Mon. Not. R. astr. Soc. (1980) **192**, 467–480

Infrared photometry of southern early-type stars

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Received 1980 January 10; in original form 1979 November 21

Summary. Infrared photometry tied to the *JHKL* (1.2–3.5 μm) system is presented for 229 southern early-type stars. Data for stars of low reddening are used to determine intrinsic visual – IR colour indices. The E_{V-K}/E_{B-V} diagram is used to evaluate the ratio of total selective extinction ($R = A_V/E_{B-V}$). A mean value of $R = 3.12 \pm 0.05$ is found for stars close to the galactic plane, but a higher value ($R \sim 4.0$) applies to the Orion and Sco–Oph regions. Infrared two-colour diagrams are used to investigate the occurrence of infrared excess emission in different classes of shell star. No excesses are found for supergiants or Of stars. It is deduced that the anomalous position HD 164740 (Herschel 36) in the two-colour diagrams is produced by strong infrared excess and not by a peculiar extinction law.

1 Introduction

Stars which have their maximum intrinsic energy output in the mid-ultraviolet may appear an unexpected choice for a programme of infrared photometry. Two factors ensure the usefulness of such observations. First, early-type stars are almost invariably chosen for studies of interstellar extinction, due to their intrinsic luminosity, relatively featureless spectra, and frequent spatial association with dusty regions: the total extinction at a wavelength of 2 μm is a factor $\sim 2 \times 10^5$ less than at 2000 Å, compensating for the low intrinsic flux in the infrared. Secondly, many early-type stars have enhanced emission at infrared wavelengths due to the contribution of circumstellar shells, in the form of free–free emission in an ionized gaseous envelope, or thermal radiation from heated dust. In this paper we present a catalogue of infrared photometry for 229 Southern stars, mostly of spectral type O–A5, observed at the South African Astronomical Observatory during the period 1973–1977. The observations are made in the standard *JHKL* broadband photometric system. Approximately two-thirds of these data are previously unpublished; for completeness, results which have already appeared in the literature (van Breda, Glass & Whittet 1974; Whittet, van Breda & Glass 1976; Whittet & van Breda 1978) are included. A subgroup of stars suitable for future use as photometric standards is selected from the catalogue (Section 3). The photometry for stars of low reddening is used to derive intrinsic visual – IR colour indices, and results are presented in Section 4. The E_{V-K} versus E_{B-V} diagram is used in Section 5 to evaluate the ratio of total to selective extinction ($R = A_V/E_{B-V}$). In the final section we investigate the occurrence of infrared excess radiation in different classes of shell star by means of the infrared two-colour diagrams.

2 The photometry

The observations were made at the Sutherland site of the South African Astronomical Observatory during three observing runs on the 1.9-m, two on the 1.0-m and one on the 0.75-m

Table 1. Infrared photometry for 229 stars.

Star	ℓ	b	Sp	V		J	H	K	L	n	Ref		E_{B-V}	E_{V-K}
(HD, etc.)	(°)	(°)				(1.25μm)	(1.65μm)	(2.2μm)	(3.5μm)					
36512	210	-21	B0V	4.61		5.13	5.27	5.37	5.56	1	a		0.03	0.08
36619	227	-27	Am	7.76		7.42	7.34	7.33	7.30	4	a		-	-
36629	208	-20	B2V	7.66		7.45	7.46	7.42	7.37	1	a		0.26	0.90
37043	210	-20	O9III	2.77		3.25	3.38	3.43	3.53	1	a		0.06	0.22
37061	209	-19	B1V	6.8v		5.73	5.54	5.45	5.49	2	a	var?	0.53	2.10
37742	206	-17	O9.5Ib	1.77	*	2.20	2.27	2.31	2.33	3	a		0.06	0.21
37903	207	-17	B1.5V	7.84		7.36	7.28	7.28	7.44	2	b		0.37	1.27
38051	209	-17	B3	8.51		7.60	7.49	7.51	7.55	1	b		0.58	1.56
NGC 2024 no.1	206	-17	B0.5Vp	12.17		7.35	6.39	5.86	5.60	1	b		1.69	7.10
38087	207	-16	B5V	8.30		7.59	7.30	7.21	7.30	2	a		0.29	1.51
38666	237	-27	O9.5V	5.17		5.71	5.84	5.94	6.03	2	a		0.02	0.09
42259	213	-12	B0Ve	8.49	*	7.79	7.71	7.59	7.58	1	a		0.68	1.74
46223	206	-2	O5f	7.28	*	6.69	6.63	6.59	6.75	1	a		0.54	1.60
46484	207	-2	B1V	7.74		6.94	6.85	6.78	6.91	1	b		0.62	1.71
46485	207	-2	O8V	8.26		7.52	7.40	7.38	7.43	1	b		0.63	1.79
46573	209	-3	O7IIIf	7.92		7.14	7.07	7.06	7.16	1	a		0.67	1.78
47240	207	-1	B1II	6.15		5.75	5.73	5.71	5.76	1	b		0.40	1.09
47432	210	-2	O9.5Ib	6.20		5.87	5.86	5.83	5.93	1	b		0.44	1.12
47839	203	2	O8III	4.65	*	5.13	5.21	5.30	5.40	1	a		0.06	0.27
50064	213	0	B6Ia	8.21	*	6.21	5.86	5.64	5.51	1	b		0.83	2.63
50707	231	-9	B1IV	4.82		5.28	5.36	5.42	5.50	3	a		0.02	0.15
52721	224	-3	B2Ve	6.59	*	6.29	6.23	6.10	5.96	2	b		0.30	1.15
53138	236	-8	B3Ia	3.04		3.21	3.24	3.21	3.21	1	a		0.05	0.10
53244	228	-4	B8III	4.10		4.30	4.36	4.35	4.44	1	a		0.00	0.00
53367	224	-2	B0e	6.96	*	5.76	5.48	5.18	4.81	2	a		0.73	2.62
53667	222	-1	B0.5III	7.75	*	7.03	6.94	6.76	6.59	1	a		0.52	1.80
57061	238	-6	O9III	4.39		4.67	4.72	4.74	4.79	1	a		0.17	0.53
57682	224	3	O9V	6.42		6.79	6.86	6.91	7.08	1	a		0.12	0.39
58350	243	-6	B5Ia	2.47		2.57	2.56	2.56	2.55	1	a		0.00	0.03
59075	233	-1	B8I	7.65		6.95	6.79	6.70	6.59	1	a		0.36	0.88
59094	231	1	B2Vne	8.44	*	7.77	7.57	7.32	7.08	1	a		0.39	1.78
60479	242	-4	B0II	8.41		7.66	7.60	7.53	7.63	1	a		0.63	1.64
61827	247	-5	O8V	7.65		6.37	6.20	6.05	5.90	3	a		0.93	2.52
62150	247	-5	B3Ia	7.67		6.53	6.33	6.23	6.16	3	b		0.65	1.71
64760	262	-10	B0.5Ib	4.24		4.53	4.60	4.64	4.69	2	a,c	var?	0.07	0.21
66811	256	-5	O5f	2.25	*	2.77	2.85	2.86	2.88	2	a		0.04	0.31
69464	254	0	O7f	8.84	*	7.92	7.80	7.67	7.65	1	a		0.63	2.09
69882	260	-4	B1IIIk	7.15		6.42	6.34	6.30	6.29	2	b		0.66	1.60
73882	260	1	O8n	7.19		6.13	5.99	5.93	5.93	4	b	var?	0.72	2.18
74272	266	-3	A5II	4.77		4.28	4.17	4.11	4.08	2	a,c		0.01	0.17
74575	255	6	B1.5III	3.70		4.09	4.15	4.19	4.24	1	a		0.07	0.21
75211	264	0	O8V	7.50		6.55	6.42	6.38	6.35	2	a		0.72	2.04
75222	258	4	B0Ik	7.41		6.52	6.37	6.33	6.41	1	a		0.62	1.76
-44° 3129	265	0	O9.5Ib	9.43		7.86	7.62	7.50	-	1	a		0.99	2.68
75821	266	-2	B0III	5.10		5.53	5.63	5.70	5.80	2	a		0.09	0.24
75860	264	0	B1.5Iab	7.59		5.67	5.38	5.18	5.07	2	a		0.91	2.88
-45° 3218	266	-1	B0.5III	8.90		7.21	6.99	6.88	6.80	2	a		1.06	2.81
-46° 3272	267	-1	B0.5Ib	9.06		6.98	6.70	6.51	6.49	1	a		1.03	3.16
76556	268	-2	O7V	8.20		7.13	7.02	6.93	-	1	a		0.73	2.19
77581	263	4	B0.5Ib	6.88		5.85	5.70	5.59	5.56	2	a,c	var?	0.78	1.90
78344	269	0	O9.5Ia	8.96		6.59	6.26	6.04	5.86	3	a		1.37	3.67
78785	268	1	B1II	8.60		7.44	7.31	7.26	7.31	1	b		0.76	2.09
80077	272	-1	B2Ia$^+$e	7.58	*	4.41	3.93	3.63	3.38	5	b		1.46	4.34
SLS 1267	272	-1	B0III	11.07		8.77	8.47	8.34	-	3	a		1.30	3.57
80558	273	-1	B7Iab	5.86	*	4.59	4.40	4.28	4.09	2	b		0.55	1.57
86440	279	0	B5II	3.54		3.70	3.70	3.69	3.76	2	a		0.05	0.12
89201	283	-1	B1Ia	7.84		6.23	5.99	5.83	5.75	4	a		0.87	2.55
90706	285	0	B3Ib	7.06		5.97	5.80	5.69	5.84	1	c		0.60	1.64
90707	285	0	B1III	8.70		7.91	7.86	7.82	-	1	a		0.55	1.63
90772	285	0	A7Ia	4.64		3.46	3.24	3.07	2.96	1	b		0.43	1.12
91316	235	53	B1Ib	3.85		4.18	4.20	4.25	4.28	2	a,c		0.05	0.14
91323	278	12	B5III	7.19		7.40	7.44	7.53	7.68	1	a		0.01	0.08
91619	286	0	B5Ia	6.15		5.10	4.90	4.79	4.42	2	b		0.52	1.48
92207	286	0	A0Iae	5.48	*	4.04	3.78	3.60	3.47	4	a,b		0.48	1.69
92693	286	1	A2Ia	6.99		4.34	3.90	3.64	3.41	2	a		1.02	3.03
92964	287	0	B3Ia	5.43	*	4.71	4.62	4.53	4.47	1	d		0.38	1.17

