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NEAR INFRARED EXCESSES IN Be STARS

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Sixty-eight bright Be stars were observed in the R and I bands of the Johnson system. Nearly all of them lie above the main sequence in a $(B-V, V-I)$ diagram, which is interpreted as a near-infrared excess (ΔI) in their energy distributions. From the computed difference with the standard main-sequence relation, a correlation of this ΔI value with the emission strength of the Hα line, previously defined as $e\alpha$ is found. On the other hand, the ultraviolet excesses derived from the Q values shows no evidence of correlation with the infrared excesses. But a correlation with polarimetric data appears reliable.

Key words: Be stars—IR excess—photometry—polarimetry

I. Introduction

During an extended observing program of Be stars with photometric techniques, 68 Be stars were also measured in the Johnson RI system. All are bright southern stars which were found to have the Hα line in emission in a survey carried out from 1960 to 1962 (Jaschek, Jaschek, and Kucewicz 1964). The RI measures obtained up to 1968 were already presented and discussed in a general review of the $UBVRI$ data (Feinstein 1968). It was shown there that Be stars presented an excess radiation in the R and I bands, a result later confirmed by Schild (1976) from measures of their energy distributions. In a general discussion, which combined the UBV data with measures of the hydrogen Balmer lines (Feinstein and Marraco 1979), the emission indices $e\alpha$ and $e\beta$, which account for the emission strength of the Hα and Hβ lines, were derived. Also the ultraviolet excesses ΔQ were obtained through the comparison of the "Q values" from the UBV data with the standard "Q values" corresponding to the spectral types. A weak correlation seems to be present between the ΔQ and the $e\alpha$ values.

As in recent years additional measures in RI were obtained, we are concerned here with the behavior of the RI data. We analyzed their connection with other photometric information already known, such as UBV, Balmer-line photometry, and polarimetric measures.

II. The Observations

The RI photometric data of those Be stars observed from 1965 through 1974 at La Plata Observatory (LP) with the 0.83-m telescope, and with different telescopes at Cerro Tololo Inter-American Observatory (CT), are presented in Table I. We list the mean values for each run, which normally includes measures obtained at nearly consecutive nights, the date (month and year), and the observing place. Table II gives for each date the place and the telescopes employed. The same photomultiplier with S-1 photocathode (RCA 7102) was used at all runs, except in December 1974 at Cerro Tololo when an FW-118 photomultiplier was employed (also S-1). The same optical filters as described by Feinstein (1966) were used during all the measures (R: Schott OG5/2 + Corning 3965; I: Schott RG8/2 + Corning 2540).

Standard stars chosen from Johnson et al. (1966) were employed always. The mean RI values obtained for those standard stars of spectral types O, B, and A with more than ten measures are presented in Table III. The comparison with the standard values for them give an average difference of $-0^{m}.02$ in R and $-0^{m}.01$ in $(R-I)$, in the sense of this paper minus Johnson's system. Therefore no systematic differences for the early-type stars appear noticeable.

From all the observing runs listed in Table I the weighted mean for each star was derived. These values are presented in Table IV. The description of the columns of this table follows: first, the HD number; second, the R magnitude; third, the $(R-I)$ color index; fourth and fifth, the standard deviations of the second and third columns, computed only when the number of runs is larger than four; sixth, the number of measures; seventh, the number of runs; last, the $(V-R)$ color index computed from the mean V magnitudes (Feinstein and Marraco 1979) minus the present R values of the second column.

An appreciable number of these stars display changes in the magnitude and in the color indices, especially in V and $(U-B)$. Thus, it may be expected that the measures we report here have some variations during the time span that they were observed. However this effect was not investigated, because the number of measures included here is not enough for this purpose. We suggest any-

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TABLE I

RI Photoelectric Measures of Be Stars

HD	R	R-I	n	Date	Observatory
28497	5.40	-0.12	2	Nov 1965	CT
	5.45	-0.12	2	Oct 1967	CT
	5.38	-0.11	4	Dec 1968	CT
	5.38	-0.06	3	Dec 1974	CT
30076	5.69	-0.06	2	Nov 1965	CT
	5.71	-0.04	2	Oct 1967	CT
	5.64	0.01	1	Feb 1968	LP
	5.69	-0.04	4	Dec 1968	CT
	5.83	-0.02	3	Dec 1974	CT
35165	6.12	-0.09	2	Feb 1965	LP
	6.10	-0.21	1	Oct 1967	CT
	6.09	-0.07	1	Feb 1968	LP
	6.14	-0.13	4	Dec 1968	CT
	6.14	-0.15	3	Dec 1974	CT
37795	2.62	-0.09	2	Feb 1965	LP
	2.60	-0.08	2	Oct 1967	CT
	2.63	-0.09	1	Feb 1968	LP
	2.66	-0.08	3	Dec 1968	CT
	2.72	-0.09	4	Dec 1974	CT
41335	5.10	0.03	3	Feb 1965	LP
	5.08	0.02	2	Oct 1967	CT
	5.11	0.04	1	Feb 1968	LP
	5.13	0.03	3	Dec 1968	CT
	5.18	0.05	3	Dec 1974	LP
42054	5.81	-0.08	3	Feb 1965	LP
	5.81	-0.08	2	Oct 1967	CT
	5.75	-0.04	1	Feb 1968	LP
	5.88	-0.09	3	Dec 1968	CT
	5.89	-0.11	3	Dec 1974	CT
43544	5.95	-0.10	3	Feb 1965	LP
	5.93	-0.13	2	Oct 1967	CT
	5.89	-0.07	1	Feb 1968	LP
	5.97	-0.13	3	Dec 1968	CT
	6.02	-0.16	3	Dec 1974	CT
44458	5.38	0.04	2	Feb 1965	LP
	5.33	0.16	2	Nov 1965	CT
	5.47	0.03	2	Oct 1967	CT
	5.36	0.04	1	Feb 1968	LP
	5.36	0.03	2	Dec 1968	CT
	5.35	0.06	2	Dec 1974	CT
45677	8.11	0.10	2	Dec 1974	CT
45910	6.28	0.56	2	Oct 1967	CT
	6.37	0.60	3	Dec 1968	CT
	6.28	0.50	3	Dec 1974	CT
48917	5.43	-0.14	1	Feb 1965	LP
	5.48	-0.17	2	Oct 1967	CT
	5.41	-0.17	3	Dec 1968	CT
	5.15	-0.02	3	Dec 1974	CT
50013	3.96	-0.16	1	Feb 1965	LP
	3.94	-0.20	3	Dec 1968	CT
	3.68	-0.08	2	Dec 1974	CT

