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INFRARED PHOTOMETRY OF HIGH-LUMINOSITY SUPERGIANTS EARLIER THAN M AND THE INTERSTELLAR EXTINCTION LAW

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ABSTRACT

Photometric measurements from 2.3 to 23 μ are reported for luminous supergiants with spectral types earlier than M. Only HD 190323 (G0 Ia–Iab) showed hitherto unreported excess emission near 10 μ. We conclude that the previously reported excess infrared emission from luminous supergiants having intermediate spectral types is not a universal feature of these stars.

A 4.9 μ absorption feature, possibly caused by the fundamental vibration band of CO or CN, appears abruptly in the supergiants near spectral type G5.

An infrared reddening law has been derived from the supergiant photometry at 2.3, 3.6, 4.9, 8.7, 10 and 11.4 μ using the color difference method. An extrapolation of this reddening curve implies a ratio of total to selective extinction of $R = 3.40 \pm 0.15$.

Subject headings: infrared — interstellar extinction — luminous stars — molecules

I. INTRODUCTION

Infrared emission near 10 μ is a well-documented feature of M supergiants (Gehrz, Ney, and Strecker 1971; Gehrz and Woolf 1971; Humphreys, Strecker, and Ney 1972; Cohen and Gaustad 1973). Certain luminous supergiants of earlier spectral type also emit considerable excess infrared radiation. Humphreys, Strecker, and Ney (1971) found intense optically thin silicate emission from the luminous G supergiants HR 5171A (G8 Ia$^+$), HR 6392 (G5 Ia), and HR 4337 (G0 Ia$^+$). Excess infrared radiation has also been reported from 89 Her (F2 Ia) by Gillett, Hyland, and Stein (1970); W Cep (K0ep Ia), by Gehrz and Woolf (1971); BM Sco (K2.5 Ib), by Humphreys and Ney (1974*b*); HD 101584 (F2e Iap), by Humphreys and Ney (1974*a*); and IRC +60370 (K0 Ia), by Humphreys and Ney (1974*c*). It has been suggested by Humphreys and Ney (1974*a*) that the infrared radiation from some of these objects might be from a cool companion rather than from the supergiant.

A study was initiated at the University of Wyoming to survey luminous supergiants having spectral classes earlier than M to determine the frequency of excess infrared emission among them. A further objective of the survey was to investigate interstellar reddening as far into the infrared as possible by using the color-difference method. Johnson (1965, 1968) has made a similar study, but many of his data longward of 5 μ refer to stars which are now known to emit excess infrared radiation. Lee's (1970) self-consistent derivation of intrinsic colors and reddening law for M supergiants extends only to a wavelength of 3.4 μ.

To measure interstellar extinction, a set of objects must be used which are bright at infrared wavelengths, have colors which can be estimated with reasonable certainty, and, to minimize errors introduced by the relatively inaccurate infrared measurements, have a high total extinction. Luminous supergiants earlier than M satisfy these criteria well. M supergiants are unsuited for extinction-law studies at wavelengths longer than 3.4 μ because the emission from circumstellar dust, which is dependent upon many parameters (Cohen and Gaustad 1973), makes it difficult to estimate intrinsic colors. Circumstellar dust emission does not appear to be a common feature of F, G, and K supergiants.

II. OBSERVATIONS

Supergiants with spectral types earlier than M and luminosities Ia or Iab were culled from the lists of Humphreys (1970) and of Smolinski (1971). As complete coverage as possible was attempted of all luminosity type Ia or Iab stars of spectral class F, G, or K accessible from Kitt Peak National Observatory. Coverage of spectral classes O, B, and A was less comprehensive.

Infrared observations were made with the 50-inch (130-cm) telescope at Kitt Peak National Observatory during the period 1972 September to 1973 November. Infrared photometers designed and built at the University of Wyoming were used to make the measurements. The operation and calibration of these instruments have been described by Gehrz, Hackwell, and Jones (1974). Filter bandwidths, effective wavelengths, and a list of calibration stars used in this study are given in table 1.