Table 1 – *continued*

Star	ℓ	b	Sp	V		J	H	K	L	n	Ref		E_{B-V}	E_{V-K}
(HD, etc.)	(°)	(°)				(1.25μm)	(1.65μm)	(2.2μm)	(3.5μm)					
93030	290	-5	O9.5V	2.75		3.30	3.37	3.44	3.50	2	a		0.07	0.17
93206	288	-1	BOIbn	6.24	*	5.55	5.38	5.28	5.24	4	a,b	var?	0.37	1.64
303308	288	-1	O3V	8.17		7.68	7.70	7.80	-	2	a		0.44	1.29
93540	290	-5	B6Vn	5.33		5.52	5.50	5.56	5.60	2	a	var?	0.01	0.06
93795	288	0	AOIa	8.40		6.54	6.15	5.93	5.65	1	a		0.79	2.28
93890	288	0	BO.5Iab	9.08		7.06	6.72	6.56	6.46	2	a		1.01	3.13
303492	288	0	O9Ia	8.85		7.28	7.04	6.88	6.81	2	a		0.88	2.78
94367	287	2	AOIa	5.26		4.86	4.76	4.70	4.60	2	a		0.16	0.37
94909	288	2	BOIa	7.34		6.21	6.06	5.97	5.94	3	b		0.72	2.05
95731	289	1	B1Ib	9.08		8.56	8.51	8.35	8.20	2	a		0.59	1.27
95880	290	0	B5Ib	6.90		6.19	6.05	5.95	5.83	3	a		0.47	1.07
96088	289	2	B3III	6.16		6.49	6.56	6.65	6.76	3	a,d		0.03	0.07
96880	290	1	B1Ib	7.57		6.41	6.23	6.08	5.96	1	a		0.65	2.03
96919	291	-1	B9Ia	5.15		4.51	4.38	4.29	4.21	2	a		0.22	0.73
306097	291	0	O9III	8.93		7.42	7.25	7.19	7.06	1	a		0.96	2.62
97048	297	-16	B9.5e	8.50	*	7.34	6.83	6.19	4.77	2	a	var?	0.39	2.37
97300	297	-15	AOV	9.06		7.61	7.28	7.12	6.92	2	a		0.39	1.96
97707	291	0	B2Ia	8.16		6.96	6.81	6.70	6.58	2	a		0.64	1.85
99171	286	17	B2III	6.11		6.48	6.60	6.65	6.83	2	c		0.05	0.12
99953	294	-2	B2Ia	6.41		5.67	5.53	5.43	5.31	2	b		0.49	1.37
100262	293	2	A2Ia	5.16		3.94	3.72	3.59	3.43	3	a,b		0.46	1.25
100841	294	-1	B9III	3.12		3.14	3.10	3.10	3.13	1	a		0.04	0.15
101205	295	-2	O8V	6.48		6.30	6.28	6.26	6.21	2	a		0.38	1.14
103516	297	-1	A2Ib	5.90		5.31	5.19	5.14	5.03	3	a		0.15	0.44
106068	299	0	B9Ia	5.92		5.14	5.03	4.94	4.86	2	a		0.31	0.85
109399	302	-10	BO.5III	7.67		7.57	7.58	7.61	7.76	2	a		0.27	0.85
110073	301	23	B8IVp	4.64		4.75	4.77	4.79	4.75	1	a		0.00	0.09
110432	302	0	B2pe	5.39	*	4.50	4.28	3.96	3.50	6	b	var?	0.50	2.09
110639	302	1	B1Ib	8.46		6.85	6.65	6.56	6.43	3	a		0.88	2.44
111124	303	0	O5	9.40	*	7.51	7.24	6.99	6.72	2	a		1.02	3.33
SLS 2778	303	0	BO	10.55		8.06	7.72	7.56	7.52	2	a		1.33	3.83
111558	302	-7	B8Iab	7.25		6.85	6.78	6.73	6.64	5	a		0.15	0.45
112244	304	6	O9Ib	5.42	*	5.29	5.27	5.26	5.20	5	a,b	var?	0.32	0.97
113034	304	1	B1Ib-II	9.30		6.81	6.47	6.26	6.09	1	b		1.28	3.69
113422	304	1	B1Ia	8.23		6.37	6.11	5.95	5.79	2	b		1.05	2.82
114213	305	1	B1Ib	8.98		6.76	6.45	6.26	6.11	3	a		1.10	3.26
114340	305	3	B1Ia+	8.09		6.83	6.65	6.51	6.35	2	b		0.69	2.12
115842	307	7	BO.5Iab	6.02	*	5.33	5.23	5.15	5.11	2	c		0.52	1.48
116119	307	1	B9Ia	7.91		6.13	5.89	5.75	5.69	3	a		0.71	2.03
117797	308	0	O8.5V	9.19		7.96	7.78	7.66	7.58	1	a		0.81	2.43
119608	320	43	B1Ib	7.51		7.61	7.67	7.70	7.75	3	a		0.13	0.35
120678	310	-1	O8IIInep	7.89	*	7.37	7.15	6.88	6.56	2	b		0.41	1.93
121190	313	9	B8V	5.66		5.81	5.85	5.85	5.81	3	a		0.01	0.05
122669	311	-1	BO.5IIpe	8.97	*	8.00	7.77	7.49	7.11	2	a		0.60	2.27
122691	311	-1	BO.5IIInep	9.20	*	8.21	7.98	7.64	7.17	2	a		0.60	2.35
122879	312	2	BOIab	6.41		6.07	6.03	6.00	5.99	4	b		0.36	1.09
124314	313	0	O8nk	6.64	*	6.40	6.35	6.30	6.22	1	b		0.52	1.26
124471	311	-5	B2Ib	5.74		5.92	5.95	6.00	6.10	3	a		0.11	0.13
124979	316	9	O8.5	8.54		8.45	8.45	8.40	-	1	a		0.38	1.04
125206	313	0	O9.5V	7.92		7.38	7.30	7.21	7.20	1	a		0.56	1.57
125241	314	0	O9.5Iab	8.28		7.10	6.94	6.85	6.80	4	a		0.76	2.10
125835	311	-7	A2Ia	5.60		4.42	4.21	4.09	3.98	4	a,b		0.49	1.19
129116	326	20	B3V	3.99		4.41	4.47	4.50	4.53	3	a		0.02	0.05
132960	328	15	B1IV	7.39		7.75	7.83	7.88	7.90	3	a	var?	0.10	0.26
134959	321	-1	B2Ia	8.20		5.82	5.48	5.29	5.09	4	b	var?	1.25	3.30
135159	320	-2	F8I	9.51		4.81	4.15	3.81	3.59	1	a		1.49	4.46
135591	320	-3	O9Ib	5.43		5.56	5.57	5.59	5.63	3	a		0.19	0.65
136664	334	17	B5V	4.53		4.87	4.93	4.97	5.03	2	c		0.01	0.02
137432	335	16	B5V	5.44		5.80	5.82	5.86	5.94	2	a		0.00	0.00
137595	337	19	B3Vn	7.49		7.37	7.39	7.41	7.51	2	a		0.30	0.64
142139	324	-5	A1V	5.75		5.68	5.63	5.60	5.57	4	a		0.03	0.08
142468	328	-1	BO.5Ia	7.85		6.60	6.44	6.32	6.19	2	c		0.80	2.14
142669	345	18	B2V	3.88		4.32	4.40	4.44	4.51	3	a		0.04	0.10
142754	337	9	B1V	8.61		8.15	8.14	8.12	8.13	2	a		0.45	1.24
144334	350	21	B8Vp	5.92		5.94	5.90	5.86	5.90	2	a		0.02	0.30
144844	351	20	B9V	5.89		5.78	5.72	5.69	5.71	2	a		0.08	0.33
144900	333	2	O9V	9.62		7.88	7.72	7.62	7.45	2	a		1.07	2.88
144969	333	2	BO.5Ia	8.28		5.92	5.58	5.36	5.13	1	c		1.16	3.53
146145	331	-2	A7V	6.31		5.74	5.60	5.56	5.63	2	a		0.06	0.29
147012	351	17	B9V	9.75		8.31	8.15	8.00	7.97	1	a		0.58	1.88
147013	351	17	AOV	9.10		7.91	7.75	7.57	7.58	1	a		0.45	1.55
147084	352	18	A5II	4.54		2.21	1.83	1.61	1.44	3	a,c		0.74	2.57
147165A	351	17	B1III	2.93		2.47	2.41	2.37	2.40	1	b		0.40	1.31
147165B	351	17	B8V	8.48		7.50	7.34	7.22	7.15	2	a		0.45	1.50
147283	352	18	A3V	10.27		8.05	7.70	7.47	7.52	1	a		0.72	2.59
147343	352	18	A1V	9.36		7.61	7.32	7.15	6.95	1	a		0.63	2.14
147384	352	18	B9.5V	8.62		7.40	7.19	7.10	7.06	1	a		0.45	1.59
147648	352	17	B8V	9.42		7.28	6.90	6.68	6.60	2	a		0.89	2.98
147701	352	17	B5V	8.35		6.69	6.41	6.21	6.06	1	a		0.72	2.56
147888	354	18	B5V	6.75		5.75	5.60	5.49	5.45	3	b		0.47	1.68
147889	353	17	B2V	7.86		5.36	4.86	4.55	4.38	2	b,d		1.08	3.97
147932	354	18	B5V	7.27		6.16	5.90	5.77	5.70	3	b		0.47	1.92
147933/4	354	18	B2IV/V	4.59		3.72	3.54	3.48	3.57	1	a		0.47	1.77
148184	358	21	B2IVe	4.34	*	3.50	3.29	3.04	2.71	2	b	var?	0.54	1.96
148379	337	2	B2Iae	5.41	*	4.01	3.81	3.67	3.55	1	c		0.72	2.13
148546	343	7	O9.5Iab	7.76		6.90	6.82	6.78	6.70	2	a		0.55	1.73
148579	353	16	B9V	7.34		6.46	6.28	6.12	5.99	4	a		0.35	1.35
148605	353	16	B2V	4.79		4.97	5.05	5.05	5.20	1	a		0.12	0.40
148688	341	4	B1Iae	5.35	*	4.36	4.23	4.11	4.03	1	c		0.53	1.78

