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NEAR-INFRARED AND VISUAL PHOTOMETRY OF h AND χ PERSEI

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RESUMEN

Se presentan mediciones fotométricas de banda ancha *JHK* (y en ocasiones *L'* y *M*) en el cercano infrarrojo de 82 estrellas de h y χ Persei. Las estrellas observadas cubren la parte alta de la secuencia principal de las regiones centrales de los cúmulos así como las gigantes y supergigantes de la región más extendida. También se reporta nueva fotometría fotoeléctrica *UBV* de 24 estrellas para las cuales existía solamente fotometría fotográfica.

Los resultados infrarrojos son consistentes con un único valor de $A_V = 1.85 \pm 0.12$ para la extinción en la dirección de ambos cúmulos. La comparación entre los datos infrarrojos y visuales sugiere que la dispersión encontrada en los valores de E(*B*−*V*) no se debe a enrojecimiento variable como se había afirmado anteriormente en la literatura, sino que puede ser intrínseco a las atmósferas de algunas estrellas de tipo espectral B. Se encuentran excesos infrarrojos en las supergigantes B y A más brillantes. Estos se explican por procesos bremsstrahlung asociados con sus vientos estelares calientes. La mayoría de las estrellas Be de χ Persei también presentan excesos infrarrojos considerables que se deben a emisión de polvo circunestelar, a bremsstrahlung o a ambos procesos.

ABSTRACT

Broad-band near-infrared photometry in the *JHK* (and sometimes *L'* and *M*) bands of 82 stars in h and χ Persei is presented. The stars observed cover the upper main sequence of the central parts of the clusters as well as the giants and supergiants of the extended region. New *UBV* photoelectric photometry of 24 stars for which only photographic photometry was previously available is also reported.

The infrared results are consistent with a unique value of the extinction in the direction of both clusters of $A_V = 1.85 \pm 0.12$. Comparisons between the infrared and visual data suggest that the observed dispersion towards large values of E(*B*−*V*) is not due to variable reddening as previously stated in the literature but that it may be intrinsic to the atmosphere of some B-type stars. Infrared excesses were found in the brightest B and A-type supergiants. These are explained by bremsstrahlung associated with their hot stellar winds. Most of the Be stars in χ Persei also present significant infrared excesses due to circumstellar dust emission or bremsstrahlung or both.

Key words: CLUSTERS – INFRARED – PHOTOMETRY

I. INTRODUCTION

Near-infrared photometry of open clusters has scarcely been reported in the literature. The published work has mainly been concentrated on very young regions where dust particles (remnants of the cluster parent cloud) are clearly present (e.g., NGC 2264; Warner, Strom, and Strom 1977). Apart from the expected variable interstellar extinction, these investigations have shown the presence of near-infrared excesses in a significant fraction of stars. These excesses are best explained as due to bremsstrahlung emission from hot ionized gas envelopes around the younger stars, among them, T Tauri-type stars. Also dust clouds were detected around some young stars.

We are undertaking a long-term program consisting of photometric observations in the *J*, *H* and *K* bands of galactic clusters whose turn-off points lie between B0 and B5, where most of the primaeval dust has been dissipated and where some of the stars have already evolved away from the main sequence. *L* and *M* measurements are included whenever the stars are brighter than our observation limits.

The double cluster in Perseus (NGC 869 and NGC 884) is an ideal region with which to start this program for the following reasons: (1) It is bright enough for complete near-infrared photometry including the upper part of the main sequence. (2) Interstellar reddening has been reported to vary across both clusters and, if real, this would call for bizarre interpretations, since no evidence of patchy dust obscuration or emission nebulae are visible on direct photographs. (3) Some weak evidence of abnormal reddening in the ultraviolet region was found (R. Stalio, private communication). (4) The clusters contain a fair number of massive giants and (blue and red) supergiants as well as Be stars. (5) Almost complete spectroscopic and visual photometric data, as well as membership criteria, are available for a large number of stars in both clusters.

There is an important number of studies on h and

TABLE 1

SUMMARY OF OBSERVATIONAL PARAMETERS OF h AND χ PERSEI

	h Persei			χ Persei			
Authors	$(m-M)_0$	d (kpc)	E(*B−V*)	$(m-M)_0$	d (kpc)	E(*B−V*)	Notes
Trumpler (1930)	11.4	1.91	-	11.9	2.40	-	-
Bidelman (1943)	10.7	1.38	-	11.0	1.58	-	-
Barhatova (1950)	10.2	1.10	-	10.6	1.32	-	-
Becker (1952)	10.34	1.17	.45	10.85	1.48	.53	-
Becker (1963)	11.67	2.15	.56	11.97	2.46	.56	Data from Johnson and Morgan (1955)
Borgman and Blaauw (1964)	11.65	2.14	.55	12.03	2.55	.54	-
Schild (1965)	11.3	1.82	.60	11.6	2.09	.55	Data also from Johnson and Morgan (1955) and Wildey (1964)
Mendoza (1967)	11.8	2.30	.54	11.8	2.30	.54	h and χ Persei reduced together. Reddening derived from (V-R) indices
Schild (1967)	-	-	-	-	-	-	Ages (h: $6.4 \cdot 10^6$ years (χ: $11.5 \cdot 10^6$ years
Crawford et al. (1970)	11.4	1.91	.59	11.4	1.91	.57	Same age for h and χ
Vogt (1971)	11.75	2.25	53	11.70	2.20	.61	Ages (h: 2 · 10[illegible] years (χ: 1 · 10[illegible] years
This paper	-	-	.58 + .03	-	-	.59 + .03	Nuclei

χ Persei: the most extensive catalogue and photographic photometry is that of Oosterhoff (1937) from which all star identifications are adopted in this paper. Photometry on various systems is available: *UBV* (Johnson and Morgan 1955; Wildey 1964; Schild 1965; Moffat and Vogt 1974); three-color (Becker 1952, 1963); seven-color narrow band (Borgman 1960; Borgman and Blaauw 1964); *UBVRI* and some *JHKL* (Mendoza 1967); *uvby* and Hβ (Crawford, Glaspey, and Perry 1970); and on the Geneva systems (Rufener 1981). Spectral classifications of the member stars are also available (Trumpler 1930; Bidelman 1943; Johnson and Morgan 1955; Schild 1965, 1966 and 1967). Other investigations of the clusters include proper motions (van Maanen 1944; Meurers 1960) and polarization (Pratt 1968; Serkowski 1965).

