.20	4.65	5.93	5.29	6.17	5.64	5.95
M5	2.34	4.85	5.26	6.68	5.73	6.90	6.25	6.47

TABLE 6
INTRINSIC COLORS OF WOLF-RAYET, T TAURI, AND CARBON STARS

Star Type	$(V-J)_0$	$(V-H)_0$	$(V-K)_0$	$(V-L)_0$	$(V-M)_0$	$(V-N)_0$
WN, WC	<0.0	<0.0	<0.5	<1.0	<1.5	<3.0
T Tauri	<1.0	<1.0	<2.0	<3.0	<4.0	<6.0
Carbon (C4 to C9)	3.0	4.0	5.0	5.0	5.0	<6.0

affected by interstellar reddening. The colors of T Tauri stars are very stable with respect to spectral class. This can be because extinction is stronger for the few blue T Tauri stars, which are, in general, embedded in clouds of dust and gas than for late T Tauri stars. The exception seems to be in the $(V-J)$ color, which is, in the near-infrared, more affected by interstellar extinction than the colors from longer wavelengths.

Table 2 presents the number of stars used in each diagram. Tables 3, 4, 5, and 6 give the intrinsic colors. It should be noted that, for the infrared, $V-\lambda$ departs from the zero-point criteria used by Johnson in the calibration in UBV , where all colors for A0 stars are set to zero. This was already observed by Johnson himself (Johnson 1966) for A0 supergiants, where $V-K = 0.10$, and even for the main sequence, where $V-K = -0.03$. Koornneef (1983b) gives $V-K = 0.21$ for A0 supergiants and 0.00 for the main sequence. In this sense, it is not surprising that in the present paper we find that $V-K = 0.08$ for supergiant stars and -0.17 for main-sequence stars. In fact, our results were derived, for the $V-K$ color, from data where 15 A0 main-sequence stars, from a total sample of 36 A0 stars, are bluer than 0.00. The curve that defines the zero-reddening envelope has the value -0.17 at the point corresponding to

A0 stars; we note that three stars have $V-K$ even bluer than the -0.17 value we adopted as the intrinsic color. We note also that the difference between $V-K = 0.00$, the value expected by a zero-point calibration, and $V-K = -0.17$, the one derived in this paper, is far larger than the expected error in the K photometry, as shown in Table 1. We therefore conclude that $(V-K)$ -values for A0 stars that differ from 0.00 are not only real, but are not even new in the literature.

We note that, for dwarfs and giants, our indices are in general bluer than those previously published. This is easily understood, because Johnson's tables, being obtained from averages, tend to produce redder colors. For supergiants, differences are smaller and, although systematic for stars hotter than F, fall within uncertainties for infrared photometry as listed in Table 1. The reason for this bias perhaps has its origin in the calibration used by Kron (1958); however, we must have in mind that our sample is far larger than Johnson's.

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