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NEAR INFRA-RED MAGNITUDES OF 248 EARLY-TYPE EMISSION-LINE STARS AND RELATED OBJECTS

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SUMMARY

Nearly 250 early-type emission-line stars have been observed in the near infra-red; approximately two thirds of these are found to exhibit excess radiation at these wavelengths. Two distinct mechanisms may contribute to the infra-red excesses: thermal radiation from circumstellar dust, and electron bremsstrahlung originating in a shell of ionized gas. It is not currently possible to distinguish between these two alternatives using infra-red photometry alone.

1. INTRODUCTION

This paper is the compilation of 13 months observing undertaken while the author was a Carnegie Fellow at the Hale Observatories. It presents observations, mostly at near infra-red wavelengths, of a sample of the early-type emission-line stars, but excludes the Wolf–Rayet stars which were the subject of a separate study (Allen, Harvey & Swings 1972; Allen & Porter 1972). Infra-red equipment built and maintained at the California Institute of Technology (CIT) was used throughout, and the observations were made on the 100- and 60-inch telescopes of the Mt Wilson Observatory and the 40-inch telescope of the Carnegie Southern Observatory, Cerro las Campanas, Chile. Measurements were made primarily at three wavelengths: 1·6 μ (*H*), 2·2 μ (*K*) and 3·5 μ (*L*). All 248 stars were measured at 2·2 μ; at 1·6 μ 239 were measured and limits set on a further four, and at 3·5 μ 122 were measured.

Infra-red magnitudes (not always at *H*, *K* or *L*) of about one fifth of the stars in this catalogue have been published by other observers. Since no two infra-red groups choose to define exactly the same wavebands or agree on a selection of standard stars, considerable caution must be exercised when intercomparing their data, especially for stars with large colour indices. The current catalogue provides a uniform collection of infra-red magnitudes of Be stars. Magnitudes were reduced by comparison with a set of standard stars measured frequently by the CIT infra-red group and using the CIT calibration last revised in November 1971. It is unlikely that subsequent revisions to the present calibration of the CIT standard stars will alter any of the magnitudes in this catalogue by as much as 0·05 mag.

The field of view projected on the sky by the PbS detector was dependent upon the effective focal length of the telescope used, but in addition could be varied by the introduction of different apertures into the focal plane. The observations presented here were made with beamwidths between 7 and 35 arc sec. A sample of these stars was measured with different beamwidths; to the limits of the photometry no beamwidth dependence could be detected (except that caused by atmospheric turbulence)

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TABLE I

Catalogue of infra-red observations

Object	V	Sp.	R.A.	Dec.	K	H-K	K-L	Type	References
			1950.0						
	m		h m	° ′	m	m	m		
HD 225095	7.9	B1e	00 00.9	+55 16	7.75	0.04	-	X	
HD 108	7.4	O8f	00 03.5	+63 24	6.71	0.09	-	X	
Lk Ha 198	15	A e	00 08.7	+58 34	6.19	1.61	1.80	Dn	A3
V376 Cas	16	-	00 08.7	+58 35	6.10	1.92	2.01	Dn	A3
BD +61 40	9.6	B2e	00 17.7	+62 07	8.13	0.2	-	X	
MWC 674	10.8	B0e	00 39.5	+63 47	7.77	0.30	-	F	
BD +61 154	10.6	B8e[]	00 40.4	+61 38	5.81	1.03	1.24	Dn	G2 S3
Lk Ha 202	13	B e	00 41.0	+61 59	8.20	0.30	-	X	
gamma Cas	2.3	B0q	00 53.7	+60 27	1.98	0.22	0.43	F	IRC+60031 J1 W2
phi And	4.2	B7q	01 06.6	+46 59	4.32	-0.03	-0.1	X	
HD 7636	6.6	B2e	01 14.3	+57 22	6.05	0.26	-	F	
HD 236689	9.5	B1q	01 15.4	+58 07	8.7	0.2:	-	F	
phi Per	4.0	B2q	01 40.5	+50 26	3.27	0.30	0.44	F	G2 J1 W2
MWC 17	13.2	e[]	01 44.2	+60 27	7.21	1.26	2.38	D	G2
BD +63 261	9.6	B e	01 53.8	+63 48	7.64	0.43	-	F	
M1-2	13.1	e[]	01 55.5	+52 39	9.81	0.28	1.6:	D	G4 G5 S5
HD 12302	8.0	B1e	01 59.1	+59 27	7.11	0.15	-	F	
HD 13661	8.6	B8e	02 11.5	+54 18	7.56	0.11	-	X	
HD 13669	7.9	B2e	02 11.6	+55 34	8.17	-0.03	-	X	
BD +56 563	9.4	B3e	02 18.2	+56 54	8.9	-0.2	-	F	
BD +56 624	9.6	B2e	02 23.1	+56 52	8.4	0.2	-	F	
HD 15253	6.5	A2e	02 25.9	+55 19	6.24	-0.01	-	X	
HD 15238	8.4	B3q	02 26.0	+60 27	7.65	0.12	-	X	
HD 236970	8.7	A2e	02 29.7	+56 06	9.3	-	-	X	
HD 15963	8.0	A0q	02 32.5	+57 52	7.65	0.02	-	X	
MWC 56	11.6	e[]	02 38.9	+61 03	6.65	0.21	0.1:	R	S5
HD 20336	4.8	B2e	03 15.6	+65 28	5.25	-0.08	-	X	
HD 21212	8.1	B2e	03 24.4	+62 19	6.14	0.27	0.4	F	
psi Per	4.2	B5q	03 32.9	+48 02	3.94	0.14	0.3	F	W2
28 Tau	5.1	B8q	03 46.2	+23 59	5.18	-0.04	0.1	X	J1
XY Per	9.2	B6+A2e	03 46.3	+38 50	6.07	0.74	1.03	Dn	*
X Per	6.1	B0q	03 52.3	+30 54	5.38	0.10	-	X	
MWC 84	11.5	B e	04 15.7	+55 53	4.96	1.14	1.41	D	
Lk Ha 101	16.5	e[]	04 27.0	+35 10	3.13	2.33	2.65	Dn	IRC+40091 C1
56 Eri	5.9	B2e	04 41.7	-08 36	5.65	0.16	-	F	
AB Aur	7.0	B9q	04 52.6	+30 28	4.31	0.90	1.01	Dn	G2 G3 S3 *
HD 31648	7.7	A2q	04 55.6	+29 46	5.69	0.66	1.08	D	*
11 Cam	5.2	B2e	05 01.8	+58 54	5.15	0.14	-	F	
105 Tau	5.8	B2e	05 04.9	+21 38	5.08	0.19	0.38	F	
HD 33232	8.2	B2q	05 07.3	+40 56	7.64	0.13	-	F	
HD 33461	7.8	B2e	05 08.7	+41 09	5.67	0.17	0.4	F	
AE Aur	5.8	O9.5	05 13.0	+34 15	5.25	0.01	-	X	
HD 34989	5.8	B1	05 19.0	+08 23	6.10	0.00	0.1:	X	J1
HD 35165	6.1	B5e	05 19.5	-34 24	6.4	-0.1	-	X	
25 Ori	4.9	B1e	05 22.2	+01 48	5.47	-0.03	-	X	
HK Ori	11.5	B8e[]	05 28.7	+12 07	7.42	0.96	1.4	Dn	G2
V380 Ori	10.4	B8e	05 34.0	-06 45	5.91	0.89	-	Dn	G2 G3 M2 S3
zeta Tau	3.0	B2q	05 34.6	+21 07	3.01	0.07	0.34	F	IRC+20113 J1 W2
RR Tau	12.2	A4q	05 36.4	+26 18	6.82	0.94	1.17	Dn	G2 S3
M1-82 IRS2	17	e	05 37.6	+35 49	7.47	2.1	2.68	Dn	A3 *