In spite of all these investigations, a number of unsolved problems are still present. Most of these concern the relation between the two clusters: their distance from the Sun, their age, the interstellar and intracluster extinction and many evolutionary questions, such as the presence and nature of Be stars, blue stragglers, B and M-type supergiants and, as will be discussed later, non-emission-line stars showing anomalies in their *UBV* colors. The only indirect evidence for the physical connection between h and χ Persei was given by Pişmiş (1953). From dynamical considerations, she showed that the two clusters most likely form a physical pair and that the system has reached dynamical equilibrium. Table 1 summarizes some basic parameters of h and χ Persei as it stands in the literature.

The present paper attempts to study mainly two aspects: the nature of the interstellar extinction by means of infrared measurements, and the evolutionary status of the aggregates. The following section describes the observations, in section III a discussion of reddening is given, section IV contains some comments on the evolution of the region with reference to the *B−V* excesses and infrared excesses observed, and the conclusions are presented in section V.

II. OBSERVATIONS

We have carried out *JHK* photometry of 82 stars in the h and χ Persei clusters, with additional *L* and *M* measurements of the brightest members. The observations were made with the infrared photometer of the Observatorio Astronómico Nacional described by Roth *et al.* (1983), attached to the 2.1-m telescope at San Pedro Mártir, during two runs: September 29 to October 7, 1982 and January 17-25, 1983.

Tables 2 and 3 present the results for the early-type stars and M-type supergiants respectively. The intrinsic errors in the *J, H* and *K* bands are less than 0.04 mag, while in the *L* and *M* filters it is less than 0.06, unless otherwise stated in parentheses. All measurements were made with a 12 arcsec aperture and 30 arcsec beam separation in the N-S direction. Throw was decreased or increased from about 20 up to about 45 arcsec in some cases in order to avoid contamination from nearby stars in the crowded regions.

TABLE 2

INFRARED PHOTOMETRY OF EARLY-TYPE STARS

Oo	HD or BD	Sp.	*V*	*B−V*	*J*	*H*	*K*	*L′*	Remarks
3	HD 13841	B2 Ib	7.39	0.23	6.79	6.74	6.73	6.62 (.11)	Mz β
16	HD 13854	B1 Iab	6.49	0.28	5.82	5.75	5.68	5.53	β M = 5.24 (.38)
49	BD 56°473	B1 IIIe	9.08	0.26	8.55	8.37	8.24	-	: β
146	HD 13900	B1 III	9.19	0.17	9.07	9.01	9.02	-	β
339	HD 13969	B1 IV:	8.85	0.31	8.27	8.26	8.25	-	Mz β
612	HD 14053	B1 II	8.41	0.25	7.96	7.94	7.93	-	β
622	-	-	10.91	0.23	10.39	10.36	10.38	-	-
662	HD 14052	B1 Ib	8.18	0.31	7.63	7.59	7.57	7.47 (.09)	Mz β h
692	-	-	9.45	0.26	9.05	9.02	9.01	8.33 (.30)	:
717	BD 56°502	B1 V	9.28	0.30	8.77	8.71	8.73	-	β h
816	-	-	11.47	0.36	10.28	10.16	10.02	-	:
843	BD 56°510	B1.5 V	9.32	0.31	8.98	8.92	8.92	8.37 (.25)	β h
847	BD 56°511	B3 III	9.11	0.38	8.40	8.28	8.20	8.17 (.32)	: β h
859	-	B2 Vn	10.78	0.32	10.25	10.20	10.21	-	h
864	BD 56°513	B2 Vn	9.91	0.31	9.43	9.34	9.34	-	β h
911	-	B2 V	11.46	0.32	10.90	10.88	10.86	-	h
919	-	-	11.08	0.39	10.11	10.04	10.02	-	h
922	BD 56°515	B0.5 Vn	9.54	0.33	9.11	9.02	9.00	8.72 (.66)	β h
926	-	B3 V	11.76	0.43	10.94	10.80	10.60	-	: h
929	BD 56°516	B2 V	10.36	0.29	9.88	9.82	9.81	-	h
936	BD 56°517	B1.5 V	10.50	0.27	10.02	9.97	9.98	-	h
950	-	B2 V	11.29	0.36	10.53	10.42	10.42	-	Mz β h
963	-	B2 IV	11.03	0.33	10.16	10.07	10.10	-	β h
977	-	B2 V	11.02	0.42	10.46	10.38	10.36	-	h
978	BD 56°518	B1.5 V	10.59	0.38	10.09	10.04	10.01	-	Mz β h
980	BD 56°519	B1.5 V	9.65	0.36	8.61	8.57	8.57	-	β h
991	-	B2 V	11.32	0.42	10.65	10.56	10.52	-	β h
992	BD 56°520	B1 Vn	9.85	0.35	9.49	9.40	9.36	-	h
1004	-	B2 V	10.86	0.38	10.28	10.18	10.03	-	β h
1041	-	B2 V	10.90	0.41	10.51	10.42	10.43	-	h
1057	HD 14134	B3 Ia	6.55	0.47	5.76	5.62	5.53	5.12	Mz β h
1078	BD 56°524	B1 Vn	9.75	0.34	9.17	9.11	9.10	-	β h
1080	-	B2 Vn	10.97	0.40	10.59	10.52	10.55	-	h
1085	-	B1.5 V	10.27	0.47	9.83	9.75	9.75	-	h
1116	-	B0.5 V	9.29	0.36	8.75	8.68	8.60	8.74 (.18)	h
1132	-	B0.5 V	8.46	0.39	7.72	7.57	7.66	7.36 (.21)	: h
1133	-	B0.5 Vn	8.98	0.41	8.47	8.41	8.32	7.99 (.19)	h
1162	HD 14143	B2 Ia	6.66	0.51	5.59	5.46	5.42	5.08 (.09)	: Mz β h
1187	-	B2 IV	10.82	0.39	10.18	10.04	9.99	-	Mz β h
1516	-	-	11.21*	-	10.09	10.03	10.01	-	-
1539	-	-	11.33	0.35	10.66	10.57	10.55	-	-
1566	-	-	11.33	0.47	10.40	10.31	10.27	-	-
1575	-	-	12.12	1.95	8.47	7.55	7.33	6.96	Nonmember
1586	HD 14250	B1 III	8.97	0.32	8.34	8.33	8.30	-	Mz β
1781	HD 14321	B1 IV:	9.21	0.30	8.80	8.71	8.75	-	: β
1899	HD 14357	B2 II	8.53	0.32	7.83	7.85	7.87	7.75 (.09)	β
2088	BD 56°563	B1.5 Vne	9.45	0.32	9.18	9.15	9.17	8.78 (.22)	β χ
2094	-	-	11.90	0.30	11.23	11.11	11.14	-	: χ
2114		B2 V	11.04	0.32	10.47	10.38	10.36	-	χ
2138	HD 14422	B0 IVpe	9.28	0.44	8.45	8.31	8.18	7.44 (.26)	Mz β
2139	-	B2 V	11.38	0.27	10.91	10.85	10.82	-	Mz β χ
2165	BD 56°566	B1 Vne	9.86	0.40	8.84	8.57	8.33	7.63 (.09)	β χ
2172	HD 14434	O5.5 Vnp	8.50	0.16	8.40	8.34	8.35	8.37 (.23)	β
2178	HD 14433	A1 Ia	6.38	0.58	5.37	5.13	5.03	4.62	Mz β M = 4.54 (.10)
2185	-	B2 Vn	10.92	0.33	10.37	10.28	10.21	-	Mz β χ
2196	-	B1.5 V	11.57	0.32	11.10	11.10	11.06	-	β χ
2227	HD 14443	B2 Ib	8.05	0.34	7.66	7.56	7.52	-	Mz β χ
2229	-	B2 Vn	11.40	0.29	10.91	10.87	10.84	-	χ
2232	-	B2 V	11.11	0.25	10.80	10.81	10.80	-	Mz β χ
2235	BD 56°571	B1 V	9.36	0.33	9.02	8.95	8.91	9.01 (.35)	Mz β χ
2242	-	B1 Vnp	10.98	0.38	10.30	10.14	9.89	-	χ
2246	BD 56°572	B2 III	9.90	0.32	9.76	9.66	9.67	-	Mz β χ
2251	-	B3 V	11.56	0.34	11.07	11.01	10.88	-	β χ
2255	-	B2 Vn	10.67	0.30	10.31	10.31	10.28	-	χ