III. RESULTS

Magnitudes of the stars measured during this survey are given in table 1. Most stars were measured more than once, and in these cases a mean is listed. Significant infrared light variations were observed only for

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TABLE 1

NEW INFRARED PHOTOMETRY OF SUPERGIANTS

Star Name	Sp	λ=	2.3μ	3.6μ	4.9μ	8.7μ	10.0μ	11.4μ	12.6μ	19.5μ	23μ
		Δλ=	0.7μ	1.2μ	0.7μ	1.0μ	5.8μ	2.0μ	0.8μ	6 μ	6μ
HD 169454	B1Ia^{+}		3.87	3.62	3.34	3.55	-	3.62	-	-	-
HD 13854	B1Iab		5.62	5.53	5.68	-	≥ 4.83	-	-	-	-
10 Per	B2Ia		5.39	5.32	5.20	-	4.72	-	-	-	-
HD 14143	B2Ia		5.26	5.16	4.93	-	≥ 5.31	-	-	-	-
HD 14134	B3Ia		5.35	5.22	5.06	-	≥ 4.99	-	-	-	-
5 Per	B5Ia		5.33	5.24	5.04	-	≥ 5.45	-	-	-	-
HD 223960	A0Ia^{+}		4.76	4.55	4.38	4.37	4.12	4.35	-	-	-
HD 12953	A1Ia		3.93	3.78	3.64	3.34	-	3.20	-	-	-
HD 14433	A1Ia		4.74	4.62	4.41	4.11	4.38	-	-	-	-
9 (ι) Per	A2Ia		4.05	3.95	3.80	3.93	3.88	3.76	-	-	-
6 Cas	A3Ia^{+}		3.41	3.20	3.10	2.98	2.99	2.89	-	-	-
HD 13476	A3Iab		4.73	4.52	4.50	4.06	4.19	4.15	-	-	-
HD 17378	A5Ia		3.70	3.53	3.41	3.49	3.60	3.13	-	-	-
φ Cas	F0Ia		3.10	2.92	2.83	2.80	2.79	2.87	-	-	-
89 Her	F2Ia		3.38	1.82	0.91	-0.42	- 0.76	- 1.08	- 1.03	- 1.48	- 1.27:
HD 10494	F5Ia		4.08	3.89	3.76	3.87	-	3.73	-	-	-
HD 17971	F5Ia		4.39	4.17	4.03	3.78	-	4.03	-	-	-
HD 231195	F5Ia		3.96	3.73	3.66	3.44	3.66	3.51	-	-	-
44 Cyg	F5Iab		3.50	3.35	3.28	3.36	3.44	3.70	2.97	-	-
T Mon	F7-K1Ia		3.67	3.52	3.62	3.45	3.48	3.17	-	-	-
HD 331777	F8Ia		4.35	4.06	3.80	3.40	3.97	3.72	≥ 2.13	-	-
δ CMa	F8Ia		0.35	0.21	0.16	0.10	0.21	0.19	0.36	≥-0.68	-
ρ Cas	F8pIa		2.10	1.91	1.63	1.63	1.62	1.76	1.77	-	-
HD 18391	G0Ia		2.35	2.09	1.96	1.88	1.91	1.94	1.93	-	-
HD 217476	G0Ia		1.23	0.97	0.71	0.36	0.50	0.59	0.46	0.18	-
HD 190323	G0Ia-Iab		4.81	4.75	4.44	4.39	-	3.45	-	-	-
HD 12399	G5Ia		3.75	3.55	3.45	3.17	3.27	3.49	-	-	-
HD 187299	G5Iab-Ib		3.52	3.36	3.75	3.30	3.18	3.69	-	-	-
HD 38247	G8Iab		3.13	2.95	3.18	3.11	2.98	2.85	-	-	-
W Cep	K0epIa+B		2.38	1.49	0.88	-0.68	- 1.18	- 1.69	- 1.40	- 2.39	- 2.67:
HD 221861	K0Iab		1.97	1.74	1.93	1.63	1.70	1.71	2.01	-	-
HD 45829	K0Iab		3.31	3.14	3.41	3.20	3.17	3.17	-	-	-
BM Sco	K2.5Ib		1.85	1.15	0.61	-0.54	- 0.85	- 1.01	- 1.11	- 1.71	-
HD 4817	K5Ib		1.54	1.32	1.59	1.39	1.34	1.27	1.23	-	-
o^{1} CMa	K3Iab		0.37	0.08	0.44	0.03	0.00	- 0.06	- 0.06	- 0.60	-
HD 187238	K3Iab-Ib		2.36	2.13	2.46	2.18	2.01	2.03	2.19	-	-
HD 11092	K5Iab-Ib		1.63	1.41	1.65	1.41	1.44	1.35	1.40	-	-
CALIBRATION STARS											
α Lyr	A0V		-0.02	-0.03	-0.03	-0.03	- 0.03	- 0.03	- 0.03	- 0.03	- 0.03
α Boo	K2III		-3.02	-3.00	-3.00	-3.16	- 3.15	- 3.21	- 3.23	- 3.20	- 3.20
β Peg	M2II-III		-2.26	-2.30	-2.30	-2.46	- 2.51	- 2.57	- 2.59	- 2.80	- 2.80
β Gem	K0III		-1.14	-1.21	-1.12	-1.22	- 1.19	- 1.22	- 1.19	- 1.24	- 1.24
α Tau	K5III		-2.86	-2.98	-2.81	-2.98	- 2.97	- 3.05	- 3.07	- 3.07	- 3.16