TABLE I—*continued*

Object	V	Sp.	R.A.	Dec.	K	H-K	K-L	Type	References
			1950.0						
	m		h m	° '	m	m	m		
HD 37806	7.9	A0e	05 38.5	-02 44	5.52	0.79	1.25	Dn	
FU Ori	8.9	F2e	05 42.3	+09 03	4.68	0.46	0.85	F	G1 G2 M2
Lk Ha 295	19	e	05 43.3	-00 13	4.02	0.52	0.45	R	
HD 38708	8.2	B3e	05 45.7	+29 07	8.0	0.0	-	X	
HD 248411	9.2	B5q	05 48.7	+28 15	8.6	0.0	-	X	
HD 249845	8.8	B2e	05 56.3	+32 53	8.7	0.0	-	X	
HD 250028	9.1	B2e	05 56.8	+25 05	7.93	0.36	-	F	
HD 250550	9.7	B7q[]	05 59.1	+16 31	6.77	0.88	1.20	Dn	G2
HD 41335	5.2	B2q	06 01.8	-06 42	4.69	0.27	0.5	F	
17 Lep	5.0	A0+M1	06 02.8	-16 29	1.59	0.33	0.66	R	IRC-20084 A2 G2 S5
Lk Ha 208	14.6	B7q[]	06 04.9	+18 40	8.88	0.97	1.6	Dn	G2 G3
HD 42111	5.6	A0e	06 06.3	+02 30	5.35	0.03	0.3	F	
MWC 137	11.2	B e[]	06 15.9	+15 18	6.41	1.07	1.34	Dn	F1 *
12 Gem	6.9	A0	06 16.3	+23 18	5.52	-0.03	-	X	
HD 44351	8.5	B3q	06 19.1	+14 20	8.08	0.01	-	X	
HD 45166	9.9	WN+Be	06 23.6	+08 03	9.28	-	-	-	
HD 45626	9.4	B7q	06 25.9	-04 26	8.9	0.2	-	F	
HD 45677	8.5	B2q[]	06 26.0	-13 01	4.62	1.87	2.47	D	G2 L1 S1
beta Mon	3.7	B3q+e	06 26.4	-07 00	3.76	0.10	0.10	F	*
HD 45871	5.8	B3q	06 26.8	-32 20	5.99	0.07	-	F	
AX Mon	6.8	B3q	06 27.9	+05 54	4.42	0.22	0.3	F	S5
Lk Ha 215	10.7	B8q	06 29.9	+10 12	6.96	0.81	1.0	Dn	
13 Mon	4.5	A0	06 30.2	+07 22	4.24	-0.01	-	X	
HD 259431	8.7	B5e	06 30.3	+10 21	5.62	0.94	1.04	Dn	G3 S3
HD 259597	8.6	B1e	06 30.8	+08 22	7.91	0.02	-	X	
R Mon	11.7	F e	06 36.4	+08 47	5.48	1.86	2.17	Dn	G2 L1 M1 M2
L Ha 25	13.0	B8q[]	06 38.0	+09 51	8.80	1.08	1.3	Dn	S2 S3 *
S Mon	4.7	07f	06 38.2	+09 57	5.21	-0.05	-	X	J1
MWC 819	15	e[]	06 42.0	+01 23	8.30	1.80	2.09	D	
kappa CMa	3.9	B2e	06 48.0	-32 27	3.57	0.22	0.50	F	
HD 50091	8.3	B3e	06 48.7	-13 10	8.37	-0.02	-	X	G2
HD 50138	6.7	B8q[]	06 49.0	-06 54	4.18	0.91	1.46	D	*
psi9 Aur	5.8	B8e	06 52.8	+46 20	6.01	-0.06	-	X	
HD 51480	7.0	B5q	06 54.8	-10 45	4.80	0.15	0.3	F	
HD 51585	11.5	B q[]	06 55.6	+16 23	8.11	1.15	1.45	D	
Lk Ha 218	13	e	07 00.4	-11 21	8.5	0.6	-	D	
Z CMa	8.8	B q[]	07 01.4	-11 29	3.51	1.09	1.57	Dn	G2 G3 S3
Lk Ha 220	12	e	07 01.8	-11 21	8.9	0.9:	-	D	
HD 53367	7.0	B0e	07 02.1	-10 23	5.25	0.20	0.3:	F	
HD 53975	6.5	08	07 04.3	-12 19	6.76	-0.09	-	X	
HD 54858	8.4	A0q	07 07.8	-09 15	7.98	0.04	-	X	G2
M1-11	13.6	e[]	07 09.1	-19 46	7.49	1.15	-	D	A1 *
omega CMa	3.8	B3e	07 12.8	-26 41	3.89	0.17	0.41	F	J1
HD 56847	8.9	B7q	07 15.9	-15 32	8.04	0.14	-	X	
HD 58978	5.6	B1q	07 24.9	-22 59	5.26	0.08	0.09	F	
M1-15	13	B e	07 29.6	-19 21	9.51	0.60	-	Dn	
Hen 40	11.4	B e[]	07 30.0	-41 29	6.3	0.4	-	R	
BN Gem	6.4	08pe	07 34.2	+17 01	6.65	0.16	-	F	
CD -24 5721	9.8	B e[]	07 37.0	-24 38	7.21	1.02	1.35	D	
3 Pup	4.0	A3q[]	07 41.8	-28 50	2.33	0.74	1.49	D	

TABLE I—*continued*

Object	V	Sp.	R.A.	Dec.	K	H-K	K-L	Type	References
			1950.0						
	m		h m	° '	m	m	m		
omicron Pup	4.5	B0e	07 46.0	-25 49	3.98	0.18	0.25	F	
HD 65875	6.5	B3q	07 58.2	-02 45	6.22	0.04	-	X	G2
HD 68468	8.5	B3e	08 09.7	-14 01	8.49	-0.14	-	X	
HD 68980	4.7	B3e	08 11.6	-35 45	4.55	0.16	-	F	J1
HD 71072	6.9	B8e	08 22.6	-12 36	7.15	-0.06	-	X	
Hen 230	11.5	B e	08 54.9	-46 12	6.4	1.2:	-	D	
HD 76868	8.0	B6e	08 56.4	+03 51	6.15	0.14	-	X	
HD 81357	7.9	B8e	09 23.7	+58 22	6.61	0.05	-	X	
HD 83953	4.7	B5e	09 39.0	-23 22	4.82	0.05	0.05	F	
He2-34	16	plan	09 39.4	-49 09	5.47	1.22	1.9	D	
HD 86612	6.2	B5e	09 56.8	-23 43	5.93	0.13	-	F	
HD 87643	8.5	B e[]	10 02.8	-58 25	3.59	1.17	1.61	Dn	
CD -57 2874	8.6	B e	10 13.6	-57 37	7.7:	0.3:	-	F	S5
HD 89249	8.7	B q	10 14.5	-55 21	5.57	0.22	-	F	
HD 89884	7.1	B5e	10 19.6	-17 47	7.22	0.03	-	X	
HR Car	8.5	B2q[]	10 21.1	-59 22	5.44	0.33	0.7	F	
HD 91120	5.6	B9e	10 28.5	-13 20	5.56	-0.07	-0.05	X	
PP Car	3.3	B5q	10 30.2	-61 26	3.05	0.19	0.37	F	
HD 92207	5.5	A0e	10 35.5	-58 28	3.65	0.19	-	X	
eta Car	6.2	q[]	10 43.1	-59 26	1.14	1.44	2.98	Dn	G2 N1 W1 *
GG Car	8.8	B q[]	10 54.0	-60 08	5.11	1.03	1.4	D	
AG Car	7.2	B5e[]	10 54.2	-60 11	5.63	0.27	-	F	S5
HD 97670	5.9	B3e	11 11.3	-59 21	5.97	0.06	-	F	
zeta Crv	5.3	B8e	12 18.0	-21 56	5.36	-0.02	-0.04	X	
He2-80	13	plan	12 19.7	-63 01	7.4	1.1:	-	D	
kappa Dra	3.9	B6e	12 31.4	+70 04	3.97	0.01	0.2	F	G2 J1 W2
He2-87	15.5	plan	12 42.9	-62 44	6.5	0.8	-	D	
He2-90	13.7	plan	13 06.5	-61 04	7.8:	>1.2	-	D	
He2-91	13	plan	13 06.8	-62 55	6.43	2.2:	-	Dn	*
mu Cen	3.5	B2e	13 46.6	-42 14	3.61	0.11	0.41	F	
He2-104	14.6	plan	14 08.6	-51 12	6.8	1.9:	2.1:	D	
He2-106	13.5	plan	14 10.4	-63 12	5.45	1.7	-	D	*
eta Cen	2.5	B3q	14 32.3	-41 56	3.04	0.04	0.05	F	P1
Hen 1044	10.4	B e[]	14 56.3	-54 06	7.5:	0.7:	-	D	S5
theta CrB	4.2	B7e	15 30.9	+31 32	4.41	-0.01	0.02	X	
He2-139	15.5	plan	15 50.9	-55 21	5.61	1.07	1.3:	D	
4 Her	5.8	B8q	15 53.8	+42 43	5.87	-0.07	0.17	X	
48 Lib	4.9	B3q	15 55.4	-14 08	4.54	0.13	0.39	F	G2
CD -52 9243	9.3	B e	16 03.2	-52 56	4.16	1.29	-	D	
He2-147	15	plan	16 09.9	-56 52	4.73	0.72	-	D	
He2-156	13.0	plan	16 17.9	-42 18	9:	-	-	-	
chi Oph	4.3	B2e	16 24.1	-18 20	3.42	0.26	0.63	F	G2
28 Her	5.6	A1q	16 30.1	+05 38	5.72	-0.06	0.00	X	
He2-173	13.5	plan	16 33.0	-39 46	7.1	0.1	-	R	
zeta Oph	2.6	09.5	16 34.4	-10 28	2.63	-0.05	0.26	F	IRC-10343 J1 W
Hen 1227	13.5	B e	16 34.9	-45 18	8.0:	>1.0	-	D	
He2-176	15	plan	16 37.9	-45 08	5.86	0.67	-	D	
Hen 1242	12.5	e[]	16 40.0	-62 32	6.20	0.4:	-	R	S5
AS 210	11.5	O e[]	16 48.2	-25 54	10.8	0.2	-	F	
M2-9	14.7	e[]	17 02.9	-10 04	7.00	2.32	2.71	D	A1 A4 *