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TABLE 2 (CONTINUED)

Oo	HD or BD	Sp.	V	$B-V$	J	H	K	L'	Remarks
2262	-	B2 Vn	10.58	0.35	9.99	9.88	9.87	-	β χ
2270	-	-	14.08	0.42	13.10		13.19	-	χ
2284	BD 56°573	B1 Vne	9.66	0.40	8.76	8.46	8.10	7.08	β χ
2296	BD 56°574	B1 III	8.53	0.30	8.13	8.03	7.99	7.62 (.09)	β χ
2299	BD 56°575	B0.5 IV	9.08	0.20	8.76	8.70	8.68	8.42 (.17)	β χ
2311	BD 56°576	B2 III	9.38	0.30	9.17	9.00	8.99	-	β χ
2330	-	-	11.42	0.24	11.08	10.97	10.79	-	: β χ
2361	HD 14476	B0.5 III	8.75	0.38	8.64	8.48	8.42	-	β
2371	BD 56°578	B2 III(e)	9.25	0.32	8.71	8.60	8.53	8.55 (.25)	β χ
2488	BD 56°586	B1 V	10.00*	-	8.62	8.52	8.50	-	β
2541	HD 14520	B2 II	9.15	0.33	8.54	8.46	8.44	8.53 (.23)	Mz β
2589	HD 14535	A2 Ia	7.44	0.72	6.06	5.79	5.63	5.19	Mz β M = 5.13 (.12)
2621	HD 14542	B8 Ia	7.00	0.61	5.86	5.65	5.53	5.15	Mz β M = 5.05 (.15)

* Photographic magnitude; Mz: Observed by Mendoza (1967); β: Observed by Crawford *et al.* (1970); h or χ: Member of the nucleus of h or χ Persei respectively, otherwise in extended region.

TABLE 3

INFRARED PHOTOMETRY OF LATE-TYPE STARS

Oo	HD, BD or Var.	Sp. Type	V	$B-V$	J	H	K	L	M
1655	AD Per	M2.5 Iab	7.85	2.23	3.43	2.45	2.11	1.77	2.00
1818	FZ Per	M1 Iab	7.91	2.27	3.81	2.87	2.59	2.19	2.48
2417	RS Per	M4.5 Iab	8.31	2.29	3.13	2.12	1.73	1.29	1.43
2691	BD 56°595	M0.5 Iab	8.29	2.23	4.04	3.09	2.80	2.46	2.90
2758	HD 14580	M0 Iab	8.31	2.25	4.46	3.32	3.02	2.70	3.03

TABLE 4

INFRARED STANDARD STARS

HR	J	H	K	L	M
718	4.40	4.40	4.41	4.42	4.41
1084	2.26	1.79	1.69	1.59	1.67
1239	3.67	3.65	3.66	3.60	3.71
1790	2.17	2.23	2.30	2.29	2.36
2943	− 0.30	− 0.50	− 0.65	− 0.69	− 0.67
3982	1.52	1.53	1.56	1.56	1.61
7525	0.37	− 0.36	− 0.58	− 0.74	− 0.59
7557	0.39	0.30	0.25	0.21	− 0.29
7615	2.24	1.74	1.64	1.54	1.65
8143	3.87	3.82	3.78	3.72	3.70
8430	2.98	2.75	2.66	2.59	2.66
8541	4.33	4.28	4.27	4.23	4.25
8781	2.54	2.53	2.53	2.48	2.50