TABLE I (Continued)

HD	R	R-I	n	Date	Observatory
52437	6.63	-0.16	1	Feb 1965	LP
	6.64	-0.20	2	Oct 1967	CT
	6.64	-0.18	2	Dec 1968	CT
	6.63	-0.18	2	Dec 1974	CT
54309	5.84	-0.12	1	Feb 1965	LP
	5.92	-0.16	2	Oct 1967	CT
	5.73	-0.09	1	Dec 1968	CT
	5.95	-0.13	2	Dec 1974	CT
56014	4.62	-0.11	2	Feb 1965	LP
	4.56	-0.16	1	Nov 1965	CT
	4.70	-0.12	2	Oct 1967	CT
	4.67	-0.13	4	Dec 1968	CT
	4.73	-0.13	2	Dec 1974	CT
56139	4.06	-0.14	2	Feb 1965	LP
	3.65	-0.15	1	Oct 1967	CT
	3.59	-0.08	3	Dec 1968	CT
	3.79	-0.07	2	Dec 1974	CT
57150	4.55	-0.06	1	Feb 1965	LP
	4.51	-0.04	2	Oct 1967	CT
	4.57	-0.07	2	Dec 1968	CT
	4.56	-0.04	2	Dec 1974	CT
58155	5.52	-0.12	2	Feb 1965	LP
	5.48	-0.14	2	Oct 1967	CT
	5.47	-0.17	2	Dec 1968	CT
	5.40	-0.07	2	Dec 1974	CT
58343	5.33	-0.02	1	Nov 1965	CT
	5.18	-0.01	1	Oct 1967	CT
	4.91	-0.01	2	Dec 1968	CT
	5.30	-0.05	2	Dec 1974	CT
58978	5.50	-0.04	1	Nov 1965	CT
	5.52	-0.05	2	Oct 1967	CT
	5.51	-0.03	2	Dec 1968	CT
	5.52	-0.01	2	Dec 1974	CT
60606	5.37	-0.06	1	Feb 1965	LP
	5.35	0.01	1	Oct 1967	CT
	5.32	0.01	2	Dec 1968	CT
60855	5.75	-0.12	1	Dec 1968	CT
	5.73	-0.09	1	Dec 1974	CT
61925	5.92	0.05	1	Nov 1965	CT
	5.98	0.01	1	Oct 1967	CT
	5.89	0.02	2	Dec 1968	CT
	5.97	0.01	2	Dec 1974	CT
63462	4.37	-0.02	1	Nov 1965	CT
	4.36	-0.04	3	Dec 1968	CT
	4.37	0.02	2	Dec 1974	CT
65875	6.54	-0.07	2	Dec 1968	CT
	6.48	-0.02	2	Dec 1974	CT
66194	5.73	-0.05	2	Dec 1968	CT
	5.84	-0.08	2	Dec 1974	CT

TABLE I (Continued)

HD	R	R-I	n	Date	Observatory
67888	6.25	0.00	1	Feb 1965	LP
	6.22	0.00	2	Dec 1968	CT
	6.22	0.02	1	Dec 1974	CT
68980	4.59	-0.07	1	Feb 1965	LP
	4.80	-0.13	2	Dec 1968	CT
	4.63	-0.04	1	Dec 1974	CT
72067	5.89	-0.15	1	Feb 1965	LP
	5.90	-0.16	2	Dec 1968	CT
	5.88	-0.15	1	Dec 1974	CT
75311	4.46	-0.15	2	Dec 1968	CT
	4.57	-0.17	1	Dec 1974	CT
77320	6.10	-0.13	2	Dec 1968	CT
	6.04	-0.12	1	Dec 1974	CT
78764	4.67	-0.13	3	Dec 1968	CT
	4.74	-0.13	1	Dec 1974	CT
83953	4.73	-0.06	2	Feb 1965	LP
	4.73	-0.09	2	Dec 1968	CT
	4.78	-0.11	1	Dec 1974	CT
86612	6.24	-0.11	3	Dec 1968	CT
	6.05	-0.01	1	Dec 1974	CT
88661	5.71	-0.07	2	Dec 1968	CT
	5.62	-0.01	2	Dec 1974	CT
88825	6.07	-0.03	2	Dec 1968	CT
	6.09	-0.02	2	Dec 1974	CT
89890	4.56	-0.09	2	Dec 1974	CT
91465	3.19	-0.08	1	Dec 1968	CT
	3.26	-0.04	2	Dec 1974	CT
92964	5.08	0.24	2	May 1965	LP
	5.45	0.60	1	Dec 1968	CT
	5.55	0.25	1	Dec 1974	CT
102776	4.38	-0.14	2	May 1965	LP
	4.40	-0.14	1	Dec 1968	CT
	4.39	-0.13	1	Dec 1974	CT
105435	2.52	-0.14	2	May 1965	LP
	2.49	-0.05	1	Dec 1974	CT
105521	5.56	-0.08	2	May 1965	LP
106911	4.24	-0.08	1	May 1965	LP
110432	4.94	0.21	1	May 1965	LP
112078	4.67	-0.15	2	May 1965	LP
115842	5.72	0.22	2	May 1965	LP
120307	3.52	-0.25	2	May 1965	LP
120324	3.37	-0.16	2	May 1965	LP
120991	6.24	-0.10	2	May 1965	LP
124367	4.90	0.04	2	May 1965	LP
127972	2.45	-0.23	1	May 1965	LP