Table 1 – *continued*

Star	ℓ	b	Sp	V		J	H	K	L	n	Ref		E_{B-V}	E_{V-K}
(HD, etc.)	(°)	(°)				(1.25μm)	(1.65μm)	(2.2μm)	(3.5μm)					
148703	346	9	B2IV	4.23		4.54	4.64	4.68	4.82	1	c		0.07	0.21
148937	336	0	O6Vf	6.71	*	5.88	5.80	5.69	5.54	1	b		0.66	1.94
149019	335	-1	A1Ia	7.45		5.21	4.90	4.72	4.63	2	b		0.87	2.47
149438	352	13	B0V	2.83		3.34	3.47	3.53	3.58	1	a		0.05	0.14
149757	6	24	O9.5V	2.56		2.59	2.62	2.62	2.70	1	b		0.32	0.80
150898	330	-8	B0Iab	5.57		5.68	5.74	5.77	5.77	2	c		0.13	0.48
151213	339	-1	B0IV	7.64		6.95	6.88	6.84	6.89	3	a		0.59	1.64
151346	357	13	B7V	7.90		6.60	6.39	6.29	6.30	2	a		0.53	1.90
152235	343	1	B0.5Ia	6.33	*	4.99	4.83	4.72	4.61	1	c		0.78	2.22
152236	343	1	B1Ia+e	4.82	*	3.47	3.27	3.11	2.94	1	c		0.69	2.25
152478	337	-5	B3Vnep	6.32	*	6.16	6.11	5.95	5.64	1	a		0.20	0.93
152667	345	1	B0Iape	6.23	*	5.51	5.41	5.33	5.24	1	a		0.54	1.58
153261	331	-10	B2Vnek	6.10	*	6.20	6.12	5.89	5.50	1	a		0.21	0.87
153919	348	2	O6f	6.56	*	5.76	5.65	5.54	5.46	2	b		0.58	1.94
154043	341	-4	B1Ik	7.08		5.54	5.36	5.21	5.12	1	c		0.81	2.41
154090	351	4	B1Iab	4.86	*	4.23	4.17	4.10	4.12	1	a		0.47	1.30
154368	350	3	O9.5Iab	6.18		5.01	4.70	4.60	4.82	1	a		0.77	2.33
154445	19	23	B1V	5.63		5.28	5.33	5.29	5.35	2	b		0.42	1.09
SLS 3981	347	-1	B0III	10.19		8.22	7.99	7.83	7.74	2	a		1.24	3.20
156201	352	1	B0.5Ia	7.90		6.30	6.08	5.95	5.86	1	c		0.89	2.56
156738	351	0	O7	9.35		7.20	6.97	6.81	6.70	2	a		1.17	3.46
157038	350	-1	B4Ia+	6.41		4.55	4.30	4.12	3.97	3	a,b		0.72	2.48
157246	335	-11	B1III	3.33		3.63	3.70	3.72	3.79	2	a		0.13	0.36
157857	13	13	O7	7.78		7.37	7.33	7.29	7.11	1	a		0.50	1.41
159864	9	7	B0.5II	8.58		8.15	8.11	8.09	8.08	1	a		0.52	1.28
160529	356	-2	A2Ia+	6.67	*	3.68	3.22	2.93	2.65	2	b		1.28	3.42
161056	19	12	B3V	6.28		5.53	5.39	5.32	5.30	2	b		0.54	1.52
161061	1	1	B2III	8.47		6.81	6.61	6.48	6.47	1	a		0.99	2.65
161961	24	13	B0.5III	7.89		7.37	7.37	7.35	7.37	1	b		0.51	1.33
162374	356	-4	B8V	5.90		6.03	6.07	6.06	6.14	1	a		0.00	0.08
162978	5	0	O8III	6.20		6.03	6.02	6.00	5.98	2	b		0.35	1.12
163800	7	1	O7IIIf	7.02		6.37	6.34	6.29	6.27	2	b		0.59	1.65
164514	7	0	A5Iae	7.28	*	4.13	3.57	3.27	3.06	1	a		0.92	3.64
164740	6	-1	O7	10.30	*	7.95	7.39	6.64	5.23	2	b	var?	0.89	4.58
164794	6	-1	O4Vf	5.97	*	5.74	5.74	5.71	5.83	1	a		0.35	1.18
164865	6	-1	B9Iab	7.62	*	5.29	4.87	4.63	4.27	1	a		0.84	2.86
165024	343	-14	B1Ib	3.67		3.83	3.88	3.91	3.97	1	a		0.16	0.30
165052	6	-1	O6Vn	6.87		6.43	6.49	6.65	-	1	a		0.40	1.14
165319	15	3	B0Ia	7.94		6.53	6.35	6.27	6.21	1	c		0.83	2.35
166197	358	-7	B2III	6.14		6.43	6.50	6.55	6.61	3	a,c	var?	0.08	0.25
166628	11	-1	B3Ia	7.16		5.75	5.54	5.41	5.38	1	c		0.70	2.02
167356	12	-1	A0Ia	6.08		5.47	5.38	5.31	5.25	2	a		0.18	0.58
167451	17	2	B0.5Ib	8.23		6.55	6.29	6.12	5.97	1	a		1.01	2.72
167838	15	0	B5Ia	6.73		5.54	5.37	5.27	5.20	1	c		0.55	1.58
167971	18	2	O8f	7.52	*	5.53	5.23	5.13	5.06	1	a		1.06	3.31
168571	14	-1	B1II	7.79		6.45	6.24	6.08	5.98	2	a,c		0.77	2.25
168607	15	-1	B9Iap	8.29	*	4.41	3.82	3.39	2.99	2	b		1.60	4.77
168625	15	-1	B8Ia	8.41	*	5.01	4.48	4.13	3.68	2	b		1.48	4.21
169034	18	0	B5Ia	8.14		5.06	4.55	4.25	4.02	1	a		1.34	4.01
-14° 5037	17	-1	B1.5Ia	8.24	*	4.98	4.51	4.18	3.92	2	a		1.57	4.52
169454	18	-1	B1Ia	6.61	*	4.42	4.08	3.85	3.69	1	c		1.13	3.30
169754	20	0	B0.5Ia	8.38		6.23	5.91	5.69	5.50	1	a		1.28	3.30
169978	333	-22	B8III	4.63		4.87	4.88	4.87	4.88	2	a		0.00	0.00
170740	21	-1	B2IV-V	5.91		5.22	5.21	5.18	5.16	2	b		0.53	1.39