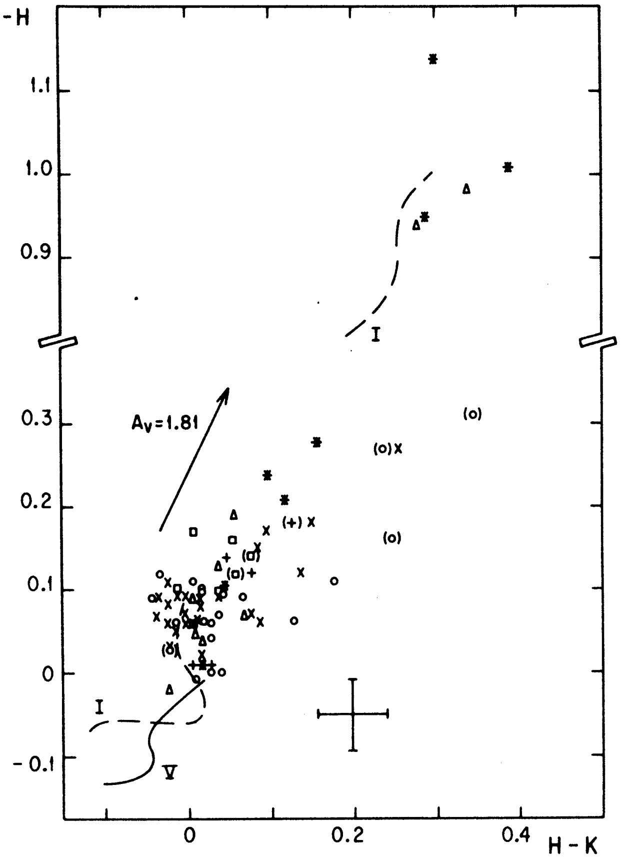

Fig. 1. (*J–H*) versus (*H–K*) diagram of all observed stars in the double cluster. Symbols are as follows: (x) dwarfs, (+) giants, (*) supergiants in h Persei; (o) dwarfs, (□) giants, (Δ) supergiants in χ Persei. Parentheses denote emission line spectra. The continuous line shows the locations of unreddened B-type main sequence stars, the broken line the B and A (lower left) and M-type (upper right) supergiants. Observational maximum error bars are drawn as well as the reddening vector of length A_V = 1.81. The vertical scale has been broken to include the M-type supergiants in the same figure.

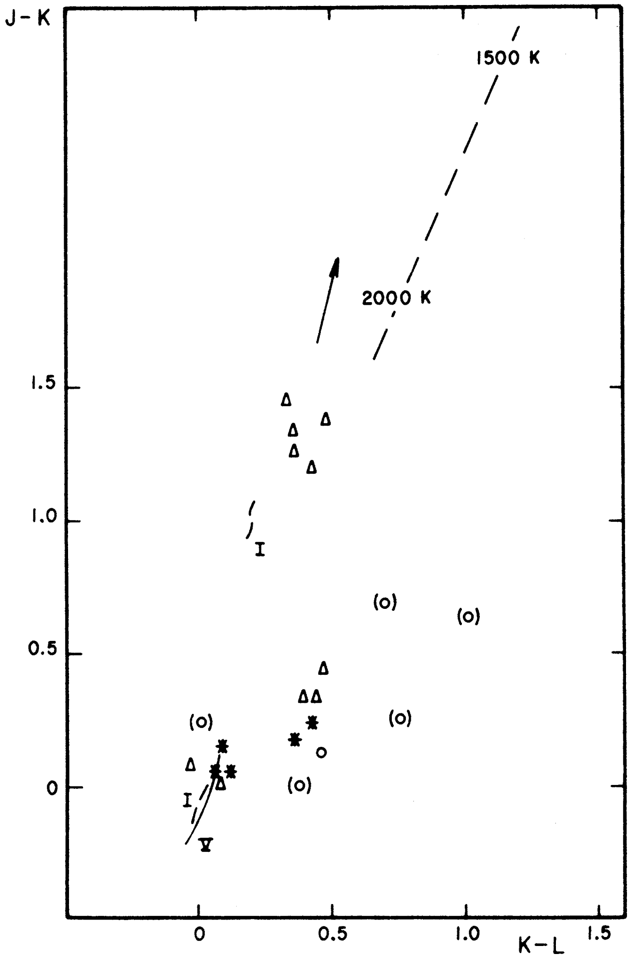

Fig. 2. (*J–K*) versus (*K–L*) diagram of the IR-brightest stars. Symbols are as in Figure 1 and the black body sequence is also included.

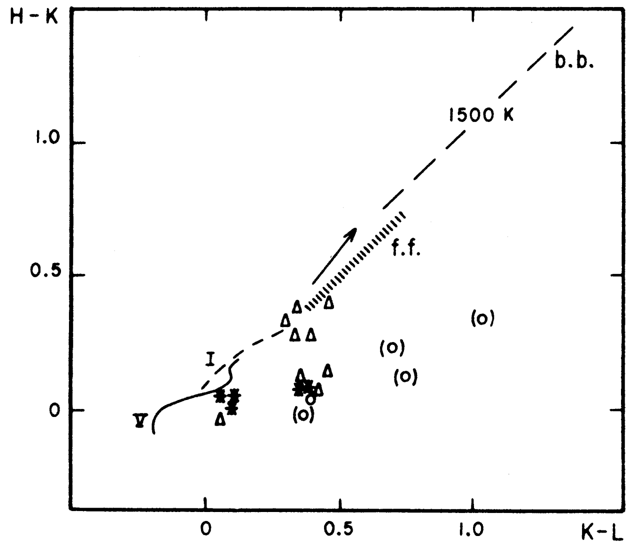

Fig. 3. (*H–K*) versus (*K–L*) diagram of the IR-brightest stars. Symbols are as in Figure 2 and the locus of pure bremsstrahlung emission of gas at 10 000 to 20 000 K is included.

The infrared photometry is referred to a net of standard stars (now being recalibrated for our system) shown in Table 4. The absolute photometry is estimated to be accurate to around ∿ 0.05 mag, but the dispersion in the infrared colors reflects only the internal errors.

The resulting (*J-H*) versus (*H-K*) diagram of all observed stars in shown in Figure 1. In Figures 2 and 3 we show the (*J-K*) versus (*K-L*) and (*H-K*) versus (*K-L*) plots for the Be and other early-type stars with infrared excess and for the B and M supergiants. In all these plots, different symbols were used for dwarfs, giants and supergiants in each cluster (see figure captions). The spectral distributions of a representative sample of the stars studied is given in Figure 4.

All the observed stars are either within the cluster nuclei or in more extended regions around them, but all