TABLE I (Continued)

HD	R	R-I	n	Date	Observatory
131492	4.87	0.08	2	May 1965	LP
137387	5.45	-0.02	1	May 1965	LP
142983	4.89	0.00	2	May 1965	LP
148184	4.18	0.20	2	May 1965	LP
148379	4.78	0.47	2	May 1965	LP
148688	4.92	0.30	2	May 1965	LP
149404	5.01	0.35	2	May 1965	LP
154090	4.59	0.17	1	May 1965	LP
157042	5.12	-0.08	1	Aug 1965	LP
167128	5.29	-0.05	1	Aug 1965	LP
	5.40	-0.01	1	Oct 1967	CT
173948	4.15	-0.17	1	Aug 1965	LP
	4.25	-0.16	1	Oct 1967	CT
178175	5.57	-0.07	1	Aug 1965	LP
	5.50	-0.01	1	Oct 1967	CT
205637	4.66	-0.10	2	Sep 1965	LP
	4.62	-0.14	2	Oct 1967	CT
	4.59	-0.15	2	Dec 1974	CT
209014	5.42	-0.03	1	Aug 1965	LP
	5.40	-0.10	1	Sep 1965	LP
	5.42	-0.07	2	Oct 1967	CT
	5.39	-0.08	2	Dec 1974	CT
209409	4.66	-0.03	1	Aug 1965	LP
	4.71	-0.03	1	Sep 1965	LP
	4.68	-0.08	2	Oct 1967	CT
	4.66	-0.07	2	Dec 1974	CT
209522	5.96	-0.12	1	Aug 1965	LP
	6.03	-0.16	1	Sep 1965	LP
	6.02	-0.15	3	Oct 1967	CT
	5.97	-0.16	2	Dec 1974	CT
212571	4.30	0.04	3	Dec 1974	CT
214748	4.13	-0.07	1	Aug 1965	LP
	4.18	-0.13	1	Sep 1965	LP
	4.16	-0.06	3	Oct 1967	CT
	4.15	-0.08	2	Dec 1974	CT

way that stars with large standard deviations in Table IV are photometrically variable.

The estimated typical mean error for a single measurement is about $0\overset{m}{.}02$ both for the R magnitudes and the $(R-I)$ color index. It may be useful to examine if systematic differences arise when comparing our data with those of other observers. From nine Be stars in common with Mendoza (1967) we get $\Delta R(M-F) = 0\overset{m}{.}000 \pm 0\overset{m}{.}040$ (s.e.), and $\Delta(R-I)(M-F) = -0\overset{m}{.}017 \pm 0\overset{m}{.}016$. From 19 Be stars in common with Johnson et al. (1966) the result is $\Delta R(J-F) = -0\overset{m}{.}039 \pm 0\overset{m}{.}134$ and

TABLE II

Journal of Observations

Date		Place	Telescope
Feb	1965	LP	83 cm
May	1965	LP	83 cm
Aug/Sep	1965	LP	83 cm
Nov	1965	CT	40 cm
Oct	1967	CT	40, 90 cm
Feb	1968	LP	83 cm
Dec	1968	CT	90 cm
Dec	1974	CT	90 cm

TABLE III

Mean Values of the Observed Standard Stars of O, B, and A Spectral Types Compared with Johnson Data

				Johnson Data	
HD	R	R-I	Sp. Type	R	R-I
5737	4.327	-0.123	B8 IIIp	4.30	-0.13
15318	4.246	-0.044	B9 III	4.27	-0.05
18331	5.037	0.064	A1 v	5.06	0.05
30836	3.706	-0.178	B2 III	3.73	-0.16
36512	4.720	-0.281	B0 v	4.74	-0.26
66811	2.308	-0.241	O5 f	2.37	-0.22

$\Delta(R-I)(J-F) = 0^{m}.005 \pm 0^{m}.036$. Omitting five stars whose R magnitudes disagree by more than 0.14 we find $\Delta R(J-F) = 0^{m}.000 \pm 0^{m}.035$ for the remaining 14 stars in common. It is clear that large discrepancies for a few stars can be attributed to their brightness variability. The differences for the R magnitudes for both authors are plotted in Figure 1 as a function of the $(R-I)$ color index.

From an earlier investigation of the *UBVRI* photometric data of the metallic-line A stars (Feinstein 1974) we derived systematic errors in our *RI* measures which amount to about $0^{m}.03$ in R and $-0^{m}.02$ in $(R-I)$, in the same sense as above. From this analysis we can conclude that, in spite of using different filters from those employed in the definition of the system, our data agree within a few hundredths of a magnitude with Johnson's.

