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THE COLORS, BOLOMETRIC CORRECTIONS AND EFFECTIVE TEMPERATURES OF THE BRIGHT STARS

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SUMARIO

El programa fotométrico en el infrarrojo, que se inició en 1959, ha sido considerablemente ampliado y estimamos conveniente informar de manera más extensa sobre el progreso de este trabajo. El presente artículo se divide en las secciones siguientes:

Observaciones. Se han hecho observaciones fotoeléctricas en diez diferentes longitudes de onda, U, B, V, R, I, J, K, L, M y N. Algunas de estas observaciones se obtuvieron con los telescopios de 82 y 36 pulgadas del Observatorio de McDonald, y otras las hizo Braulio Iriarte con el telescopio de 40" del Observatorio Astronómico Nacional de la Universidad de México. La gran mayoría de las observaciones se obtuvieron con los telescopios de 21" y 28" del Lunar and Planetary Laboratory de la Universidad de Arizona.

El número total de las estrellas presentadas en este trabajo es de 256, del cual 241 tienen observaciones completas en U, B, V, R, I, J y K. Las observaciones en L, M y N se proporcionan para un buen número de las estrellas más brillantes. Los valores dados en R, I, J, K, L, M y N deben considerarse como valores estandards para futuros trabajos fotométricos.

Colores Intrínsecos de las Estrellas. La información de la que disponemos es suficiente como para derivar los colores intrínsecos de muchos tipos de estrellas. Estas son las gigantes de Luminosidad 3 desde G8 hasta M5, las supergigantes desde 0 a M5, y las estrellas de la secuencia principal de 0 a K7. Los índices de colores intrínsecos, U—B, B—V, V—R, V—I, V—J y V—K, se derivaron para la mayoría de los tipos correspondientes a las clases de luminosidad anteriormente mencionadas; además V—L, V—M y V—N fueron derivados para los tipos espectrales y clases de luminosidad en los casos en que se cuenta con información.

Intensidades Absolutas y Correcciones Bolométricas. El procedimiento de calibración absoluta hizo posible la derivación de la energía total y esta información se utilizó para obtener las Correcciones Fotométricas de muchos tipos de estrellas, de las cuales se habían derivado los colores intrínsecos.

Temperaturas Efectivas. La energía total calculada, conjuntamente con las medidas de diámetros aparentes de 10 estrellas se utilizaron para obtener las Temperaturas Efectivas de muchos tipos de estrellas, para las cuales se dan los colores intrínsecos.

La Secuencia Principal de Edad O (ZAMS) y Estrellas Seleccionadas. Las Correcciones Fotométricas y las Temperaturas Efectivas se usaron para construir el diagrama M_B vs. Log T_e de la secuencia principal de edad O. Esta secuencia se ha extendido a estrellas más débiles a través de estrellas enanas M, para las cuales se conoce sólo R y R—I; no obstante, la validez de esta extensión resulta dudosa dado que existe alguna evidencia de que las pocas enanas M que hasta ahora se han observado en el presente programa pudieran no ser enanas M típicas, en cuanto a su distribución de energía espectral se refiere.

En este programa se observaron 3 estrellas sub-enanas; de éstas, 2 (τ Cet y Gmb 1830) tienen paralajes trigonométricos grandes. En el diagrama M_B vs. Log T_e, τ Cet cae exactamente en la secuencia principal de edad O, en tanto y que Gmb 1830 cae alrededor de 0.4 magnitudes debajo.

Medidas para el Futuro. El presente análisis ha indicado 3 áreas en donde se necesita más material de observación:

1) Se requieren más observaciones de estrellas enanas M en U, B, V, R, I, J y K.

2) Se necesitan, de manera apremiante, más medidas de los diámetros angulares de las estrellas. El interferómetro de Brown y Twiss ayudará para las estrellas de tipos tempranos, pero un nuevo interferómetro del tipo Michelson será necesario para las estrellas más frías.

3) Se necesita un mayor número de observaciones de mejor calidad en longitudes de onda más cortas que 0.3 micrones. Tales medidas sólo pueden hacerse fuera de la atmósfera terrestre.

ABSTRACT

The infrared photometric program that was begun in 1959 has been continued and the time has come for a fairly extensive report on the progress of the work. This paper is divided into several sections, as follows:

Observations. Photometric observations in ten wavelength bands, U, B, V, R, I, J, K, L, M and N, have been made. Some of these observations were made with the 82-inch and 36-inch telescopes of the McDonald Observatory and others were made by B. Iriarte with the 40-inch telescope of the Observatorio Astronómico Nacional of the University of Mexico but the majority were made with the 21-inch and 28-inch photometric telescopes of the Lunar and Planetary Laboratory (University of Arizona).

Data for a total of 256 stars are given in this paper; of these, 241 have complete observations in U, B, V, R, I, J and K. Observations in L, M and N are given for a number of the brighter stars. For the R, I, J, K, L, M and N systems, the data here should be regarded as the standard values for additional photometric work.

Intrinsic Colors of Stars. The data that are now available proved to be sufficient for the derivation of the intrinsic colors of many types of stars. These are giants of Luminosity Class III from G8 to M5, supergiants from O to M5 and main-sequence stars from O to K7. The intrinsic color-indices, U—V, B—V, V—R, V—I, V—J and V—K were derived for most types of stars within these ranges; in addition, V—L, V—M and V—N were derived for the ranges of spectral type and luminosity class for which data are available.

Absolute Intensities and Bolometric Corrections. An absolute calibration procedure has made possible the derivation of the total energy outputs and these data were used to obtain the Bolometric Corrections for many types of stars for which intrinsic colors were derived.

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Effective Temperatures. The computed total energies have also been used, in conjunction with the apparent diameter measures that are available for ten stars, to derive the Effective Temperatures of many of the types of stars for which intrinsic colors are given.

The Zero-Age Main Sequence (ZAMS) and Selected Stars. The Bolometric Corrections and Effective Temperatures were used to derive the M_B *versus* Log T_e diagram for the zero-age main sequence. This sequence has been extended to fainter stars by a number of M-dwarfs for which only R and R—I are yet available; however, the validity of this extension is open to question since there is some evidence that the few M-dwarfs that have so far been observed on this program may not be typical M-dwarfs, so far as their spectral-energy distributions are concerned.

Three subdwarfs have been observed on this program; of these, two (τ Cet and Gmb 1830) have large trigonometric parallaxes. In the M_B *versus* Log T_e diagram, τ Cet falls exactly on the ZAMS while Gmb 1830 falls about 0.4 mag. below.

Measures for the Future. The analysis of the present data has exposed three areas where more observational material is needed. These are:

1) We need more observations of M-dwarf stars in U, B, V, R, I, J and K.

2) More measures of stellar angular diameters are sorely needed. The intensity interferometer of Brown and Twiss will help for the early-type stars, but a new Michelson interferometer is needed for the cooler stars.

3) We need more and better observations at wavelengths shorter than 0.3 microns. Such measures can be made only from above the Earth's atmosphere.

I.—Introduction

The infrared photometric program that was started in 1959, and upon which a first report was published in January 1962 (Johnson 1962), has been continued. Since 1962, major improvements and additions have been made to the photometric apparatus, resulting in greatly increased sensitivity, and a considerable augmentation of the range of wavelengths at which observations can be made. We are now making stellar observations in ten wavelength bands ranging from 0.35 microns in the ultraviolet to approximately 10 microns in the infrared.

During the past year, two short reports on the progress of specific portions of the program have been published; these are, a note on measurements of several stars at the wavelength of 5 microns (Johnson and Mitchell 1963) and one on similar measures at 10 microns (Low and Johnson 1964). The latter publication also includes a comparison with the 10-micron measures of Wildey and Murray (1964), and a preliminary interpretation of some of the data included in this paper. In addition to these reports, a description of some of the photometric apparatus, which is completely digitized so that the observations are entirely reduced by electronic computer, has been published (Johnson and Mitchell 1962).

It became plain that sufficient data had been collected to improve the 1962 discussion and this paper contains the consequent emendation. During the course of the analysis, certain deficiencies of the present program have become evident and remedial action is being taken.

II.—The Observations

The principal modifications of the photometric apparatus described by Johnson and Mitchell (1962) have been (1) the installation in the IJK photometer of a special PbS cell possessing a sensitive area ¼ × ¼ mm and very high sensitivity, and (2) the addition of a 5 micron (magnitude M) filter in the InSb photometer. The photometry at 10 microns has been carried out with a liquid helium-refrigerated bolometer designed and constructed by F. J. Low, installed in a photometer similar

TABLE 1

Characteristics of the filter bands

Band	*Effective Wavelength (Microns)*
U	0.36
B	0.45
V	0.555
R	0.67
I	0.87
J	1.20
K	2.20
L	3.50
M	5.0
N	9.0

to those employed for the shorter wavelengths. A short description of this photometer and the measured transmission of the filter is given by Low and Johnson (1964). Thus, we can now observe stars in all ten wavelength bands, U, B, V, R, I, J, K, L, M and N. The effective wavelengths of these bands are given in Table 1.

Some of the observations upon which this paper depends were made with the 82-inch and 36-inch telescopes of the McDonald Observatory; for example, the 5- and 10-micron measures were made with the 82-inch. Measures made by B. Iriarte at the Tonantzintla Observatory have been included in the data for some of the southern stars. The majority of the observations, however, were obtained with the 21- and 28-inch photometric telescopes of the Lunar and Planetary Laboratory of the University of Arizona.

The observational data which are available at this time are listed in Table 2. The first column of this Table contains the number of the star in the Bright Star Catalogue, the Henry Draper Catalogue or the Bonner Durchmusterung; the second, the constellation name of the star; the third through twelfth columns contain the photometric data; and the last column, the spectral type by W. W. Morgan or P. C. Keenan if one of them has classified the star, otherwise from various sources. Inasmuch as the photometric program is continuing, additional photometric data will be obtained for some of the stars in Table 2; this means that some of these data may be modified slightly in the future, but the probability that such modifications will require significant alterations of the conclusions of this work is slight.

The U, B, V data are on the system defined by Johnson and Morgan (1953), Johnson and Harris (1954) and Johnson (1955). Most of the U, B, V observations were made with the same filters and photomultiplier that were used in the original definition of the system.

It was intended originally that the R, I portion of the data should be on the system of Kron, Gascoigne and White (1953, 1957) but it was later decided to retain the instrumental system and, to be consistent with the other color-indices, to set the zero-point so that V—R = V—I = 0.00 at B—V = 0.00 for Luminosity Class V stars. The transformation between the data of Kron, Gascoigne and White, and R—I in Table 2 is well defined but slightly non-linear. The R, I data of Johnson and Borgman (1963) are on the same system as those of Table 2, except that they should be corrected in zero-point as follows: Δ (V—R) = + 0.09 mag., Δ (V—I) = + 0.05 mag.

The J, K and L systems are the same as those defined by Johnson (1962) and Johnson and Borgman (1963). Table 2, however, contains many more observations and many more stars than were available earlier and the new values should be taken as the definitions of the systems for these three magnitudes.

The M and N systems are essentially those of Johnson and Mitchell (1963) and of Low and Johnson (1964), respectively. A few stars for which data were not published by Low and Johnson or by Wildey and Murray (1964) are included in Table 2.

III.—The Intrinsic Colors of Stars

The data of Table 2 are sufficient to enable the derivation of the intrinsic colors of stars of many spectral types. There are tabulated nearly 70 stars of Luminosity Class III of spectral type G8 or later. An examination of the data for these stars yielded no indication that they are significantly affected by interstellar reddening; the stars of each individual spectral type form homogeneous groups so far as their color-indices are concerned and there is no significant change of these indices with apparent magnitude. This is a result that is to be expected from these stars, none of which is fainter than V = 5.5. Furthermore, Eggen (1963) has shown that, for the B- and A-type stars he investigated, there is no evidence of interstellar reddening out to distances of 50 to 100 parsecs from the Sun. Kron (1958) has also noted the evidence that these giants are not significantly reddened; he also points out that the fact (Stebbins and Kron 1957) that the Sun has the same color as much more distant stars of the same spectral type makes it quite unlikely that the Sun is enclosed in a small ball of reddening material. Kron's comment, plus Eggen's (1963) result, argues against Schmidt's (1958) contention that the nearby stars are reddened by 0.02 mag. We have assumed that simple averages of the observational data for the spectral types, G8 III and later, are satisfactory. These mean values, smoothed somewhat, especially for the later spectral types, are given in Table 3, in which the first column gives the spectral type, ranging from G8 III to M5 III, and the second through the tenth columns, the mean color-indices. The Bolometric Corrections and Effective Temperatures listed in the last two columns will be explained later.