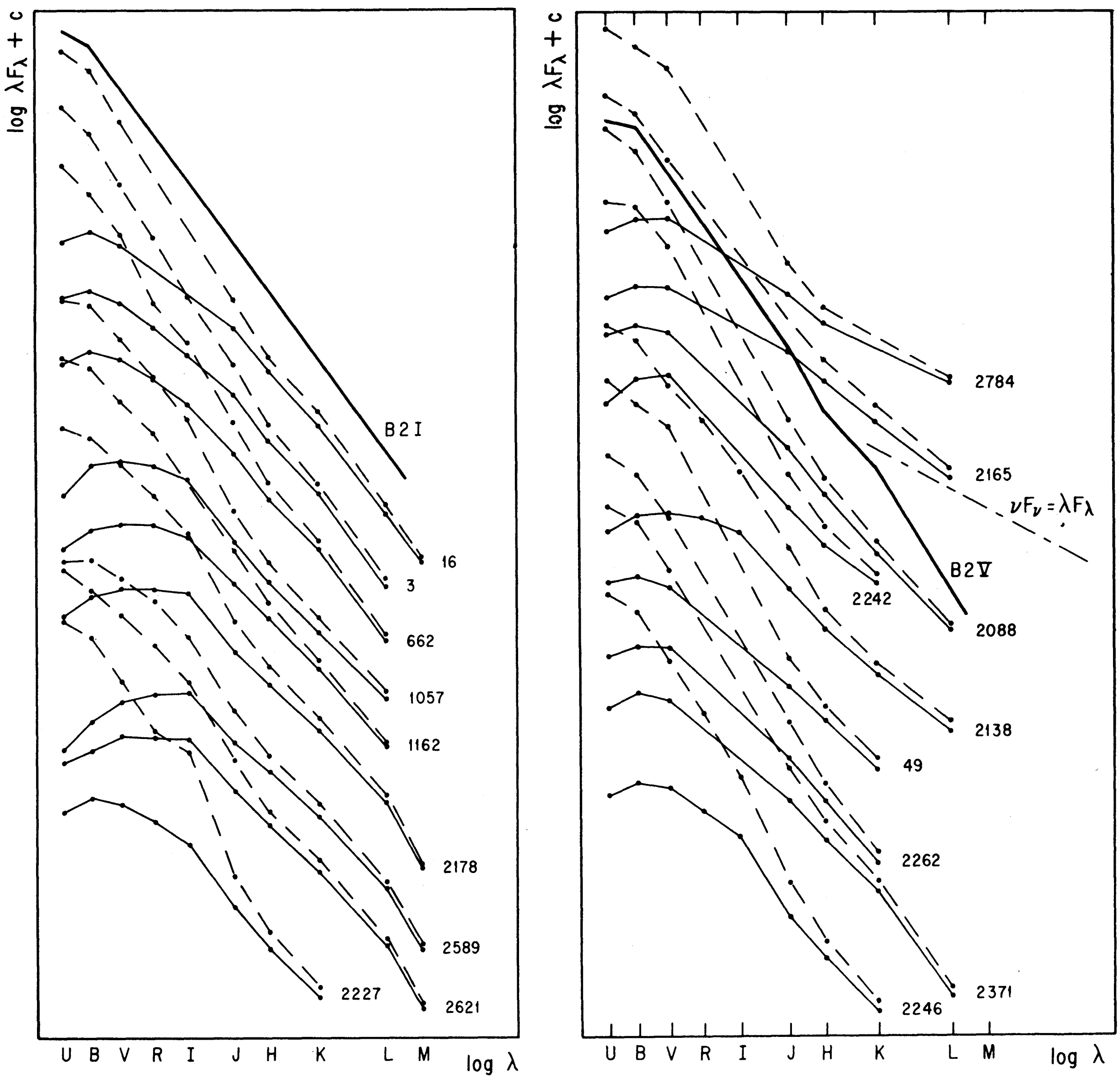

Fig. 4. Energy distribution of a representative sample of stars in h and χ Persei. Solid lines represent the raw data, while broken lines show the same stars after dereddening.

stars are within the boundaries of maps 1 and 3 by Oosterhoff (1937).

In order to complement the available good quality *UBV* photometry of h and χ Persei, 24 B-type main sequence stars, mainly in the nucleus of h Persei, were observed in these bands using the pulse-counting photometer with an RCA 31034 cell attached to the newly refurbished 1.5-m telescope at San Pedro Mártir. The observations are given in Table 5. The stars were measured once or twice on August 22, 1983 using as standard stars Oo 843, 1057, 1162, 2227 and 2296. The estimated erros are within 0.03 magnitudes. With one exception, the observed program stars had only photographic *UBV* photometry available, most of them by Wildey (1964). We found large differences ($|\Delta V| \lesssim 0.6$ and $|\Delta(B-V)| \leqslant 0.15$) between Wildey's and our values. Although the scatter is in both directions, most stars (∼ 70%) showed larger (fainter) V magnitudes and smaller (bluer) $B-V$ color indices in *our* measurements. In general, this greatly alleviates the large E_{B-V} dispersion reported by Wildey (1964).

III. INTERSTELLAR EXTINCTION

As mentioned in section I, no agreement has been reached as to whether the amount of interstellar material causing the reddening in the direction of h and χ Persei is constant or variable, from one cluster relative to the

TABLE 5

VISUAL PHOTOMETRY

Oo	V	$B-V$	$U-B$
622	10.91	0.23	− 0.53
692	9.45	0.26	− 0.67
859	10.78	0.32	− 0.39
911	11.46	0.32	− 0.45
919	11.08	0.39	− 0.25
922	9.54	0.33	− 0.54
926	11.76	0.43	...
929	10.36	0.29	− 0.46
936	10.50	0.27	− 0.51
963	11.03	0.33	− 0.52
977	11.02	0.37	− 0.42
980	9.65	0.35	− 0.46
991	11.32	0.42	...
992	9.85	0.35	− 0.49
1004	10.86	0.38	− 0.44
1041	10.90	0.41	− 0.42
1080	10.97	0.40	− 0.39
1085	10.27	0.47	− 0.47
2094	11.90	0.30	− 0.51
2114	11.04	0.32	− 0.48
2229	11.40	0.29	− 0.47
2242	10.98	0.38	− 0.60
2255	10.67	0.30	− 0.49
2262	10.58	0.35	− 0.49

other, or even within each cluster. Nevertheless, no question has been raised about the shape of the reddening law in that direction. We are assuming that it is "normal", characterized by van de Hulst's curve No. 15 (Johnson 1968).

Early photoelectric photometry by Borgman and Blaauw (1964) in the seven-color system and by Johnson and Morgan (1955) as analysed by Becker (1963) provided the bases for reddening and distance moduli determinations which are in excellent agreement with each other, although the methods used were virtually independent. Their results imply a difference in the distance to h and χ Persei of around 30 pc, the former being closer to the Sun (see Table 1). In a pioneering work Pişmiş (1941) analysed Oosterhoff's (1937) data and found evidence of differences in the amount of interstellar extinction in the direction of each cluster and in the average color indices. A very extensive photometric (photoelectric and photographic) study of the double cluster in Perseus was reported by Wildey (1964), who also provided evidence for significant variations in the reddening across both clusters. His use of a rather sophisticated technique led to the construction of detailed E($B-V$) maps, interpreted as representative of the extinction in those regions. The scale in the "clumpiness" of dust implied by these diagrams is extremely small.

Vogt (1971) analysed the photographic photometry of Moffat and Vogt (1974) but, although the sample included most stars brighter than $V = 17$ in a large area around the double cluster, the data contains many errors and inaccuracies.