TABLE I—*continued*

Object	V	Sp.	R.A.	Dec.	K	H-K	K-L	Type	References
			1950.0						
	m		h m	° '	m	m	m		
HD 326823	9.0	q[]	17 03.3	-42 32	5.43	0.76	1.1:	D	
KK Oph	12.2	A e[]	17 07.0	-27 12	5.43	1.25	1.4	D	A1
HD 155851	8.2	B0q	17 12.3	-32 38	7.03	0.24	-	F	
AS 239	12	e[]	17 40.4	-22 45	9.18	>1.8	-	D	
XX Oph	9.1	Apq[]	17 41.3	-06 15	2.84	0.47	0.31	R	IRC-10376 G2 S5
HD 161261	8.3	B9e	17 41.8	+05 44	8.08	0.04	-	X	
HD 316248	11.5	plan	17 42.8	-30 11	8.12	1.00	-	D	
HD 316285	9.6	B e[]	17 45.1	-28 00	3.58	0.55	0.62	R	S5
88 Her	6.4	B8q	17 48.7	+48 24	6.92	-0.02	0.1:	X	
HD 163296	6.6	A2q	17 53.3	-21 57	4.49	0.73	0.9	D	
Lk Ha 123	11	B e	17 59.4	-23 02	6.93	0.44	1.2:	Dn	
Lk Ha 108	13	. e	18 00.8	-24 22	8.5	0.9	-	Dn	
HD 164906	7.5	B1e	18 01.4	-24 24	6.26	0.25	-	F	
HD 167362	11.8	WC []	18 12.9	-30 53	8.52	1.19	-	Dn	
EU Ser	13.8	B e	18 16.3	-13 52	10.0	1.6:	-	Dn	
MWC 922	12.5	e[]	18 18.4	-13 03	9.7	0.0	-	R	S5
HD 169226	9.1	Be(+M)	18 21.4	-12 15	4.35	0.27	0.28	R	*
HD 169454	6.6	B1e	18 22.4	-14 00	3.84	0.18	0.33	F	
RY Sct	9.7	e[]	18 22.7	-12 43	5.48	0.32	0.8	F	G2 S5
MWC 297	11.5	B e[]	18 25.0	-03 52	3.08	1.46	1.58	Dn	A1
VV Ser	11.7	A2e	18 26.2	+00 07	6.15	1.14	1.49	Dn	
HD 170235	6.6	B1e	18 26.3	-25 17	6.41	-0.02	-	X	
MWC 300	11.6	e[]	18 26.7	-06 07	5.92	2.07	2.84	D	
HD 172694	8.1	B0q	18 39.4	-15 54	6.84	0.33	0.3	F	
MWC 957	13	plan[]	18 43.5	-23 30	10.7	0.5:	-	F	
BD -11 4747	9.3	B e[]	18 44.3	-11 44	9.3	0.2:	-	X	
HD 177291	8.7	B8q	19 01.9	-18 47	6.43	0.18	0.2:	F	
HD 179343	7.0	A0q	19 09.5	+02 32	6.57	-0.02	0.10	X	
BD +14 3887	9.9	B e[]	19 19.3	+14 47	5.28	0.44	0.65	R	G2 S5
BD +30 3526	9.2	A0q	19 19.7	+31 04	9.3	0.0:	-	X	
Vy2-2	13.8	e[]	19 22.0	+09 48	9.70	1.0	-	D	A1
Hen 1751	10.4	e	19 24.6	+23 48	7.73	0.68	-	Dn	
V923 Aql	6.0	B5q	19 28.0	+03 20	5.87	-0.02	-	X	
M1-92	11	e[]	19 34.3	+29 26	6.15	1.74	2.14	Dn	A1 *
He2-442	14	plan[]	19 37.6	+26 24	5.28	1.71	1.97	D	A1 *
II +22 8	11.8	B9e	19 38.1	+22 25	9.6	0.3	-	X	S5
He2-446	13.5	B e[]	19 42.0	+23 20	8.43	1.30	1.59	Dn	A1
HD 187399	7.7	B7q	19 46.7	+29 17	6.18	0.08	-	X	
HD 225985	9.1	B1e	19 47.6	+32 50	8.30	0.24	-	F	
MWC 623	10.5	B e[]	19 54.6	+30 58	5.26	0.72	1.41	D	
V1016 Cyg	10.4	e[]	19 55.3	+39 42	5.59	1.83	2.31	D	K1 S5
HD 351123	9.0	B8q	19 55.4	+17 14	9.8	-	-	X	
HD 190073	7.9	A0q[]	20 00.6	+05 36	5.78	0.79	1.20	D	G2
HD 333424	9.6	O8	20 02.8	+29 01	7.68	0.44	-	F	
HD 190944	8.8	B1e	20 03.9	+46 32	7.21	0.09	0.7:	F:	
V425 Cyg	10.2	B5e	20 06.2	+35 59	8.82	0.37	-	F	
Hen 1835	9.8	B e	20 07.7	+25 03	6.21	0.20	-	X	
FG Sge	8.9	(B9q)	20 09.7	+20 11	7.14	0.14	-	R	G3 S5 *
HD 192954	7.3	A0q	20 14.9	+15 43	7.73	0.00	-	X	
HD 193182	6.5	B9q	20 15.6	+39 26	6.51	0.12	-	F	

TABLE I—*continued*

Object	V	Sp.	R.A.	Dec.	K	H-K	K-L	Type	References
			1950.0						
	m		h m	° ′	m	m	m		
P Cyg	4.8	B1e	20 15.9	+37 53	3.34	0.17	0.38	F	G2 J1 W2
HD 334060	9.1	B8q	20 16.1	+30 17	9.05	0.01	-	X	
BD +40 4124	10.6	B2q[]	20 18.7	+41 12	5.63	1.01	1.34	Dn	A1 C2 G3 S4
Lk Ha 224	12.8	e	20 18.7	+41 12	6.17	1.28	1.60	Dn	C2 S4
Lk Ha 225	15.5	e	20 18.7	+41 12	6.03	1.72	-	Dn	C2 S4 *
MWC 342	10.6	q[]	20 21.2	+39 20	4.90	1.06	1.91	D	G2
BD +41 3731	9.9	B3e	20 22.5	+42 08	9.7	0.0	-	X	
Lk Ha 228	13	e	20 22.6	+42 06	9.72	1.0	-	Dn	
HD 195407	7.8	B0q	20 27.9	+36 49	6.17	0.29	0.5:	F	
1 Del	5.9	A1q	20 27.9	+10 44	6.03	0.07	-	X	
HD 195358	6.6	B9e	20 28.0	+19 15	7.03	-0.05	-	X	
V729 Cyg	9.2	07f	20 30.6	+41 08	4.34	0.26	0.28	X	
MWC 349	12.7	e[]	20 31.0	+40 29	3.36	1.44	2.08	D	G2 *
HD 197434	7.9	A0q	20 40.0	+54 02	7.51	0.04	-	X	
AS 441	11.5	B e	20 45.0	+43 34	9.63	-	-	-	
V517 Cyg	12	A2e	20 45.5	+43 32	8.91	1.2	-	Dn	
AS 442	10.3	B e	20 45.9	+43 36	6.50	1.09	1.43	Dn	
Lk Ha 134	10.8	B e	20 46.3	+43 36	7.99	0.67	1.2:	Dn	
Lk Ha 135	10.0	B e	20 46.6	+43 29	6.59	0.91	1.4	Dn	
HD 198931	8.7	B1e	20 50.4	+44 15	6.56	0.32	0.2	F	
HD 199356	7.2	B1q	20 53.5	+40 06	5.92	0.26	-	F	
V1057 Cyg	9.5	A7e	20 57.1	+44 04	4.63	0.44	0.78	F	C1 R1 S6 *
HD 200775	7.4	B3q[]	21 01.0	+67 58	4.56	0.86	1.15	Dn	G3 S3
eta Cap	4.8	A4e	21 01.6	-20 03	4.42	-0.09	-0.1	X	
HD 201733	6.7	B2e	21 08.2	+45 18	6.98	0.13	-	F	
BD +41 4064	9.0	B3e	21 14.3	+42 20	7.86	0.06	-	X	
BD +47 3487	9.1	B3q	21 34.0	+47 41	5.70	0.31	0.3	F	S5
epsilon Cap	4.7	B3q	21 34.3	-19 41	4.76	-0.04	0.2	X	
HD 206773	6.9	B0e	21 40.8	+57 30	5.44	0.39	-	F	
Lk Ha 234	13	B6e	21 41.8	+65 54	6.91	1.08	-	Dn	
BD +46 3471	10.1	A1q	21 50.7	+46 59	6.77	0.94	1.6	Dn	S3
MWC 645	13.4	e[]	21 51.7	+52 46	6.99	1.47	2.19	D	G2
Lk Ha 257	13.2	A e	21 52.4	+46 58	9.9:	>1.	-	Dn	
BD +44 4014	8.8	A q	21 58.2	+45 22	8.69	0.30	-	F	
MWC 1055	13.5	B e	22 06.6	+53 59	8.29	1.03	2.1:	D	
BD +52 3147	9.4	B8q	22 11.7	+53 22	9.3	0.2	-	F	
HD 212044	7.0	B1e	22 18.4	+51 37	6.47	0.21	-	F	
pi Aqr	4.7	B1e	22 22.7	+01 07	3.87	0.20	0.43	F	W2
Lk Ha 233	13.8	A7e	22 32.5	+40 23	8.44	1.4	-	Dn	
EW Lac	5.2	B3q	22 54.9	+48 25	5.00	0.23	0.28	F	
HD 217543	6.6	B3q	22 58.6	+38 26	6.92	-0.05	-	X	
omicron And	3.6	B6e	22 59.6	+42 03	3.86	-0.06	-0.0	X	
beta Psc	4.5	B5e	23 01.3	+03 33	4.68	0.01	0.09	F	
HD 236031	8.7	B3q	23 01.8	+53 56	7.98	0.13	-	F	
HD 218393	6.9	A5q	23 04.9	+49 55	5.19	0.14	0.21	X	
MWC 1080	11.8	B e	23 15.2	+60 35	4.65	1.20	1.47	Dn	
BD +60 2522	8.7	07f	23 18.5	+60 55	7.29	0.11	-	X	
HD 220300	7.8	A0q	23 19.9	+56 04	4.98	0.18	-	X	