III. Discussion of the Data

In Figures 2 and 3 are plotted the $(B-V)$ vs. $(V-R)$ and $(B-V)$ vs. $(V-I)$ arrays for all the Be stars listed in Table IV. In each diagram the solid curve represents the main sequence according to Johnson (1966). The locations of both curves were also checked through the values of the Pleiades main-sequence stars obtained by Iriarte (1969), but no systematic difference was noted. In both diagrams we also include the reddening lines corre-

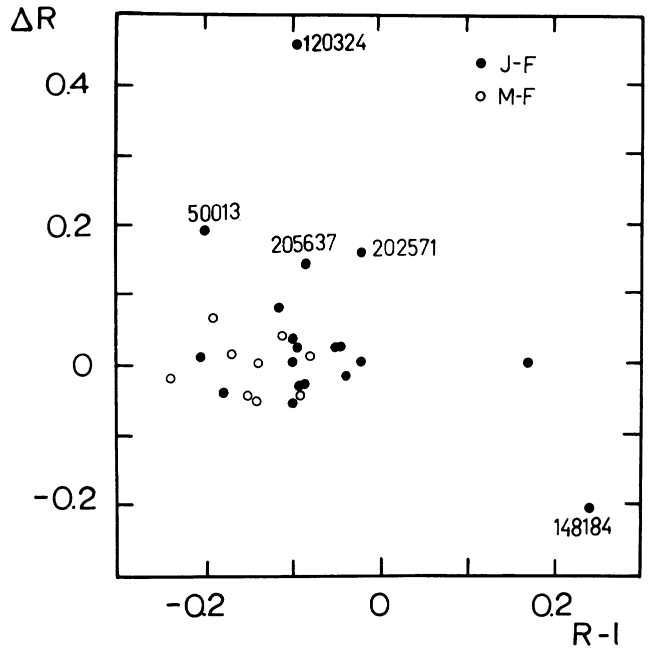

FIG. 1—For the Be stars the differences in ΔR between the measures given by Johnson et al. (1966) and Mendoza (1967) and those listed in Table IV, versus the $(R-I)$ color index. The stars with HD numbers show discrepancies $\Delta R > 0^{m}.14$.

sponding to a normal extinction law, $R = A_v/E_{B-V} = 3.0$. The color-excess ratios employed are those given by

$$\frac{E(V-R)}{E(B-V)} = 0.8 \text{ and } \frac{E(V-I)}{E(B-V)} = 1.6 \quad ,$$

which are represented by dashed lines.

One can see in both diagrams that nearly all stars lie above the main sequence. The most convincing interpretation of this fact is its attribution to an excess radiation in the R and I bands with a stronger effect in the last one. Consequently, we decided to estimate the amount of the I excess for each particular star. The excess was computed as the difference of the observed $(V-I)$ color index minus the intrinsic $(V-I)_0$ value corresponding to a main-sequence star of the same $(B-V)$ color index. This difference is called ΔI. Our Be stars may have been affected by the interstellar reddening, but as the reddening line is nearly parallel to the main sequence, this additional effect must be very small. We can estimate the error in computing the difference from the main sequence instead of doing first the dereddening of the star and then computing this difference. In a very extreme case it may be estimated that the error can be as much as $0^{m}.05$ for a reddened B2 star with an observed color index of $(V-I) = 0.3$, and about $0^{m}.02$ for a similar reddened star with $(V-I) = 0^{m}.1$. Consequently, this error is always much smaller than $0^{m}.05$.

TABLE IV

RI Data for the Be Stars

HD	R	R-I	σ_R	σ_{R-I}	Measures	Runs	V-R
28497	5.40	-0.10	$\pm$0.028	$\pm$0.026	11	4	0.04
30076	5.72	-0.03	.066	.019	12	5	0.13
35165	6.13	-0.13	.018	.038	11	5	-0.05
37795	2.66	-0.09	.048	.005	12	5	0.00
41335	5.12	0.03	.037	.011	12	5	0.10
42054	5.84	-0.09	.048	.019	12	5	0.00
43544	5.96	-0.12	.040	.028	12	5	-0.03
44458	5.38	0.06	.049	.050	11	5	0.17
45677	8.11	0.10	--	--	2	1	0.13
45910	6.31	0.55	--	--	8	3	0.49
48917	5.34	-0.12	.146	.073	9	4	0.00
50013	3.86	-0.15	--	--	6	3	0.01
52437	6.64	-0.18	.005	.014	7	4	-0.11
54309	5.88	-0.13	.086	.026	6	4	-0.03
56014	4.67	-0.13	.051	.013	11	5	-0.02
56139	3.76	-0.10	.200	.035	8	4	0.10
57150	4.55	-0.05	.026	.015	7	4	0.10
58155	5.47	-0.12	.046	.039	8	4	-0.05
58343	5.16	-0.02	.197	.020	6	4	0.21
58978	5.51	-0.03	.008	.017	7	4	0.09
60606	5.34	-0.01	--	--	4	3	0.11
60855	5.74	-0.10	--	--	2	2	-0.03
61925	5.94	0.02	.042	.015	6	4	0.08
63462	4.36	-0.02	--	--	6	3	0.12
65875	6.51	-0.04	--	--	4	2	-0.01
66194	5.78	-0.06	--	--	4	2	0.04
67888	6.23	0.00	--	--	4	3	0.11
68980	4.70	-0.09	--	--	4	3	0.03
72067	5.89	-0.16	--	--	4	3	-0.05
75311	4.50	-0.16	--	--	3	2	-0.02
77320	6.08	-0.13	--	--	3	2	0.00
78764	4.69	-0.13	--	--	4	2	0.01
83953	4.74	-0.08	--	--	5	3	0.03
86612	6.19	-0.08	--	--	4	2	0.02
88661	5.66	-0.04	--	--	4	2	0.04
88825	6.08	-0.02	--	--	4	2	0.03
89890	4.56	-0.09	--	--	2	1	-0.08
91465	3.24	-0.05	--	--	3	2	0.06
92964	5.29	0.33	--	--	4	3	0.09
102776	4.39	-0.14	--	--	4	3	-0.04
105435	2.51	-0.11	--	--	3	2	0.06
105521	5.56	-0.08	--	--	2	1	0.02
106911	4.24	-0.08	--	--	1	1	0.00
110432	4.94	0.21	--	--	1	1	0.40
112078	4.67	-0.15	--	--	2	1	-0.04
115842	5.72	0.22	--	--	2	1	0.31
120307	3.52	-0.25	--	--	2	1	-0.10
120324	3.37	-0.16	--	--	2	1	-0.03
120991	6.24	-0.10	--	--	2	1	-0.18
124367	4.90	0.04	--	--	2	1	0.13
127972	2.45	-0.23	--	--	1	1	-0.07
131492	4.87	0.08	--	--	2	1	0.31
137387	5.45	-0.02	--	--	1	1	0.05
142983	4.89	0.00	--	--	2	1	-0.02
148184	4.18	0.20	--	--	2	1	0.37
148379	4.78	0.47	--	--	2	1	0.56
148688	4.92	0.30	--	--	2	1	0.40
149404	5.01	0.35	--	--	2	1	0.45
154090	4.59	0.17	--	--	1	1	0.27
157042	5.12	-0.08	--	--	1	1	0.10
167128	5.34	-0.03	--	--	2	2	0.02
173948	4.20	-0.16	--	--	2	2	0.01
178175	5.54	-0.04	--	--	2	2	-0.03
205637	4.62	-0.13	--	--	6	3	0.00
209014	5.41	-0.07	.015	.023	6	4	0.02