Crawford *et al.* (1970) obtained *uvby* and Hβ photometry of the central parts of h and χ Persei. They employed two different and independent methods to determine both the reddening correction and distance modulus to the clusters. The data presents compelling evidence that the interstellar reddening is constant over the field of the cluster nuclei and that the distance to the two clusters in nearly the same, while the values of A_V and m-M differ slightly form those of Borgman and Blaauw (1964) and Becker (1963). A number of stars in h and χ Persei are also included in the third Geneva Observatory photometric catalogue (Rufener 1981).

Mendoza (1967) provided the only available red (*R* and *I* bands) photometry of h and χ Persei. He encountered some problems when comparing the colors of these stars with those of other aggregates in his study, such as the Hyades, Pleiades, etc., a fact which he attributed to "reddening effects". From the ($V-R$) indices, Mendoza obtained an average value of $A_V = 1.64$ for the double cluster. The brightest stars in the more extended region were also observed in the *JHK* and *L* bands, but since the numbpr of these stars common to the present work is very small, they will receive no special attention. Where comparison is possible, Mendoza's infrared colors agree reasonably well with ours except naturally in (K-L), because the two *L* filters differ considerably in effective wavelength.

On a careful examination of the (J-H) versus (H-K) diagram presented in Figure 1, it is possible to establish the behavior of three physical groups of stars: (1) Normal giant and supergiant stars in the nuclei and the extended region, all of them lying along the reddening vector drawn from the position of their corresponding unreddened colors. (2) Main sequence stars with no clear evidence of infrared excess. Those stars in h Persei show little scatter around the position corresponding to the mean value of interstellar extinction. χ Persei stars show somewhat larger scatter but consistent with the locus defined by h Persei. (3) Main sequence and giant stars with infrared excesses. These are mainly Be stars and a few non-emission stars.

We determined the value of the reddening in the direction of each cluster nucleus by computing and averaging the individual values of E($J-K$) of all those stars with known spectral type and where infrared excesses are not clearly present. A few stars with large uncertainty in the ($J-K$) measurements as well as late-type supergiants were not considered in the computation. The stars omitted were Oosterhoff numbers: 49, 816, 926, 1116, 1132, 1133, 1655, 1818, 2138, 2165, 2232, 2242, 2284, 2417, 2691 and 2758. The assumed intrinsic ($J-K$) indices for each spectral type were taken

TABLE 6

AVERAGE COLOR EXCESSES

Luminosity Class	Number of Stars	⟨E(J–K)⟩	Notes
V	22	0.278 ± 0.011	Nucleus of h Persei
V	13	0.284 ± 0.012	Nucleus of χ Persei
I to III	21	0.282 ± 0.016	Nuclei and extended region
All	56	0.281 ± 0.008	...

from Johnson (1966) and the resulting values of E(*J–K*) are shown in Table 6. Assuming a "normal" reddening law, i.e., E(*J–K*) = 0.48 E(*B–V*) (Johnson 1968), we calculated E(*B–V*) for each cluster. These values are shown in the last line of Table 1 (this paper). The average ⟨E(*B–V*)⟩ = 0.59 ± 0.02 calculated for both cluster nuclei and extended region, is in excellent agreement with previous (independent) results.

The data strongly suggest a unique value of the extinction in the direction of h and χ Persei. Although the observational uncertainties in the (*J–K*) indices are large (approximately ± 0.04) as shown in Figure 1, the present observations rule out the large gradients in the extinction reported by Wildey (1964); furthermore, our independent value for A_V is in excellent agreement with that found by Crawford *et al.* (1970), backing our assumed "normal" extinction law in the direction of the clusters.

A (*V–K*) versus (*B–V*) plot is presented in Figure 5. Here, as in Tables 2 and 3, the *B* and *V* data come from Table 5, Wildey (1964), Johnson and Morgan (1955), Schild (1965) and in a few cases from Moffat and Vogt (1974).

Examining Figure 5, it is clear that a number of B-type stars lie off the reddening line. Excesses in the (*V–K*) indices, due to the presence of infrared excess emission from circumstellar envelopes, locate the stars above the normal reddening line in the (*V–K*) versus (*B–V*) diagram and these cases will be discussed in the next section. Those stars located below and to the right of the reddening vector by amounts that exceed the formal photometric errors cannot be easily explained.

Among the possible explanations for such an effect is the presence of very large differences in the extinction properties of the dust particles giving rise to completely different reddening properties of the dust in the direction of those stars as compared to the rest of the clusters. This possibility can be ruled out since it is extremely difficult to understand such changes over a very small distance scale; furthermore, this anomaly would go in the opposite sense to that observed in certain other regions (i.e., in Ophiuchus by Carrasco, Strom, and Strom 1973) where values of the total to selective absorption are larger than 3.3. Other possible mechanisms which cause the abnormal ratio E_{V-K}/E_{B-V} will be discussed in section IV(*c*).

IV. DISCUSSION

The evolutionary status of h and χ Persei has been discussed by Schild (1965, 1967). This author shows that there is a significant difference in their stellar content which is, at least in part, the result of a difference in the ages of h and χ Persei, the former being

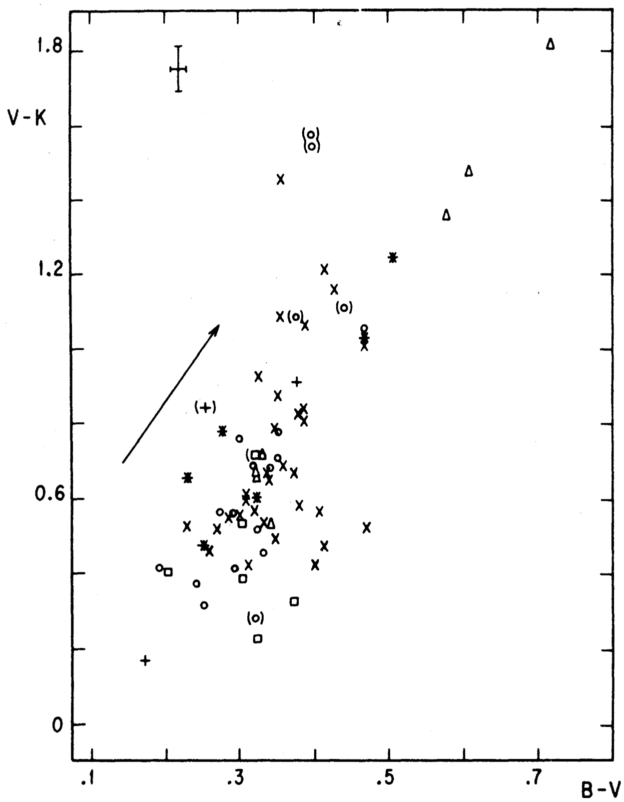

Fig. 5. (*V–K*) versus (*B–V*) diagram for all observed stars in h and χ Persei. Symbols are as in Figure 1 except that the length of the reddening vector is not calibrated. A colon denotes uncertain *K* magnitudes.

younger (see Table 1). Furthermore, Schild presented some evidence of a third (younger) age group composed by the O-stars located within a radius of some 200 pc centered in h Persei.

