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INFRARED PHOTOMETRY OF SOUTHERN EMISSION-LINE STARS

D. A. Allen and I. S. Glass

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SUMMARY

A search for 2·2-μm continua in southern compact planetary nebulae and emission-line stars has proved about 50 per cent successful. The objects detected are probably not conventional planetary nebulae and appear to form two groups, one of which is identified with symbiotic stars and the other with early-type forbidden-line stars.

1. INTRODUCTION

The first complete objective-prism Hα survey of the northern sky was undertaken at the Mount Wilson Observatory some 40 yr ago. Prior to its publication, a sizeable number of the emission-line objects recorded were examined in greater detail, mostly by means of low-dispersion spectra; these objects were thus given a variety of classifications including Of and Be stars, symbiotic stars and low-excitation stars whose spectra generally show only emission lines (Merrill & Burwell 1933, 1943, 1949), planetary nebulae and other emission nebulae (Minkowski 1946, 1947, 1948) and, finally, 'additional stars' whose nature was undetermined (Merrill & Burwell 1950). More recent surveys in both hemispheres, and in particular that of the southern sky by Henize (unpublished, and 1967), have not been followed up in such great detail as the original one; the emission-line objects recorded have therefore been loosely classified as either Be stars or planetary nebulae according to whether continuum emission is or is not present on the objective prism plate. A considerable amount of work is needed before the nature of most of the stars in these surveys is established.

Infrared photometry in the 1- to 3·5-micron region affords a rapid and quite efficient method of distinguishing between several of the different types of objects with Hα in emission: (1) Most Be and Of stars exhibit the infrared colours of hot ($\sim 10^4$ K) blackbodies modified by the presence of thermal bremsstrahlung from their circumstellar ionized hydrogen shells (Woolf, Stein & Strittmatter 1970). (2) Symbiotic and VV Cep stars mostly exhibit late-type stellar continua in the visible and near-infrared (Swings & Allen 1972); there is some risk in this case of confusion with hotter stars experiencing the appropriate interstellar extinction. (3) A class of stars with low-excitation emission spectra (especially those with such lines as [O I], [S II], Fe II and [Fe II]) is characterized by large infrared excesses at wavelengths around 2 μm (Allen & Swings 1972). (4) Pre-main-sequence stars (T Tau stars and Ae and Be stars associated with nebulosity) also show prominent infrared excesses at 2 μm (Strom 1972 and references therein). (5) Planetary nebulae mostly have uncontaminated bremsstrahlung spectra, sometimes with small excesses at 3·5 μm (Willner, Becklin & Visvanathan 1972; Persson & Frogel 1973). Those with late WC nuclei usually have 2-μm excesses. Many conventional planetary nebulae have infrared excesses at wavelengths longer than 3·5 μm (Gillett, Merrill & Stein 1972); such long-wavelength excesses are usually not detected by the near-infrared photometry described here.

The infrared technique was first employed by Allen & Swings (1972) in a search for stars of category 3. Four such objects were found from a selection of stellar planetary nebulae measured at 1·6 and 2·2 μm. Subsequently Allen & Porter sampled some southern stellar planetary nebulae from the list of Henize (1967). Their results are mostly unpublished, but the brighter sources were included in Allen (1973). A number of known southern emission-line stars have already been examined by Glass & Webster (1973) who showed (*inter alia*) the usefulness of infrared photometry in detecting the cool components of symbiotic stars in cases where they were not already known from spectroscopic evidence. This paper reports a survey in the intermediate infrared of approximately 200 southern emission-line objects most of which were selected from the class I (stellar) planetary nebulae of Perek & Kohoutek (1967). It supersedes the work of Allen & Porter and, for completeness, incorporates the data of Glass & Webster (1973) and Webster & Glass (1974).

2. THE OBSERVATIONS

Our observations were made with an infrared photometer constructed by Glass (1973) which employs a PbS detector and operates at effective wavelengths of 1·25 μm (*J*), 1·65 μm (*H*), 2·2 μm (*K*) and 3·5 μm (*L*). Most of the data were secured on the 40-in. reflector of the South African Astronomical Observatory, Sutherland. A few additional data taken with the 74-in. Radcliffe reflector, and four unpublished observations made with the Mount Wilson 100-in., were also incorporated. The results given in Table I will be used in the statistical discussions below. Most of these objects have angular diameters of less than 2–3 arcsec. However, bright (and hence, presumably, local) resolved planetary nebulae up to about 5 arcsec in diameter were also included (examples: He2–131, M1–26). We also examined a smaller number of extended planetary nebulae, selecting principally those of distinctive morphological type, and obtained mostly upper limits. These are given in Table II. The nomenclature employed in these tables is that of Perek & Kohoutek (1967).

Many of the data in Tables I and II are given as upper limits. We adopted a 2·5 standard deviation (sd) signal as our detection criterion. For objects falling below this level we give a 3 sd upper limit. About a dozen of the compact planetary nebulae were recorded at the 1·5–2·5 sd level. When the statistical error of an observation is less than about 0·12 mag, we quote its magnitude to two decimal places; otherwise we give only one. In cases where the accuracy is particularly low we give in brackets following the magnitude the number of standard deviations at which the source was detected.