Since the number of stars for which V—L, V—M and V—N are available is relatively small, it is necessary to plot the observational data for these indices against the spectral types or V—K and to draw smooth curves through the points. The values for V—L, V—M and V—N that are listed in Table 3 were read from such curves. The actual procedure that was used is illustrated by Figure 1, the relationship between K—N and V—K. The solid line is the adopted relationship and the values read from

TABLE 2

Bright star photometry

B.S.	NAME	V	U-V	B-V	V-R	V-I	V-J	V-K	V-L	V-M	V-N	SP. TYPE
15	α And	2.05	-0.55	-0.11	-0.04	-0.14	-0.24	-0.35	.	.	.	B9p
21	β Cas	2.26	+0.45	+0.35	+0.26	+0.49	+0.61	+0.79	+0.84	.	.	F2 IV
39	γ Peg	2.83	-1.10	-0.23	-0.13	-0.29	-0.50	-0.61	.	.	.	B2 IV
45	χ Peg	4.80	+3.50	+1.58	+1.33	+2.46	+3.12	+4.15	+4.19	.	.	M2 III
74	ι Cet	3.54	+2.40	+1.23	+0.85	+1.45	+1.89	+2.58	.	.	.	K2 III
130	κ Cas	4.15	-0.66	+0.14	+0.15	+0.20	+0.16	+0.19	.	.	.	B1 Ia
163	ε And	4.39	+1.33	+0.86	+0.69	+1.20	+1.52	+2.16	.	.	.	G8 III
165	δ And	3.30	+2.77	+1.30	+0.92	+1.58	+2.02	+2.78	.	.	.	K3 III
168	α Cas	2.22	+2.32	+1.18	+0.80	+1.35	+1.79	+2.46	.	.	.	K0 II - III
188	β Cet	1.98	+1.88	+0.98	+0.72	+1.22	+1.56	+2.19	.	.	.	K1 III
215	ζ And	4.08	+1.97	+1.11	+0.85	+1.44	+1.88	+2.55	.	.	.	
219	η Cas	3.44	+0.60	+0.58	+0.50	+0.86	+1.07	+1.46	.	.	.	G0 V
224	δ Psc	4.44	+3.39	+1.52	+1.17	+2.04	+2.58	+3.52	.	.	.	
264	γ Cas	2.41	-1.21	-0.11	+0.09	+0.01	-0.10	-0.20	.	.	.	B0 IV:pe
334	η Cet	3.42	+2.32	+1.15	+0.83	+1.42	+1.85	+2.58	.	.	.	K3 III
337	β And	2.06	+3.52	+1.57	+1.24	+2.24	+2.88	+3.87	+4.03	+3.67	+3.91	M0 III
360	φ Psc	4.66	+1.87	+1.03	+0.75	+1.27	+1.63	+2.27	.	.	.	
402	θ Cet	3.59	+1.98	+1.07	+0.75	+1.35	+1.75	+2.40	.	.	.	K0 III
403	δ Cas	2.69	+0.26	+0.14	+0.14	+0.22	+0.28	+0.39	.	.	.	A5 V
434	μ Psc	4.83	+2.95	+1.38	+1.06	+1.80	+2.40	+3.31	.	.	.	K4 III
437	η Psc	3.62	+1.72	+0.97	+0.73	+1.21	+1.57	+2.16	.	.	.	G8 III
458	50 And	4.10	+0.59	+0.53	+0.45	+0.74	+0.98	+1.26	.	.	.	F8 V
464	51 And	3.58	+2.72	+1.28	+0.96	+1.62	+1.98	+2.74	.	.	.	K3 III
483		4.95	+0.74	+0.62	+0.53	+0.84	+1.05	+1.40	.	.	.	G2 V
489	ν Psc	4.45	+2.93	+1.39	+1.06	+1.77	+2.26	+3.17	.	.	.	K3 III
496	φ Per	4.06	-0.97	-0.04	+0.19	+0.20	+0.24	+0.69	.	.	.	B2 pe
509	τ Cet	3.50	+0.92	+0.72	+0.62	+1.05	+1.32	+1.76	.	.	.	G8 Vp
510	ο Psc	4.25	.	+0.98	+0.72	+1.23	+1.55	+2.12	.	.	.	
539	ξ Cet	3.73	+2.24	+1.16	+0.80	+1.35	+1.80	+2.49	.	.	.	K2 III
542	ε Cas	3.35	-0.75	-0.16	-0.01	-0.15	-0.34	-0.45	.	.	.	B3 IVp
544	α Tri	3.43	+0.57	+0.49	+0.42	+0.70	+0.94	+1.17	.	.	.	F6 IV
553	β Ari	2.65	+0.23	+0.13	+0.11	+0.16	+0.17	+0.30	.	.	.	A5 V
585	υ Cet	4.06	+3.37	+1.56	+1.27	+2.31	+2.91	+3.90	.	.	.	gM1
603	γ And	2.12	+2.08	+1.16	+0.93	+1.64	+2.07	+2.92	+2.98	+2.67	.	K3 II+A
617	α Ari	2.00	+2.27	+1.15	+0.84	+1.48	+1.88	+2.61	+2.73	+2.50	.	K2 III
622	β Tri	3.00	+0.30	+0.16	+0.15	+0.22	+0.23	+0.37	.	.	.	A5 III
648	19 Ari	5.68	+3.53	+1.55	+1.14	+2.19	+2.80	+3.76	.	.	.	M0 III
649	ξ^{1} Cet	4.37	+1.48	+0.88	+0.67	+1.17	+1.50	+2.05	.	.	.	
681	ο Cet	8.12	+1.35	+1.59	+4.20	+7.60	+9.12	+10.38	.	.	.	M7 e
753A		5.83	+1.76	+0.97	+0.85	+1.37	.	.	.	.	.	dK4

TABLE 2 (continued)

B.S.	NAME	V	U-V	B-V	V-R	V-I	V-J	V-K	V-L	V-M	V-N	SP. TYPE
753B		11.65	+2.75	+1.61	+1.86	+3.47	.	.	.	.	.	dM6
799	θ Per	4.12	+0.50	+0.48	+0.46	+0.76	.	.	.	.	.	F7 V
804	γ Cet	3.47	+0.17	+0.09	+0.11	+0.17	+0.18	+0.26	.	.	.	A2 V
824	39 Ari	4.52	+2.14	+1.11	+0.80	+1.38	+1.82	+2.49	.	.	.	
834	η Per	3.79	+3.60	+1.70	+1.23	+2.11	+2.70	+3.64	.	.	.	K3 Ib
843	17 Per	4.53	+3.54	+1.60	+1.22	+2.18	+2.72	+3.69	.	.	.	
854	τ Per	3.98	+1.23	+ .76	+0.65	+1.09	+1.41	+1.95	.	.	.	
874	η Eri	3.86	+2.11	+1.13	+0.80	+1.38	+1.78	+2.42	.	.	.	K1 III-IV
911	α Cet	2.53	+3.67	+1.64	+1.34	+2.50	+3.08	+4.13	+4.27	+3.85	+4.06	M2 III
921	ρ Per	3.39	+3.38	+1.67	+1.81	+3.43	+4.10	+5.30	.	.	+5.36	M4 II-III
937	ι Per	4.05	+0.74	+0.59	.	+0.74	+0.98	+1.32	.	.	.	G0 V
1017	α Per	1.80	+0.84	+0.48	+0.49	+0.81	+0.92	+1.24	+1.26	.	+1.64	F5 Ib
1030	ο Tau	3.59	+1.51	+0.89	+0.65	+1.15	+1.46	+2.01	.	.	.	G8 III
1035		4.22	+0.16	+0.40	+0.39	+0.77	+1.01	+1.25	.	.	.	B9 Ia
1040		4.55	+0.46	+0.56	+0.51	+1.01	+1.35	+1.68	.	.	.	A0 Ia
1084	ε Eri	3.73	+1.46	+0.89	+0.73	+1.20	+1.46	+2.00	+2.20	.	.	K2 V
1101	10 Tau	4.28	+0.65	+0.58	+0.48	+0.79	+0.98	+1.33	.	.	.	F8 V
1135	ν Per	3.78	+0.71	+0.43	+0.39	+0.66	+0.83	+1.11	.	.	.	F5 II
1136	δ Eri	3.52	+1.60	+0.93	+0.71	+1.19	+1.54	+2.10	.	.	.	K0 IV
1155		4.48	+4.01	+1.88	+1.71	+3.50	+3.96	+5.11	.	.	.	M2 IIa
1203	ζ Per	2.85	-0.66	+0.11	+0.14	+0.23	+0.21	+0.20	.	.	.	B1 Ib
1228	ξ Per	4.04	-0.91	+0.01	+0.15	+0.14	+0.11	+0.07	.	.	.	O7
1231	γ Eri	2.94	+3.60	+1.59	+1.26	+2.25	+2.84	+3.82	+3.94	.	.	M0 III
1256	37 Tau	4.38	+2.10	+1.08	+0.79	+1.32	+1.70	+2.41	.	.	.	
1303	μ Per	4.20	+1.57	+0.96	+0.81	+1.37	+1.66	+2.22	.	.	.	G0 Ib
1346	γ Tau	3.62	+1.82	+0.99	+0.73	+1.21	+1.52	+2.08	.	.		K0 III
1373	δ Tau	3.76	+1.80	+0.98	+0.74	+1.24	+1.60	+2.16	.	.	+3.44	K0 III
1409	ε Tau	3.55	+1.89	+1.03	+0.72	+1.24	+1.60	+2.18	.	.	.	K0 III
1411	θ^1 Tau	3.85	+1.70	+0.96	+0.75	+1.21	+1.54	+2.12	.	.	.	K0 III
1412	θ^2 Tau	3.41	+0.31	+0.18	+0.18	+0.29	+0.36	+0.53	.	.	.	A7 III
1454	58 Per	4.28	+2.01	+1.23	+0.98	+1.68	+2.16	+2.91	.	.	.	
1457	α Tau	0.86	+3.43	+1.53	+1.24	+2.18	+2.70	+3.68	+3.90	+3.51	+3.56	K5 III
1543	π^3 Ori	3.19	+0.44	+0.45	+0.42	+0.69	+0.77	+1.06	.	.	.	F8 V
1577	ι Aur	2.68	+3.32	+1.52	+1.07	+1.89	+2.33	+3.27	.	.	+4.02	K3 II
1605	ε Aur	2.92	+0.84	+0.55	+0.49	+0.90	+1.09	+1.45	.	.	+4.34	F0 Iap
1612	ζ Aur	3.74	+1.58	+1.25	+1.11	+1.98	+2.58	+3.53	.	.	.	K5 II+B
1641	η Aur	3.16	-0.82	-0.16	-0.05	-0.23	-0.42	-0.61	.	.	.	B3 V
1654	ε Lep	3.14	+3.23	+1.47	+1.09	+1.91	+2.45	+3.33	.	.	.	K5 III
1666	β Eri	2.80	+0.23	+0.13	+0.12	+0.19	+0.25	+0.38	.	.	.	A3 III
1698	ρ Ori	4.42	+2.28	+1.20	+0.87	+1.49	+1.84	+2.56	.	.	.	K3 III