170836	14	-5	B6III	8.95		8.21	8.16	8.12	8.12	2	b		0.47	1.19
170938	17	-3	B1Ia	7.87		5.76	5.47	5.29	5.12	1	c		1.04	3.12
171012	15	-4	B0.5Ia	6.82	*	5.78	5.67	5.54	5.40	1	c		0.67	1.89
172252	21	-3	B2Vne	9.52	*	7.99	7.81	7.51	7.12	1	a		0.90	2.67
172275	25	-1	O6	9.35		7.77	7.57	7.43	7.37	1	a		1.09	2.84
172488	24	-2	B0.5II	7.62		6.49	6.39	6.28	6.31	1	c		0.82	2.04
172910	0	-14	B3V	4.87		5.20	5.27	5.31	5.40	1	c		0.02	0.12
173438	28	-1	B0.5Ia	8.23		6.68	6.39	6.35	-	1	a		1.02	2.49
175754	16	-10	O8f	7.04	*	7.16	7.22	7.21	7.24	1	a		0.22	0.75
175876	15	-11	O6.5III	6.95		7.16	7.26	7.29	7.27	1	a		0.21	0.58
178175	17	-12	B2Ve	5.54	*	5.31	5.28	5.16	4.96	1	a		0.13	1.04
179406	28	-8	B3IV	5.34		5.06	5.06	5.03	5.03	2	b		0.36	0.87
184915	32	-13	B0.5III	4.95		5.02	5.05	5.04	5.01	2	b		0.28	0.70
186660	37	-13	B3p	6.47		6.40	6.42	6.40	6.38	1	a		0.25	0.63
186842	46	-9	B8	9.45		8.69	8.54	8.39	8.41	1	a		0.43	1.30
189103	6	-28	B3IV	4.35		4.67	4.77	4.78	4.80	1	a		0.05	0.13
191639	34	-22	B1V	6.48		6.83	6.94	6.94	6.95	2	a		0.10	0.29
203532	309	-32	B3IV	6.37		6.11	6.12	6.05	6.05	2	b		0.35	0.88
212571	66	-45	B1nek	4.67	*	4.26	4.16	3.84	3.39	1	a		0.23	1.58
214080	45	-57	B1Ib	6.82		7.17	7.26	7.26	7.26	3	a,c		0.05	0.10

Notes: (1) SLS numbers refer to the Southern Luminous Star catalogue of Stephenson and Sanduleak (1971).

(2) An asterisk in column 6 indicates emission lines or other evidence for shell activity.

(3) References in column 12 are:-

(a) Previously unpublished.

(b) Whittet and van Breda (1978).

(c) Whittet et al (1976).

(d) van Breda et al (1974).

telescopes between 1973 April and 1977 July. The instruments used were the SAAO infrared photometers (Glass 1973), the MkI on the 1.9 and 1.0-m, and the MkII on the 0.75-m. The results were reduced to the Glass *JHKL* photometric system, which is tied to the Johnson system, by observation of standard stars (Glass 1974); transmission curves for the filters are presented by Glass (1973) and the effective wavelengths are 1.25, 1.65, 2.2 and 3.5 μm. Results are presented in Table 1. The stars are identified (by HD number unless otherwise indicated) in column 1, and galactic coordinates appear in columns 2 and 3. MK spectral types and visual magnitudes are given in columns 4 and 5, taken mainly from Blanco *et al.* (1968) and Kennedy & Buscombe (1974). At asterisk in column 6 denotes emission line stars (e.g. Wackerling 1970) or others suspected of shell activity. The *JHKL* photometry is given in columns 7–10, based on the number of observations per filter indicated in column 11. The references (column 12) are as follows:

(a) previously unpublished;
(b) Whittet & van Breda (1978);
(c) Whittet *et al.* (1976);
(d) van Breda *et al.* (1974).

In a few cases, results from two sources are combined, giving a double entry in column 12. The mean error of a single observation is ± 0.03 mag at J, H and K, while at L the errors are ± 0.05 mag for stars brighter than $L = 7.0$ mag, rising to ± 0.08 mag at $L = 7.5$ mag and ± 0.15 mag at $L = 8.0$ mag. The colour excesses E_{B-V} and E_{V-K}, listed in columns 14 and 15,, are deduced using the intrinsic colours of FitzGerald (1970) for E_{B-V}, and those derived in Section 4 for E_{V-K}. Few of the stars show any evidence for variability on the basis of our observations: for the comment 'var?' appears in column 13 of Table 1 in the doubtful cases.

Table 2. List of 35 potential photometric standard stars.