3. INFRARED COLOURS

Fig. 1 is a set of histograms showing the distribution of the sources we have measured according to the three colour indices *J–H*, *H–K* and *K–L*. Considering first the latter index, we find strong evidence for the existence of two populations. A *K–L* index less than 0·9 can be explained by a normal star with, when necessary,

TABLE I

Magnitudes of compact planetary nebulae

i) detected sources

Object		J m	H m	K m	L m	Class	Notes
265- 2°1	Ve 26		9.5	8.9		S	
266+ 2 1	Pe2-3	7.40	6.21	5.81	>5.5	S	
266- 0 1	He2-17	9.06	7.67	6.54	5.09	D	1; =Hen 230
266- 1 1	Ve 27		10.1	8.51	5.73	D	
274+ 2 1	He2-34	8.99	7.24	5.79	3.95	D	1,9
280- 2 1	He2-38	8.60	7.04	5.64	4.01	D	
281- 5 1	IC 2501		>10.1	9.09		D	2
288+ 5 1	He2-61			10.2 (2.5)			
298- 1 1	He2-79		10.3	8.03	5.23	D	
299- 0 1	He2-80	9.9	8.5	7.30	5.72	D	1
302- 0 1	He2-87	8.17	6.68	5.98	5.56	S	1
305+ 1 1	He2-90		9.7	7.79	5.07	D	1
305- 0 1	He2-91	9.49	7.89	6.34	4.55	D	1
307- 9 1	He2-97			9.8 (5.1)			
311+ 3 1	He2-101		10.1	8.39		D	
312- 2 1	He2-106	10.1	7.67	5.72	3.58	D	1
315+ 9 1	He2-104		8.45	6.69	4.63	D	1
315-13 1	He2-131	9.31	9.6	9.08	>8.0	S	10; = HD 138403
319- 9 1	He2-134	8.98	7.96	7.67		S	3; = Hen 1092
320- 9 1	He2-138		10.9 (3.5)	10.5 (2.8)	8.3 (3.5)	D?	8; = HD 141969
321+ 3 1	He2-113	9.77	8.83	7.39	4.64	D	1,4; = Hen 1044
326- 1 1	He2-139	8.10	6.40	5.32	3.99	D	1
326-10 1	Cn1-2	7.21	6.25	5.92	5.76	S	1,3; = Hen 1242
327- 4 1	He2-147	7.06	5.73	4.92	4.03	S	1
330+ 4 1	Cn1-1	9.0	8.15	7.58	5.89	D	5; = HD 330036
331- 5 1	PC 11	10.7 (4.1)	10.6 (3.0)	10.2 (3.0)		S	= HD 149427
334+ 0 1	Pe2-9		8.80	7.04	4.83	D	
337+ 1 1	Pe1-7			8.6			
338+ 5 2	He2-156	9.5	8.46	8.06		S	1
338+ 1 1	He2-174		9.8	7.93	5.30	D	1; = Hen 1227
339+ 0 1	He2-176	7.69	6.25	5.51	4.96	S	1
339+ 0 2	He2-179	6.20	4.90	4.07	3.29	S	
342+ 5 1	He2-173	8.48	7.10	6.78		S	1
344- 8 1	PC 18	7.50	6.55	6.26	5.9	S	= AE Ara
346+ 8 1	He2-171	9.52	7.64	6.26	4.46	D	
350+ 4 1	H2-1			9.4 (5.5)			= MWC 247
351+ 3 1	H2-2	7.48	6.37	5.92	5.59	S	= V455 Sco
352+ 3 1	H2-4		8.07	7.49		S	= AS 221
354+ 4 2	H2-5	7.13	5.95	5.53	5.27	S	
355+ 3 2	H1-9			9.2 (6.2)			=AS 226
356+ 4 2	M3-38			9.6 (3.1)			
356+ 2 1	Th3-13			9.9 (2.9)			
356- 7 1	He2-349	8.94	7.94	7.69	>7.1	S	
357+ 2 3	Th3-20	9.8	9.08	8.41		S	
357+ 2 4	H1-18	8.92	8.06	7.91		S	
357+ 1 1	H1-23		8.8	7.8		D?	11
357- 3 1	He2-294			9.6 (3.4)			
357- 4 3	H1-43		8.58	8.22		S	
358+ 3 1	M3-10			9.6 (2.7)			
358+ 3 5	Th3-18	9.6	8.38	8.03		S	
358+ 1 2	Th3-31	9.23	8.03	7.57		S	
358- 0 2	M1-26		9.16	8.15		D	11,12; = HD 316248
1- 0 1	B13-11		8.61	8.75		S	13
1- 6 1	CnMy 17	8.92	7.78	7.50		S	
1- 6 2	SwSt 1		9.71	8.52		D	6; = HD 167362