We have constructed observational H-R diagrams of h and χ Persei in a way which is less dependent on, and therefore less contaminated by, reddening corrections. Figure 6 shows the $K(2.2\ \mu m)$ magnitudes versus spectral type plot for each cluster, leaving out the M supergiants and stars with unknown spectrum. Since the range in effective temperatures in small and all stars are approximately at the same distance from the Sun, the K magnitudes represent well the total luminosity of the stars and are little affected by interstellar extinction ($A_K = 0.09\ A_V$) except for a few stars showing emission spectrum with near-infrared excess (these stars are in parentheses in Figure 5). The infrared excesses found in some B and A supergiants are significant only at $\lambda > 3\ \mu m$.

The continuous lines in Figure 6 represent the locus of the main sequence computed by adopting the M_V (from Allen 1973) and intrinsic $(V-K)$ colors (from Johnson 1966), corresponding to each spectral type, and by assuming a distance modulus to the clusters of 11.8 and a 2.2 μm, extinction $A_K = 0.18$.

The well defined turn-off points in both H-R diagrams and the presence of cooler blue supergiants in χ Persei strengthen Schild's suggestion that h Persei is younger, maybe by a factor of two in age, than χ Persei. The presence of a number of Be and peculiar stars in the nucleus of the latter cluster, which are absent in h Persei, points in the same direction.

a) Supergiants

The role of supergiants in the stellar evolution theory is well established and the reader is referred to the work by Humphreys (1978) and the compilation by de Jager (1981). Tables 3 and 6 list the M and B-type supergiants and bright giant stars, respectively, in h and χ Persei which were included in the present study. Since they are the brightest stars in the clusters, they are well documented in the literature. (See also Schild 1970).

The M-type supergiants have been studied in the range 3 to 18 μm by Cohen and Gaustad (1973) who found excess emission at 11 μm, indicative of a circumstellar silicate dust shell. These excesses correlate with higher luminosity and lower surface temperature. Since the spectral distribution characteristic of silicates (e.g., SiC, Mg_2SiO_4) peaks steeply in ∿ 10 and 20 μm and its contribution at $\lambda \leqslant 5\ \mu m$ is rather small, no clear infrared excess at the shorter wavelengths is expected. In fact this is evident from our measurements as seen, for example, in Figures 2, 3 and 4.

A more interesting result is that obtained for the B and A supergiants (Table 7). We found two clearly distinguishable groups from their near-infrared properties: (1) those with no apparent infrared excess, which turn out to be the less luminous and (2) five bright supergiants (luminosity class Ia), with excess emission at $\lambda > 2\ \mu m$. The shape of the excesses (e.g., Figures 3 and 4) is similar for these stars and fit extremely well with those arising from bremsstrahlung in hot gas ejected from the stars as part of strong stellar winds. A number of authors have obtained mass loss rates from the 10 μm excess emission (e.g., Barlow and Cohen 1977).

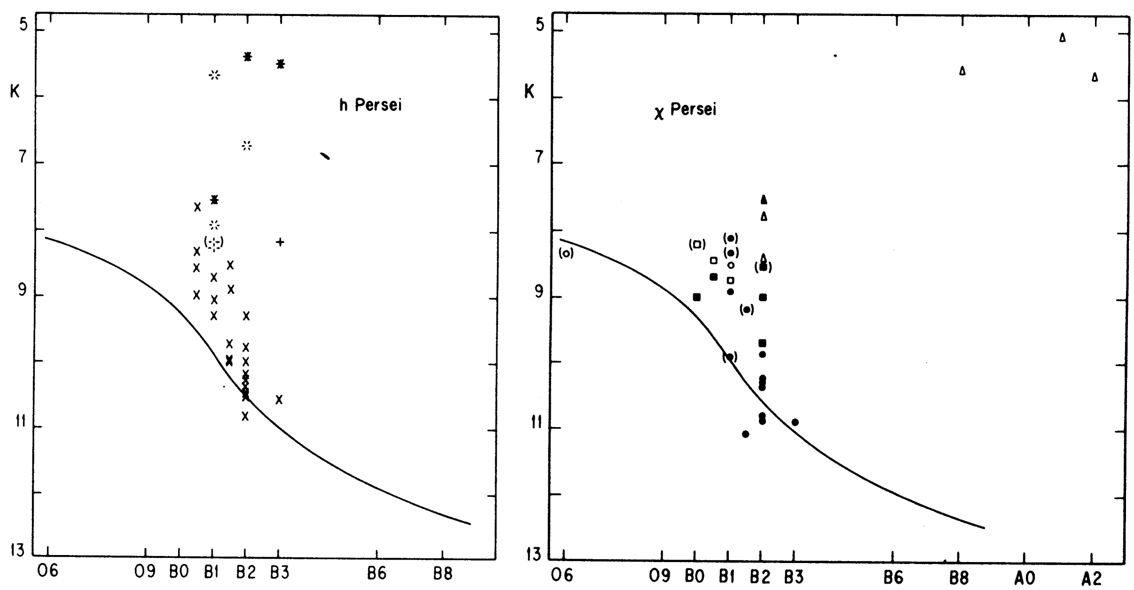

Fig. 6. K magnitude versus spectral type diagram for stars in the nuclei of h (a) and χ (b) Persei. Symbols are as in Figure 1. Broken symbols denote that the stars are outside the nuclei. The full lines represent the ZAMS (see text).