BS	RA(1980)			Dec(1980)			V	J	H	K	L
	h	m	s	°	'	"					
1996	05	45	15.2	-32	18	47	5.17	5.71	5.84	5.94	6.03
2571	06	52	41.0	-20	11	55	4.82	5.28	5.36	5.42	5.50
3165	08	02	52.9	-39	56	47	2.25	2.77	2.85	2.86	2.88
3452	08	40	33.7	-47	14	43	4.77	4.28	4.17	4.11	4.08
3708	09	18	02.6	-51	28	32	5.86	4.59	4.40	4.28	4.09
4133	10	31	45.5	+09	24	36	3.85	4.18	4.20	4.25	4.28
4147	10	32	39.8	-58	05	13	6.15	5.10	4.90	4.79	4.42
4169	10	36	41.0	-58	37	45	5.46	4.04	3.78	3.60	3.47
4250	10	51	41.5	-57	08	01	5.26	4.86	4.76	4.70	4.60
4338	11	07	43.7	-61	50	18	5.15	4.51	4.38	4.29	4.21
4442	11	30	52.9	-59	24	18	5.16	3.94	3.72	3.59	3.43
4563	11	53	59.8	-63	10	03	5.90	5.31	5.19	5.14	5.03
4644	12	11	17.8	-62	50	22	5.92	5.14	5.03	4.94	4.86
5027	13	19	33.3	-55	41	45	6.02	5.33	5.23	5.15	5.11
5230	13	53	54.3	-52	03	46	5.66	5.81	5.85	5.85	5.81
5281	14	04	59.8	-59	37	13	6.41	6.07	6.03	6.00	5.99
5320	14	15	02.8	-66	29	43	5.74	5.92	5.95	6.00	6.10
5379	14	23	25.6	-68	06	18	5.60	4.42	4.21	4.09	3.98
5471	14	40	42.8	-37	42	29	3.99	4.41	4.47	4.50	4.53
5680	15	17	11.6	-60	25	25	5.43	5.56	5.57	5.59	5.63
5712	15	21	52.4	-36	47	15	4.53	4.87	4.93	4.97	5.03
5736	15	26	01.0	-36	41	53	5.44	5.80	5.82	5.86	5.94
5905	15	54	24.3	-60	25	25	5.75	5.68	5.63	5.60	5.57
5928	15	55	38.8	-29	09	23	3.88	4.32	4.40	4.44	4.51
6003	16	07	31.8	-23	37	58	5.89	5.78	5.72	5.69	5.71
6081	16	19	25.7	-24	07	20	4.54	2.21	1.83	1.61	1.44
6219	16	45	36.9	-58	18	21	5.57	5.68	5.74	5.77	5.77
6353	17	04	30.2	-00	51	56	5.63	5.28	5.33	5.29	5.35
6462	17	23	42.3	-56	21	37	3.33	3.63	3.70	3.72	3.79
6601	17	42	42.2	-07	04	16	6.28	5.53	5.39	5.32	5.30
6672	17	53	40.0	-24	53	03	6.20	6.03	6.02	6.00	5.98
6825	18	14	20.1	-18	40	08	6.08	5.47	5.38	5.31	5.25
7279	19	11	35.5	-07	58	26	5.34	5.06	5.06	5.03	5.03
7709	20	10	04.9	-08	54	09	6.48	6.83	6.94	6.94	6.95
8176	21	30	46.1	-82	46	19	6.37	6.11	6.12	6.05	6.05

3 Infrared standards

With the advent of new and improved facilities for ground-based infrared astronomy in the last decade, the general accessibility and reliability of photometric standards has assumed particular importance. Several stars in Table 1 are considered suitable for future use as photometric standards, as a supplement to those of Glass (1974). These stars, listed in Table 2, are selected by the criteria: $n \geqslant 2$, no evidence for variability (either in the visual or infrared), and visually bright enough to appear in the bright star catalogue. In accordance with Glass (1974) and Voelcker (1975), standards are identified by BS numbers in Table 2. For convenience, we also list 1980 coordinates along with the visual and infrared magnitudes from Table 1.

4 Intrinsic colours

Fifty-four stars with low reddening ($E_{B-V} \lesssim 0.3$) were chosen from Table 1 for an investigation of the intrinsic colours. Emission line stars were excluded. To these were added a further 20 early-type stars from the Glass (1974) standards. Of these 74 stars, 19 were supergiants (luminosity classes Ia, Iab, Ib). Extinction corrections were applied to the colour indices to give intrinsic colours for each star, using the standard van de Hulst extinction curve (see Johnson 1968) as follows:

$$(V-J)_0 = (V-J) - 2.30\, E_{B-V};$$

$$(V-H)_0 = (V-H) - 2.56\, E_{B-V};$$

$$(V-K)_0 = (V-K) - 2.78\, E_{B-V};$$

$$(V-L)_0 = (V-L) - 2.91\, E_{B-V}.$$

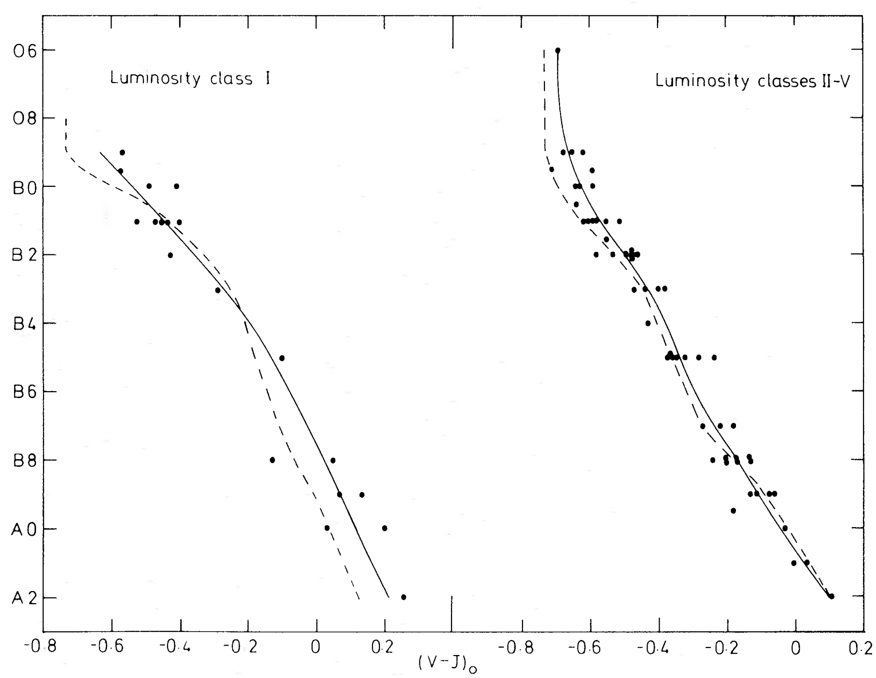

Figure 1. Plots of spectral type against intrinsic colour index $(V-J)_0$ for supergiants (left) and other luminosity classes. The continuous curve in each case is the best fit to the points, and the broken curve represents the relationship tabulated by Johnson (1966).

Each set of corrected colours is plotted against spectral type (O–A2) for the two luminosity groups (supergiants and non-supergiants) in Figs 1–4. The best fit to the points (estimated graphically) appears as a continuous curve, and the relationship tabulated by Johnson (1966) for $(V\text{–}J)_0$, $(V\text{–}K)_0$ and $(V\text{–}L)_0$ appears as a broken curve. Table 3 lists the intrinsic colour–spectral type relationship deduced from our data in Figs 1–4. The mean errors are 0.10 (supergiants) and 0.05 (non-supergiants).

It is notable that there is a tendency for the Johnson intrinsic colours to be bluer than those deduced here, particularly for B5–A2 supergiants where the difference is ~ 0.1 mag.

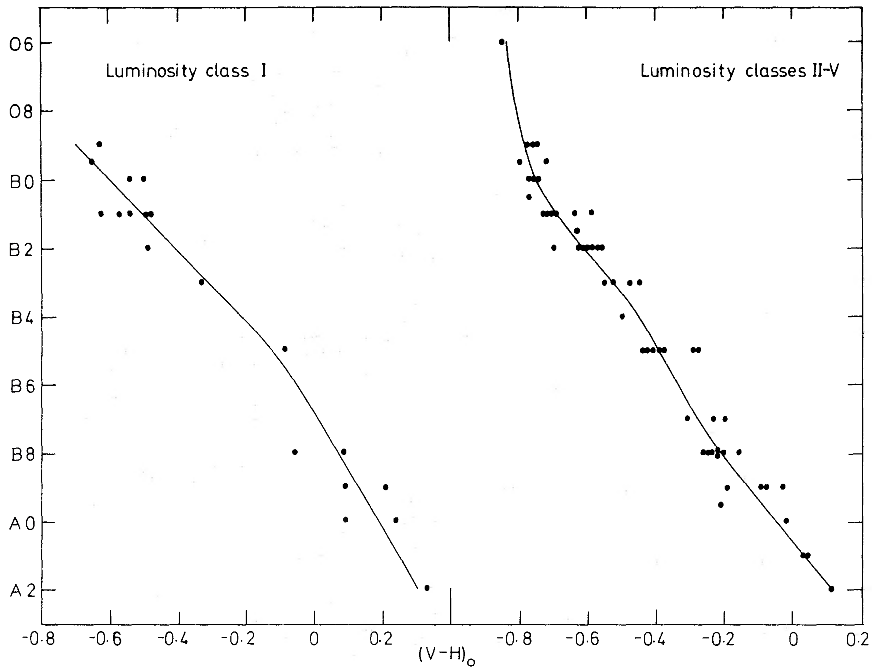

Figure 2. As Fig. 1 for $(V\text{–}H)_0$. (There is no Johnson data for $V\text{–}H$.)