TABLE I—*continued*

Object		J m	H m	K m	L m	Class	Notes
2- 2 1	H1-45	9.26	7.73	6.52	4.82	D	
2- 5 1	He2-370	9.01	8.03	7.76		S	= AS 29
3+ 3 1	H2-17			10.0 (6.5)			
3- 1 1	He2-325		9.6	9.1		S	
3- 4 1	Ap1-10	8.28	7.26	6.95		S	= AS 28
3- 4 2	Ap1-9		9.1	8.8		S	
3- 4 6	Ap1-11		8.9	8.42		S	= AS 28
3- 4 9	H2-43		10.3	8.44	>7.2	D?	= AS 28
3-14 1	Hb 7		9.3	9.3		S	7
5- 5 2	He2-390		>10.8	7.66	5.48	D	
6+ 7° 1	M1-21	8.77	7.63	7.21		S	
16- 4 2	M1-56			10.5 (2.5)			
19- 4 1	M1-60			9.8 (4.0)			
19- 5 1	M1-61		8.44	8.46		S	
23- 2 1	M1-59			9.8 (3.2)			
28+ 5 1	K3-2			12.5 (3.0)			7
29- 2 1	Pe2-16		8.59	8.09		S	
31+ 1 1	PC 20			9.5 (3.8)			
33- 4 1	K4-17			9.8 (3.1)			
35+ 5 1	K3-8	8.80	7.78	7.06		S	
36- 6 1	K4-25	8.57	7.57	6.97		S	
37+ 7 1	K4-2	8.56	7.17	6.59		S	
37- 2 1	Ap3-1		9.07	8.50		S	
37- 3 1	K4-18	7.66	6.55	6.04		S	
37- 6 2	K4-26	6.33	5.30	4.74	4.23	S	
58-10 1	IC 4997		10.7 (4.4)	9.7 (5.6)		D	2,14

ii) upper limits for undetected objects

Object		K m	Notes
263- 5° 1	PB 2	10.0	
266+ 2 2	Pe2-2	9.9	
266+ 1 1	Pe2-1	9.9	
266+ 0 1	Ve 22	9.6	
268+ 2 1	PB 5	9.6	
274+ 2 2	He2-35	10.3	
275- 3 1	He2-25	9.5	
278- 6 1	He2-26	9.7	
285+ 2 1	Pe2-7	9.7	
285- 2 1	He2-47	9.9	
285- 5 1	IC 2553	10.0	15
286- 6 1	He2-41	10.3	
291- 4 1	IC 2621	10.1	
294- 4 1	He2-68	9.3	
295- 9 1	He2-62	10.1	
296- 6 1	He2-71	9.6	
304+ 5 1	He2-88	9.4	
304- 4 1	IC 4191	9.7	
307- 1 1	Th2-B	9.8	
321-16 1	He2-185	9.4	
325+ 4 1	He2-128	9.5	
325+ 4 2	He2-127	9.5	
325-12 1	He2-182	9.8	= HD 151895
326- 6 1	He2-151	10.1	
327+13 1	He2-118	9.5	15

Object		K m	Notes
355- 3° 3	H1-35	9.9	
356+ 4 1	M2-11	10.0	
357+ 7 1	M4-3	9.9	
357- 3 4	M2-18	9.5	
358+ 3 2	H2-10	9.5	
358+ 3 4	H1-19	9.6	15
358+ 3 7	H1-17	9.7	
358- 4 1	H1-46	9.4	15
358- 6 1	He2-354	9.4	= AS
359+ 5 1	M2-12	9.4	
359+ 4 1	Th3-14	9.6	
359+ 3 2	Th3-25	10.1	
359+ 2 1	Th3-20	9.2	15
359- 6 1	H1-62	9.5	= AS
0+17 1	PC 12	10.0	
0+ 4 1	H2-11	9.1	
0- 2 1	Bl3-13	10.6	
0- 7 1	M2-35	9.6	
0- 7 2	H2-46	9.6	15
1- 3 1	H1-47	9.7	
1- 4 1	H1-55	9.6	
1- 4 2	H1-56	9.5	= Hen
2- 2 2	M3-20	9.4	
2- 3 3	M1-37	10.5	
2- 4 1	H1-54	9.5	15; =

TABLE I—*continued*

331- 2 1	He2-157	9.6	
331- 3 1	He2-162	9.5	
332- 4 1	He2-170	11.1	
341- 0 1	He2-183	9.5	15
341- 9 1	He2-248	10.0	
342- 6 1	Cn1-4	9.7	15
343+11 1	H1-1	9.6	
344+ 4 1	Vd1-1	9.7	15
345+ 4 1	Vd1-2	9.5	
345- 4 1	Cn1-3	9.7	
346- 6 1	Fg 2	9.7	15
347+ 5 1	H1-2	9.9	= AS 208
349+ 4 1	M2-4	10.1	
350- 2 1	H1-22	9.6	15
351+ 9 1	PC 13	9.4	
351+ 7 1	H1-4	9.9	
351+ 4 1	M1-19	10.1	
351- 5 1	He2-275	9.3	15
352+ 3 2	H1-8	9.3	
352- 7 1	Fg 3	9.7	
353+ 8 1	MyCn 26	9.7	
355+ 2 2	Th3-10	10.3	
355+ 2 3	Th3-11	10.1	
355- 2 2	H1-29	9.9	
355- 3 1	H1-33	9.3	
355- 3 2	H2-23	10.3	= Hen 1489
2- 6 2	H1-63	9.2	15
4- 2 1	H1-53	10.4	
4-22 1	He2-436	9.5	
5- 3 1	H1-58	9.6	
6+ 8 1	M1-20	9.8	
6+ 2 2	H2-28	10.3	= AS 245
6- 3 1	H1-61	10.2	
7- 4 1	H1-65	9.8	= AS 301
7- 6 2	Vy2-1	9.9	
8- 7 2	NGC 6644	9.9	
9- 9 1	M3-32	11.8	7
10+ 3 1	Th4-10	9.6	
10- 6 1	IC 4732	9.6	
11+11 1	M2-13	11.7	7
11- 6 1	M1-55	10.1	
11- 9 1	H2-48	9.9	1; = MWC 957
12- 2 1	M1-45	10.1	
15+ 3 1	M1-39	9.8	
18- 2 1	M3-54	9.6	
25- 4 1	K4-8	10.0	
27- 9 1	IC 4846	10.0	= BD $-9^{\circ}5069$
32- 2 1	M1-66	10.0	
32- 2 2	K3-19	10.2	
38- 3 1	K4-19	9.7	
43+11 1	M3-27	9.8	16
44-10 1	K4-36	9.6	