B.S.	NAME	V	U-V	B-V	V-R	V-I	V-J	V-K	V-L	V-M	V-N	SP. TYPE
1708	α Aur	0.08	+1.25	+0.80	+0.61	+1.04	+1.36	+1.88	+2.00	+1.76	+1.92	G8 III+F
1713	β Ori	0.08	-0.72	-0.03	-0.06	-0.08	-0.14	-0.11	-0.21	.	-0.03	B8 Ia
1845	119 Tau	4.35	+4.28	+2.07	+1.75	+3.19	+4.02	+5.19	.	.	.	M2 Ib
1852	δ Ori	2.19	-1.23	-0.20	-0.09	-0.31	-0.55	-0.66	.	.	.	09.5 II
1899	ι Ori	2.77	-1.33	-0.25	-0.06	-0.25	-0.48	-0.72	.	.	.	09 III
2004	κ Ori	2.06	-1.21	-0.18	-0.01	-0.19	-0.47	-0.56	.	.	.	B0.5 Ia
2061	α Ori	0.69	+3.93	+1.87	+1.60	+3.04	+3.65	+4.75	+5.07	+4.68	+5.30	M2 Iab
2088	β Aur	1.90	+0.07	+0.03	+0.08	+0.09	+0.04	+0.03	.	.	.	A2 IV
2091	π Aur	4.25	+3.58	+1.73	+1.67	+3.15	+3.86	+4.99	.	.	.	M3.5 II
2134	Gem	4.15	+1.39	+0.87	+0.68	+1.13	+1.47	+2.01	.	.	.	
2135	χ^2 Ori	4.63	-0.40	+0.28	+0.29	+0.51	+0.52	+0.76	.	.	.	B2 Ia
2219	κ Aur	4.33	+1.83	+1.04	+0.79	+1.33	+1.73	+2.40	.	.	.	G8 III
2227	γ Mon	3.96	+2.73	+1.30	+0.99	+1.61	+2.12	+2.86	.	.	.	K3 III
2286	μ Gem	2.83	+3.76	+1.71	+1.49	+2.82	+3.60	+4.69	.	.	.	M3 III
2421	γ Gem	1.93	+0.03	0.00	+0.05	+0.03	+0.01	+0.02	+0.19	.	.	A0 IV
2427	ψ^2 Ori	4.79	+2.55	+1.24	+0.90	+1.50	+1.98	+2.71	.	.	.	K3 III
2429	ν^2 CMa	3.90	+2.07	+1.07	+0.76	+1.30	+1.65	+2.29	.	.	.	K1 IV
2443	ν^3 CMa	4.40	+2.20	+1.18	+0.87	+1.48	+1.87	+2.59	.	.	.	K1 II-III
2473	ε Gem	2.97	+2.93	+1.45	+1.01	+1.60	+1.98	+2.73	.	.	.	G8 Ib
2491	α CMa	-1.46	-0.04	0.00	0.00	-0.03	-0.12	-0.14	-0.12	-0.20	-0.19	A1 V
2653	o^2 CMa	3.00	-0.87	-0.07	0.00	-0.08	-0.25	-0.24	.	.	.	B3 Ia
2697	τ Gem	4.42	+2.66	+1.25	+0.99	+1.63	+2.03	+2.82	.	.	.	
2701	20 Mon	4.91	+1.83	+1.03	+0.77	+1.29	+1.73	+2.34	.	.	.	K0 III
2777	δ Gem	3.52	+0.38	+0.34	+0.43	+0.61	+0.68	+0.91	.	.	.	
2852	ρ Gem	4.18	+0.30	+0.32	+0.35	+0.53	+0.60	+0.78	.	.	.	F0 V
2890	α Gem	1.59	+0.06	+0.04	+0.12	+0.10	+0.08	+0.09	.	.	.	A1 V+Am
2943	α CMi	0.37	+0.47	+0.43	+0.42	+0.67	+0.76	+1.03	+1.07	+1.01	+1.16	F5 IV-V
2990	β Gem	1.15	+1.85	+1.00	+0.74	+1.29	+1.64	+2.24	+2.37	+2.05	+2.39	K0 III
3003	81 Gem	4.86	+3.26	+1.48	+1.15	+1.98	+2.58	+3.50	.	.	.	K5 III
3145		4.40	+2.53	+1.24	+1.02	+1.69	+2.11	+2.90	.	.	.	K2 III
3165	ζ Pup	2.26	-1.38	-0.29	-0.08	-0.30	-0.52	-0.73	.	.	.	05 f
3185	ρ Pup	2.82	+0.65	+0.44	+0.40	+0.61	+0.68	+0.91	.	.	.	F6 IIp
3188	ζ Mon	4.34	+1.69	+0.99	+0.76	+1.22	+1.50	+2.07	.	.	.	G2 Ib
3211	19 Pup	4.73	+1.68	+0.96	+0.73	+1.21	+1.54	+2.11	.	.	.	K0 III
3249	β Cnc	3.52	+3.26	+1.48	+1.13	+1.91	+2.44	+3.35	+3.44	.	.	K4 III
3569	ι UMa	3.14	+0.25	+0.18	+0.20	+0.24	+0.38	+0.43	.	.	.	A7 V
3705	α Lyn	3.16	+3.46	+1.55	+1.22	+2.12	+2.78	+3.78	.	.	.	M0 III
3873	ε Leo	2.98	+1.30	+0.81	+0.68	+1.06	+1.35	+1.79	.	.	.	G0 II
3982	α Leo	1.36	-0.47	-0.11	-0.03	-0.13	-0.20	-0.28	-0.33	.	.	B7 V
4058	γ Leo	2.01	+2.11	+1.12	+0.80	+1.41	+1.96	+2.72	+2.81	.	.	K0 IIIp

TABLE 2 (continued)

B.S.	NAME	V	U-V	B-V	V-R	V-I	V-J	V-K	V-L	V-M	V-N	SP. TYPE
4069	μ UMa	3.04	+3.46	+1.60	+1.33	+2.29	+2.93	+3.96	+4.08	.	+3.97	MO III
4133	ρ Leo	3.85	-1.09	-0.14	-0.04	-0.20	-0.34	-0.46	.	.	.	B1 Ib
4232	ν Hya	3.11	+2.53	+1.24	+0.98	+1.62	+2.05	+2.83	.	.	.	K3 III
4301	α UMa	1.80	+1.98	+1.06	+0.81	+1.40	.	+2.38	+2.53	.	+2.43	KO III
4335	ψ UMa	3.01	+2.26	+1.14	+0.77	+1.37	+1.86	+2.59	.	.	.	K1 III
4357	δ Leo	2.55	+0.24	+0.12	0.09	+0.13	+0.26	+0.31	.	.	.	A4 V
4359	θ Leo	3.34	-0.01	-0.04	-0.01	-0.01	+0.04	+0.05	.	.	.	A2 V
4534	β Leo	2.14	+0.16	+0.09	+0.05	+0.07	+0.12	+0.17	.	.	.	A3 V
4540	β Vir	3.61	+0.65	+0.55	+0.43	+0.71	+0.97	+1.28	.	.	.	F8 V
4550		6.45	+0.92	+0.75	+0.65	+1.09	+1.49	+2.03	.	.	.	G8 Vp
4554	γ UMa	2.44	+0.01	0.00	0.00	-0.04	+0.04	+0.06	.	.	.	AO V
4660	δ UMa	3.31	+0.15	+0.08	+0.06	+0.06	+0.19	+0.21	.	.	.	A3 V
4757	δ Crv	2.94	-0.14	-0.04	-0.05	-0.10	-0.04	-0.14	.	.	.	B9.5 V
4825	γ Vir	2.73	+0.33	+0.36	+0.31	+0.50	+0.65	+0.87	.	.	.	FO V
4905	ε UMa	1.76	0.00	-0.02	-0.02	-0.05	+0.05	+0.03	.	.	.	AO p
4914	α CVnB	5.60	+0.31	+0.34	.	+0.55	+0.69	+0.77	.	.	.	FO V
4915	α CVnA	2.86	-0.44	-0.11	-0.04	-0.12	-0.17	-0.33	.	.	.	Ap
4932	ε Vir	2.84	+1.71	+0.93	+0.64	+1.09	+1.48	+2.04	.	.	.	G9 II-III
4983	β Com	4.28	+0.64	+0.57	+0.49	+0.78	+1.14	+1.42	+1.64	.	.	GO V
5020	γ Hya	3.01	+1.58	+0.92	+0.57	+1.05	+1.48	+2.09	.	.	.	G5 III
5056	α Vir	0.96	-1.18	-0.24	-0.08	-0.32	-0.52	-0.72	-0.93	.	.	B1 V
5192	2 Cen	4.26	+2.91	+1.48	+2.13	+4.02	.	+5.91	+6.11	.	.	
5235	η Boo	2.69	+0.77	+0.58	+0.45	+0.75	+0.99	+1.32	+1.31	.	.	GO IV
5287	π Hya	3.26	+2.19	+1.16	+0.93	+1.46	+1.85	+2.57	.	.	.	K2 III
5288	θ Cen	2.04	+1.90	+1.00	+0.75	+1.28	.	+2.27	+2.40	.	.	KO III-IV
5299		5.27	+3.26	+1.58	+1.87	+3.53	+4.47	+5.66	+5.94	.	+4.93	M4-4.5 III
5340	α Boo	-0.06	+2.50	+1.23	+1.03	+1.69	+2.14	+2.97	+3.10	+2.90	+2.71	K2 IIIp
5435	γ Boo	3.03	+0.31	+0.19	+0.13	+0.22	+0.35	+0.46	.	.	.	A7 III
5506	ε Boo	2.37	+1.73	+0.97	+0.73	+1.24	+1.54	+2.20	.	.	.	K1 III:+A
5530	α LibB	5.16	+0.37	+0.41	.	+0.63	+0.78	+1.03	.	.	.	F5 IV-V
5531	α LibA	2.75	+0.23	+0.15	+0.15	+0.19	+0.25	+0.32	.	.	.	A3m
5603	σ Lib	3.26	+3.65	+1.71	+1.51	+2.79	+3.54	+4.72	.	.	.	M4 III
5685	β Lib	2.61	-0.48	-0.11	-0.04	-0.13	-0.23	-0.30	.	.	.	B8 V
5744	ι Dra	3.30	+2.38	+1.16	+0.78	+1.38	+1.90	+2.59	.	.	.	K2 III
5854	α Ser	2.65	+2.41	+1.17	+0.81	+1.37	+1.85	+2.53	+2.64	.	+2.21	K2 III
5868	λ Ser	4.43	+0.70	+0.60	+0.51	+0.83	.	.	.	.	.	GO V
5947	ε CrB	4.15	+2.51	+1.23	+0.89	+1.52	+2.07	+2.83	+2.95	.	.	K3 III
5953	δ Sco	2.33	-1.01	-0.11	-0.02	-0.16	-0.26	-0.39	.	.	.	BO V
6056	δ Oph	2.74	+3.56	+1.60	+1.27	+2.29	+2.94	+3.97	.	.	.	M1 III
6075	ε Oph	3.23	+1.72	+0.99	+0.67	+1.16	+1.66	+2.25	.	.	.	G9 III

TABLE 2 (continued)

B.S.	NAME	V	U-V	B-V	V-R	V-I	V-J	V-K	V-L	V-M	V-N	SP. TYPE
4069	μ UMa	3.04	+3.46	+1.60	+1.33	+2.29	+2.93	+3.96	+4.08	.	+3.97	MO III
4133	ρ Leo	3.85	-1.09	-0.14	-0.04	-0.20	-0.34	-0.46	.	.	.	B1 Ib
4232	ν Hya	3.11	+2.53	+1.24	+0.98	+1.62	+2.05	+2.83	.	.	.	K3 III
4301	α UMa	1.80	+1.98	+1.06	+0.81	+1.40	.	+2.38	+2.53	.	+2.43	KO III
4335	ψ UMa	3.01	+2.26	+1.14	+0.77	+1.37	+1.86	+2.59	.	.	.	K1 III
4357	δ Leo	2.55	+0.24	+0.12	0.09	+0.13	+0.26	+0.31	.	.	.	A4 V
4359	θ Leo	3.34	-0.01	-0.04	-0.01	-0.01	+0.04	+0.05	.	.	.	A2 V
4534	β Leo	2.14	+0.16	+0.09	+0.05	+0.07	+0.12	+0.17	.	.	.	A3 V
4540	β Vir	3.61	+0.65	+0.55	+0.43	+0.71	+0.97	+1.28	.	.	.	F8 V
4550		6.45	+0.92	+0.75	+0.65	+1.09	+1.49	+2.03	.	.	.	G8 Vp
4554	γ UMa	2.44	+0.01	0.00	0.00	-0.04	+0.04	+0.06	.	.	.	AO V
4660	δ UMa	3.31	+0.15	+0.08	+0.06	+0.06	+0.19	+0.21	.	.	.	A3 V
4757	δ Crv	2.94	-0.14	-0.04	-0.05	-0.10	-0.04	-0.14	.	.	.	B9.5 V
4825	γ Vir	2.73	+0.33	+0.36	+0.31	+0.50	+0.65	+0.87	.	.	.	FO V
4905	ε UMa	1.76	0.00	-0.02	-0.02	-0.05	+0.05	+0.03	.	.	.	AO p
4914	α CVnB	5.60	+0.31	+0.34	.	+0.55	+0.69	+0.77	.	.	.	FO V
4915	α CVnA	2.86	-0.44	-0.11	-0.04	-0.12	-0.17	-0.33	.	.	.	Ap
4932	ε Vir	2.84	+1.71	+0.93	+0.64	+1.09	+1.48	+2.04	.	.	.	G9 II-III
4983	β Com	4.28	+0.64	+0.57	+0.49	+0.78	+1.14	+1.42	+1.64	.	.	GO V
5020	γ Hya	3.01	+1.58	+0.92	+0.57	+1.05	+1.48	+2.09	.	.	.	G5 III
5056	α Vir	0.96	-1.18	-0.24	-0.08	-0.32	-0.52	-0.72	-0.93	.	.	B1 V
5192	2 Cen	4.26	+2.91	+1.48	+2.13	+4.02	.	+5.91	+6.11	.	.	
5235	η Boo	2.69	+0.77	+0.58	+0.45	+0.75	+0.99	+1.32	+1.31	.	.	GO IV
5287	π Hya	3.26	+2.19	+1.16	+0.93	+1.46	+1.85	+2.57	.	.	.	K2 III
5288	θ Cen	2.04	+1.90	+1.00	+0.75	+1.28	.	+2.27	+2.40	.	.	KO III-IV
5299		5.27	+3.26	+1.58	+1.87	+3.53	+4.47	+5.66	+5.94	.	+4.93	M4-4.5 III
5340	α Boo	-0.06	+2.50	+1.23	+1.03	+1.69	+2.14	+2.97	+3.10	+2.90	+2.71	K2 IIIp
5435	γ Boo	3.03	+0.31	+0.19	+0.13	+0.22	+0.35	+0.46	.	.	.	A7 III
5506	ε Boo	2.37	+1.73	+0.97	+0.73	+1.24	+1.54	+2.20	.	.	.	K1 III:+A
5530	α LibB	5.16	+0.37	+0.41	.	+0.63	+0.78	+1.03	.	.	.	F5 IV-V
5531	α LibA	2.75	+0.23	+0.15	+0.15	+0.19	+0.25	+0.32	.	.	.	A3m
5603	σ Lib	3.26	+3.65	+1.71	+1.51	+2.79	+3.54	+4.72	.	.	.	M4 III
5685	β Lib	2.61	-0.48	-0.11	-0.04	-0.13	-0.23	-0.30	.	.	.	B8 V
5744	ι Dra	3.30	+2.38	+1.16	+0.78	+1.38	+1.90	+2.59	.	.	.	K2 III
5854	α Ser	2.65	+2.41	+1.17	+0.81	+1.37	+1.85	+2.53	+2.64	.	+2.21	K2 III
5868	λ Ser	4.43	+0.70	+0.60	+0.51	+0.83	.	.	.	.	.	GO V
5947	ε CrB	4.15	+2.51	+1.23	+0.89	+1.52	+2.07	+2.83	+2.95	.	.	K3 III
5953	δ Sco	2.33	-1.01	-0.11	-0.02	-0.16	-0.26	-0.39	.	.	.	BO V
6056	δ Oph	2.74	+3.56	+1.60	+1.27	+2.29	+2.94	+3.97	.	.	.	M1 III
6075	ε Oph	3.23	+1.72	+0.99	+0.67	+1.16	+1.66	+2.25	.	.	.	G9 III