TABLE IV (Continued)

HD	R	R-I	σ_R	σ_{R-I}	Measures	Runs	V-R
209409	4.68	-0.06	.020	.024	6	4	-0.03
209522	6.00	-0.15	.030	.014	7	4	-0.05
212571	4.30	0.04	--	--	3	1	0.19
214748	4.16	0.08	$\pm$0.015	$\pm$0.025	7	4	0.01

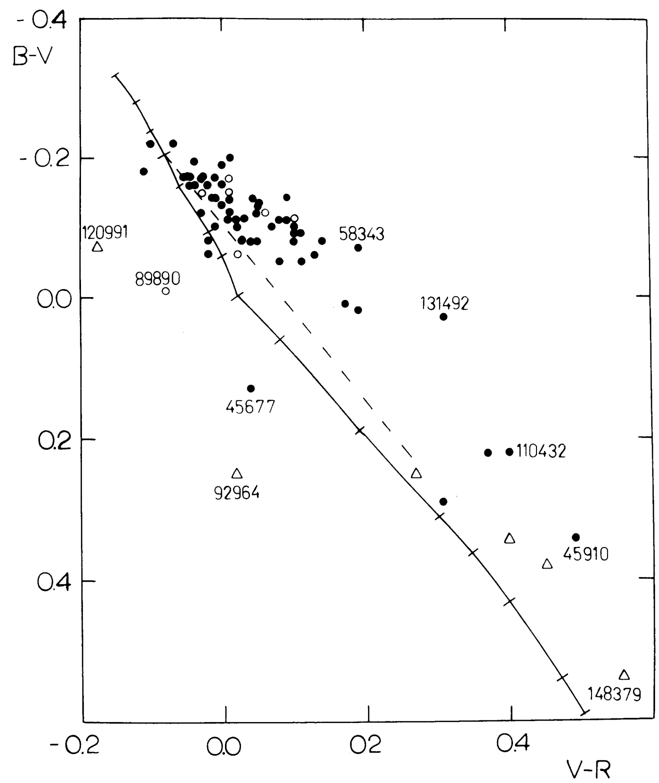

FIG. 2—The $(B-V)$ vs. $(V-R)$ diagram for the Be stars. The dots represent dwarf stars, the open circles correspond to giants, and the triangles are supergiants. The solid line is the main sequence according to Johnson (1966). The dashed line gives the reddening line for a B2 star. The HD numbers of stars situated far from the mean relation are indicated.

Now, it is interesting to compare the ΔI values with the emission strength of the Hα line. Thus the computed differences $(V-I) - (V-I)_0 = \Delta I$ versus the emission indices $e\alpha$, as defined by Feinstein and Marraco (1979), are plotted in Figure 4. A good correlation between the infrared excess in the I band and the amount of the Hα emission is seen, as most of the points are displayed within a relatively narrow band. Four stars HD 45677, HD 89890, HD 120307, and HD 120991 are not included in the diagram since they fall far from the mean relation and outside the figure. These four stars plus those plotted as open circles were not included in the computation of the least-squares solution, which fits the linear relation $\Delta I = 0.793\ e\alpha + 0.034$, with a correlation coefficient $r = 0.81$.

Some relevant data about the stars not included in the computation are listed in Table V. Nearly all of them are