TABLE 2

ESTIMATED PHOTOMETRIC ACCURACY (percent)

MAGNITUDE	WAVELENGTH (μ)								
	2.3	3.6	4.9	8.7	10.0	11.4	12.6	19.5	23
>0..........	±5	±5	± 5	± 5	± 5	± 5	± 5	±10	±15
0 to +1........	±5	±5	± 5	± 5	± 5	± 5	± 5	±20	...
+1 to +2........	±5	±5	± 5	± 5	± 5	± 5	±10	...	...
+2 to +3........	±5	±5	± 5	±10	±10	±10	±20	...	...
+3 to +4........	±5	±5	± 5	±15	±15	±20	±30	...	...
+4 to +5........	±5	±5	± 5	±30	±30	±30	...	...	...
+5 to +6........	±5	±5	±10	...	...	...	...	...	...

TABLE 3

INFRARED REDDENING FOR SUPERGIANTS

Star Name	Sp	Δ(B-V)	Δ(V-[2.3])	Δ(V-[3.6])	Δ(V-[4.9])	Δ(V-[8.7])	Δ(V-[10.0])	Δ(V-[11.4])	Source	l	b
HD 169454	B1Ia^{+}	1.13	3.32	3.57	3.85	3.64	-	3.57	A	18°	-01°
HD 13854	B1Iab	0.47	1.43	1.52	1.37	-	-	-	A	134°	-04°
10 Per	B2Ia	0.47	1.28	1.35	1.47	-	1.95	-	A	136°	-04°
HD 14143	B2Ia	0.67	1.80	1.90	2.13	-	-	-	A	135°	-04°
HD 14134	B3Ia	0.61	1.53	1.66	1.82	-	-	-	A	135°	-04°
5 Per	B5Ia	0.42	1.24	1.33	1.53	-	-	-	A	134°	-04°
HD 223960	A0Ia^{+}	0.69	2.06	2.22	2.44	2.45	2.70	2.47	A	116°	-01°
HD 12953	A1Ia	0.59	1.59	1.74	1.88	2.18	-	2.32	A	133°	-03°
HD 14433	A1Ia	0.54	1.52	1.64	1.85	2.15	1.88	-	A	135°	-04°
9 (ι) Per	A2Ia	0.32	0.91	1.01	1.16	1.03	1.08	1.20	A	136°	-05°
6 Cas	A3Ia^{+}	0.59	1.80	2.01	2.11	2.23	2.22	2.32	A	116°	0°
HD 13476	A3Iab	0.52	1.46	1.67	1.69	2.13	2.00	2.04	A	134°	-03°
HD 17378	A5Ia	0.78	2.19	2.36	2.48	2.40	2.29	2.76	A	138°	-02°
ϕ Cas	F0Ia	0.49	1.25	1.43	1.52	1.45	1.56	1.48	A	127°	-04°
HD 10494	F5Ia	0.86	2.29	2.48	2.61	2.50	-	2.64	A	129°	0°
HD 17971	F5Ia	0.69	2.43	2.65	2.79	3.04	-	2.79	A	138°	+01°
44 Cyg	F5Iab	0.64	1.76	1.91	1.98	1.90	1.82	1.56	A	76°	-01°
δ CMa	F8Ia	0.12	0.27	0.41	0.46	0.52	0.41	0.43	A	238°	-08°
HD 18391	G0Ia	1.25	3.10	3.36	3.49	3.57	3.54	3.51	A	139°	-01°
HD 12399	G5Ia	0.68	1.79	1.34	1.44	2.38	2.28	2.06	A	131°	+03°
HD 187299	G5Iab-Ib	0.59	1.65	1.81	1.42	1.88	2.00	1.49	A	62°	0°