TABLE 7

SUPERGIANT STARS

Oo	Spectral Type	$E_{rc}(J-K)$	$E_{rc}(K-L)$
With IR Excess			
1057	B3 Ia	+ 0.02	+ 0.34
1162	B2 Ia	− 0.02	+ 0.28
2178	A1 Ia	− 0.04	+ 0.29
2589	A2 Ia	+ 0.03	+ 0.32
2621	B8 Ia	+ 0.20	+ 0.26
Without IR Excess			
3	B2 Ib	− 0.09	+ 0.02
16	B1 Ib	− 0.01	+ 0.06
1899	B2 II	− 0.13	+ 0.08
2227	B2 Ib	− 0.05	− 0.02
2541	B2 II	+ 0.02	+ 0.08

Since the emission at $\lambda > 10\,\mu m$ originates too close to the stellar surface ($V_{wind} > V_\infty$) we cannot apply that method for deriving mass loss rates from the present measurements.

b) *Be Stars*

Dealing with a sample of emission-line B stars is a frustrating task even if there is confidence (as in the present case) that the whole sample is at the same distance from the Sun and requires the same reddening corrections. The reason is that a single star can develop rapid and drastic variations in its atmosphere on time-scales of months or years; it can change from being a normal B-type star into a Be star and back to the previous phase, and vice versa (see Costero *et al.* 1981). Models of Be stars always fall short of explaining their sometimes bizarre behavior and observational data always contribute to the understanding (or misunderstanding) of the nature of these stars. The reader is referred to the recent monography by Underhill and Doazan (1982) on B and Be stars. Previous observations of Be stars in h and χ Persei are reported in Schild (1978) and references therein.

Table 8 summarizes the results of the present near-infrared study for the seven Be stars in or near the nucleus of χ Persei and one in the vicinity of h Persei. As in the case of the blue supergiants, we have divided these stars into two groups, according to their infrared properties.

Most of the stars present significant infrared emission in addition to the photospheric one, as can be seen in Figures 1, 2 and 3 and values of the excesses in the $(J-K)$ and $(K-L)$ indices shown in the last columns of Table 7. These were computed individually assuming the intrinsic $(J-K)$ and $(K-L)$ colors for normal stars of the same spectral types from Johnson (1966) and the contribution of interstellar reddening to the excesses ($E(J-K) = 0.28$ and $E_R(K-L) = 0.07$) has been subtracted in all cases. With the possible exception of Oo 2284, 2138 aand 2165 the shape of the infrared excesses out to $\lambda = 3.8\,\mu m$ strongly resemble that caused by ionic free-free emission with gas temperatures $T < 10^4$ K. While stars Oo 2284, 2138 and 2165 can also be modelled by hot dust emission, a significant contribution of bremsstrahlung emission from gas at $T_i > 10^4$ in envelopes of these stars should also be considered, though it is difficult to distinguish unambiguously from these two processes without going into longer wavelengths (Allen 1973; Gehrz, Hackwell, and Jones 1974).

Schild and Romanishin (1976) made a spectroscopic search for Be stars in 29 young open clusters, including h and χ Persei. Apart from the previously classified Be stars in χ Persei, they also found that Oo 2262 exhibit emission lines in its spectrum, although the original classification by Schild (1965) did not refer to emission lines. This may be caused by a change in the spectrum of Oo 2262 or by selection effects. The latter seems difficult to establish, as Schild does not give limits for his searches. Apart from the lack of infrared excess, this star present the same photometric anomalies as the Be stars.

Schild (1978) also found two distinct components to the "intrinsic reddening" (excesses in the $(B-V)$ index after correction for interstellar reddening), one due to H^- free-bound continuum emission (Schild and Romanishin 1976) and a second component whose origin is not yet clearly understood. Schild reached this conclusion after detailed comparisons of the continuum of Be cluster stars with those of "normal" cluster B stars from 3200 A to 8572 A. Although he used too few "normal" comparison stars in χ Persei, the reality of the effect has not been questioned. The values of the "intrinsic excess" of the $(B-V)$ index derived by Schild (1978) compare reasonably well with those given in Table 8, allowing for the fact that the interstellar reddening (ISR) correction applied by Schild was $\{E(B-V)\}_{ISR} = 0.55$ while we adopted $\{E(B-V)\}_{ISR} = 0.59$.

TABLE 8

Be AND Bp STARS

Oo	Spectral Type	$E_{rc}(B-V)$	$E_{rc}(J-K)$	$E_{rc}(K-L)$
With IR Excess				
49	B1 IIIe	− 0.07	+ 0.23	...
2088	B1.5 Vne	− 0.02	− 0.07	+ 0.44
2165	B1 Vne	+ 0.07	+ 0.43	+ 0.75 Var.
2284	B1 Vne	+ 0.07	+ 0.58	+ 1.07
2138	B1 IVpe	+ 0.15	+ 0.19	+ 0.79
2242	B1 Vnp	+ 0.12	+ 0.33	...
Without IR Excess				
2262	B2 Vn(e)	+ 0.09	− 0.04	... Var.
2371	B2 III(e)	− 0.03	− 0.02	− 0.04

c) *Stars with Anomalous (V–K)/(B–V) Indices*

The (V–K) versus (B–V) diagram of h and χ Persei shown in Figure 5 presents seven anomalous B-type stars which lie below and to the right of the "reddening band" where all stars should lie if the interstellar extinction and their intrinsic colors were "normal". In section III we arrived at the conclusion that the reddening in the direction of h and χ Persei is constant and does not differ from the one represented by van de Hulst's No. 15 curve. Observational errors are improbable in most cases, since *UBV* photometry was performed twice for Oo 1080, 1085 and 1041 giving the same values, and accurate photoelectric data exist for Oo 1133, 2246 and 2361. The last two are giants in χ Persei and the former are main sequence stars in the nucleus of h Persei. Oo 2088 is a, presumably variable, Be star. No fully acceptable explanation can be offered for the bizarre $V–K/B–V$ ratio of these stars but this effect could be related to the so called "instrinsic reddening" discovered in the continuum spectra of some Be stars (Schild 1978). For the dwarfs, the implied (B–V) color index excesses obtained from Figure 5 are confirmed by those computed independently from their corresponding intrinsic colors.

The star Oo 816 of unknown spectral type is possibly a field star and its infrared photometry is not accurate.

V. CONCLUSIONS

Our main conclusions are:

1) Reddening in the direction of h and χ Persei is homogeneous and follows a normal reddening law with $E(B-V) = 0.58 \pm 0.03$ and 0.59 ± 0.03 respectively.

2) The evolutionary status of both clusters, as derived from observational H-R diagrams, confirms the fact that h Persei is younger than χ Persei.

3) For those stars which show infrared excesses, we find that, in the case of A and B supergiants, these can be explained by bremsstrahlung associated with hot stellar winds. The excess shown by Be stars might be due to bremsstrahlung, dust or both.

4) The fact that most Be stars belong to (older) χ Persei, while *all B* dwarfs which deviate from the normal (V – K) versus (B – V) locus belong to h Persei, leads us to speculate that these abnormal colors might be indicators (providing a suitable tool for the detection) of a group of stars which seems to be unstable, at times showing Be characteristics while behaving as normal B stars otherwise. The question of whether Be stars are in an evolutionary phase towards the supergiant stage is still open.

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