TABLE I—*continued*

Notes

XY Per	Both components included
AB Aur	Possibly variable
HD 31648	HD gives $V = 7{\cdot}46$, but magnitudes at R and I suggest $V = 7{\cdot}7$
M1–82 IRS2	Probably a cluster of Be or other emission stars, not resolved by photometer
beta Mon	Combined magnitudes of three stars
MWC 137	Central star of Sharpless 266. Frogel *et al.* (1972) found the infra-red signal to be coincident with the star
L Ha 25	Small variations suspected
HD 50138	Fading slightly without change of H–K and K–L indices
M1–11	Possibly variable
eta Car	Measured with 35 arc sec beam
He 2–91	Possibly variable
He 2–106	Variations of several magnitudes suspected
M 2–9	Infra-red data refer to central condensation
HD 169226	Late-type companion dominates infra-red flux
M 1–92	Entire nebula within beam, but flux probably confined to heavily reddened central star
He 2–442	Variations suspected
FG Sge	Brightening at H and K; see text for further discussion
Lk Ha 225	Varies by over 3 magnitudes at K. Data correspond to maximum observed. K–$L > 2$ mag, but L not measured at maximum
MWC 349	Possibly an outlying member of the Cyg OB2 association. Suffers 9·1 mags of interstellar extinction at V; correction for this reddening gives $K = 2{\cdot}58$, H–$K = 0{\cdot}88$, K–$L = 1{\cdot}65$
V1057 Cyg	= Lk Ha 190. Has recently brightened in the visual; should be compared to FU Ori

References

A1	Allen & Swings 1972a
A2	Allen & Ney 1972
A3	Allen 1972
A4	Allen & Swings 1972b
C1	Cohen & Woolf 1971
C2	Cohen 1972
F1	Frogel *et al.* 1972
G1	Geisel *et al.* 1970
G2	Geisel 1970
G3	Gillett & Stein 1971
G4	Gillett *et al.* 1971
G5	Gillett *et al.* 1972
IRC	Neugebauer & Leighton 1969
J1	Johnson *et al.* 1966
K1	Knacke 1972
L1	Low *et al.* 1970
M1	Mendoza 1966
M2	Mendoza 1968
N1	Neugebauer & Westphal 1968
P1	Price 1968
R1	Rieke *et al.* 1972
S1	Swings & Allen 1971
S2	S. E. Strom *et al.* 1972a
S3	S. E. Strom *et al.* 1972b
S4	K. M. Strom *et al.* 1972
S5	Swings & Allen 1972
S6	Simon *et al.* 1972
W1	Westphal & Neugebauer 1969
W2	Woolf *et al.* 1970

and there is no reason to suppose that the magnitude of any object is rendered faint by the failure to include all the signal within the beam.

The catalogue is presented in Table I. Stars are arranged in right ascension order for 1950 coordinates. V magnitudes and spectral types are taken from a variety of sources, and where necessary averaged; the majority will be found in Jaschek, Conde & de Sierra (1964), in Guetter (1968), in the photoelectric catalogue (Blanco *et al.* 1968), in Lee (1970), in Wackerling (1970), in S. E. Strom *et al.* (1972b) or in Herbig & Rao (1972). A valuable source of reference is the Be star catalogue of Jaschek, Ferrer & Jaschek (1971). Magnitudes of some planetary nebulae are from Shao & Liller (private communication). When necessary, estimated visual magnitudes are given. The symbol [ ] following a spectral type signifies the presence of forbidden emission lines in the spectrum.

The infra-red data comprise the magnitude at 2·2 μ (K) and the colour indices H–K and K–L. Magnitudes are given to two decimal places for probable errors less than about 0·10 mag and to one decimal place otherwise. A colon signifies a detection in the range three to five standard deviations. The references in the last column are to published descriptions of the infra-red continuum (wavelengths longer than 1·5 μ), and an asterisk here refers to the notes which follow Table I. The literature search is complete to August 1972.

2. STATISTICS

Whereas previous publications of infra-red data have dealt exclusively with limited subsets of the Be stars—usually those with large infra-red colours—the present catalogue will be found to contain data on a wide range of different types of star. As a first aid to interpreting the near infra-red colours, the stars have been grouped into four categories given in Table I under the heading *type*. In assigning a star to a category, data at visible and at other infra-red wavelengths were usually considered. Especially valuable in this context were photoelectric R and I data secured for about one quarter of the programme stars. In cases where available data are few, this assignment can be a rather subjective task, and no dogmatic pronouncement on the nature of any star's infra-red continuum is intended. The four categories are as follows:

X The observed magnitudes fall within the observational uncertainty of the continuum expected on the basis of spectral type, visible magnitude and deduced interstellar reddening.

R The continuum resembles that of a late-type star. The star may be either symbiotic (Swings & Allen 1972) or heavily reddened by interstellar or very cool circumstellar material.

F The observed colour indices fall close to the range of values expected for an early-type star combined with optically thin free-free radiation from the star's ionized hydrogen envelope.

D The colour indices are too large (H–$K \gtrsim 0·7$ mag or K–$L \gtrsim 1·0$ mag) to be readily accounted for by hot free-free radiation. The infra-red excess is traditionally ascribed to reradiation from circumstellar dust clouds. If the star additionally lies in association with nebulosity, a suffix *n* is added to the letter D.

The distribution of stars in the four categories is:

X		69
R		12
F		75
D	43	89
Dn	46	
Unclassified		3
		248

Although the selection of stars in this catalogue is wider than in most published discussions of the Be stars, it is by no means random. Stars included comprise the majority of the known shell stars, P Cygni stars and forbidden-line stars, a large selection of Ae and Be stars associated with nebulosity (especially those studied by Herbig 1960) and a small number of ' normal ' Be stars. As many as possible of the stars classed AQ or BQ by Wackerling (1970) were measured. A few O stars were also included, and two Wolf–Rayet stars, both unusual objects not discussed by Allen *et al.* (1972). Other associated objects include 20 stellar planetary nebulae.

The result of this selection seems to be to bias the distribution heavily in favour of category D. However, the ratio of stars assigned to categories F and X is probably representative of Ae and Be stars as a whole. That the assigned categories are heavily dependent on spectral type may be seen from Table II. There is a pronounced drop in the proportion of stars assigned to the free-free category for spectral types later than B5; the latest spectral type found in category F is A0[*]. Conversely, large infra-red colours are rare in early B stars, and are found in significant numbers only later than B8. We may conjecture that the 29 stars of category D which are classified Be, if indeed they are early-type at all, are mostly of late B or early A spectral types. In many cases, however, the continuum is extremely weak or even absent in the spectra of these stars. No spectral types can be assigned to such objects, and their current classification as Be is purely an assumption.

TABLE II

Distribution of stars by category and by spectral type

Spectral type	X	F	D	F/F+X	D/D+F+X
O	6	4	—	0·40	—
B0, 1	6	20	—	0·77	—
B2	4	17	2	0·81	0·08
B3	10	11	1	0·52	0·05
B5, 6	6	10	3	0·63	0·16
B7, 8, 9	18	4	9	0·18	0·29
A	17	3	12	0·15	0·38

There seems to be no correlation between the presence of excess radiation attributable to free-free emission (category F) and such spectral peculiarities as shell or P Cygni line profiles, or bright forbidden lines. There is a weak correlation with bright Fe II lines in the spectrum. The incidence of category D colours does correlate strongly with the spectral features, in particular with the presence and intensity of low-excitation forbidden lines, or with the proximity to the star of bright nebulosity. The reliability of these correlations is examined in Table III, but it

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[*] This excludes the unusual stars FU Ori and V1057 Cyg. For a discussion of the origin of the infra-red excesses in these stars see Simon *et al.* (1972).

TABLE III

Distribution of stars by category and by forbidden emission lines or associated nebulosity

Feature	X	F	R	D	D/D+R+F+X
Nebulosity	6	2	1	47	0·84
[O I]	—	—	1	25	0·96
[O II]	—	1	—	9	0·90
[O III]	—	2	—	9	0·82
[N II]	1	1	—	10	0·83
[S II]	—	1	1	17	0·89
[Fe II]	—	3	8	24	0·69
[Fe III]	—	—	3	10	0·77
All stars observed					0·36

should be noted that the inclusion of the symbiotic and VV Cephei stars into the sample would significantly increase the proportion of forbidden-line stars in category R. At the time of writing, a number of category D objects are not known to have either forbidden-line spectra or associated nebulosity; HD 31648 and HD 163296 are the brightest of these. Both are included in the list of four ' special ' shell stars of Merrill (1949). The other two members of Merrill's group are AB Aur (Dn) and HD 236031 (F).