HD 38247	G8Iab	0.59	1.49	1.67	1.44	1.53	1.66	1.79	A	189°	-05°
HD 231195	F5Ia	1.06	2.85	3.09	3.16	3.38	3.46	3.31	A	49°	0
HD 331777	F8Ia	0.99	2.60	2.89	3.15	3.55	3.88	3.23	A	75°	+08°
HD 221861	K0Iab	0.68	1.71	1.94	1.75	2.09	2.02	2.01	A	117°	+10°
HD 45829	K0Iab	0.46	1.16	1.33	1.06	1.31	1.34	1.34	A	204°	-01°
HD 4817	K5Ib	0.36	1.81	2.03	1.76	2.07	2.19	2.19	A	121°	-01°
o^{1} CMa	K3Iab	0.35	0.75	1.04	0.68	1.20	1.23	1.29	A	235°	-10°
HD 11092	K5Iab-Ib	0.42	1.21	1.43	1.19	1.56	1.53	1.62	A	128°	+07°
α Cam	O9.5Ia	0.30	0.91	0.96	1.10	-	1.10	-	B	144°	+14°
δ Ori	O9.5Ib+B3e	0.06	0.31	0.30	0.24	0.40	0.39	0.43	B	206°	-17°
ζ Ori	B0Ia	0.05	0.38	0.36	0.41	0.35	0.31	0.41	B	205°	-17°
κ Cas	B1Ia	0.33	0.93	1.02	1.02	1.52	1.28	-	B	121°	0°
ρ Leo	B1Ib	0.05	0.19	0.19	0.23	0.51	0.26	-	B	235°	+53°
χ^{2} Ori	B2Ia	0.44	1.27	1.40	1.48	1.58	1.67	1.54	B	190°	+01°
β Ori	B8Ia	0.01	-0.02	0.00	0.00	0.14	0.13	0.00	B	209°	-25°
η Leo	A0Ib	-0.05	0.04	0.07	0.05	0.00	0.04	0.20	B	220°	+51°
HD 183143	B7Ia	1.29	3.55*	3.81	3.92	4.30	-	4.08	C	53°	+01°
HD 168607	B9Ia^{+}p	1.60	-	5.10	5.83	5.69	-	5.48	C	15°	-01°
α Cyg	A2Ia	0.04	0.14*	0.32	0.26	0.22	-	0.20	D	84°	+02°

*2.3μ point from Johnson *et al.* (1966). Sources of infrared magnitudes:
A = this work
B = Gehrz, Hackwell, and Jones (1974)
C = Hackwell, Gehrz and Woolf (1971)
D = Gehrz and Woolf (1971)

HD 217476. Johnson *et al.* (1966) also note that this star is variable. Where the final measured signal-to-noise ratio was less than three standard deviations of the mean ($3\ \sigma$), a $3\ \sigma$ upper limit is given. Spectral types in table 1 were taken from Humphreys (1970) except for HD 331777 (Smolinski 1971), BM Sco (Humphreys and Ney 1974*c*), and T Mon (Kukarkin *et al.* 1970). Table 2 lists estimated photometric accuracy including random and systematic errors.