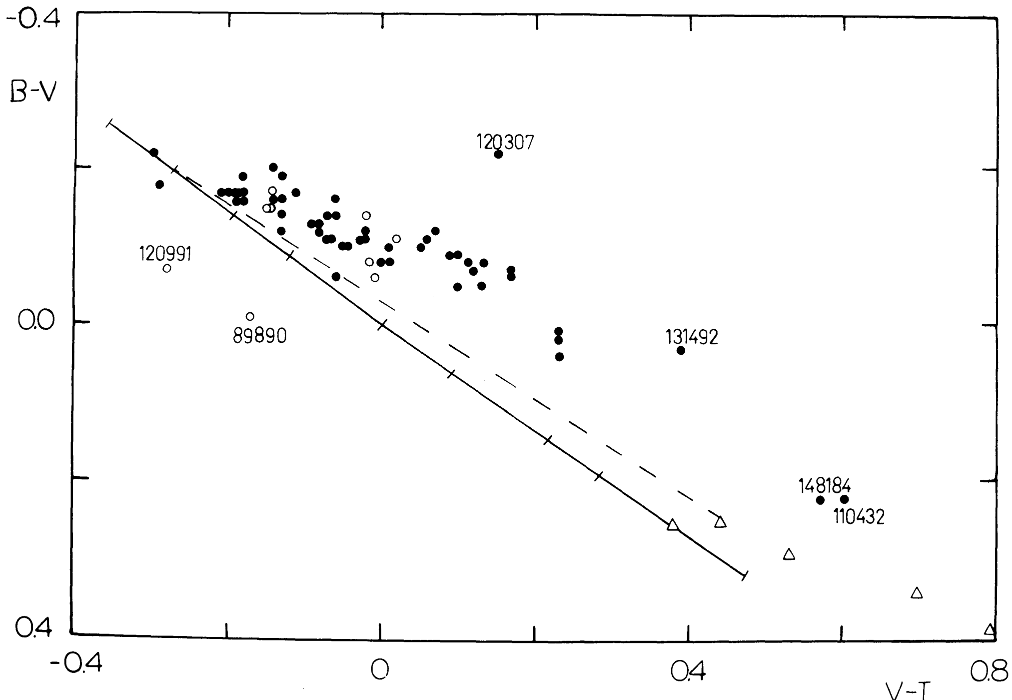

FIG. 3—The $(B-V)$ vs. $(V-I)$ diagram for the Be stars. The symbols have the same meaning as in Figure 2.

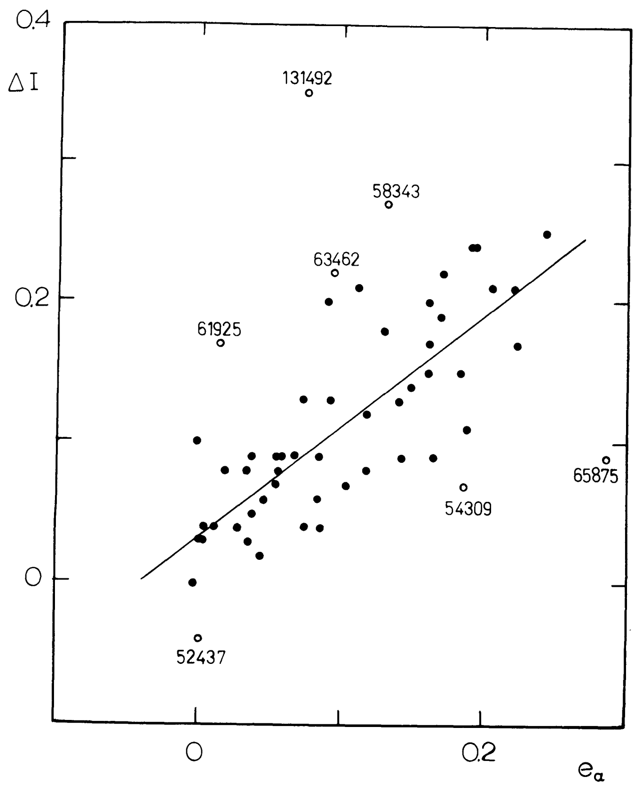

FIG. 4—The ΔI vs. $e\alpha$ plot for the Be stars. The dots correspond to the Be stars employed in the computations of the solid line. Those points indicated by open circles were not used, and also the stars HD 45677, HD 89890, HD 120307, and HD 120991, which if plotted would be off the diagram.

TABLE V

Discordant Stars in Figure 4

a) Stars not included in Figure 4

HD	e_α	ΔI	Remarks
45677	0.490	0.17	variable
89890	0.001	-0.15	
120307	-0.008	0.45	
120991	0.123	-0.18	variable in V

b) Stars slightly discordant

HD	Remarks from our data
52437	variable in V
54309	variable in V, U-B and R
58343	variable in V and R
61975	slightly variable in V and U-B
65875	variable in V and U-B
131492	variable in V and U-B

quite variable, $\Delta V > 0.15$, and a few also in the R magnitude according to our measures. Therefore, their very peculiar positions in the plot can be interpreted as due to the fact that photometric data (UBV, RI, α, and β) were not obtained simultaneously.

One interesting point to look at is the ΔI versus ΔQ relation (Fig. 5), which should give the infrared excess versus the ultraviolet excess. The ultraviolet excess is computed for each star as the difference between the Q values derived from the observed colors, and the Q related to its spectral type (see Feinstein and Marraco 1979). From the distribution of points in Figure 5 there