3. INTERPRETATION—CATEGORIES X, R AND F

That emission lines in the spectrum of a star are evidence for the existence of an extended stellar atmosphere (circumstellar shell) is well established. If the density of material in that atmosphere is sufficiently high, its presence should additionally be manifested by radiation mostly at longer wavelengths that that of the underlying star. We therefore seek to explain the infra-red excesses of the early-type emission-line stars in terms of the circumstellar material we believe to lie in clouds around them.

In a review of plausible mechanisms for producing infra-red excesses in galactic sources, Burbidge & Stein (1970) rejected non-thermal sources, line emission and thermal bremsstrahlung (free-free radiation), and adopted the now traditional explanation of thermal radiation from circumstellar dust. In the same year, however, it was shown by Woolf, Stein & Strittmatter (1970) that free-free radiation is indeed a most attractive mechanism to explain the infra-red excesses of many of the Be stars. In the present paper, both thermal radiation from dust grains and free-free emission will be discussed.

In Fig. 1, H–K is plotted against K–L to aid further the interpretation of the near infra-red colours. Objects with black- or grey-body energy distributions lie on the heavy diagonal line of Fig. 1(a), which may be closely approximated by $H\text{–}K = K\text{–}L$. The figures accompanying this line are black-body colour temperatures (T_C) in K. Normal stars lie close to this line in the region $H\text{–}K \lesssim 0{\cdot}5$ mag, and the early-type stars (including those in category X) are generally found in the region $-0{\cdot}1 \lesssim H\text{–}K \approx K\text{–}L \lesssim 0{\cdot}1$. Combinations of two or more black or grey bodies must lie below the black-body line ($K\text{–}L > H\text{–}K$). Only interstellar reddening or an unusual concentration of emission lines in the K waveband can carry a star above the black-body line. In Fig. 1(b) the principal diagonal (the free-free line) indicates the colours of pure free-free radiation for different values of the electron temperature, T_e, computed from the volume emission coefficient given by Allen (1963).

In the discussion that follows, Fig. 1 should be compared to Fig. 2, in which are plotted all the objects from the present survey for which *H–K* and *K–L* are available, together with an histogram in *H–K* for those objects with no determination at *L*.

The effect of interstellar reddening on the near infra-red colours is not accurately known, but there seems little evidence in favour of the assumption that theoretical calculations are a bad fit, except perhaps in certain restricted parts of the sky. The line in Fig. 1(b) labelled *interstellar reddening vector* is an average of the calculations of van de Hulst (1949) and the observations of stars in Perseus made by Johnson (1965); it is marked at intervals of 10 magnitudes of visual absorption. For $A_V \lesssim 10$ mag, it is not possible at these wavelengths to distinguish unambiguously between late-type stars and reddened early-type stars. Both may therefore be found in category R.

Following Woolf *et al.* (1970), the infra-red excesses of the stars in category F can be explained by free-free radiation from an ionized hydrogen envelope in which $T_e \sim 10^4$ K. Such stars would be found on the *H–K*/*K–L* diagram in the narrow, banded area indicated on Fig. 1(b). Interstellar reddening can carry points above this area. Since the total energy output of the circumstellar H II region is fed by and cannot exceed the stellar flux short of the Lyman limit, the relative intensity of the free-free contribution (and hence the magnitude of the infra-red excess) might be expected to increase with earlier spectral type. Such a trend is indeed indicated by the data and is manifested in Table II. It is to be expected that all Ae and Be stars have circumstellar H II regions, but that in some (in practice about one half) the emission measure is too small to be recorded by the present photometry.

4. STARS IN CATEGORY D

Two distinct mechanisms for producing the observed colour indices of the category D stars are currently under consideration. Until recently it was believed that these infra-red excesses could be explained only by the presence in the circumstellar environment of solid particles which absorb the visible radiation and degrade it to infra-red wavelengths. The term *dust shell* has often been applied to such cases, although it unfortunately brings to mind a spherical cocoon of material entirely enveloping the star, a gross exaggeration of the likely situation.

As an alternative to the dust hypothesis, Dyck & Milkey (1972) proposed that free-free emission can account for the infra-red excesses of these stars. As an inspection of Fig. 1(b) will reveal, large colour indices can be produced by free-free radiation if the electron temperature is much lower than the values typical in the ionized hydrogen envelopes of Be stars (a fact also noted by Frogel, Persson & Kleinmann 1972). Surrounding the H II region of a hot star are zones in which hydrogen is neutral but the metals are ionized and release electrons. In these zones, T_e adopts values in the range 10^3 to 4×10^3 K. Dyck & Milkey argue that in these zones of low T_e, free-free emission can arise from electron bremsstrahlung on neutral or molecular hydrogen.

The free-free model of Dyck & Milkey is as yet preliminary and awaits refinement. Although it can adequately explain the infra-red excesses of many of the stars in Table I, it is not certain that it can account for the more extreme objects such as η Car or M2–9. Perhaps both mechanisms are active. The free-free model, it should be noted, readily explains the apparent correlation between the near infra-red colour indices and the prominence of the emission spectrum. This relationship was noted above in the case of forbidden line stars, and has also been explored by Strom

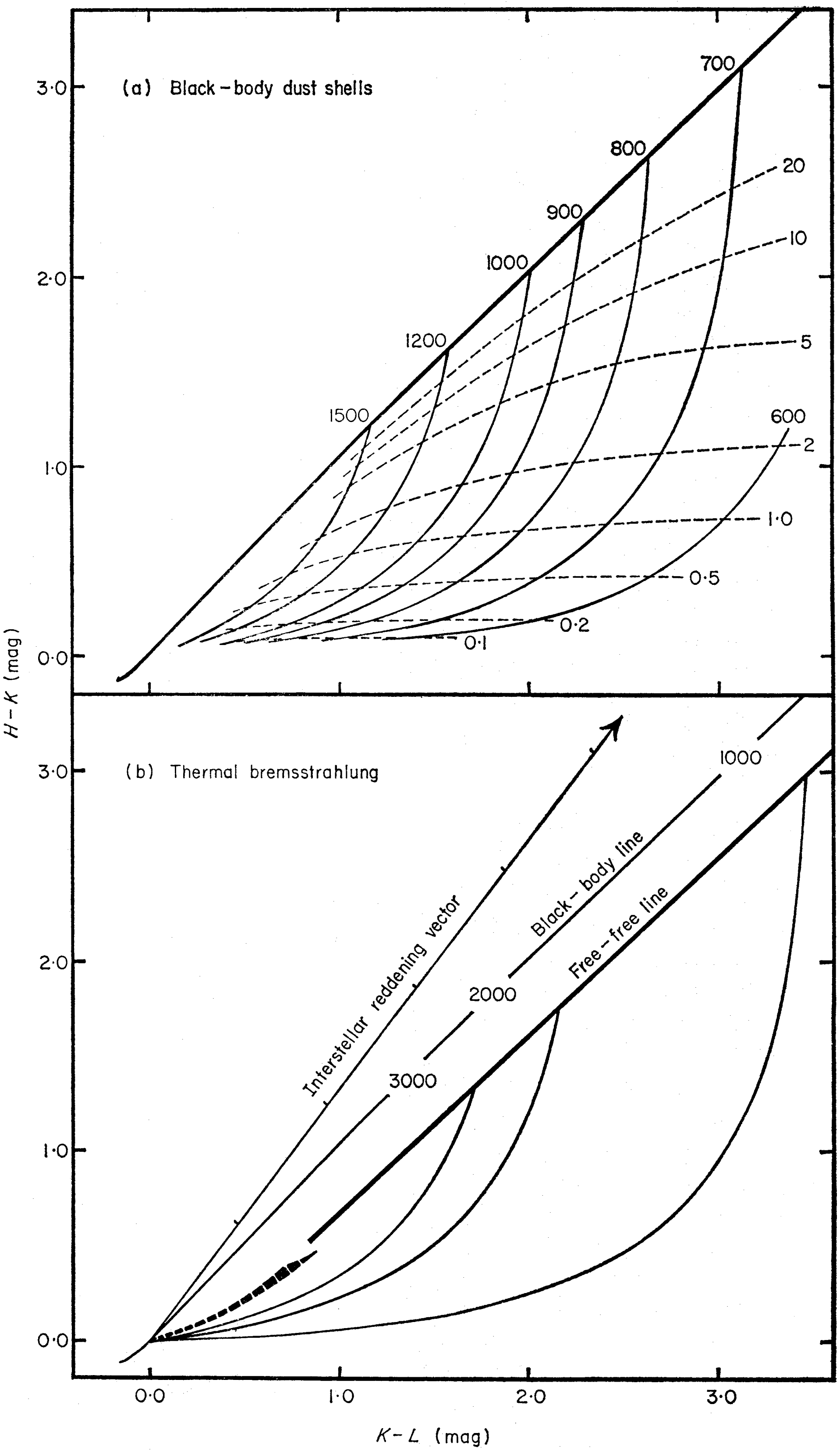


Fig. 1. *H–K plotted against K–L for early-type stars, illustrating the effects of interstellar reddening, free-free emission and thermal radiation from circumstellar dust, as described in the text* (*Sections* 3 *and* 4).