TABLE 2 (continued)

B.S.	NAME	V	U-V	B-V	V-R	V-I	V-J	V-K	V-L	V-M	V-N	SP. TYPE
6084	σ Sco	2.86	-0.53	+0.16	+0.16	+0.30	+0.44	+0.50	.	.	.	B1 III
6132	η Dra	2.73	+1.61	+0.90	+0.64	+1.10	+1.52	+2.13	.	.	.	G8 III
6134	α Sco	0.88	+3.19	+1.84	+1.57	+2.77	+3.61	+4.74	+5.06	.	+4.88	M1 Ia+B
6148	β Her	2.77	+1.64	+0.94	+0.63	+1.10	+1.54	+2.14	.	.	.	G8 III
6175	ζ Oph	2.56	-0.84	+0.02	+0.08	+0.05	-0.01	-0.07	.	.	.	O9.5 V
6212	ζ Her	2.82	+0.85	+0.64	+0.47	+0.83	+1.16	+1.52	+1.36	.	.	G0 IV
6406	α Her	3.05	+2.49	+1.47	+2.09	+4.23	+5.23	+6.49	+6.70	+6.25	+6.41	M5 II+G
6410	δ Her	3.13	+0.16	+0.08	+0.05	+0.09	+0.18	+0.31	.	.	.	A3 IV
6453	θ Oph	3.26	-1.10	-0.23	-0.13	-0.30	-0.52	-0.54	.	.	.	B2 IV
6536	β Dra	2.78	+1.62	+0.99	+0.68	+1.16	.	.	.	.	.	G2 Ib
6603	β Oph	2.77	+2.40	+1.16	+0.77	+1.36	+1.83	+2.53	+2.64	.	.	K2 III
6623	μ Her	3.42	+1.15	+0.75	+0.53	+0.91	+1.25	+1.65	.	.	.	G5 IV
6698	ν Oph	3.34	+1.87	+1.00	+0.64	+1.13	+1.61	+2.22	.	.	.	G9 III
6705	γ Dra	2.22	+3.38	+1.52	+1.12	+2.00	.	+3.47	+3.66	.	+3.43	K5 III
6913	λ Sgr	2.80	+1.97	+1.04	+0.73	+1.28	+1.77	+2.43	.	.	.	K2 III
7001	α Lyr	0.04	-0.01	0.00	-0.04	-0.06	0.00	+0.02	+0.04	+0.08	+0.04	A0 V
7139	δ^2 Lyr	4.31	+3.33	+1.67	+1.78	+3.41	+4.33	+5.48	.	.	+5.55	M4 II
7157	R Lyr	4.00	+2.98	+1.58	+2.04	+3.95	+4.85	+6.00	.	.	+6.11	M4.5 III
7328	κ Cyg	3.77	+1.70	+0.97	+0.61	+1.08	+1.54	+2.14	.	.	.	K0 III
7352	τ Dra	4.45	+2.70	+1.25	+0.90	+1.48	+1.99	+2.67	.	.	.	
7377	δ Aql	3.36	+0.39	+0.33	+0.25	+0.45	+0.61	+0.79	.	.	.	F0 IV
7405	6 Vul	4.46	+3.35	+1.51	+1.21	+2.20	+2.90	+3.89	.	.	.	M0 III
7417	β Cyg	3.08	+1.75	+1.13	+0.88	+1.54	+2.06	+2.90	+2.96	.	.	K3 II:+B:
7462	σ Dra	4.69	+1.17	+0.80	+0.65	+1.06	+1.35	+1.83	+2.06	.	.	K0 V
7525	γ Aql	2.75	+3.22	+1.54	+1.08	+1.83	+2.44	+3.34	.	.	.	K3 II
7557	α Aql	0.77	+0.30	+0.22	+0.16	+0.24	+0.33	+0.50	+0.56	.	.	A7 IV,V
7564	χ Cyg	11.84	.	+2.53	+5.91	+9.89	+11.97	+13.60	+14.40	+14.45	+15.26	S10
7582	ε Dra	3.89	+1.42	+0.90	+0.68	+1.17	+1.65	+2.20	.	.	.	G8 III
7602	β Aql	3.71	+1.34	+0.88	+0.63	+1.12	+1.48	+1.97	.	.	.	G8 IV
7615	η Cyg	3.93	+1.92	+1.02	+0.72	+1.27	+1.66	+2.25	.	.	.	
7685	ρ Dra	4.50	+2.81	+1.31	+0.93	+1.58	+2.13	+2.90	.	.	.	
7710	θ Aql	3.21	-0.18	-0.06	-0.07	-0.07	-0.18	-0.15	.	.	.	B9.5 III
7735	31 Cyg	3.80	+1.70	+1.28	+0.97	+1.77	+2.38	+3.30	.	.	.	K3 Ib+B3 V
7747	α^1 Cap	4.26	+1.88	+1.08	+0.79	+1.32	+1.72	+2.34	.	.	.	G3 Ib
7751	o^2 Cyg	3.98	+2.55	+1.52	+1.20	+2.12	+2.77	+3.80	.	.	.	
7763	P Cyg	4.80	-0.17	+0.41	+0.54	+0.80	+1.07	+1.55	.	.	.	P Cyg
7796	γ Cyg	2.23	+1.21	+0.67	+0.49	+0.85	+1.09	+1.51	.	.	.	F8 Ib
7834	41 Cyg	4.02	+0.69	+0.41	+0.36	+0.59	.	.	.	.	.	F5 II
7882	β Del	3.63	+0.55	+0.44	+0.40	+0.65	+0.74	+0.98	.	.	.	
7884	71 Aql	4.33	+1.66	+0.97	+0.67	+1.13	+1.45	+1.99	.	.	.	

TABLE 2 (continued)

B.S.	NAME	V	U-V	B-V	V-R	V-I	V-J	V-K	V-L	V-M	V-N	SP. TYPE
7924	α Cyg	1.26	-0.14	+0.09	+0.10	+0.20	+0.24	+0.36	+0.43	.	.	A2 Ia
7942	52 Cyg	4.22	+1.91	+1.05	+0.78	+1.30	+1.62	+2.32	.	.	.	
7949	ε Cyg	2.45	+1.90	+1.03	+0.73	+1.25	+1.70	+2.35	+2.46	.	.	K0 III
7951	3 Aqr	4.45	+3.58	+1.66	+1.48	+2.80	+3.45	+4.58	.	.	.	
7957	η Cep	3.43	+1.51	+0.92	+0.67	+1.17	+1.38	+2.06	.	.	.	K0 IV
8079	ξ Cyg	3.70	+3.45	+1.65	+1.20	+2.10	+2.66	+3.69	.	.	.	K5 Ib
8085	61 CygA	5.23	+2.27	+1.16	+1.03	+1.67	+2.14	+2.84	.	.	.	K5 V
8086	61 CygB	6.02	+2.60	+1.36	+1.15	+1.95	+2.49	+3.29	.	.	.	K7 V
8115	ζ Cyg	3.19	+1.76	+1.00	+0.69	+1.17	+1.51	+2.06	.	.	.	G8 II
8130	τ Cyg	3.73	+0.43	+0.40	+0.35	+0.59	+0.76	+1.06	.	.	.	F0 IV
8143	σ Cyg	4.23	-0.26	+0.13	+0.15	+0.29	+0.36	+0.49	.	.	.	B9 Iab
8162	α Cep	2.45	+0.32	+0.21	+0.21	+0.33	+0.43	+0.55	.	.	.	A7 IV,V
8173	1 PegA	4.10	+2.15	+1.11	+0.78	+1.33	+1.80	+2.47	.	.	.	K1 III
8232	β Aqr	2.85	+1.42	+0.84	+0.61	+1.03	+1.27	+1.73	.	.	.	G0 Ib
8238	β Cep	3.24	-1.16	-0.21	-0.09	-0.31	-0.52	-0.72	.	.	.	B2 III
8252	ρ Cyg	4.04	+1.47	+0.90	+0.71	+1.21	+1.51	+2.05	.	.	.	
8279	9 Cep	4.74	-0.24	+0.30	+0.31	+0.45	+0.43	+0.48	.	.	.	B2 Ib
8297	DS Peg	5.84	+7.13	+2.48	+1.74	+3.13	+4.01	+5.61	+6.11	.	+6.36	$C6_3$
8308	ε Peg	2.38	+3.21	+1.53	+1.05	+1.81	+2.34	+3.15	.	.	.	K2 Ib
8313	9 Peg	4.31	+2.14	+1.18	+0.79	+1.35	+1.80	+2.42	.	.	.	G5 Ib
8316	μ Cep	4.16	+4.72	+2.27	+2.10	+3.73	+4.67	+5.81	+6.28	+6.11	+7.50	M2 Ia
8322	δ Cap	2.81	+0.40	+0.29	+0.24	+0.40	+0.46	+0.67	.	.	.	A6m
8334	ν Cep	4.29	+0.64	+0.52	+0.49	+0.94	+1.13	+1.44	.	.	.	A2 Ia
8383	VV Cep	4.90	+2.12	+1.75	+1.73	+3.06	+3.80	+5.00	.	.	.	M2 Iab
8413	ν Peg	4.83	+3.25	+1.46	+1.07	+1.84	+2.40	+3.24	.	.	.	K4 III
8414	α Aqr	2.92	+1.77	+0.98	+0.67	+1.14	+1.41	+1.94	.	.	.	G2 Ib
8430	ι Peg	3.76	+0.40	+0.44	+0.40	+0.67	+0.73	+1.11	.	.	.	F5 V
8469	λ Cep	5.05	-0.50	+0.24	+0.26	+0.40	+0.43	+0.47	.	.	.	06f
8498	1 Lac	4.16	+3.04	+1.45	+1.05	+1.76	+2.28	+3.12	.	.	.	
8538	β Lac	4.44	+1.99	+1.02	+0.75	+1.32	+1.77	+2.37	.	.	.	
8572	5 Lac	4.38	+2.78	+1.68	+1.40	+2.48	+3.14	+4.22	.	.	.	
8622	10 Lac	4.88	-1.24	-0.20	-0.08	-0.29	-0.54	-0.76	.	.	.	09 V
8650	η Peg	2.95	+1.40	+0.85	+0.64	+1.12	+1.47	+2.01	.	.	.	G2 II-III
8694	ι Cep	3.57	+2.00	+1.08	+0.93	+1.42	+1.73	+2.36	.	.	.	
8728	α PsA	1.15	+0.15	+0.10	+0.01	+0.02	+0.02	0.00	.	.	.	A3 V
8729	51 Peg	5.48	+0.87	+0.67	+0.54	+0.88	+1.13	+1.46	.	.	.	
8775	β Peg	2.54	+3.62	+1.67	+1.49	+2.82	+3.59	+4.70	+4.95	.	+4.87	M2 II-III
8781	α Peg	2.48	-0.09	-0.04	+0.01	-0.01	-0.06	-0.05	.	.	.	B9 V
8795	55 Peg	4.51	+3.46	+1.58	+1.26	+2.29	+2.85	+3.80	.	.	.	M2 III
8832		5.57	+1.90	+1.01	+0.83	+1.34	+1.71	+2.29	.	.	.	K3 V

TABLE 2 (concluded)