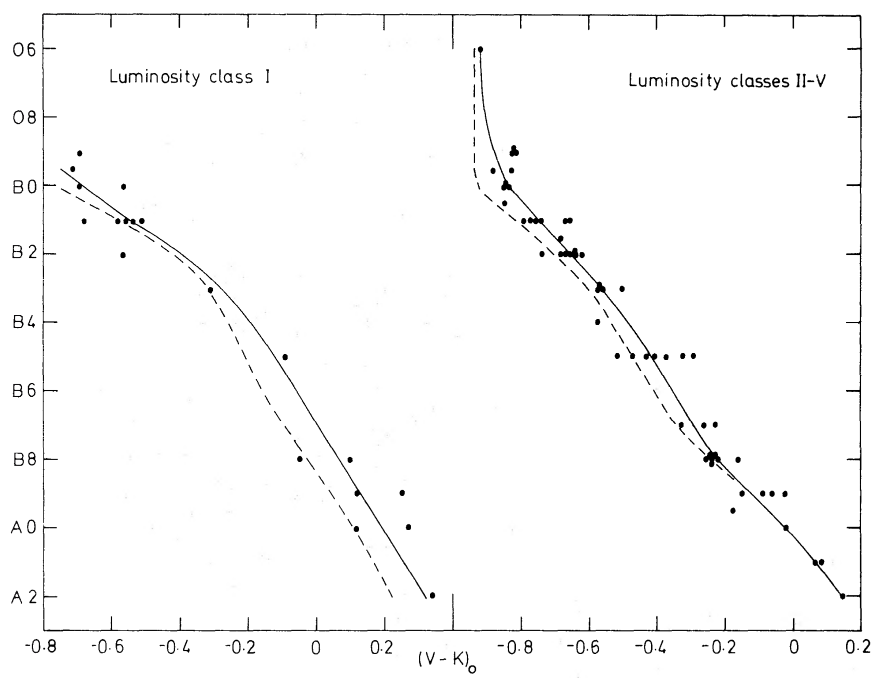

Figure 3. As Fig. 1 for $(V\text{–}K)_0$.

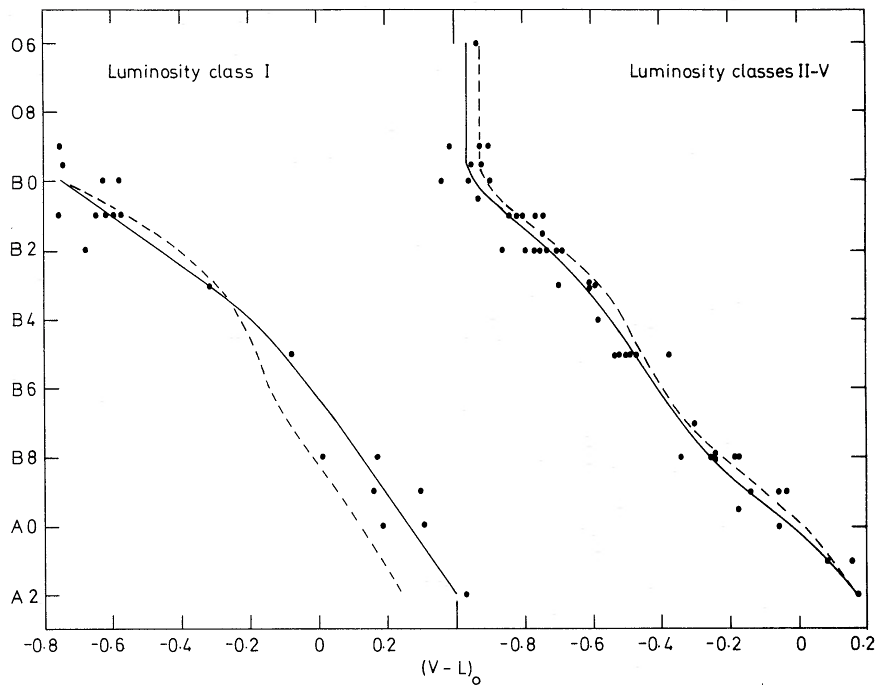

Figure 4. As Fig. 1 for $(V-L)_0$.

Table 3. Intrinsic infrared colour indices.

	Luminosity class I				Luminosity classes II-V			
Sp	V - J	V - H	V - K	V - L	V - J	V - H	V - K	V - L
O6-O8	-	-	-	-	-0.69	-0.82	-0.92	-0.97
O9	-0.63	-0.70	-0.81	-0.89	-0.66	-0.78	-0.88	-0.97
O9.5	-0.59	-0.65	-0.75	-0.82	-0.64	-0.77	-0.86	-0.96
B0	-0.54	-0.60	-0.68	-0.75	-0.62	-0.76	-0.84	-0.94
B0.5	-0.49	-0.55	-0.61	-0.68	-0.60	-0.73	-0.79	-0.90
B1	-0.45	-0.50	-0.54	-0.61	-0.57	-0.70	-0.75	-0.84
B2	-0.35	-0.41	-0.39	-0.46	-0.50	-0.62	-0.66	-0.74
B3	-0.27	-0.32	-0.27	-0.32	-0.42	-0.53	-0.56	-0.63
B4	-0.19	-0.22	-0.19	-0.20	-0.37	-0.45	-0.49	-0.55
B5	-0.13	-0.14	-0.12	-0.10	-0.33	-0.39	-0.42	-0.48
B6	-0.08	-0.06	-0.06	-0.03	-0.29	-0.34	-0.36	-0.41
B7	-0.03	+0.01	+0.01	+0.05	-0.23	-0.28	-0.29	-0.36
B8	+0.02	+0.07	+0.07	+0.12	-0.17	-0.21	-0.24	-0.25
B9	+0.07	+0.13	+0.13	+0.19	-0.11	-0.14	-0.13	-0.14
A0	+0.12	+0.19	+0.19	+0.26	-0.04	-0.05	-0.02	-0.01
A1	+0.16	+0.25	+0.26	+0.33	+0.03	+0.04	+0.07	+0.09
A2	+0.21	+0.31	+0.32	+0.40	+0.11	+0.11	+0.14	+0.18

This may explain an effect noted by Sneden *et al.* (1978) that the best straight line fit to the E_{V-K}–E_{B-V} diagram crosses the E_{V-K} axis at a small but distinct positive value rather than at the origin. This is also discernible in the corresponding diagram of Smyth & Nandy (1978), although these authors constrained their best straight line to pass through the origin. This point is discussed further in the following section.

5 Interstellar extinction

The continuum extinction in the visual and infrared may be represented, to a first approximation, by Mie scattering produced by spherical dielectric grains of mean radius $\sim 0.2\,\mu$m (see, e.g. Whittet *et al.* 1976). Fluctuations or systematic regional changes in the grain size distribution may modify the extinction curve and produce variations in the ratio of total to selective extinction

$$R = \frac{A_V}{E_{B-V}} \approx 1.1 \frac{E_{V-K}}{E_{B-V}}.$$

The approximation on the right hand side of this equation, which is deduced from the standard van der Hulst theoretical curve, is widely used to deduce R from E_{V-K}/E_{B-V} or A_V from E_{V-K}. Recent work suggests that the infrared extinction law differs significantly from this standard curve (Jones & Hyland 1980). The assumption of widely different power laws (e.g. λ^{-1} or λ^{-4}) when extrapolating the observational extinction curve to $\lambda^{-1} = 0$ leads to modest changes in the R value deduced (see, e.g. Hackwell & Gehrz 1974). An investigation of theoretical curves suggests that the ratio of A_V to E_{V-K} does not change appreciably with the R value (Whittet & van Breda 1978). Thus, any error introduced by assuming a constant value of 1.1 for A_V/E_{V-K} is likely to be small and systematic, and is unlikely to affect comparison of R values for different galactic regions. Considerable effort has been expended evaluating R, which is an important parameter in photometric distance determinations as well as being a grain size indicator (see, e.g. Johnson 1968; Aannestad & Purcell 1973). R is related to the wavelength of maximum interstellar polarization (Serkowski, Mathewson & Ford 1975): we have previously presented an analysis of the photometry for reddened stars in Table 1 which have polarimetric data available (Whittet & van Breda 1978). Here we evaluate R by means of the $E_{V-K}-E_{B-V}$ diagram.