Only HD 190323 (GO Ia–Iab) was found to have a hitherto unreported infrared excess. This star shows emission at 11.4 μ similar to the optically thin silicate feature discussed by Humphreys *et al.* (1971).

It is interesting to note that no measurable infrared excess near 10 μ is seen in our sample of K-type supergiants and that the silicate emission from late-type supergiants discussed by Humphreys *et al.* (1972) and Cohen and Gaustad (1973) apparently does not occur systematically until at least spectral type M0.

IV. INTERSTELLAR REDDENING

Where luminous supergiants are reddened, it is usually by virtue of their large distance rather than by obscuration by a single thick dust cloud. If good intrinsic colors are known for reddened supergiants, the mean reddening law for interstellar space can be estimated. This reddening can then be compared with extinction derived for H II regions or areas of heavy obscuration for which spurious results are sometimes reported.

To derive a reddening law using infrared photometric data, known variables and stars with infrared excess must be identified and removed from the sample. Broadband measurements of the heavily reddened star VI Cyg No. 12 (Stein and Gillett 1971) and of the Galactic center (Hackwell, Gehrz, and Woolf 1971) imply that even the most heavily extinguished supergiant at 0.55 μ should show very little differential extinction for broad bandpasses in the 7- to 14-μ spectral region. Stars with infrared excesses can then be identified easily from their [8.7] − [11.4] color. In order that photometric errors did not bias our sample too greatly, a star was assumed to have no infrared excess, and thus included in the reddening law calculation, if the color $[8.7] - [11.4] < 0.5$. The infrared photometry of table 1 and that of Gehrz *et al.* (1974), Gehrz and Woolf (1971), Hackwell *et al.* (1971), and Humphreys *et al.* (1971) were examined for inclusion in the reddening law determination. Table 3 lists the color excesses for all supergiants from the above lists which are earlier than M, are not known variables, and do not have an infrared excess.

V-magnitudes were taken from Humphreys (1970), Johnson *et al.* (1966), and Blanco *et al.* (1970). Differential extinctions at 2.3 and 3.6 μ were derived, using the intrinsic colors for supergiants of Johnson (1966). At longer wavelengths, intrinsic colors were estimated by assuming the stars to radiate as blackbodies at a temperature equal to the T_e given by Johnson (1966). Reddening was calculated for $\lambda =$ 2.3, 3.6, 4.9, 8.7, 10.0 and 11.4 μ by fitting a straight line to $E(V - [\lambda])/E(B - V)$. The errors in $E(B - V)$ were assumed to be negligible compared with those in $E(V - [\lambda])$. Measurements at 12.6 μ and at longer wavelengths were not included in the calculation because of the paucity of measurements at these wavelengths and their poor photometric accuracy. Little dependence of the derived reddening law was seen on spectral type (to K5), $E(B - V)$, galactic longitude, or the source of the infrared data as evidenced by the dependences explored in table 4. However, a 4.9-μ absorption occurs in stars of spectral type G5 and later, causing spurious results if these stars are included in the reddening calculation. The 4.9-μ absorption is discussed further below.

Figure 1 shows a plot of the color excesses $E(V - [2.3])$ versus $E(B - V)$ and has been included to demonstrate how well the data fit a single reddening law. The 2.3-μ measurement was chosen for figure 1 because photometric errors are usually least at this wavelength. The anomaly for HD 4817 (K5 Ib) probably arises because intrinsic colors for later spectral types are not well known. HD 17971 may have a poorly estimated intrinsic $B - V$ color possibly arising from variability. For consistency, both stars were included in the final reddening calculations; however, their effect on the final results is small.

The mean derived $K(2.2\ \mu)$ and $L(3.5\ \mu)$ reddening of Johnson (1968) for stars in Perseus, Ophiuchus, Cygnus, Aquila, and Cepheus (omitting μ Cep), which represent approximately the areas included in the present study, give $E(V - K)/E(B - V) = 2.66$ and $E(V - L)/E(B - V) = 2.96$. These values compare well with the differential extinctions at 2.3 and 3.6 μ given in table 4. When the data of Johnson (1968) are compared with those of table 4, it should be borne in mind that the two studies use slightly different effective wavelengths.