B.S.	NAME	V	U-V	B-V	V-R	V-I	V-J	V-K	V-L	V-M	V-N	SP. TYPE
8841	ψ' Aqr	4.24	+2.11	+1.11	+0.79	+1.35	+1.73	+2.43	.	.	.	K0 III
8860	8 And	4.86	+2.65	+1.67	+1.46	+2.72	+3.36	+4.43	.	.	.	
8905	υ Peg	4.38	+0.74	+0.61	.	+0.81	+1.02	+1.38	.	.	.	F8 IV
8961	λ And	3.76	+1.72	+1.02	+0.78	+1.35	+1.76	+2.41	.	.	.	G8 III-IV
9064	ψ Peg	4.65	+3.22	+1.60	+1.46	+2.80	+3.51	+4.59	.	.	.	
9089	30 Psc	4.40	+3.44	+1.62	+1.57	+2.98	+3.81	+4.86	.	.	+4.32	M3 III
HD	36395	7.97	+2.68	+1.47	+1.44	+2.58	.	.	.	.	.	dM1
HD	95735	7.49	+2.63	+1.51	+1.50	+2.69	+3.39	+4.18	+4.41	.	.	M2 V
HD	140283	7.22	+0.30	+0.49	+0.59	+0.91	+1.09	+1.45	.	.	.	sdF5
HD	157881	7.53	+2.63	+1.36	+1.30	+2.10	.	.	.	.	.	K7 V
BD	-12°2918	10.07	+2.69	+1.54	+1.61	+2.99	.	.	.	.	.	dM5
BD	+04°3561	9.54	+3.03	+1.74	+1.83	+3.44	+4.04	+4.90	.	.	.	M5 V
BD	+17°1320	9.63	+2.68	+1.50	+1.29	+2.26	.	.	.	.	.	dM0
BD	+43°44A	8.07	+2.81	+1.56	+1.35	+2.54	+3.22	+4.06	.	.	.	M1 V
BD	+43°44B	11.03	+3.20	+1.80	+1.74	+3.38	+4.22	+5.21	.	.	.	M6 V
YY	Gem	9.07	+2.53	+1.49	+1.38	+2.40	+2.91	+3.93	.	.	.	M0.5 V

TABLE 3

Mean colors, bolometric corrections, and effective temperatures for giants of luminosity class III

Sp	*U–V*	*B–V*	*V–R*	*V–I*	*V–J*	*V–K*	*V–L*	*V–M*	*V–N*	*B. C.*	T_e (°K)
G8	+1.58	+0.95	+0.69	+1.18	+1.56	+2.15	+2.23	+1.99	+2.20	–0.23	4850
K0	+1.83	+1.01	+0.73	+1.25	+1.63	+2.24	+2.34	+2.06	+2.26	–0.27	4760
K1	+2.07	+1.07	+0.76	+1.30	+1.73	+2.39	+2.49	+2.20	+2.34	–0.33	4580
K2	+2.28	+1.14	+0.82	+1.39	+1.84	+2.54	+2.66	+2.34	+2.22	–0.41	4460
K3	+2.57	+1.24	+0.92	+1.56	+2.00	+2.76	+2.89	+2.54	+2.44	–0.56	4340
K4	+3.15	+1.43	+1.07	+1.82	+2.36	+3.26	+3.40	+3.03	+3.10	–0.83	3960
K5	+3.33	+1.51	+1.16	+2.04	+2.65	+3.55	+3.70	+3.31	+3.46	–1.06	3820
M0	+3.49	+1.57	+1.23	+2.23	+2.85	+3.85	+4.01	+3.59	+3.80	–1.29	3680
M1	+3.52	+1.60	+1.27	+2.32	+2.94	+3.97	+4.14	+3.70	+3.94	–1.37	3600
M2	+3.52	+1.60	+1.31	+2.42	+3.02	+4.02	+4.20	+3.75	+3.99	–1.43	3600
M3	+3.53	+1.60	+1.48	+2.65	+3.32	+4.41	+4.60	+4.11	+4.47	–1.74	3370
M4	+3.57	+1.63	+1.76	+3.35	+4.13	+5.29	+5.49	+4.98	+5.17	–2.51	3060
M5	–	+1.71	+2.09	+4.05	+4.95	+6.15	+6.36	+5.93	+5.97	–3.33	2800

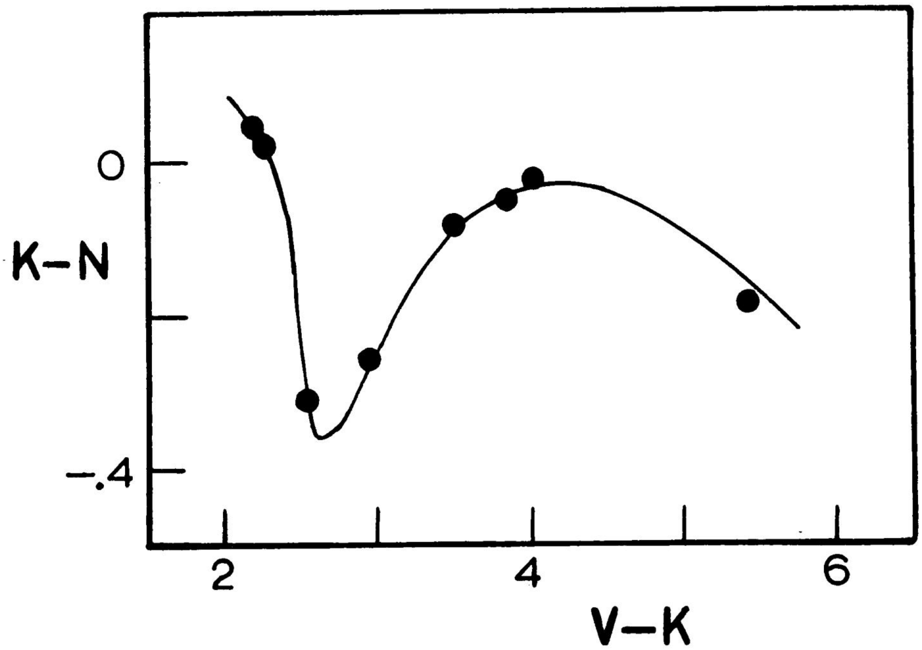

Figure 1.—*The relation between K—N and V—K for stars of Luminosity Class III.*

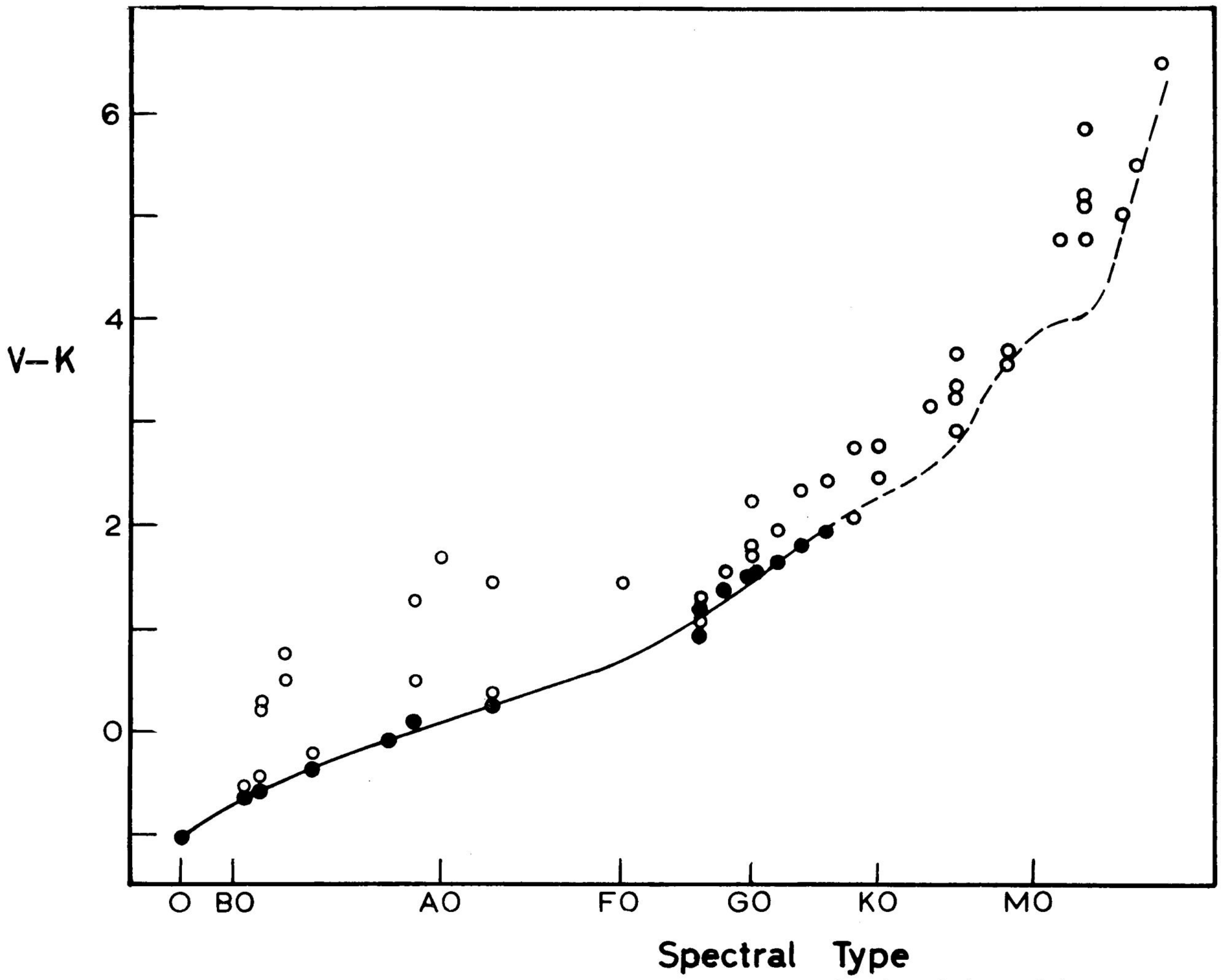

Figure 2.—*V—K versus Spectral Type for supergiants. See text for explanation of the symbols.*

it were added to V–K to obtain the tabulated values of V–N. Figure 1 also draws our attention to another interesting point –the dip in K–N at V–K = + 2.75. This dip corresponds to an absorption in the N filter band at about spectral type K2 or K3. The observational data for two stars, α Boo and α Ser, as well as the general trend of the plotted points for the other stars, are in agreement regarding the reality of this absorption. Nevertheless, confirmatory observations on other stars must be obtained before we can accept unreservedly the existence of this 10-micron absorption. The absorption at 5 microns, noticed by Low and Johnson (1964), appears again in these data and is shown, by a plot of K–M versus V–K, to be strongest at about M5; the data for χ Cyg (only one star, of course) suggest that this absorption becomes weaker in stars later than M5.

Next, we turn to the supergiant stars of Luminosity Class I and, for spectral types later than F5, Class II. Unfortunately, most of these stars are affected by interstellar reddening and the simple procedure that was adopted for Luminosity Class III cannot be employed. Nevertheless, a reasonably accurate determination of the intrinsic colors of these stars can be made, if we select only those stars which, according to Kron (1958), are little reddened. The procedure that has been used is illustrated in Figure 2, where the open circles designate supergiants of relatively small reddening, the filled circles, the positions of most of these stars earlier than G8 after correction for the reddening derived by Kron. (It was necessary to assume a mean Cygnus absorption law from Johnson and Borgman 1963, in order to compute the color-excesses in V–K. Since the excesses are small for these selected stars, variations in the law of extinction in different regions of the sky have little effect.) The dotted line is the relationship for Luminosity Class II-I taken from Table 3, and the solid line is the relationship adopted for the stars

TABLE 4

Mean colors, bolometric corrections and effective temperatures for supergiants of luminosity class I