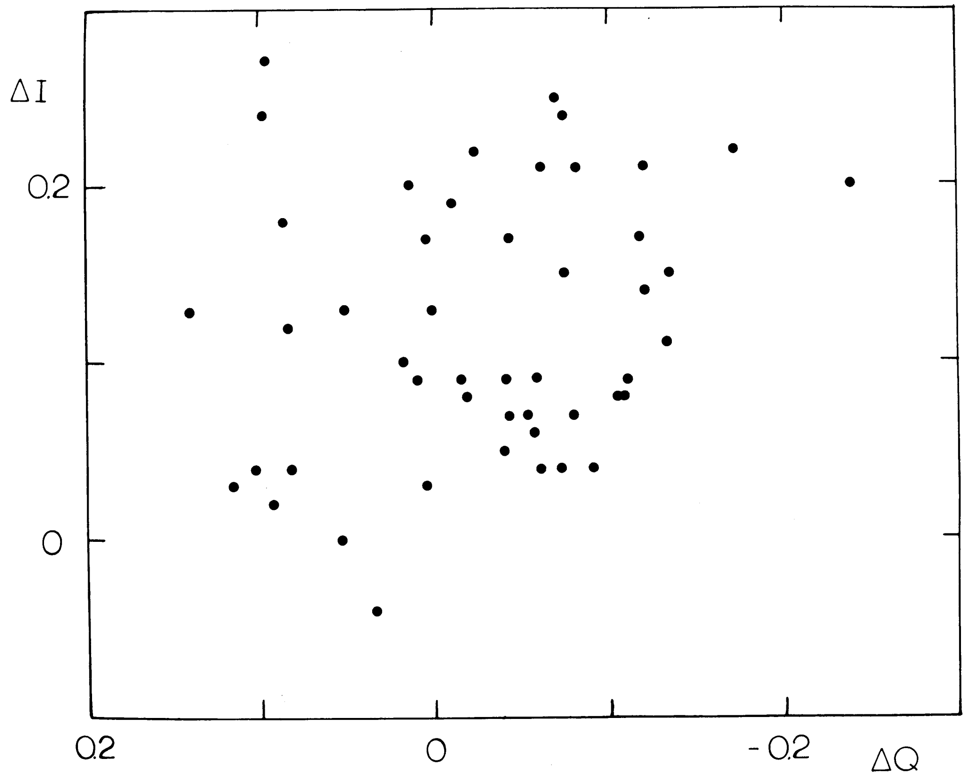

FIG. 5—The ΔI vs. ΔQ plot for all Be stars.

is a clear lack of correlation. However, several of those stars with ΔI greater than that expected from the relation with the $e\alpha$ indices given above are located in the region of positive ΔQ, which would suggest that in some cases the ultraviolet excess is correlated with a great infrared excess.

It is interesting to point out that in a recent paper, Briot (1977) found that Be stars with Paschen lines in emission show a greater excess radiation in the infrared than stars with Paschen lines in absorption. Unfortunately, we observed very few stars from her list to check this conclusion. But, it is important to notice that she has not found any correlation between the infrared excess in the R and I bands with the intensity of emission in Paschen lines; neither could she detect any relation between the flux excess in the R band and the emission intensity in Hα. But, from Figure 6 it becomes clear that a relation of these two values is evident. These ΔR values were defined in a similar way as the ΔI.

Some doubt may arise about systematic errors in photometric systems which especially affect stars with unusual energy distributions, like these Be stars. To check this possibility two diagrams are presented: Figure 7 is the relation of the color excesses ΔI vs. the residuals in the R band (ΔR) for those Be stars in common with Johnson, and also with Mendoza. In Figure 8 the same is given for the residuals in $(R-I)$. No systematic trend in the data appears noticeable.

On the other hand, our conclusion agrees with that of

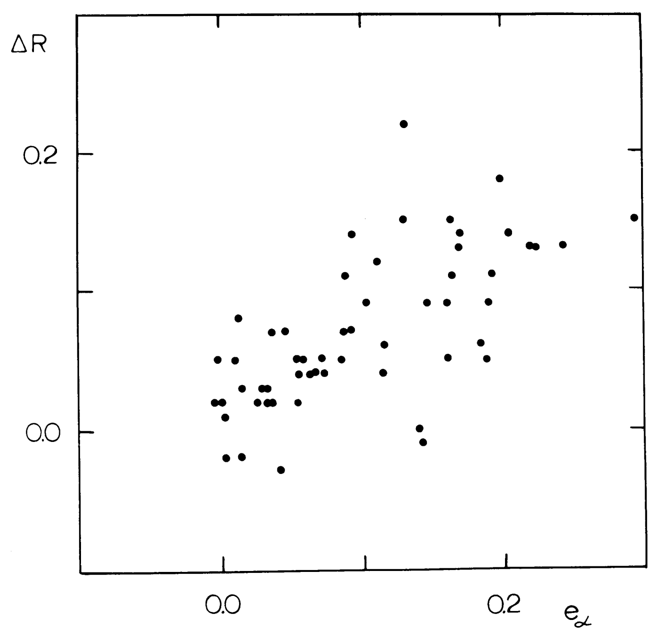

FIG. 6—The ΔR vs. $e\alpha$ plot for the Be stars.

Elias, Lanning, and Neugebauer (1978), who from the study of the Be star γ Cassiopeiae (HD 4180), suggest that the infrared variations (from 1.2 to 10 μm) are produced by changes in an ionized region around the star, and that the Balmer lines were seen more strongly in emission when the infrared excess (10 μm) was greater. Therefore, they interpreted the variations as ascribed to

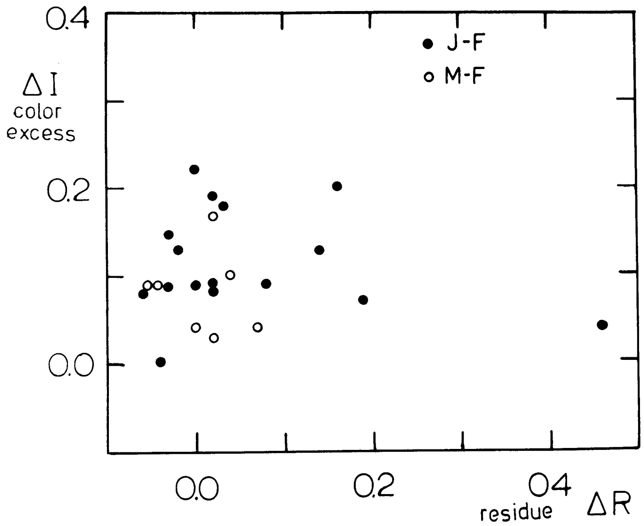

FIG. 7—The color excess ΔI vs. the residue in R for the stars in common with Johnson et al. (1966), represented by dots, and with Mendoza (1967) indicated by open circles.