Notes to Table I

1 *cf* Allen (1973).

2 Persson & Frogel (1973) give a similar result.

3 Taken from Glass & Webster (1973).

4 Taken from Webster & Glass (1974).

5 Includes the data of Glass & Webster (1973).

6 Taken from Allen (1973).

7 Measured with the Mount Wilson 100-in. telescope.

8 $V\text{–}K \sim 0{\cdot}0$.

9 This measurement refers to the star 0·7 arcsec north of the pair indicated by Perek & Kohoutek (1967).

10 Persson & Frogel (1973) find a 3·4 σ signal at L, implying a D classification.

11 Measured in a poor sky.

12 A measurement $L = 7{\cdot}6$ under poor conditions seem inconsistent with V, H and K.

13 Not HD 316285 as mistakenly stated by Allen (1973).

14 Infrared excess at longer wavelength found by Gillett & Stein (1971). Khromov & Moroz (1971) give a similar result.

15 Possible signal at K, in the range 1·5–2·5 σ.

16 Detected by Persson & Frogel (1973) at $K \sim 11{\cdot}5$ and with a possible excess at L.

TABLE II

Magnitudes of non-stellar planetary nebulae

		K	
278 − 4°1	He2–32	> 10·2	
289 + 7°1	He2–63	9·7	
289 − 1°1	He2–57	10·0	
290 + 7°1	Fg 1	10·0	
291 + 3°1	He2–64	10·0	
292 + 4°1	PB 8	= 9·9	(2·8 σ)
292 + 1°1	NGC 3699	> 9·9	
292 + 1°2	He2–67	9·6	
294 + 4°1	NGC 3918	= 8·6	(5·5 σ)*
298 − 0°1	He2–77	= 9·5	(3·6 σ)
298 − 1°2	He2–76	> 9·7	
299 − 1°1	He2–81	8·5	
300 − 0°1	He2–84	9·7	
307 − 4°1	MyCn 18	9·9	
310 − 2°1	He2–103	9·6	
311 + 2°1	He2–102	10·0	
312 + 10°1	NGC 5307	9·2	
316 + 8°1	He2–108	10·0	
317 − 5°1	He2–119	9·8	
319 + 15°1	IC 4406	10·1	
331 + 16°1	NGC 5873	10·1	
349 + 1°1	NGC 6302	= 8·14	H = 9·09†
21 − 0°1	M3–28	> 9·6	

* Persson & Frogel (1973) record a similar flux.

† Measured with a 25 arcsec beam centred on the bright knot. This source has also been measured by Danziger, Frogel & Persson (1973).

a not unreasonable amount of reddening. K–L indices greater than 1·3 cannot readily be explained in this way, since an A_V in excess of 15 mag would be required. Instead we regard the second group as having infrared excesses, probably caused by thermal radiation from circumstellar dust.

The K–L colour is not available for all the detected stars in Table I. In the cases where it is not, we resort to slightly less reliable separation by H–K, also shown in Fig. 1. Of the sources with no determination at L, none has H–K in the range 0·73–0·99; this is therefore adopted as the distinguishing criterion. J–H alone is not a reliable statistic for distinguishing the two types. We have labelled the two groups S (star) and D (dust) in Table I and in Fig. 1. It is unlikely that any of the sources labelled D are incorrectly classified. However, any or all of the S-class of planetary nebulae may have infrared excesses at wavelengths longer than our observing wavebands. Cn1-1 (= HD 330036) is classified D on the basis of its K–L index of 1·7 but would be classified S from its H–K index of 0·6. Its dustiness was established by Glass & Webster (1973) from the large excess found at longer wavelengths. He2–138 (= HD 141969) may well be another example.

We may construct several colour/colour diagrams for the compact planetary nebulae using the data of Table I. Fig. 2 comprises two such plots. The upper is an H–K/K–L diagram which has been described in detail elsewhere (Allen 1973).