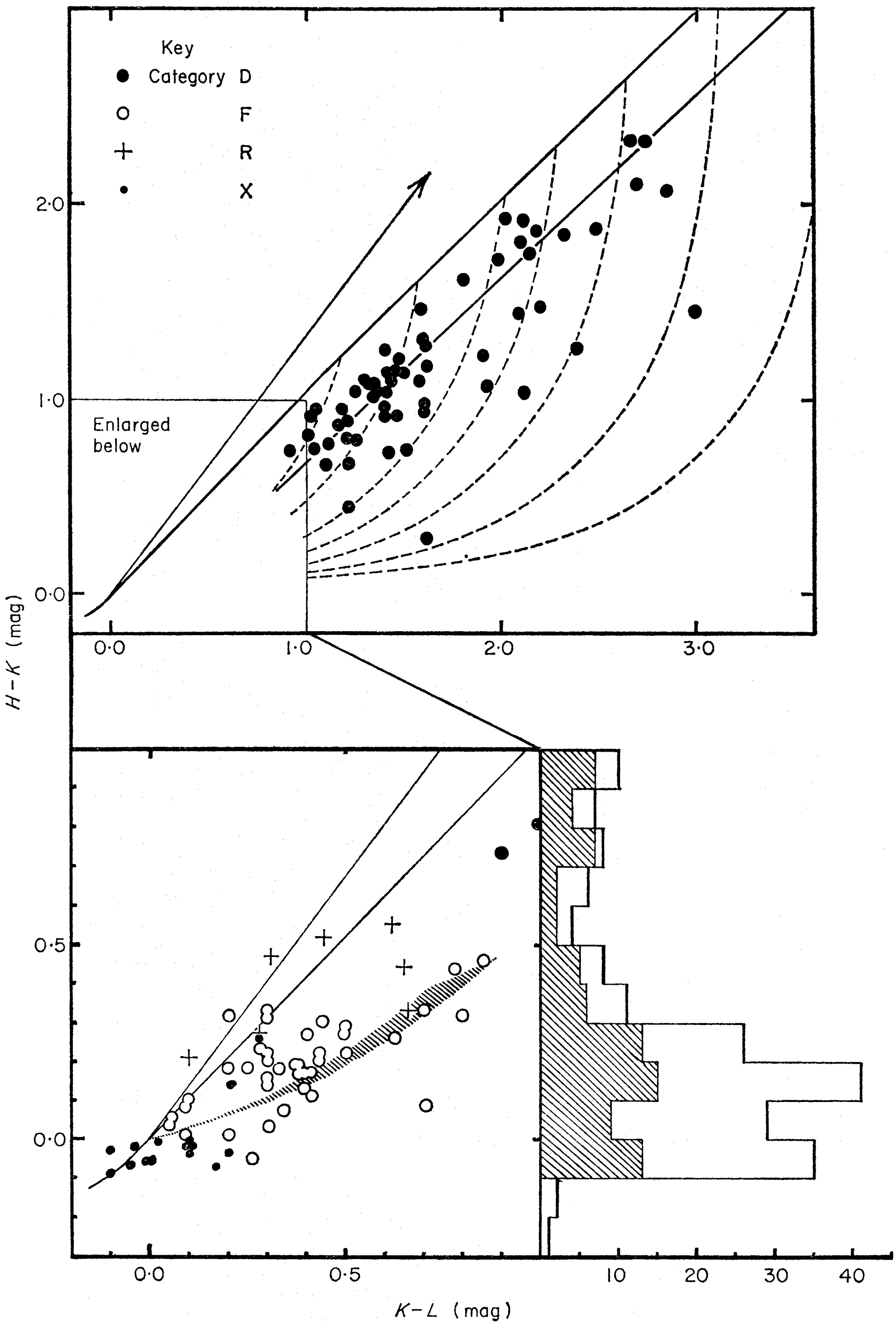


FIG. 2. *The distribution of the measured stars on the H–K/K–L diagram. The histogram in H–K indicates the proportion of plotted (shaded) and unplotted data. The black-body and free-free lines, contours of* T_c *and the region occupied by stars with hot free-free continua are marked.*

(1972) who found a linear dependence of the 3·5 μ flux on the Hα intensity for a number of the stars in category Dn.

Fig. 1(a) is constructed for an idealized two-component model representing an early-type star with a spherical dust shell of small physical thickness. The star is approximated by a 10 000 K black body and the dust shell by a second, cooler, black-body continuum. We may describe any point below the black-body line on the *H–K/K–L* diagram by two parameters. These are chosen to be (i) the colour temperature, T_c, of the cool component, and (ii) R, the ratio of the intensities of the two components at 2·2 μ. Contours of T_c are plotted as thin solid lines terminating on the black-body line at the appropriate colour temperature; contours of R are shown as broken lines. From Fig. 2 we may determine approximate values for T_c and R when both infra-red colour indices are known. The range of colour temperatures for the objects in category D is from 680 K (η Car) to about 1600 K (HD 163296).

A similar construction for the free-free model is shown in Fig. 1(b), but only the temperature contours are plotted. The situation here is complicated if the free-free radiation arises in a region which is not optically thin. As the shell becomes optically thick, the free-free line is displaced progressively closer to the black-body line. Even on the free-free model, therefore, the entire region below the black-body line is accessible. We note from Fig. 2 that approximately half of the stars in category D lie between the free-free and black-body lines. Thus the optically thin shells discussed by Dyck & Milkey probably represent a rather poor approximation in many cases.

The observations discussed hereafter will be interpreted in terms of the traditional dust-shell theory. An alternative interpretation based on the free-free model of Dyck and Milkey is, however, possible in all cases.

Observations from 3 to 20 μ of a number of the stars in category D were made with the University of Minnesota/University of California 60-inch infra-red telescope on Mt Lemmon, Arizona. These data indicate that in many cases the energy distribution of the cool component is wider in wavelength than a black body. Since a single colour temperature is clearly inapplicable, we must question how valuable is the parameter T_c determined from Fig. 2.

In practice the infra-red component may be fitted extremely well from 1 to 4 or 5 μ by a single black body, but the extension of this black body to longer wavelengths tends to fall below the measured fluxes. This is illustrated in Fig. 3 in which energy distributions of eight stars are plotted. A black body is fitted through the shorter infra-red data after the contribution from the star and, if necessary, a hot free-free continuum have been subtracted. The temperature of this black body we call T_{shell}. If a circumstellar dust cloud has a sharply defined inner boundary, the material at the inner edge, being hottest, dominates the short wavelength radiation. T_{shell} may be interpreted as the ambient radiation temperature at that distance from the star. T_c determined from the *H–K/K–L* diagram is in most cases a good approximation to T_{shell}, as indicated in Fig. 3. When we know T_{shell} and the luminosity of the central star, we may deduce the inner radius of the postulated dust cloud, though this value is rather dependent on the scattering optical depth of the outer parts of the cloud. Typical values are a few A.U. The long wavelength radiation in excess of the hottest black body is accounted for by the presence of cooler material further from the star. There is no evidence for a wavelength dependence of the emissivity.

On the free-free model, all the reddening in the optical region is of *interstellar* origin. The dust-shell model, however, predicts a considerable contribution from *circumstellar* reddening. In the latter case, we must ask whether sufficient reddening is observed to account for the luminosity of the infrared component. For almost all the stars under discussion, reddening is entirely adequate. Even for HD 45677 we need not invoke a peculiar reddening law (as was thought necessary by Swings & Allen 1971) if the stellar temperature is a little higher than is normal for a B2 star. A star for which E_{B-V} is too small, and hence for which normal reddening cannot explain the infrared excess, is LHα 25 (S. E. Strom *et al.* 1972a). However, our photoelectric R and I measurements and the photographic R and I data of Nandy (1971) suggest that an abnormal reddening law is indeed operative for this star. A similar, though less remarkable, extinction law operates on the nearby B2 star Walker 67 (also in NGC 2264). Using data from U to K for this star, we find a ratio of total to selective absorption (A_V/E_{B-V}) of about 4·2.

5. COMPACT PLANETARY NEBULAE

The inclusion in the catalogue of several compact planetary nebulae demands justification. The classification of faint planetary nebulae is based on objective prism surveys, the usual criterion being that if no continuum is observed the object is classed as a planetary nebula, and if a continuum is definitely present it is regarded as an emission-line star. As a result, many of the fainter emission-line stars find their way into planetary nebula lists. A comparison of emission-line star and planetary nebula catalogues reveals that, even excluding the central stars of very extended planetary nebulae, over 80 objects are found in common to both; these are listed in Table IV. All these objects have been differently classified according to the divergent opinions of different authors. More recent investigations by Allen & Swings (1972a) have added more planetary nebulae to the list of emission-line stars, and it is inevitable that other such misclassifications exist, especially in the Southern Hemisphere where the planetary nebulae of Henize's (1967) survey have been very little studied. The fact that it is not known whether many of the entries in Table IV are stellar or nebulous is further evidence for the confusion in this field.