Sp	*U–V*	*B–V*	*V–R*	*V–I*	*V–J*	*V–K*	*V–L*	*V–M*	*V–N*	*B. C.*	T_e *(°K)*
0	–1.45	–0.31	–0.15	–0.42	–0.66	–0.92	–	–	–	–	–
	Ia *Ib*										
B0	–1.29 –1.27	–0.24	–0.13	–0.33	–0.54	–0.73	–	–	–	–	–
B1	–1.19 –1.15	–0.19	–0.10	–0.26	–0.45	–0.60	–	–	–	–	–
B2	–1.13 –1.08	–0.17	–0.09	–0.23	–0.40	–0.53	–	–	–	–	–
B3	–1.00 –0.95	–0.13	–0.07	–0.17	–0.31	–0.43	–	–	–	–	–
B5	–0.87 –0.81	–0.09	–0.05	–0.12	–0.26	–0.33	–	–	–	–	–
B7	–0.73 –0.67	–0.05	–0.03	–0.10	–0.20	–0.22	–	–	–	–	–
B8	–0.62 –0.55	–0.02	–0.01	–0.05	–0.12	–0.12	–0.15	–	–	–	–
B9	–0.56 –0.48	0.00	0.00	0.00	–0.05	0.00	–0.03	–	–	–	–
A0	–0.47 –0.41	+0.02	+0.01	+0.05	+0.05	+0.10	+0.06	–	–	–	9600
A2	–0.23	+0.05	+0.06	+0.12	+0.14	+0.22	+0.21	–	–	0.00	8850
A5	+0.01	+0.08	+0.10	+0.21	+0.25	+0.38	+0.37	–	–	+0.10	8000
F0	+0.21	+0.15	+0.20	+0.35	+0.45	+0.67	+0.67	–	–	+0.07	7400
F2	+0.31	+0.18	+0.23	+0.40	+0.54	+0.76	+0.76	–	–	+0.07	7100
F5	+0.60	+0.36	+0.37	+0.63	+0.72	+1.07	+1.09	–	–	+0.07	6520
F8	+0.98	+0.55	+0.45	+0.77	+0.84	+1.25	+1.28	–	–	+0.08	6200
G0	+1.19	+0.73	+0.52	+0.88	+0.98	+1.43	+1.47	–	–	+0.04	5900
G2	+1.39	+0.86	+0.58	+0.96	+1.15	+1.61	+1.66	–	–	+0.01	5550
G3	+1.56	+0.90	+0.62	+1.02	+1.28	+1.77	+1.83	–	–	–0.07	5330
G5	+1.73	+0.95	+0.65	+1.08	+1.42	+1.96	+2.03	–	–	–0.16	5070
G8	+1.92	+1.00	+0.69	+1.18	+1.56	+2.15	+2.23	+1.99	(+2.18)	–0.25	4850
K0	+2.11	+1.05	+0.73	+1.25	+1.63	+2.24	+2.34	+2.06	(+2.27)	–0.30	4760
K1	+2.33	+1.13	+0.77	+1.30	+1.73	+2.39	+2.49	+2.20	–	–0.37	4580
K2	+2.60	+1.21	+0.83	+1.39	+1.84	+2.54	+2.66	+2.34	–	–0.40	4460
K3	+2.87	+1.32	+0.95	+1.56	+2.00	+2.76	+2.89	+2.54	–	–0.55	4340
K4	+3.20	+1.51	+1.10	+1.82	+2.36	+3.26	+3.40	+3.03	–	–0.85	3960
K5	+3.38	+1.59	+1.20	+2.08	+2.65	+3.55	+3.70	+3.31	–	–1.10	3820
M0	+3.54	+1.65	+1.25	+2.29	+2.85	+3.85	+4.01	+3.59	+3.84	–1.30	3680
M1	+3.57	+1.68	+1.29	+2.38	+2.94	+3.97	+4.14	+3.70	+3.96	–1.38	3600
M2	+3.57	+1.68	+1.33	+2.48	+3.02	+4.02	+4.20	+3.74	+4.01	–1.44	3600
M3	+3.58	+1.68	+1.50	+2.71	+3.32	+4.41	+4.60	+4.11	+4.39	–1.75	3370
M4	+3.62	+1.71	+1.78	+3.41	+4.13	+5.29	+5.49	+4.98	+5.27	–2.52	3060
M5	–	+1.79	+2.11	+4.11	+4.95	+6.15	+6.36	+5.93	+6.12	–3.34	2800

earlier than G8. Note that, for spectral types G8 and later, the Class III line represents the boundary of the supergiant area of the diagram and that, in fact, some of the supergiants lie on the Class III line. For V—K, the Class III line was adopted for Classes I and II, for spectral types G8 and later.

For the supergiants earlier than A0, color-excesses have been computed from the intrinsic colors tabulated by Johnson (1963) and a mean Cygnus-type absorption law, and by the procedures used by Johnson and Borgman (1963). Between A0 and G8, the line has been drawn in as well as possible to represent the lower envelope of the supergiant region.

Similar procedures were followed for the other color-indices. For V—I, V—R, B—V and, especially, U—V, there is evidence that the colors of supergiants differ from those of giants, even for the G8 to M5 stars. The intrinsic colors that were derived from this analysis are given in Table 4. For the early-type stars, data at the longest wavelengths are not available. Also, there are not sufficient data to establish whether or not the 10-micron absorption shown in Figure 1 also exists in the supergiants; the values of V—N from K1 to K5, therefore, have been omitted from the table. The Bolometric Corrections and Effective Temperatures in the last two columns will be explained below.

TABLE 5

Mean colors, bolometric corrections and effective temperatures for main-sequence stars of luminosity class V

U—V	*B—V*	*V—R*	*V—I*	*V—J*	*V—K*	*V—L*	*V—M*	*V—N*	*B. C.*	T_e (°K)
—1.45	—0.31	—0.15	—0.42	—0.66	—0.92	—	—	—	—	—
—1.38	—0.30	—0.14	—0.40	—0.65	—0.89	—	—	—	—	—
—1.14	—0.25	—0.14	—0.34	—0.55	—0.71	—	—	—	—	—
—0.91	—0.20	—0.10	—0.27	—0.44	—0.55	—	—	—	—	—
—0.67	—0.15	—0.08	—0.20	—0.32	—0.39	—	—	—	—	—
—0.44	—0.10	—0.06	—0.13	—0.19	—0.24	—	—	—	—	—
—0.20	—0.05	—0.03	—0.06	—0.09	—0.12	—	—	—	—	—
0.00	0.00	0.00	0.00	0.00	0.00	0.00	—	—	+0.03	9500
+0.18	+0.10	+0.09	+0.13	+0.18	+0.23	+0.26	—	—	+0.07	8650
+0.28	+0.20	+0.17	+0.28	+0.36	+0.49	+0.54	—	—	+0.07	7800
+0.35	+0.30	+0.28	+0.44	+0.52	+0.70	+0.76	—	—	+0.07	7350
+0.40	+0.40	+0.37	+0.59	+0.70	+0.95	+1.04	—	—	+0.07	6790
+0.53	+0.50	+0.44	+0.72	+0.85	+1.18	+1.28	—	—	+0.05	6350
+0.72	+0.60	+0.51	+0.84	+1.02	+1.40	+1.52	—	—	0.00	5940
+0.96	+0.70	+0.58	+0.95	+1.18	+1.61	+1.74	—	—	—0.04	5570
+1.24	+0.80	+0.65	+1.07	+1.33	+1.83	+1.98	—	—	—0.11	5310
+1.54	+0.90	+0.73	+1.21	+1.49	+2.04	+2.21	—	—	—0.20	5080
+1.84	+1.00	+0.84	+1.36	+1.67	+2.26	+2.44	—	—	—0.32	4930
+2.11	+1.10	+0.94	+1.54	+1.89	+2.57	+2.76	—	—	—0.48	4640
+2.35	+1.20	+1.04	+1.72	+2.13	+2.89	+3.09	—	—	—0.67	4350
+2.54	+1.30	+1.15	+1.90	+2.37	+3.20	+3.41	—	—	—0.87	4120
+2.64	+1.40	+1.25	+2.08	+2.67	+3.47	+3.69	—	—	—1.09	3950

The intrinsic colors for main-sequence stars, listed in Table 5, were derived by a combination of the techniques used for the giants and the supergiants. It was assumed that the main-sequence stars later than A0 are unreddened. Plots of the several color-indices versus B—V were constructed, smooth curves drawn in, and the tabulated values read from these curves. For the main-sequence stars earlier than A0, color-excesses have been computed from the intrinsic colors of Johnson (1963) and a mean Cygnus-type absorption law, and by the procedures used by Johnson and Borgman (1963). The relation between spectral type on the main sequence and B—V, essentially that of Harris (1963), is given in Table 6. The Bolometric Corrections and Effective Temperatures are derived in the next two sections of this paper.

TABLE 6

Mean B—V colors, bolometric corrections, and effective temperatures for main-sequence stars of luminosity class V

Sp	B—V	B. C.	T_e (°K)
0	—0.31	—	—
B0	—0.30	—	—
B2	—0.24	—	—
B5	—0.16	—	—
B7	—0.12	—	—
B8	—0.09	—	—
B9	—0.06	—	—
A0	0.00	+0.03	9500
A2	+0.06	+0.05	8990
A5	+0.15	+0.07	8220
A7	+0.20	+0.07	7800
F0	+0.33	+0.07	7180
F2	+0.38	+0.07	6900
F5	+0.45	+0.06	6570
F8	+0.53	+0.03	6230
G0	+0.60	0.00	5940
G2	+0.63	0.00	5800
G5	+0.68	—0.03	5640
G8	+0.72	—0.05	5520
K0	+0.81	—0.12	5290
K2	+0.92	—0.23	5050
K5	+1.15	—0.64	4410
K7	+1.35	—0.95	4090

IV.—Absolute Intensities and Bolometric Corrections

No direct absolute-intensity measures have yet been made as a part of this program. It is possible, however, to use the comparison of the Sun with various stars (Stebbins and Kron 1957) to provide a reasonably satisfactory absolute calibration. Several of the stars with which Stebbins and Kron compared the Sun are listed in Table 2 and these data, plus the known stellar spectral type of the Sun (G2 V), made possible the derivation of the color-indices that are listed in Table 7. The apparent visual magnitude, V, of the Sun is that determined by Stebbins and Kron.

TABLE 7

The magnitude and colors of the sun

V	U—V	B—V	V—R	V—I	V—J	V—K	V—L	V—M	V—N	B. C.	T_e(°K)
—26.73	+0.73	+0.63	+0.53	+0.87	+1.07	+1.45	+1.58	+1.40	+1.60	0.00	5800

The next step in the calibration procedure was the computation of the ratios of the energy at magnitude V to that for the other nine magnitudes, from the Solar energy data of Allen (1963). These ratios, converted to magnitudes, were combined with the color-indices in Table 7 to provide an absolute calibration of the photometry in Table 2.

If we assume that there are no unknown or unusually strong stellar spectral features, such as water-vapor bands, in the spectral regions inaccessible because at atmospheric absorption, we can integrate under the derived absolute energy curves and obtain the total stellar energies reaching the Earth. These integrations have been carried out, using V = —26.73 for the Sun and a Solar Constant of 1.99 cal/cm²/min (Allen 1963).

This procedure is rather indirect and, consequently, it is possible that the conclusions are systematically in error, especially for the longer wavelengths and the cooler stars. Fortunately, the radiometric data of Pettit and Nicholson (1928) can be used to evaluate these errors. Figure 3 shows the relation between the absolute intensity measures of Pettit and Nicholson and the absolute intensities integrated as indicated above, for a number of stars common to both investigations. Two types of systematic differences are evident: (1) The absolute intensities derived from the data of this paper are systematically larger than those of Pettit and Nicholson, by a factor of 1.21 for Solar-type stars. (2) The intensities from the present data become progressively smaller, compared with those of Pettit and Ni cholson, for the cooler stars.

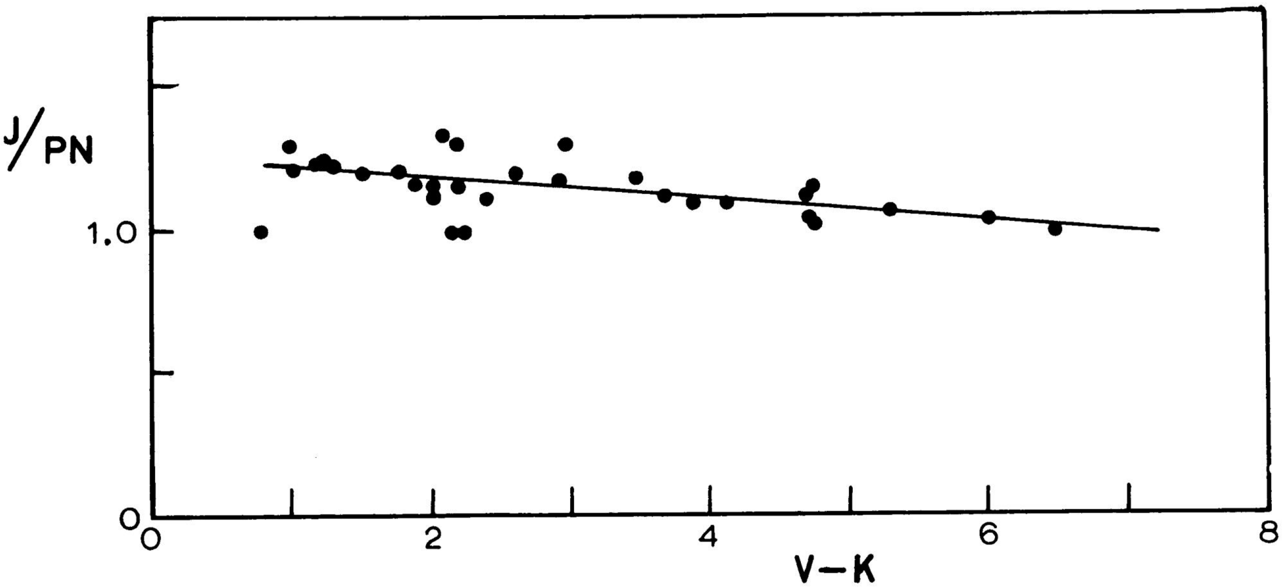

Figure 3.—*The ratio, J/PN, of the absolute intensities from these investigations to those of Pettit and Nicholson as a function of V–K.*

The systematic difference for the Solar-type stars is due almost entirely to our acceptance of the apparent visual magnitude of the Sun (V = –26.73) obtained by Stebbins and Kron; Kuiper (1938) has shown that the radiometric data of Pettit and Nicholson lead to an apparent visual magnitude for the Sun of –27.94 mag. This interpretation implies that Pettit and Nicholson underestimated the losses in the 100-inch telescope by about 20%. A small portion of the difference is due to our assumption that the Solar Constant is 1.99 cal/cm²/min, rather than the 1.93 adopted by Pettit and Nicholson.