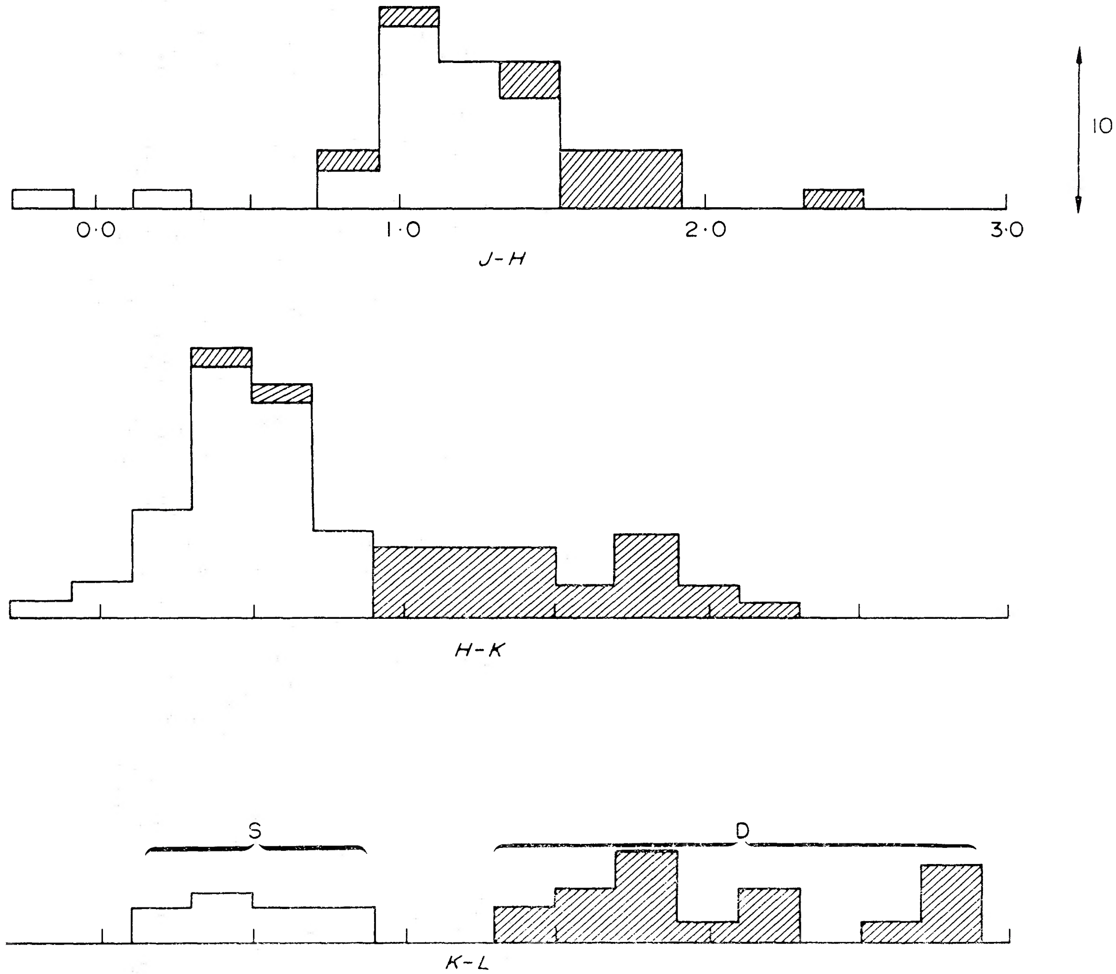

FIG. 1. *Histograms.*

We use it now to illustrate the division of the compact planetary nebulae into the two groups. Class S sources lie close to the blackbody and interstellar reddening lines in the lower left corner of the figure, thereby adding weight to our belief that they represent red or reddened stars. There is no indication of a contribution from free-free radiation. Class D sources, on the other hand, lie below the blackbody line in the region occupied by stars with circumstellar dust clouds. From the diagram we may deduce an appropriate colour temperature for the infra-red component of each: the range of values is from 700 to 1300 K; the average is 1000 K.

The lower part of Fig. 2 is a plot of J–H against H–K. The two groups are here not so clearly distinguished, and in particular HD 330036 lies among the class S objects. The J–H/H–K diagram allows us to shed some light on the nature of the S-class sources, for the reddening vector diverges at a significant angle from the vector joining normal stars of different spectral types (as determined from unpublished data by Glass using the same photometer). It is therefore possible to 'de-redden' each star and deduce an approximate spectral type for it. We find that, unless particularly abnormal reddening laws apply, the majority of these sources probably have continua resembling late-type stars. There is no evidence for the presence of either a hot star or free-free radiation such as is found in conventional planetary nebulae. Remembering that these stars are selected on the