A deeper question concerns the definition itself: is it meaningful to distinguish between the stellar planetary nebulae and the emission-line stars simply because the former have continua too weak to detect? The emission spectra of many of the stellar planetary nebulae are little different from those of some emission-line stars, and there is little to link them to the conventional, extended planetary nebulae. It transpires from the present survey that the stellar planetary nebulae whose spectra most closely resemble the forbidden-line B stars have prominent infra-red continua typical of the stars in category D. It is not the intention of this paper to delve too deeply into the possible relationship between the Be stars and a certain subset of the planetary nebulae. The justification for the inclusion of the 20 planetary nebulae in Table I is simply that there may be no difference between these objects and many of the forbidden-line stars which are admitted by their loose definition as ' Be '.

6. VARIABILITY

Infra-red photometry, even at short wavelength, is not so precise as many observers would like to suppose. At apparently photometric sites occasional variations in the transparency of the sky can be quite large. Further, most observations

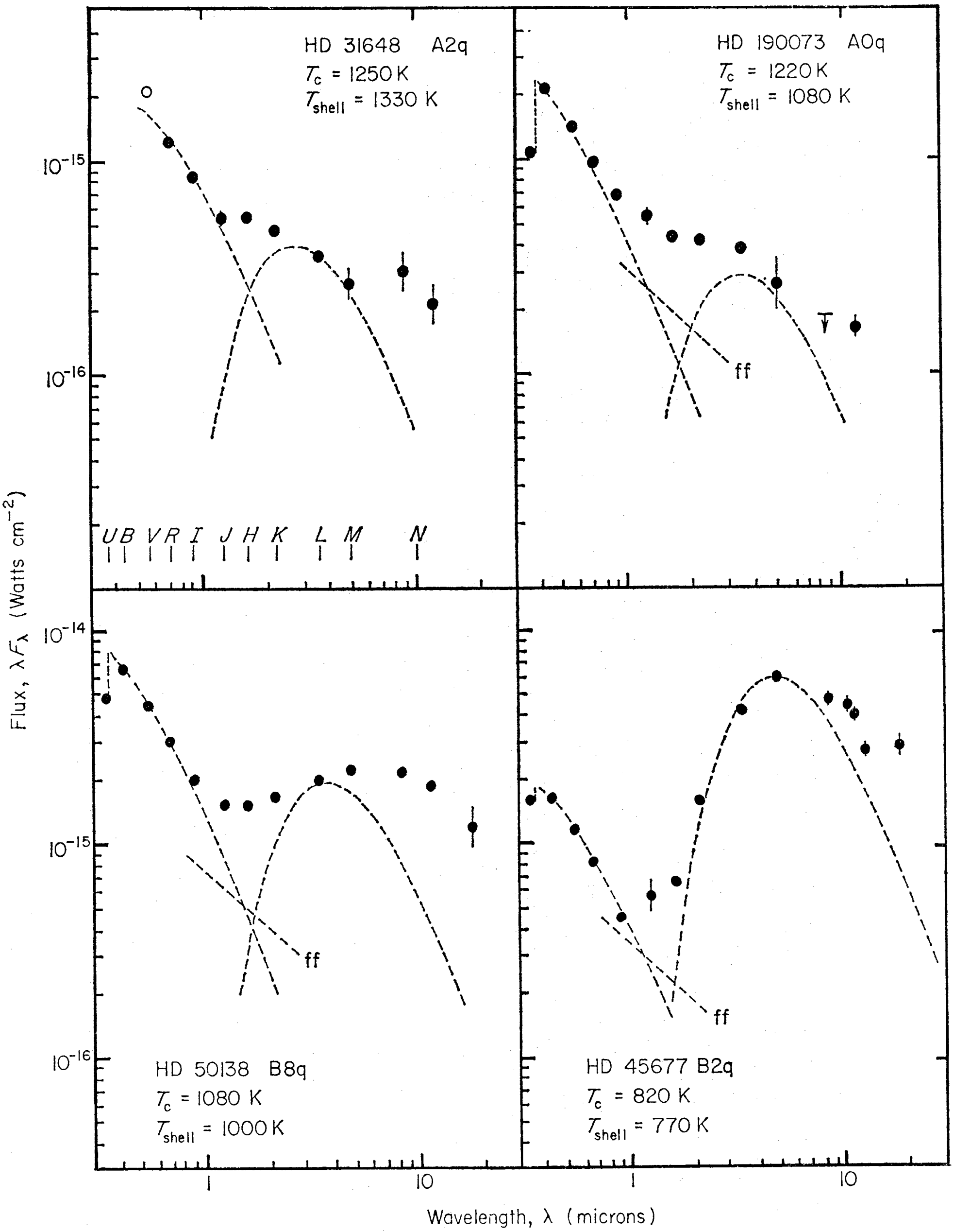
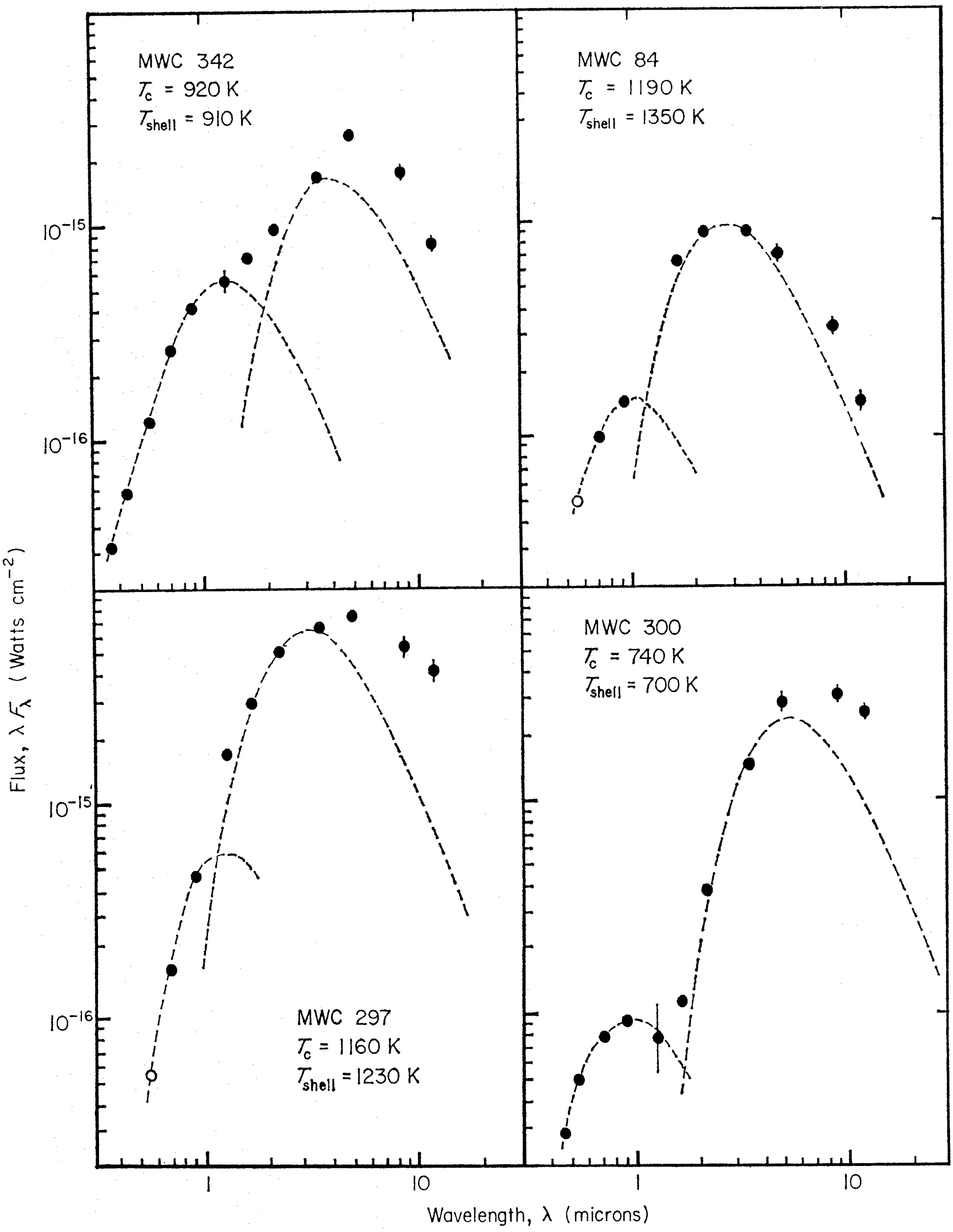


FIG. 3. *Energy distributions of eight stars from the visible to 20 μ. For each star,* T_c *(determined from Fig. 2) is compared to* T_{shell}*, the highest black-body temperature revealed by*

are of stars which give a rather small signal-to-noise ratio. When one compares data on the same star secured on different nights, he may sometimes find discrepancies which exceed the anticipated errors, and in such cases is tempted to speculate that it is the source, rather than the photometry, which varies. In practice, however, additional observation usually provides no further evidence of variation. In short, a stringent criterion must be adopted by which to judge whether variation of a source has been observed. Only 3 per cent of the objects in Table I showed evidence of genuine variation; all are mentioned in the notes.