Figure 2 shows the reddening law derived using all of the stars in table 3. Stars with spectral type G5 and later were not included in the 4.9-μ reddening. The *UBVRIJ* reddening law shown on the same plot was derived from the data of Johnson (1968) in a similar manner to the *K* and *L* data discussed above.

To obtain a value of $R = A_V/E(B - V)$, the ratio of total to selective absorption, it is necessary to extrapolate the multicolor reddening curve to $1/\lambda = 0$. Little is known about the composition, sizes, and shapes of the interstellar grain; thus it is difficult to extrapolate the reddening curve accurately. Two possible limiting extrapolations which make the most general assumptions about light scattering by small particles (i.e., that the extinction has a wavelength dependence between λ^{-1} and λ^{-4}) are shown in figure 2. The best value for the ratio of total to selective extinction derived in this way is 3.40 ± 0.15. Martin (1971), using a radial-velocity method to measure the extinction in "thin" space, derives a value of $R = 3.3 + 0.7, -0.5$. Lee (1970) finds $R = 3.6$ for M supergiants.

The value of R derived from the present work compares favorably with that measured in many clusters and associations (e.g., Garrison 1970; Schild

TABLE 4

COLOR EXCESS RATIOS

	λ =	2.3μ	3.6μ	4.9μ	8.7μ	10.0μ	11.4μ
All stars G0 and earlier listed in Table 3 with $\Delta(B-V) \geq 0.3$	no. of stars	25	26	26	20	16	18
	$E(V-[\lambda])/E(B-V)$	2.76	3.01	3.22	3.38	3.36	3.27
	mean error	±.04	±.06	±.07	±.08	±.11	±.08
All stars G0 and earlier listed in Table 3 with all $\Delta(B-V)$	no. of stars	32	33	33	27	22	24
	$E(V-[\lambda])/E(B-V)$	2.76	3.00	3.22	3.38	3.36	3.26
	mean error	±.04	±.05	±.07	±.08	±.10	±.08
Stars of all spectral types listed in Table 3 with all $\Delta(B-V)$	no. of stars	39	40	40	34	29	31
	$E(V-[\lambda])/E(B-V)$	2.76	3.02	3.16*	3.37	3.36	3.26
	mean error	±.05	±.06	±.07	±.08	±.10	±.08
All stars in Table 3 with galactic longitude $0° \leq l \leq 90°$	no. of stars	7	8	5	8	4	8
	$E(V-[\lambda])/E(B-V)$	2.76	3.06	3.30†	3.37	3.44	3.19
	mean error	±.04	±.05	±.10	±.07	±.19	±.09
All stars in Table with galactic longitude $90° \leq l \leq 180°$	no. of stars	22	22	19	16	15	14
	$E(V-[\lambda])/E(B-V)$	2.78	2.99	3.13†	3.40	3.34	3.37
	mean error	±.08	±.11	±.10	±.15	±.16	±.16
All stars in Table 3 with galactic longitude $180° \leq l \leq 270°$	no. of stars	10	10	7	10	10	9
	$E(V-[\lambda])/E(B-V)$	2.56	2.96	3.42†	3.05	3.18	3.21
	mean error	±.14	±.12	±.27	±.22	±.17	±.20

*Point is unreliable because of 5μ absorption feature which occurs later than G0
†Stars later than G0 have been omitted

Neugebauer, and Westphal 1971; Lodén and Sundman 1972).