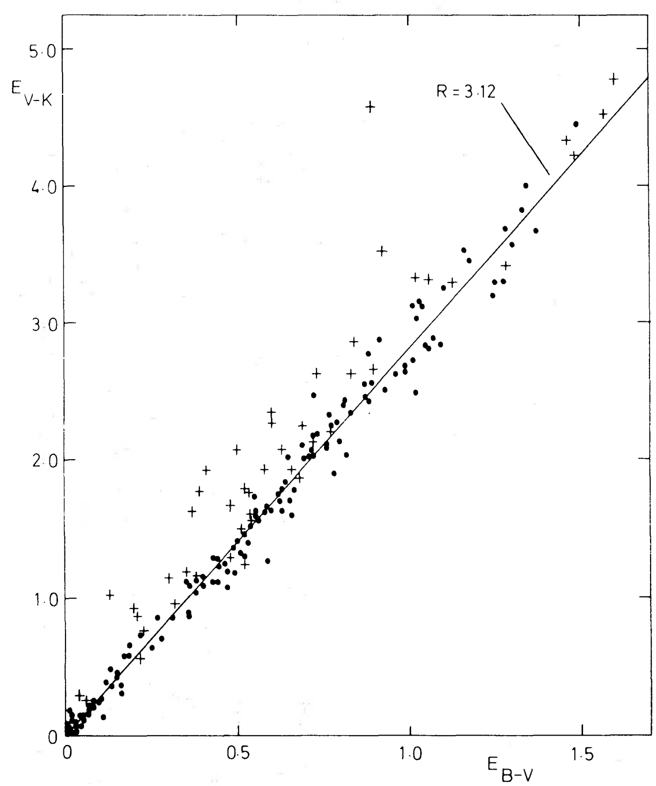

Figure 5. Plot of E_{V-K} against E_{B-V} for stars within 10° of the galactic plane. Emission line stars are distinguished by crosses.

Fig. 5 is a plot of E_{V-K} versus E_{B-V} for all stars in Table 1 which lie within 10° of the galactic plane. The E_{V-K} values, listed in Table 1, are deduced from the intrinsic colours in Table 3 for stars of spectral type O–A2, and from Johnson (1966) for the few later than A2. Emission line stars are distinguished by crosses; if these are ignored, the best straight line, fitted by least squares to the remaining 129 points, passes through the origin to within the errors, justifying use of the intrinsic colours deduced in Section 4. The value of R deduced from the slope is

$$R = 3.12 \pm 0.05.$$

The good agreement between this result and that of Harris (1973), who deduced $R = 3.15 \pm 0.20$ by the cluster diameter method, argues against any significant errors introduced by the extrapolation of the extinction curve, discussed above, as his method is independent of such effects. The presence of significant neutral extinction is also excluded.

There is no clear evidence for regional variation in R with galactic longitude from our data for stars close to the galactic plane, covering the longitude interval 200–30° in the southern Milky Way. Smyth & Nandy (1978) deduced $R = 3.12 \pm 0.05$ from the $E_{V-K}-E_{B-V}$ diagram for 40 stars in the galactic anticentre region ($l = 160$–$235°$). However, the affect already noted of forcing the line fitted to pass through the origin produces an R value which is slightly too large: removing this constraint gives $R = 3.05$. Similarly, the $E_{V-K}-E_{B-V}$ diagram of Sneden *et al.* (1978) for 98 northern Milky Way stars ($l = 10$–$215°$) gives $R = 3.01$ and 2.96 for the constrained and unconstrained fits, again with errors ~ 0.05. Comparing this last value with our result above gives marginal support for the conclusions of Whittet (1977) that there is a small but significant increase in R in the southern Milky Way compared with the north. Since each set of infrared data covers a wide range of galactic longitude, some averaging out of any variation in R is to be expected; the infrared data is not of sufficient accuracy to show in detail the sinusoidal variation found by Whittet (1977, 1979) from a study of the wavelength of maximum polarization data. Straight averages over the sinusoidal $\lambda_{max}-l$ curve (Whittet 1977) have been calculated for the galactic longitude ranges covered by the three sets of infrared data (Sneden *et al.* 1978; Smyth & Nandy 1978; this paper). The following comparisons may then be made between the polarization R value ($R_P = 5.6\,\lambda_{max}$, Whittet & van Breda 1978) and the photometry R value ($R_K = 1.1\,E_{V-K}/E_{B-V}$) averaged over the same longitude intervals:

$l = 10$–$215°$	$R_P = 2.96$	$R_K = 2.96$
$l = 160$–$235°$	$R_P = 3.08$	$R_K = 3.05$
$l = 200$–$30°$	$R_P = 3.15$	$R_K = 3.12.$

Thus, the variation with longitude are in good agreement.

The observed variation in the extinction law has been attributed by Whittet (1979) to dust in the local dark cloud system associated with Gould's Belt. We present in Figs 6 and 7 E_{V-K} versus E_{B-V} plots for stars in the Orion and Sco–Oph dark cloud regions, respectively, which lie ~ 20° from the galactic plane at opposite ends of Gould's Belt. In both cases the best straight line leads to an R value substantially greater than the normal value:

$$R = 4.0 \pm 0.5 \qquad \text{(Orion)}$$

and

$$R = 3.9 \pm 0.1 \qquad \text{(Sco–Oph)}$$

The scatter is high in Orion, suggesting that R may vary from star to star, although the sample is small. The good correlation in Fig. 7 indicates an R value close to 3.9 throughout

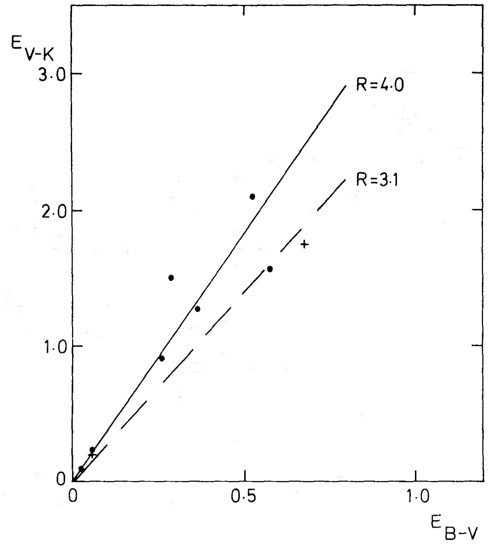

Figure 6. Plot of E_{V-K} against E_{B-V} for stars in the Orion region.

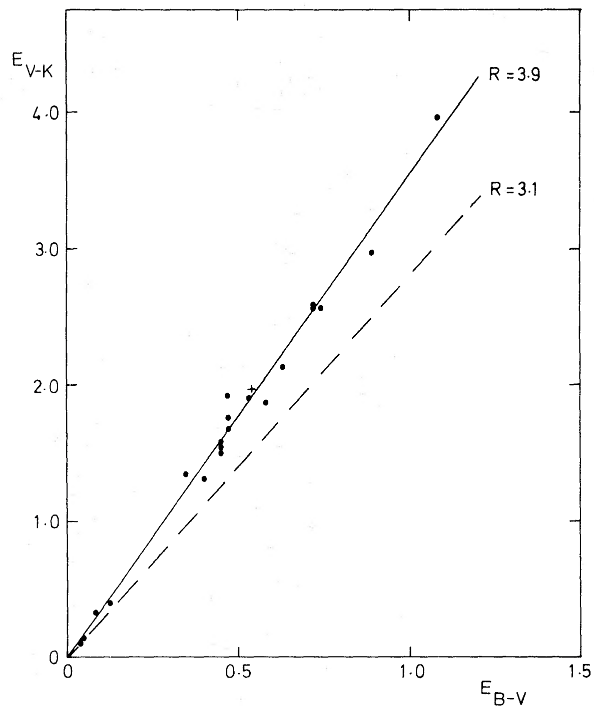

Figure 7. Plot of E_{V-K} against E_{B-V} for stars in the Sco–Oph dark cloud region.

the Sco–Oph region, which includes the ρ Ophiuchi dark cloud. This result is slightly surprising in view of the fact that Carrasco, Strom & Strom (1973) deduced the mean grain size to increase with optical depth in this complex. There is considerable independent evidence to show that R reaches a maximum value around 4.3 in the central molecular cloud (Whittet *et al.* 1976, Table 6); the value deduced here refers to the outer regions with $A_V < 4$ mag.