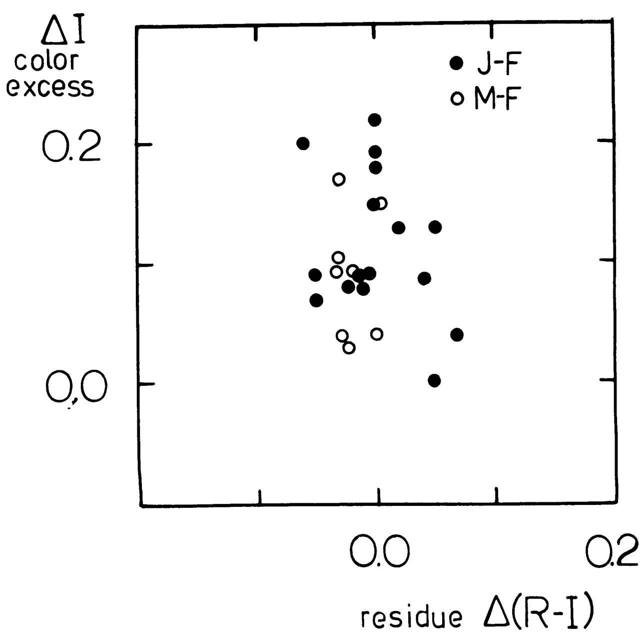

FIG. 8—The color excess ΔI vs. the residue in $(R-I)$. The symbols have the same meaning as in Figure 7.

an ionized region around the stars itself. It is possible that we are in the same situation.

IV. Comparison with Polarization Data

In Figure 9 the polarization data from McLean and Brown (1978) are plotted against the infrared excesses. The polarization is represented by

$$K_B = P_B/(V \sin i)^2$$

in units of 10^{-6} % sec^2 km^{-2} and the infrared excess as the ΔI. This election of the parameter is suggested by

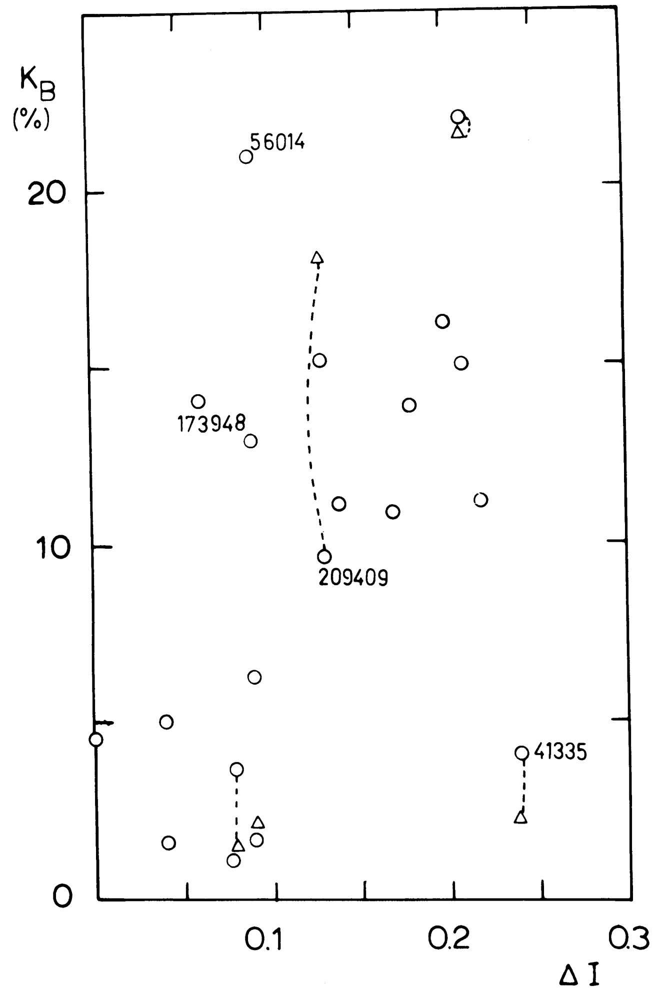

FIG. 9—The $K_B = P_B/(V \sin i)^2$ vs. the ΔI. Circles stand for data from McLean and Brown (1978) and triangles from Poeckert, Bastien, and Marlborough (1979). See text for the units of K_B.

Poeckert and Marlborough (1976) and confirmed by the more-detailed models of Jones (1979). The $V \sin i$ values were obtained from the compilation of Uesugi (1978). We have 19 stars in common from which three are somewhat out of the general correlation shown by the remaining: these are HD 56014 and HD 173968, both photometrically variable, and the spectroscopic binary HD 41335. The 16 remaining stars give a regression

$$K_B = 68.44\, \Delta I + 1.40$$

with a correlation coefficient $r = 0.80$. Five stars from the paper by Poeckert, Bastien, and Landstreet (1979) were added in the figure as triangles. With only the exception of HD 209409 the other four stars show very good coincidence with McLean and Brown.

The correlation shown in Figure 9 is in agreement with the conclusion reached by Jones (1979) that the IR excess is produced by the same electrons that scatter the stellar and diffuse flux. Note that the IR excess measured here is the short wavelength tail of the IR excess dealt with in Jones' paper. The mean value of our infrared excesses ΔI is about 0.12 which fits nicely with the measured values in Table 4 of Jones (1979) extrapolated to 0.9 micron.

V. Conclusions

The RI data listed here demonstrate that most of the Be stars have an infrared excess radiation in the I band which is related to the strength of the Hα emission. A few stars with large brightness variations appear not to follow this relation and the most plausible explanation for this fact is that both sets of photometric measures, in the RI system and in the Balmer lines, were not made simultaneously.

Our data lead to the conclusion that there is a lack of correlation between the excess in the U band, given by the ΔQ values with the excess in the I band derived from the ΔI values. Then, both may originate from different sources, possibly two different parts of the envelope.

On the other hand the near IR excess seems to be produced by the same electrons that produce the optical polarization.

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