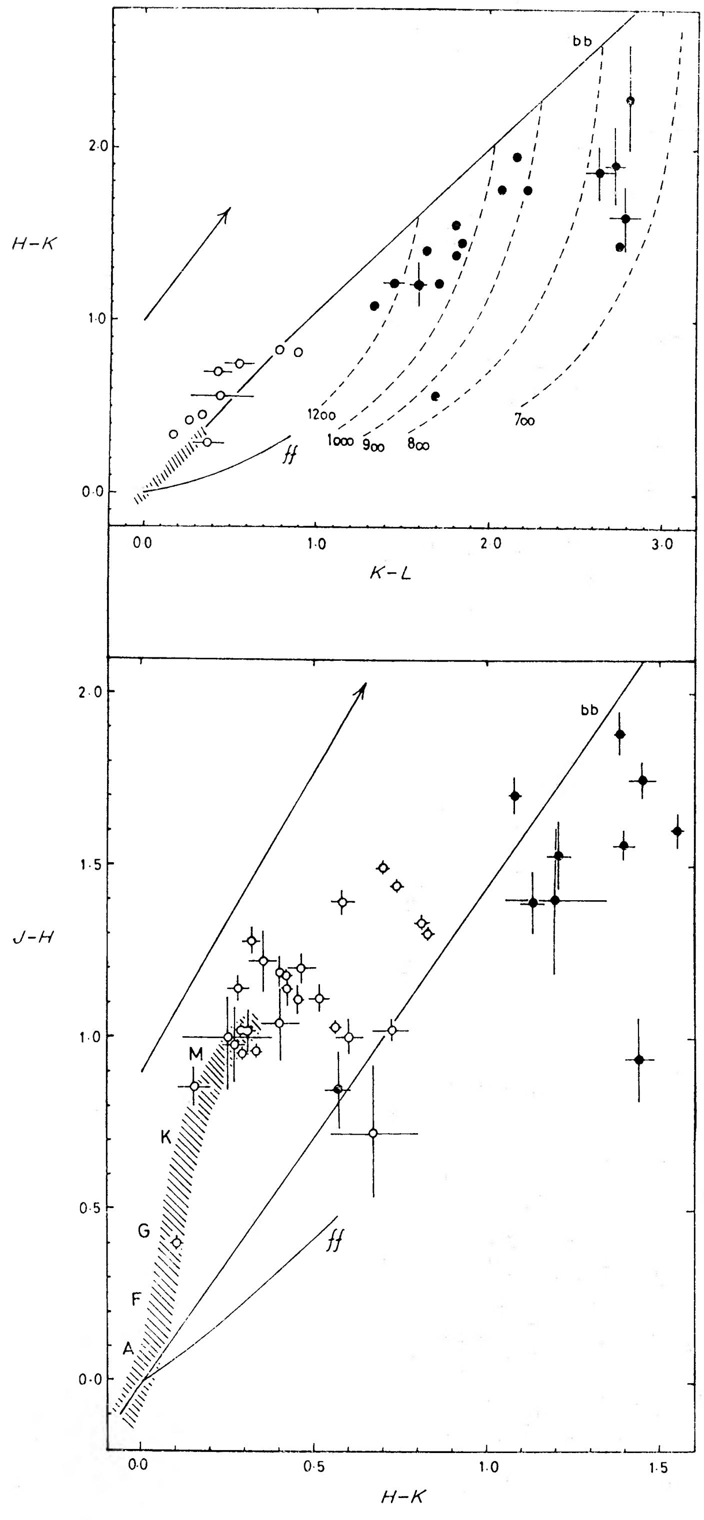

FIG. 2. *Colour–colour plots for the compact planetary nebulae. Open circles, class S; filled circles, class D. Blackbodies lie on the line bb and hot stars with free–free emission cluster around the line ff. The arrow represents the mean interstellar reddening vector for $A_V = 10$. The hatched area is the domain of normal stars, and is marked with spectral types on the lower diagram. The dashed lines on the upper diagram indicate the positions of hot stars with blackbody dust shells at the Kelvin temperature indicated.*

basis that they have very strong Hα emission relative to their red continua, we expect the majority of them to be symbiotic.

4. CONTAMINATION FROM OTHER STARS

The beam size we employed for most of these observations was 25 arcsec. We might expect occasional instances of contamination of the signal by the presence of other stars in the beam. In only a few cases was a prospective contaminating star visible, and for most of these no signal was detected from either the star or the planetary nebula. We may estimate the number of spurious signals due to contamination in the following way: we adopted the usual beam-switching mode of measurement in which there are two reference beams each of the same area but only half the effective sensitivity of the main beam. On seven occasions we recorded negative signals produced by visible stars in one or other reference beam.* We suspect, therefore, that two or three of our detected signals may have arisen from other sources contaminating the beam. Such contamination would almost certainly be by a late-type star and would give rise to a spurious S classification for the neighbouring planetary nebula.

5. THE UNDETECTED PLANETARY NEBULAE

It has already been noted that about a dozen compact planetary nebulae may have just escaped detection. Most of these would have $K \sim 10$ to 11. Approximately 90, or just half of our sample, gave no hint of a signal. For these the average $V-K$ index is not more than about 4, and in some cases we can tighten this limit to $V-K \lesssim 2$. Thus we can eliminate the possibility that the majority of the undetected objects are late-type stars or have sizeable infrared excesses, and we are left with two likely choices: that they are Be stars or normal planetary nebulae for which the reddest component at 2·2 μm is free-free radiation. Since the Be stars without infrared excesses seem rarely to have very strong emission lines, we believe the majority of the compact objects not detected in our survey to be more-or-less conventional but unresolved planetary nebulae.