V. THE 4.9-μ ABSORPTION FEATURE

Figure 3 shows the [3.6] – [4.9] color, corrected for interstellar reddening, plotted versus spectral type for Ia and Iab supergiants taken from table 1 and from Gehrz *et al.* (1974), Humphreys *et al.* (1971), Gehrz and Woolf (1971), and Hackwell *et al.* (1971). Most of the supergiants with spectral types earlier than G5 have a [3.6] – [4.9] color ~0. It is remarkable that for spectral types later than about G5 the [3.6] – [4.9] color abruptly drops to approximately

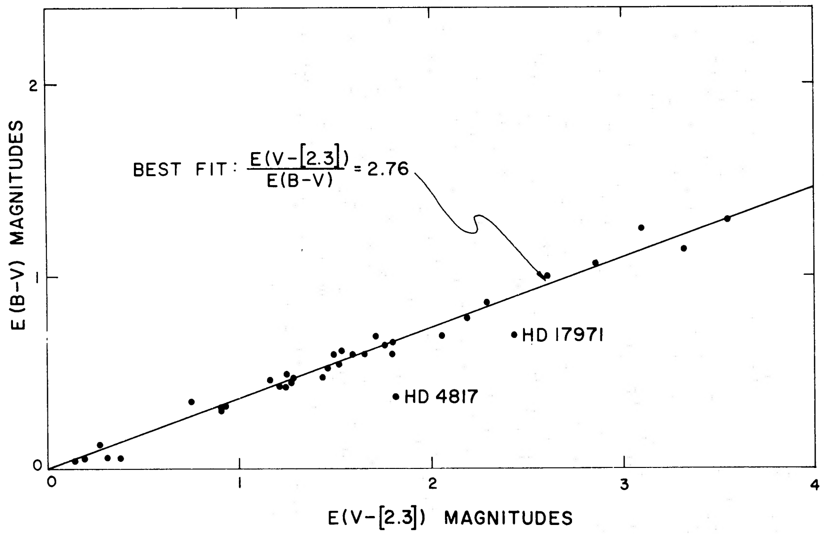

Fig. 1.—Plot of the color excess, $E(B-V)$ vs. $E(V-[2.3])$. Note how well the observations fit a single reddening law. The stars HD 4817 and HD 17971 are discussed in the text.

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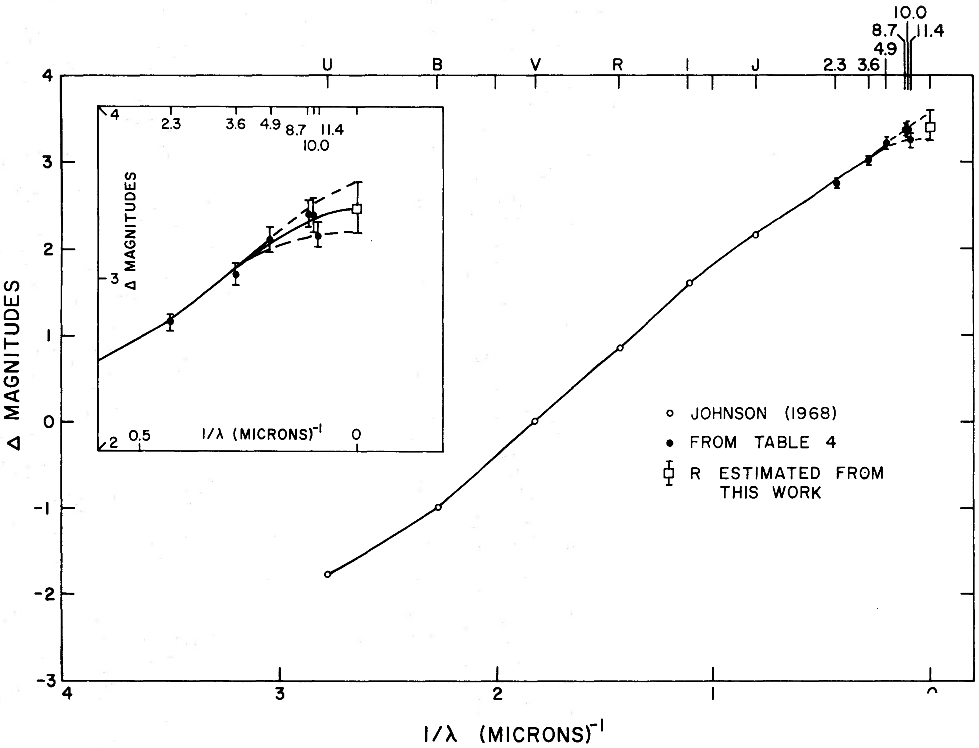

FIG. 2.—Interstellar reddening plotted vs. $1/\lambda\ \mu^{-1}$ normalized to $E(B-V) = 1$. The *UBVRIJ* points were taken from Johnson (1968) (see text). The extrapolation to $1/\lambda = 0$ gives a ratio of total to selective extinction of $R = 3.40 \pm 0.15$.