The computation of total absolute energies received at the Earth from Solar-type stars is dependent only upon the measured stellar V magnitudes (from Table 2) and the adopted values of the Solar Constant and Solar visual magnitude. The computation of energies for other types of stars depends also upon the details of the integrations under the absolute spectral energy curves derived from the data of Table 2, as outlined above. The results depend upon the exact effective wavelengths that are used for the several filter bands and, since we have only ten rather widely spaced points in the spectrum, the exact way in which the interpolation between the observed points is made. Sample computations have shown that small modifications of the effective wavelengths and the interpolations, permitted by the precision of the data, can remove the temperature dependence between our total energies and those of Pettit and Nicholson. There is no reason to suppose that the thermocouples employed by Pettit and Nicholson would respond differently for cool stars than for Solar-type stars, since this would imply improbably poor-blackening of the thermocouples. On the other hand, our absolute calibration procedure could introduce such an error. Accordingly, we have corrected our derived absolute intensities so that they are, on the average, 1.21 times those of Pettit and Nicholson. The correction factor is 1.21 divided by J/PN, read from Figure 3 for the V–K of the star. If the assumption that the radiometric data of Pettit and Nicholson are independent of stellar temperature is incorrect (and the fact that they appear to have underestimated the telescope losses may cause some hesitation), the Bolometric Corrections and Effective Temperatures derived here may be slightly too large, for the cooler stars.

The Bolometric Correction, B. C., is defined as $m_B - V$ and is the correction to be applied to V to obtain the apparent Bolometric magnitude. The apparent Bolometric magnitude is simply the integrated absolute intensity expressed in magnitudes, and we have set the zero-point so that B. C. = 0.00 for the Sun. The values of B. C. = $m_B - V$ were computed as indicated and are listed in the next-to-last columns of Tables 3, 4, 5 and 6.

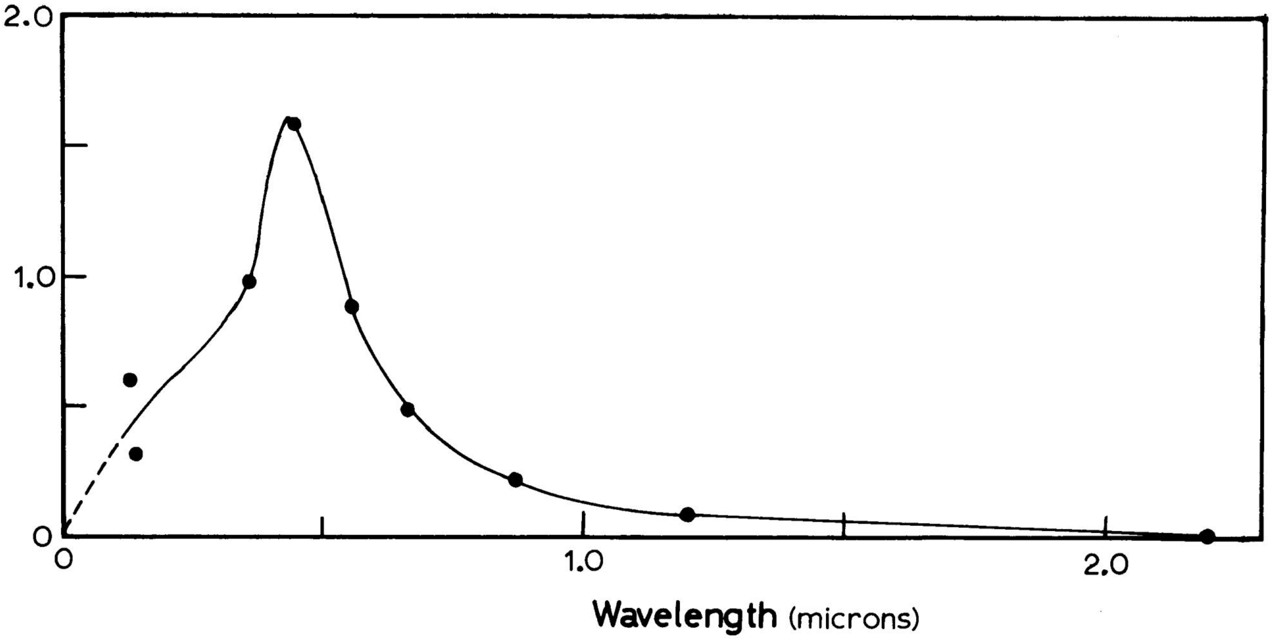

Figure 4.—*The absolute spectral energy distribution for α Gem. The scale of the ordinate is in units of* 10^{-9} *erg/cm*^{2}*/sec/A.*

The reader will notice that the Bolometric Corrections for A-type stars are smaller (more positive) than those obtained previously (Kuiper 1938; Popper 1959; Harris 1963) for such stars. These new values for B. C. are dependent upon the rocket observations at 1314 and 1427 A by Chubb and Byram (1963), who found that stellar brightnesses at these wavelengths are less than expected from Kuiper's results. The derived absolute intensity curve for the A1V star, α Gem, is shown in Figure 4. The curve plainly differs from that for a black body; for example, while the effective temperature probably is near to 9200°K (see below), the peak radiation occurs at approximately 4200A, rather than at 3150A as predicted from the black-body curve for this temperature.

V.—Effective Temperatures

The Effective Temperature of a star is defined as the temperature of a black body which produces the same total energy per unit surface area as does the star. Therefore, in order to compute the effective temperature of a star, we must know both its angular diameter and the total flux of energy received from the star per unit area on the earth; only for the Sun are these quantities known with sufficient precision that an accurate effective temperature (5800°K; Allen 1963) can be computed. Several other stars listed in Table 2 have had their angular diameters determined, however, and when these dia-

TABLE 8

The stars with known angular diameters

Star	*B. C.*	*V*	*Diameter*	*T. (°K)*
α CMa	+0.03	−1.46	0″.0072	8830
β Aur	+0.05	+2.65*	0″.000826	10084
α Boo	−0.70	−0.06	0″.020	4169
α Tau	−1.15	+0.86	0″.020	3775
α Ori	−1.44	−0.60	0″.041	3981
α Sco	−1.38	−0.04	0″.040	3475
β Peg	−1.43	+1.66	0″.021	3300
o Cet	−7.57	+8.12	0″.053	2014
YY Gem	−1.38	+9.82*	0″.000415	3793
Sun	0.00	−27.73	1958″.7	5800
α Lyr	—	—	—	9500
σ Boo	—	—	—	6800

* Magnitude of mean component.

meters are combined with the total energies computed according to the procedures outlined in Section IV, their effective temperatures may be determined. These stars, their Bolometric Corrections, Visual magnitudes, measured diameters and computed Effective Temperatures are listed in Table 8. The diameter of α CMa is that of Brown and Twiss (1956) as rediscussed by Popper (1959); that of β Aur also follows from the discussion of Popper. The diameter of the mean component of YY Gem was taken from Kron's (1952) investigation, and combined with the trigonometric parallax of 0".072 (Jenkins 1952). The diameter of o Cet was estimated for the phase of our observations from the curve of Pettit and Nicholson (1933). For the other stars, the diameters are those given by Kuiper (1938); with the exception of α Ori, these diameters are the same as those given by Pettit and Nicholson (1928) and were derived from the interferometric observations of Michelson and Pease. The corrections for limb darkening computed by Kuiper (1938) have been used for the stars to which they apply. Three of the stars, α Ori, α Sco and β Peg are affected by interstellar absorption; for these stars, the visual magnitude in Table 8 is the observed magnitude from Table 2 corrected by the color-excess in V—N. (We have assumed that the absorption in N is zero and that the absorption in V is equal to E_{V-N}). For these three stars, the Bolometric Corrections were read from Tables 2 and 3 for their spectral types. Because of the uncertainties in the interstellar absorption corrections, these three stars were given one-third the weight of the other stars. The temperatures for α Lyr (Hunger 1955) and σ Boo (Code 1954) have been included in the table but, because they are not direct determinations, have been given very little weight in the analysis.

There are only ten stars, including the Sun, for which direct determination of the Effective Temperature is possible. We must, therefore, find some means of interpolating between the data for these

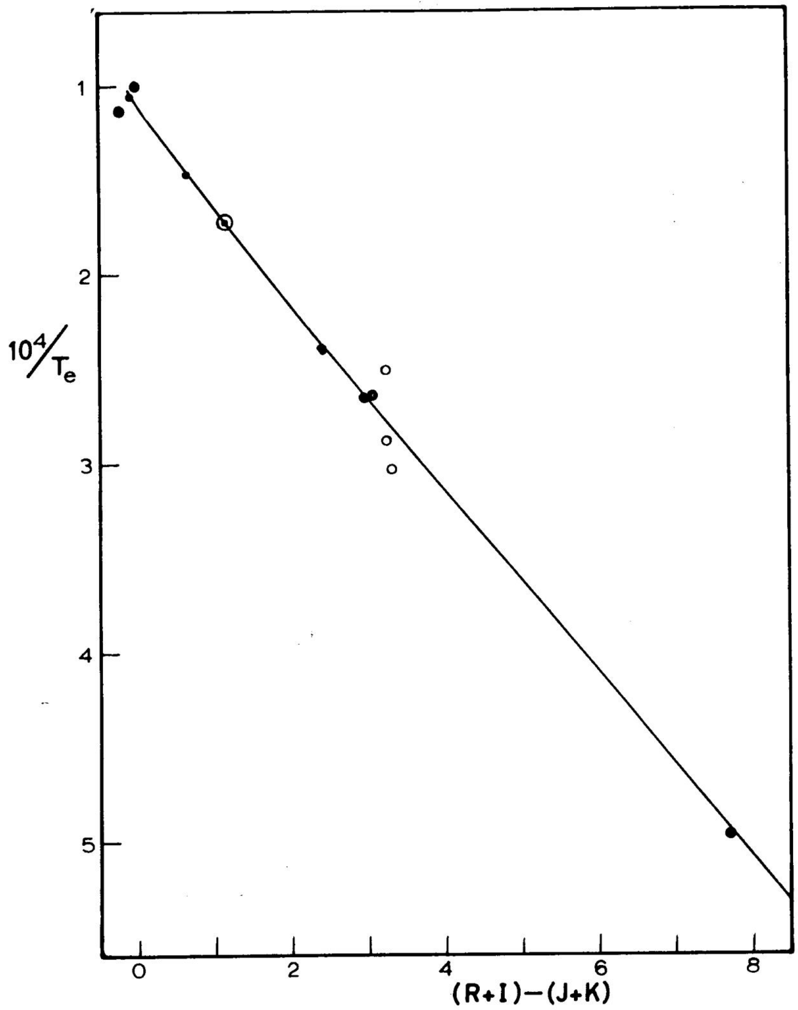

Figure 5.—*The calibration of Effective Temperature in terms of (R + I) — (J + K). The large spots designate α CMa, β Aur, α Tau, o Cet, and YY Gem; the open circles, the reddened stars, α Ori, α Sco and β Peg. The small spots designate α Lyr and σ Boo, which have been given little weight. The spot contained within the largest circle designates the Sun.*

stars if we are to determine the effective temperatures of other stars; fortunately, the range of temperatures for which there are direct determinations is such that, for spectral types later than A0, the process is indeed interpolation, rather than extrapolation. The only procedure open to us is to find some satisfactory relationship between the color-indices of Table 2 and the Effective Temperatures as defined by the stars of Table 8. Several combinations of these indices have been tried, all leading to nearly the same temperatures. We have adopted the color-index, (R + I) − (J + K), formed from measures centered around the wavelength of one micron, for this interpolation. The relationship between Effective Temperature (in the form of $10^4/T_e$) and this index is illustrated in Figure 5. The solid line is the adopted interpolation formula, which is not simply a line drawn on the diagram, but has been computed for black body radiation passing through the filter bands, R, I, J and K. This theoretical curve was adjusted slightly to pass through the point for the Sun and to fit with the other points. The Effective Temperatures in the last columns of Tables 3, 4, 5 and 6, and elsewhere in this paper, were computed from this interpolation formula. As Figure 5 shows, this formula represents satisfactorily the available data.