6 Circumstellar shells

Fig. 5 shows that some, but by no means all, of the emission line stars have unusually high E_{V-K} values with respect to E_{B-V}. This may be due to infrared excess radiation, or to an anomalous extinction law, in individual lines of sight. Infrared two-colour diagrams have been used to distinguish between the effects of interstellar reddening and circumstellar shell emission (see, e.g. Allen 1973; Rydgren 1976; Glass 1979). In this section we present and discuss the (*J–H, H–K*) and (*H–K, K–L*) diagrams for stars in Table 1.

Bidelman (1976) has grouped early-type shell stars into four categories:

(1) high luminosity shell stars (supergiants and Of stars);
(2) single, high-rotation Be stars;
(3) binary shell stars and
(4) nebular shell stars.

We have assigned one of these types to each of the emission line stars (denoted by an asterisk) in Table 1, basing our choice on spectral classifications, rotational velocities and radial velocity variations (where known), and association with nebulosity. An unambiguous classification was not always possible. The majority were assigned to classes 1 or 2, typical examples being HD 152236 (ζ_1 Sco) and HD 148184 (χ Oph) respectively. Only two stars were placed in group 3, namely HD 93206 (QZ Car) and HD 153919, an X-ray binary. Four stars were assigned to group 4, all of which are embedded in nebulosity in regions of recent star formation: HD 52721 and HD 53367 lie in the CMa R1 association, HD 97048 in the Cha T association, and HD 164740 (Herschel 36) illuminates the 'hourglass' nebula in Messier 8.

The (*J–H, H–K*) diagram for stars in Table 1 appears in Fig. 8. Normal stars are represented by circles and shell stars by numbers corresponding to the Bidelman classifications. The expected unreddened star distribution differs from the blackbody line because of an opacity minimum in stellar atmospheres, which occurs close to the effective wavelength of the H filter (Gingerich & Kumar 1964). Unreddened early-type stars lie in the lower left-hand part of the diagram, having colour indices < 0.1 mag. Reddening vectors, with moduli equivalent to $E_{B-V} = 0.5$, are indicated for the normal extinction law ($R = 3.1$) and that found in the central region of the ρ Oph dark cloud ($R = 4.3$). Reddened stars appear to

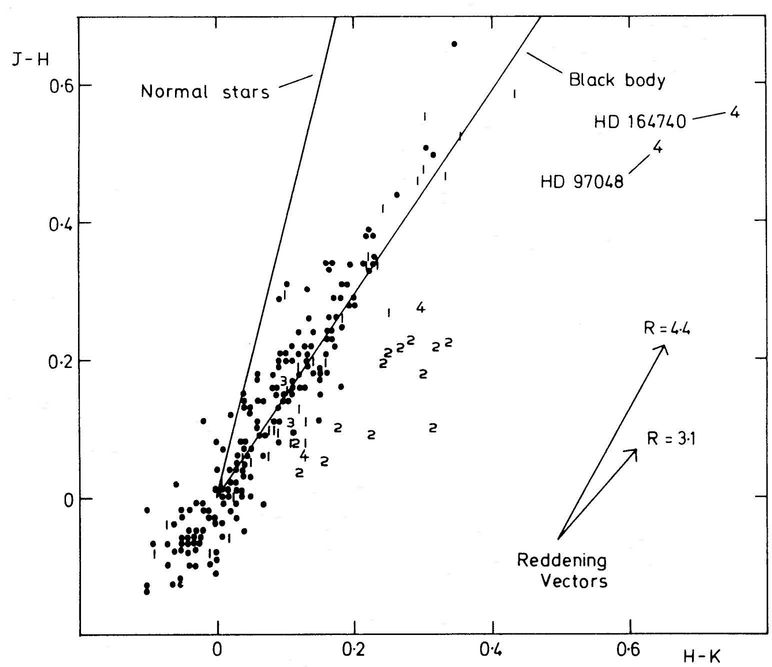

Figure 8. (*J–H, H–K*) diagram for stars in Table 1. Numbers represent shell stars according to the Bidelman classification.

be distributed along the blackbody curve in Fig. 8 because it happens to be almost parallel to the normal reddening vector.

Two general conclusions may be drawn from Fig. 8. First, the distribution of class 1 and class 3 shell stars is that expected for normal stars with normal reddening: no infrared excesses are apparent for these stars, in agreement with the results of Barlow & Cohen (1977). Secondly, the class 2 and class 4 shell stars occupy a region to the right of this distribution, and cannot be re-reddened into the domain of normal unreddened stars: infrared excesses must therefore be present. Two of the class 4 stars lie in the same region as the class 2 stars, but HD 97048 and HD 164740, are clearly much redder objects.

Fig. 8 enables us to distinguish between the effects of anomalous extinction and infrared excess in photometry-based R value determinations. HD 164740 is one of the 'deviant four' discussed by Breger (1979): the R value deduced from the wavelength of maximum polarization is markedly less than that deduced from infrared photometry (see Whittet & van Breda 1978; McMillan 1978; Serkowski *et al.* 1975). It is evident from Fig. 8 that an infrared excess must be responsible for this, as neither a normal nor dark cloud reddening correction can place the star in the domain of unreddened early-type stars. We conclude that an R value of 3.8, as deduced from the polarimetry, is appropriate to this star.

The $(H-K, K-L)$ diagram is shown in Fig. 9. The normal reddening vector with $E_{B-V} = 0.5$ is shown; the slope of the dark cloud reddening vector is almost identical in this case, and both have steeper slopes than the blackbody curve. In general, Fig. 9 supports the conclusions drawn from Fig. 8. The separation of the class 2 shell stars from the general distribution is somewhat less pronounced in Fig. 9, but that of the two extreme class 4 stars, HD 97048 and 164740, is enhanced.

As pointed out by Allen (1973), it is not possible to distinguish unambiguously between free–free and thermal dust mechanisms for the excess radiation of Be stars by means of infrared two-colour diagrams alone. However, we argue here that the former is more probable for the class 2 Be stars. The brightest members of this group are virtually unreddened, and, in general, the reddening observed is attributable to foreground material. The absence of associated reflection nebulosity and dark cloud obscuration, and the presence of high rotation, further point to a gaseous rather than a dusty envelope. In contrast, HD 97048 and 164740 are clearly embedded in dust, as both are associated with dark and bright

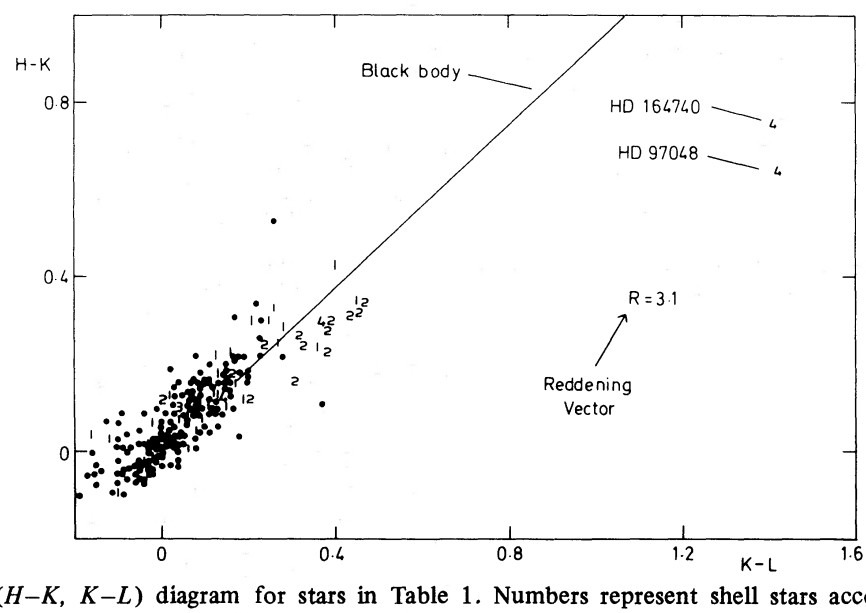

Figure 9. **($H-K$, $K-L$) diagram for stars in Table 1. Numbers represent shell stars according to the Bidelman classification.**

nebulosity and have substantially greater colour excesses than expected for foreground reddening (Blades & Whittet 1980; Woolf 1961). Glass (1979) deduced that the infrared excess of HD 97048 is characteristic of a dust shell of temperature ~ 800 K.

Acknowledgments

We are grateful to Dr I. S. Glass for discussion and support during our observing runs, and to the UK Science Research Council for observing time and financial support. We thank a referee for useful comments.

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