-0.4 mag. This dip must be due to a ~5-μ absorption in the stars, as the color [2.3] − [3.6] ~ 0 mag for all spectral types and the 2.3- and 3.6-μ magnitudes are consistent with the colors predicted from measurements in the visible part of the spectrum. The large scatter in figure 3 is mainly due to the difficulty of making accurate photometric measurements around 5 μ where the transmission "window" is rather poor.

HD 168625 and HD 168607 probably have excess free-free emission (see Gehrz *et al.* 1974), and HR 5171A has a small infrared excess near 5 μ arising from a circumstellar shell (Humphreys *et al.* 1971). It should be noted that 89 Her and W Cep, which have considerable infrared excess at 4.9 μ, have colors too large to be included in figure 3.

The ~4.9-μ absorption is probably due to the

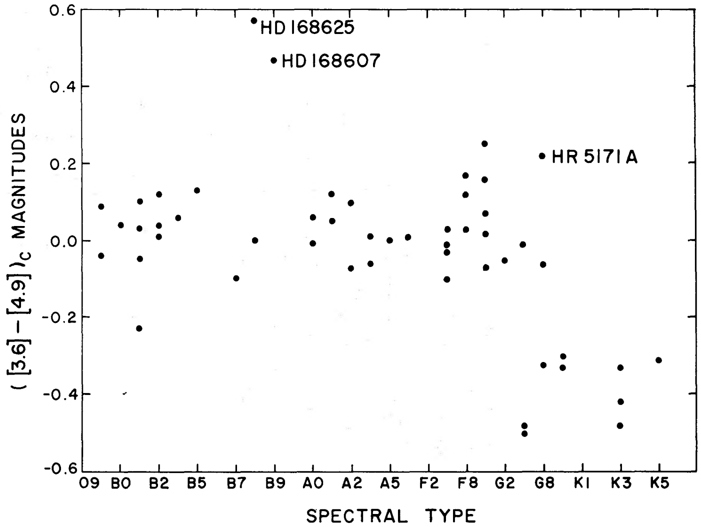

FIG. 3.—The color [3.6] − [4.9] corrected for interstellar reddening plotted vs. spectral type for luminosity type Ia and Iab supergiants. Note the abrupt onset of a 4.9-μ absorption feature near spectral type G5.

fundamental vibrational bands of CO or CN which are centered at 4.7 and 4.9 μ, respectively. Both fundamentals are included in the 4.9-μfilter bandpass which stretches from approximately 4.6 μ to 5.2 μ. Studies are needed at higher resolution to make a definite identification.

An absorption near 5 μ with a similar strength to that seen in the supergiants later than G5 has also been reported in M stars (Gillett, Merrill, and Stein 1971; Humphreys *et al.* 1972; Cohen and Gaustad, 1973) and is seen in some K- and M-type giants commonly used as infrared standards (see table 1).

VI. SUMMARY

The infrared excesses reported for some luminous F, G, and K supergiants do not appear to be representative of the class. Infrared excess near 10 μ apparently occurs systematically only in supergiants of spectral type M0 and later.

The absence of an infrared excess in the intermediate-spectral-type supergiants makes them an important vehicle for the study of interstellar extinction. The color-excess method yields a reddening curve which given a value for the ratio of total to selective extinction of $R = 3.40 \pm 0.15$. No significant variations of the reddening law with galactic latitude, spectral type earlier than M or $E(B - V)$ is seen.

At 4.9 ± 0.3 μ an absorption feature with a depth of 0.4 mag appears abruptly in the supergiants near spectral type G5. We suggest that this feature is due to absorption by the fundamental vibration band of either CO or CN.

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