In some cases the variation takes the form of a consistently observed monotonic increase or decrease of a few tenths of a magnitude per year. Over the period of



these graphs, and a black body at the temperature T_{shell} *is drawn. ff = free-free radiation. Open circles represent doubtful V magnitudes.*

observation (1971 February to 1972 January), HD 50138 has faded, but no visual observations are available to help decide whether the star itself varies or whether the circumstellar shell has become thinner. In the case of FG Sge, at 2 μ only the continuum is seen. An analysis of this peculiar star by Arkhipova (1972) revealed that a slow decrease in the colour temperature accompanied by a corresponding change in the spectral type has recently occurred. The V magnitude currently varies very little, and therefore the colour index V–K is increasing, in good agreement with Arkhipova's findings.

More dramatic variations, far in excess of the probable errors of the measurements, have been observed on a shorter time scale for several of the objects in Table I. The most remarkable was a brightening by nearly an order of magnitude in

TABLE IV

Objects common to emission-line star and planetary nebula catalogues

Perek & Kohoutek (1967), or Kohoutek (1969, 1972) designation	Wackerling (1970) designation	Other designation	Note
M1–2	133 –8 1	VV 8	
Sh 2–266		MWC 137	1
K 4–49	MWC 819		
	HD 63099	IC 2206	
He 2–9		AS 200	
Ve 27	HenP 14		
He 2–15		AS 204	
	Hen 230	He 2–17	
AG Car	AG Car		
He 2–61	Hen 573		
He 2–79	HenP 79		
He 2–80	HenP 80		
He 2–87	HenP 87		
He 2–91	HenP 91		
He 2–101	HenP 101		
	Hen 1044	He 2–113	
He 2–131	HD 138403		
He 2–134	Hen 1092		
Cn 1–1	HD 330036		
He 2–139	HenP 139		
He 2–138	HD 141969		
He 2–147	HenP 147		
He 2–172	HD 149427	Hen 1223	
He 2–174	Hen 1227		
He 2–176	HenP 176		
Cn 1–2	Hen 1242	He 2–177	
He 2–179	HenP 179		
H 1–2		AS 208	
V 1–4		Hen 1261	
He 2–182		HD 151895	
He 2–183	HenP 183		
H 2–1		MWC 247	
H 2–2	V 455 Sco	Hen 1334	
H 1–7		HD 326971	
H 2–4	AS 221	Hen 1348	
H 1–9		AS 226	
Th 3–20	Hen 1410		
He 2–260		AS 235	
PC 18	AE Ara	Hen 1451	
H 2–17	HenP 263		
Tc 1		HD 161044	
H 2–19		AS 241	
He 2–275	HenP 275		
M1–26	HD 316248		
Bl 3–11	HD 316285	Hen 1482	
H 2–23	Hen 1489		
H 2–28	AS 245		
Hb 6		AS Sgr	
H 1–41		AS 256	
Ap 1–7	HD 316989	Hen 1553	
M3–21		V 567 Sgr	
H 1–49		AS 269	

Table IV—*continued*

H 1–54		AS 272	
H 1–56		Hen 1592	
M1–40		AS 278	
He 2–354		AS 280	
Ap 1–10		AS 281	
Ap 1–11		AS 282	
Ap 1–12		AS 283	
H 2–43		AS 288	
H 1–62		AS 290	
He 2–370		AS 293	
He 2–376		AS 294	
SwSt 1	HD 167362		
H 1–65		AS 301	
H 1–66		AS 303	
V–V 1–8		AS 310	1
(Vy 1–3)	IV −4 14	Roberts 89	
He 2–417		AS 316	
H 2–48	MWC 957		
K 4–7		AS 323	
K 3–14		AS 324	
K 4–12		AS 338	
M1–67	II +16 4		
He 2–430		AS 345	
IC 4846	BD −9° 5069	AS 348	2
Na 2	AS 350		
(Razmadze)	BF Cyg		
(My 129)	Hen 1761		
He 1–4		(AS 375)	3
K 4–51	AS 389		
M1–77	III +46 54		
M2–54	III +51 42		

Notes

1 Central star of small H II region classified as planetary in Perek & Kohoutek (1967).
2 The position given by Perek & Kohoutek (taken from Schembor 1930) seems to be in error.
3 Overlapping spectra.

two days exhibited by the southern planetary nebula He 2–106. Since, however, the first measurement was made through thin cirrus clouds which produced an extinction at 2·2 μ typically of a few tenths of a magnitude, this measurement is suspect. A better documented case is that of Lk Hα 225. For this star, variations of over three magnitudes were recorded within a period of one month in 1971. On each occasion the nearby Lk Hα 224 was measured, but no significant variations in this star were found. Table V documents the available data on Lk Hα 225, including observations by K. M. Strom *et al.* (1972) and Cohen (1972). The data strongly suggest a deep minimum to have occurred between 1971 October 10 and early December, and if this variation is real it imposes severe limits on the sort of model which can account for the infra-red excess, especially since no corresponding change in the visible seems to have occurred.

If solid circumstellar material is involved, a change at 2 μ can best be explained by a reduction in the number density of dust grains at the very inner edge of the cloud. If the motion of material is outwards, dust grains originally radiating at

TABLE V

2·2 μ observations of Lk Hα 225

Date 1971 U.T.	K magnitude	Observer	Notes
August 4	$7^{m}\cdot 9$	Allen	Uniform thin cirrus gave about 0·2 mag extinction
October 6	6·03	Allen	Sky photometric
October 10	6·17	Strom	
November 6	9·3	Allen	Good sky, star definitely in the beam
November 26	6·8	Cohen	Probable error of measurement ±0·2 mag
December 11	6·05	Strom	
December 15	6·28	Strom	

about 1000 K must move to a region where the ambient temperature is 700 K in order that the 2·2 μ flux falls by three magnitudes. Similar constraints apply if the material is falling into the star. A doubling of the distance from the star to the dust is implied; the corresponding linear distance moved must be several A.U., and on a time scale of 30 days the velocity required is distinctly in excess of 100 km s^{-1}. Ejection velocities of this magnitude are found in the more extreme P Cygni stars, and we would expect to find deep violet absorption fringes to the emission lines. On a very low dispersion spectrogram of Lk Hα 225, Herbig (1960) found no absorption lines. Since then, however, the star has faded considerably (perhaps as a result of the formation of a circumstellar dust cloud), and no further spectroscopic studies of it have been made.

7. CONCLUSIONS

A near infra-red study of approximately 5 per cent of the known early-type emission-line stars has been presented. Two thirds of the stars selected are found to exhibit excess infra-red emission in varying degrees, and in some cases most of the observed energy is emitted in the infra-red. At least two mechanisms—free-free radiation and thermal emission from dust grains—are probably active in producing the observed infra-red excesses.

Particular interest has recently devolved upon the stars with very prominent infra-red continua, those for which the presence of unusually extended circumstellar envelopes is implied. Two kinds of Be stars have been found to be members of this group: the P Cygni stars (Geisel 1970) and in particular those with [O I], [S II] or [Fe II] lines in their spectra (Allen & Swings 1972a), and the pre-main-sequence B stars usually found associated with visible nebulosity (S. E. Strom *et al.* 1972a, b). The present observations extend the list of observed forbidden-line objects and stars associated with nebulosity, and confirm the relationships already noted. Additional stars of both types are possibly suggested by the photometry: further study may reveal that the southern planetary nebulae of Table I are low-excitation forbidden-line stars, or that HD 37806, MWC 137, VV Ser and Hen 1751 are isolated pre-main-sequence B stars.

A small proportion of the objects measured resemble late-type stars in their energy distributions. In some cases this is because a late-type *comes* is included in the beam of the detector, but outstanding exceptions are the stars MWC 56, HD 316285, MWC 922* and BD +14° 3887. All these objects have been classified Be and have [Fe II] lines in their spectra (Swings & Struve 1945; Swings & Struve

1941; Merrill & Burwell 1949; Swensson 1943, respectively). By analogy with other such stars we should expect the infra-red continua to be dominated by radiation from a circumstellar shell. Notwithstanding, the apparent absence of late-type features, these stars are probably symbiotic, as noted by Swings & Allen (1972). HD 316285 is probably the first object to be classified as a Be star, a planetary nebula and a symbiotic star!

Near infra-red photometry is a powerful tool in selecting peculiar objects, since the presence of measurable infra-red radiation from a visually faint star can be determined in a few minutes' observation. It is the intention of the author to extend the present survey to fainter Be stars and stellar planetary nebulae in the belief that many more will be found to have large *H–K* and *K–L* indices. By this means it might prove possible to add considerably to current lists of symbiotic stars, pre-main-sequence A and B stars and peculiar emission-line objects.

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* There is a possibility of misidentification of MWC 922. The positional information given by Merrill & Burwell (1949) is confusing.

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NOTE ADDED IN PROOF

In a paper to be published in *Astrophys. J.*, Milkey & Dyck show that H^- free–free radiation can be ruled out as a source of the infra-red excesses in Be stars. H_2^- free–free is not excluded.