6. DISTRIBUTION OF THE SOURCES

In Fig. 3 we have plotted the distribution of the planetary nebulae of our sample in galactic coordinates. The familiar concentration of objects towards the galactic centre is clearly apparent despite the incompleteness of our sampling in that region. Equally apparent is the reduction in the proportion of detected sources towards the galactic centre; this is not a surprising result since many of the planetary nebulae in that direction are very distant. Thus a large number of extended planetary nebulae with very weak infrared continua will be included in the sample, whilst others which do have significant infrared fluxes will fall below our detection threshold. It will also be seen from Fig. 3 that the numbers of D-class objects do not increase so rapidly towards the galactic centre as those of class S. We might therefore argue that the D-class objects are predominantly of Population I whereas the S-class and undetected planetary nebulae belong to Population II. In order to

* As a result we cannot classify the planetary nebulae Vd1–4, H1–32, H1–34, Ap1–12 and K3–7. It is unlikely, however, that any of these emits strongly at K.

investigate this hypothesis we divided our sample into various equal bands of galactic longitude and performed χ^2 tests on the number of class S and class D in each band. The two classes exhibit different galactic distributions with about a 98 per cent probability. However, a significant contribution to χ^2 arises from the region $10° < l^{II} < 45°$ in which no class D sources were found. The absence of them here may be attributed in part to the limited sampling we performed and in part to the number of such stars in this region already sifted from the planetary nebula lists by the Mount Wilson researchers and others. We note, however, that the concentration of Be stars has a pronounced minimum in the region $20° < l^{II} < 60°$ (Wackerling 1970). Indeed the distribution of class D objects is not significantly different from that of Be stars over the sampled range of galactic longitude.

7. SPECTRA OF THE SOURCES

We anticipate that the classification we have made according to the infrared colours will be borne out by subsequent spectroscopic measurements. We suggest that most of the undetected objects are more-or-less conventional planetary nebulae and that the S-class objects are mostly symbiotic stars. By analogy with the work of Swings & Allen in the Northern Hemisphere, those of class D may be Be stars with weak forbidden lines (principally [O I], [S II] or [Fe II]), have low-excitation (η Car-type) spectra or be pre-main-sequence Ae or Be stars. One or two may be high-excitation symbiotic stars like RX Pup (Swings 1970) and V1016 Cyg (FitzGerald, Houk & McCuskey 1966) or be late WC stars. We may, in fact, almost certainly rule out the pre-main-sequence stars because (i) these usually have fairly weak Hα emission, and (ii) the finding charts of Perek & Kohoutek (1967) afford no evidence of the associated nebulosity typical of such stars (Herbig 1960). A possible exception to the latter is He2–91 which lies in an obscured area and appears to have a faint associated nebula on the Perek & Kohoutek finding chart.

Descriptions of the spectra of about one-fifth of the sources we examined have already been published; brief summaries of these are given in Table III. Broadly they confirm our expectations.

TABLE III

Known spectral characteristics of compact planetary nebulae

	(i) Class D objects	
He2–17	Not a planetary nebula	Henize (1967)
	Emission-line star with [O I], [S II]	Swings (1973)
He2–38	High density, symbiotic star?	Sanduleak & Stephenson (1972)
IC 2501	Planetary nebula	Campbell & Moore (1918)
He2–79	Emission-line star with [O I], [S II], [Fe II]	Webster (unpublished)
He2–80	Emission-line star with [O I]	Swings (1973)
He2–90	Low-excitation object	Swings (1973)
He2–106	Similar to NGC 7027	Swings (1973)
He2–104	High density, high excitation object	Swings (1973)
He2–113	Not a planetary nebula	Henize (1967)
	WC9+ star	Carlson (1968)
	WC10 star	Webster & Glass (1974)
Cn1–1	Peculiar G-type symbiotic star	Webster (1966); Glass & Webster (1973)
He2–174	Emission-line star with [O I]	Swings (1973)

TABLE III—*continued*

M1–26	Emission-line star with [O I]	Henize (1967)
SwSt 1	WC9 + planetary nebula	Swings & Struve (1940); Carlson (1968)
IC 4997	High density, high excitation planetary nebula	Numerous authors—see Perek & Kohoutek (1967)
	(ii) Class S objects	
He2–131	Low excitation planetary nebula with carbon lines	Thackeray (1956); Koelbloed (1962); Henize (1967)
He2–134	Symbiotic star	Glass & Webster (1973)
Cn1–2	High excitation symbiotic star	Webster (1966, 1973)
PC 11	High density, high excitation object	Webster (1966)
H2–2	Symbiotic star?	Merrill & Burwell (1950)
CnMy 17	Emission-line star	Herbig (1969)
He2–370	Symbiotic star?	Herbig (1969)
Ap1–10	Symbiotic star?	Herbig (1969)
Ap1–9	Be star with [O III], [Ne III]	Herbig (1969)
	(iii) Unclassified objects	
He2–25	High density, symbiotic star?	Sanduleak & Stephenson (1972)
IC 2621	Planetary nebula	Campbell & Moore (1918)
He2–138	Low-excitation planetary nebula	Thackeray (1953)
H1–62	Emission-line star with [O II]	Herbig (1969)
H1–54	Planetary nebula	Herbig (1969)
H2–28	Emission-line star with [Fe VII]	Merrill & Burwell (1950)
H1–65	Emission-line star	Herbig (1969)
NGC 6644	Planetary nebula	Campbell & Moore (1918)
IC 4732	Planetary nebula	Aller (1951)
M1–55	Emission-line star with [O II]	Herbig (1969)
H2–48	Be star	Vyssotsky *et al.* (1945)
	Planetary nebula?	Herbig (1969)
	Low-excitation object with [O II]	Sanduleak & Stephenson (1973)
M1–59	Planetary nebula	Herbig (1969)
IC 4846	Planetary nebula	Aller (1951)