VI.—The Zero-Age Main Sequence (ZAMS)

On the reasonable assumption that the colors of stars on the zero-age main sequence (ZAMS) are the same as those of other stars of Luminosity Class V, the values of Aboslute Bolometric Magnitude, M_B, and Log T_e that are given in Table 9 were computed. The zero-age main sequence is that of Johnson (1963) and Johnson and Iriarte (1958).

TABLE 9

The Zero-Age main sequence (ZAMS)

B−V	M_v	M_B	*Log* T_e
−0.25	−2.10	—	—
−0.20	−1.10	—	—
−0.15	−0.30	—	—
−0.10	+0.50	—	—
−0.05	+1.10	—	—
0.00	+1.50	+1.53	3.978
+0.05	+1.74	+1.79	3.957
+0.10	+2.00	+2.07	3.937
+0.20	+2.45	+2.52	3.892
+0.30	+2.95	+3.02	3.866
+0.40	+3.56	+3.63	3.832
+0.50	+4.23	+4.28	3.803
+0.60	+4.79	+4.79	3.774
+0.70	+5.38	+5.34	3.746
+0.80	+5.88	+5.77	3.725
+0.90	+6.32	+6.12	3.706
+1.00	+6.78	+6.42	3.693
+1.10	+7.20	+6.72	3.666
+1.20	+7.66	+6.99	3.638
+1.30	+8.11	+7.24	3.615

By now, the reader has undoubtedly noticed that Tables 5, 6 and 9 contain no data for stars later than about K7 V. We would like very much, of course, to extend these data to stars of later type but, unfortunately, only a few such stars have yet been observed on this program. Furthermore, the analysis of the data now available suggests that the few red dwarfs that have been observed may not be typical, in spectral energy distribution, of red dwarfs in general. The derived data for the few stars that have been observed is, however, of interest and is included in Table 10, along with the similar data for three subdwarfs.

There are several other M-dwarfs for which only U, B, V, R, and I are listed in Table 2; Kron, Gascoigne and White (1957) have published R and R − I for many more. If we assume that satisfactory values of M_B and Log T_e can be computed for these stars from the data that are available (but this is the contretemps; compare the colors for BD + 4° 3561 and BD + 43° 44B), Figure 6 may be drawn. The solid line is the ZAMS from Table 9 and has been extended to fainter, redder stars. Note, however, that the open circles, which represent the stars of Table 10, deviate systematically from the other points.

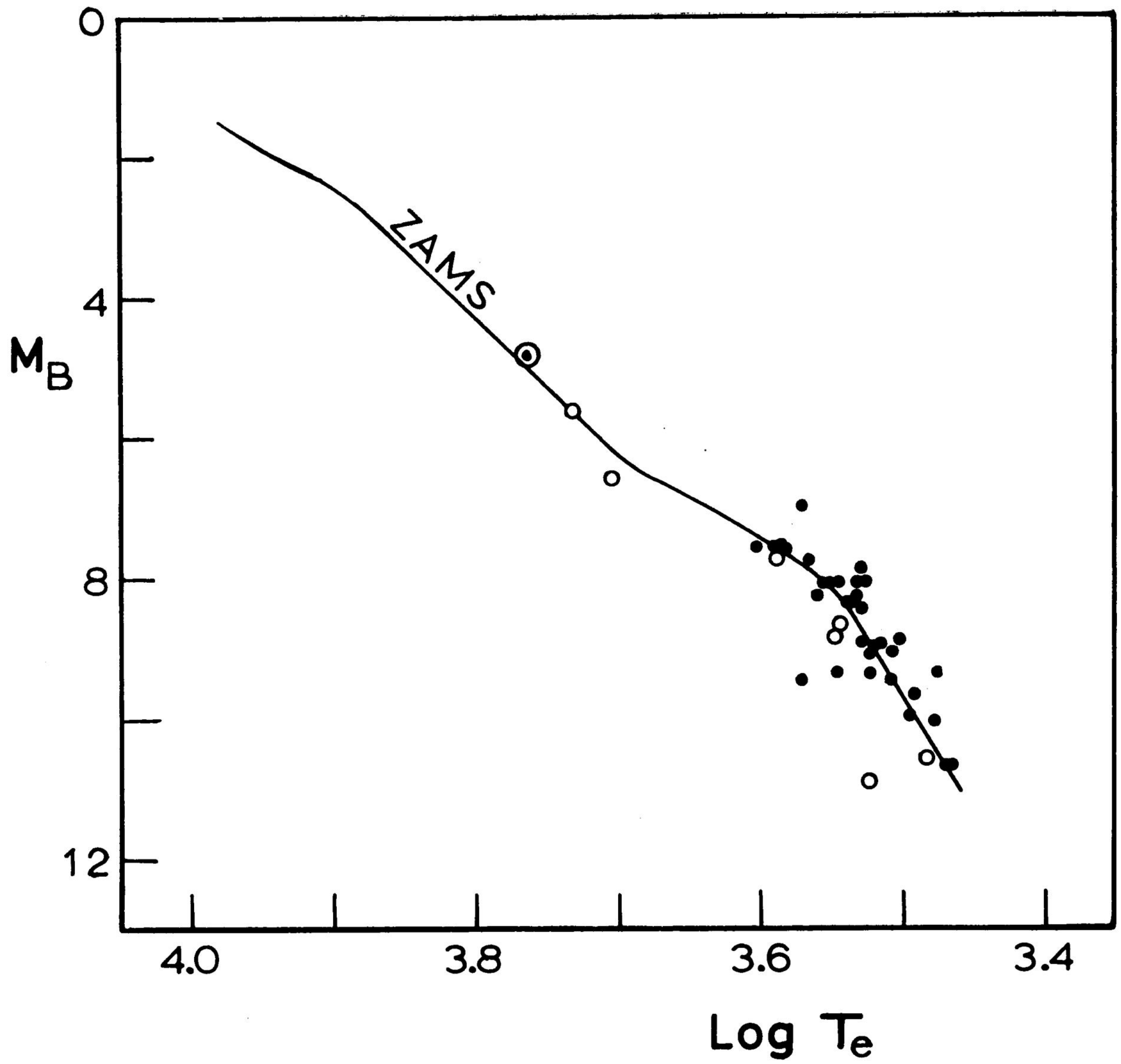

Figure 6.—M_B *versus Log* T_e *for the Zero-Age Main Sequence (ZAMS). The open circles designate the stars of Table 10; the small spots, stars for which* M_B *and Log* T_e *were determined from R and R—I only. The spot contained within the largest circle designates the Sun.*

TABLE 10

Selected stars

Star	π	*Sp*	*B. C.*	M_B	T_e *(°K)*
YYGem	″.072 ± 4	M0.5V	– 1.38	7.73	3790
BD +43°44A	″.278 ± 7	M1V	– 1.55	8.74	3510
HD 95735	″.398 ± 5	M2V	– 1.71	8.78	3520
BD +4° 3561*	″.545 ± 3	M5V	– 2.31	10.91	3330
BD +43°44B	″.278 ± 7	M6V	– 2.64	10.62	3040
HD 140283		sdF5	– 0.06		5900
BS 4550*	″.116 ± 5	G8Vp	– 0.21	6.56	5050
BS 509*	″.275 ± 5	G8Vp	– 0.12	5.58	5400

* B. D. + 4°3561 = Barnard's Star
BS 4550 = Groombridge 1830
BS 509 = τ Cet.

With regard to the subdwarfs included in Table 10, it is worthy of mention that τ Cet falls exactly on the ZAMS in the M_B vs. Log T_e diagram. On the other hand, BS 4550 = Groombridge 1830 still falls below by about 0.4 mag, in excellent agreement with the value, 0.35 mag, found by Sandage and Eggen (1959) from theoretical line blanketing corrections. The value of T_e for HD 140283, 5900°K, is in good agreement with that derived by Sandage and Eggen.

VII.—Conclusion

While it is necessary to say again that this paper is a report on a program which is still in progress, it is nevertheless evident that this second approximation is better than the first one (Johnson 1962). We have been able to provide intrinsic colors for many supergiants, giants and dwarfs, as well as improved Bolometric Corrections and Effective Temperatures.

A comparison of these new Bolometric Corrections and Effective Temperatures with those of Kuiper evinces several differences. The new values for stars around A0 differ from Kuiper's mainly because the rocket data of Clubb and Byram indicate that hot stars produce less ultraviolet energy than was thought previously. Our Effective Temperatures for the cooler stars are higher than Kuiper's because of the new Solar visual magnitude by Stebbins and Kron. Kuiper had very little actual data for the M-dwarfs and his values are chiefly extrapolations from warmer stars. There have been several more recent discussions of stellar Bolometric Corrections and Effective Temperatures (Kopal 1955; Popper 1959; Harris 1963).

This analysis of the new data in Table 2 has brought to our attention three points where the present program is deficient. First, we need more U, B, V, R, I, J, K observations of M-dwarfs, and a program to remedy this deficiency has been begun. Second, there is a great need for more measures of the angular diameters of stars; the new intensity interferometer of Brown and Twiss will be of considerable help in this matter, but it is useful only for hot stars for which the surface brightness is high. A Michelson interferometer is necessary for the cooler stars. Third, the derivation of Effective Temperatures and Bolometric Corrections for the hot stars, earlier than A0, stands in need of more and better observations at wavelengths shorter than 0.3 micron.

Much of the observational work in this program has been aided by financial support from the Office of Naval Research to the University of Arizona. The construction of the photometric apparatus, including the 28-inch telescope at the Catalina Station of the Lunar and Planetary Laboratory was aided financially by the National Science Foundation. The construction of the equipment for the photometry at 10 microns was financed by the National Aeronautics and Space Administration. This paper was written during an extended visit to the Observatorio Astrofísico Nacional de Tonantzintla, in the winter of 1963-64.

Observers on this program have been R. I. Mitchell, K. Underwood, D. Steinmetz, W. Wiesniewski and S. Svolopoulos. The reductions of the photometric data were carried out under Mr. Mitchell's direction.

R E F E R E N C E S

Allen, C. W. 1963, *Astrophysical Quantities* (London: Athlone Press).

Brown, R. H. and Twiss, R. Q. 1956, *Nature*, **178**, 1046.

Chubb, T. A. and Byram, E. T. 1963, *Ap. J.*, **138**, 617.

Code, A. D. 1954, *Proceedings of the N. S. F. Conference on Stellar Atmospheres*, ed. M. H. Wrubel (Bloomington: Univ. of Indiana Press), p. 14.

Eggen, O. J. 1963, *A. J.*, **68**, 697.

Harris, D. L. III 1963, *Compendium of Astronomy and Astrophysics*. (Univ. of Chicago Press), **3**, 263.

Hunger, K. 1955; *Zs. f. Ap.*, **36**, 42.

Jenkins, L. F. 1952, *General Catalogue of Trigonometric Stellar Parallaxes*, (Yale Univ. Obs.)

Johnson, H. L. 1955, *Ann. d' Ap.* **18**, 292.

Johnson, H. L. 1962, *Ap. J.*, **135**, 69.

Johnson, H. L. 1963, *Compendium of Astronomy and Astrophysics* (Univ. of Chicago Press), 3, 204.

Johnson, H. L. and Borgman, J. 1963, *B. A. N.*, **17**, 115.

Johnson, H. L. and Harris, D. L. 1954, *Ap. J.*, **120**, 196.

Johnson, H. L. and Iriarte, B. 1958, *Lowell Obs. Bull.*, **4**, 47.

Johnson, H. L. and Mitchell, R. I. 1962, *Communications of the Lunar and Planetary Lab.*, No. 14.

Johnson, H. L. and Mitchell, R. I. 1963, *Ap. J.*, **138**, 302.

Johnson, H. L. and Morgan, W. W. 1953, *Ap. J.*, **117**, 313.

Kopal, Z, 1955. *Ann. d'Ap.*, **18**, 379.

Kron, G. E. 1952, *Ap. J.*, **115**, 301.

Kron, G. E. 1958, *Pub. A. S. P.*, **70**, 561.

Kron, G. E., Gascoigne, S. C. B. and White, H. S. 1953, *Ap. J.*, **118**, 502.

Kron, G. E., Gascoigne S. C. B. and White H. S. 1957, *A. J.*, **62**, 205.

Kuiper, G. P. 1938, *Ap. J.*, **88**, 429.

Low, F. J. and Johnson, H. L. 1964, *Ap. J.*, **139**, 1130.

Pettit, E. and Nicholson, S. B. 1928, *Ap. J.*, **68**, 279.

Pettit, E. and Nicholson, S. B. 1933, *Ap. J.*, **78**, 320.

Popper D. M. 1959, *Ap. J.*, **129**, 647.

Sandage, A. R. and Eggen, O. J. 1959, *M. N.*, **119**, 278.

Schmidt, T. 1948, *Zs. f. Ap.*, **46**, 145.

Stebbins, J. and Kron, G. E. 1957, *Ap. J.*, **126**, 266.

Wildey, R. and Murray, B. 1964, *Ap. J.*, **139**, 435.