8. BE STARS

We may adopt exactly the same procedure for analysing the Hα objects classed as Be stars as we have done for the stellar planetary nebulae. We examined a small number of the fainter Be stars of Henize's list (unpublished, but reproduced in Wackerling 1970), and detected six (Table IV). Three are of class S and are probably reddened Be stars. The other three have larger infrared colours and probably possess circumstellar dust clouds. These may be pre-main-sequence objects or Be stars with forbidden emission lines. We also identified MWC 922 and found a strong infrared signal from it. This star was misidentified in previous papers (Swings & Allen 1972; Allen 1973) because of confusing positional information given by Merrill & Burwell (1949). The star is much fainter than Merrill & Burwell suggest, having a visual magnitude of about 14. Its 1950 position (measured from the Palomar Sky Survey prints) is:

$$\alpha = 18^{h}\,18^{m}\,26^{s}{\cdot}3 \qquad \delta = -13^{\circ}\,03'\,06''$$

and it lies nearly 1 arcsec south preceding and almost in line with a much brighter pair of stars. Its J, H, K and L magnitudes are given in Table IV; unreduced

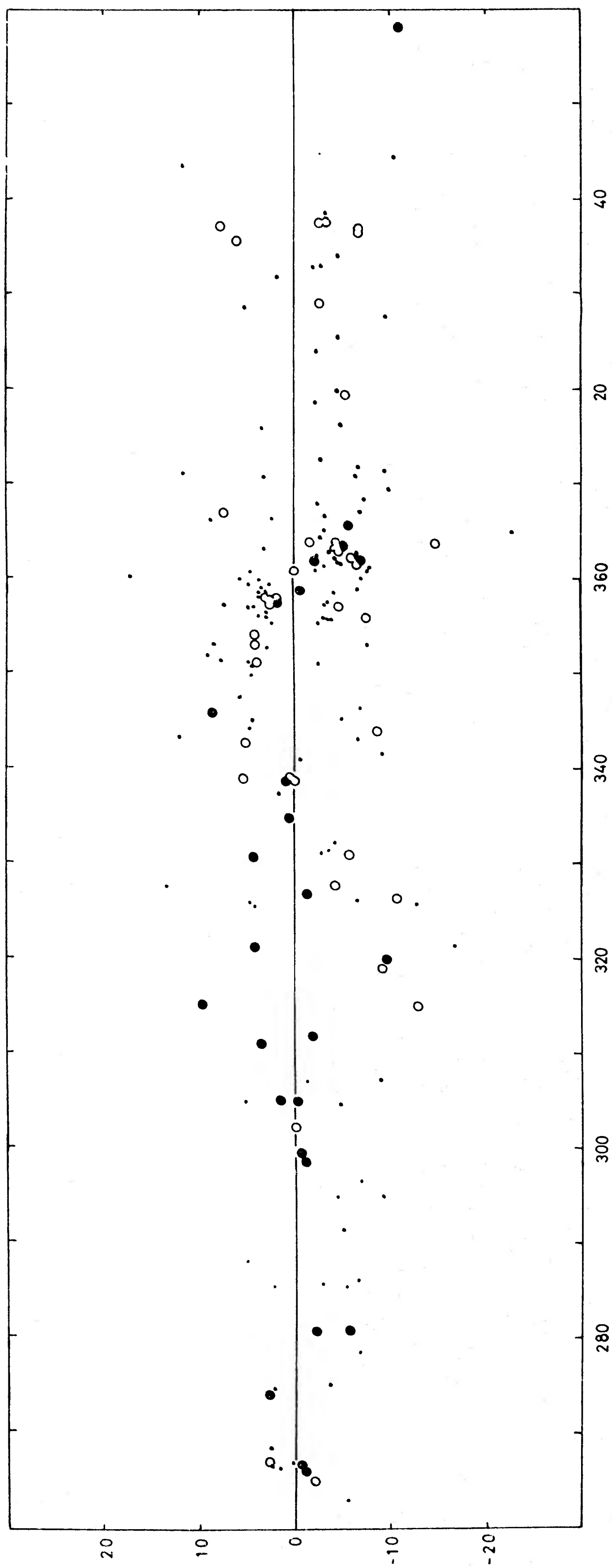

FIG. 3. *Distribution in galactic coordinates of the compact planetary nebulae. Filled circles, class D; open circles, class S; dots, undetected or unclassified.*

observations made with the Mt Lemmon infrared telescope suggest the magnitudes at 10 and 20 μm to be -2 and -4, respectively. This will be reported more fully in a later paper. The spectrum according to Merrill & Burwell and to Webster (unpublished) has Fe II and [Fe II] lines. Thus it is probably an η Car-type object like MWC 645 and MWC 819 (Swings & Allen 1973).

TABLE IV

Magnitudes of emission-line stars

Star	*V*	*J*	*H*	*K*	*L*
Hen 519	10·0	8·07	7·63	7·42	
Hen 591	10·7	7·61	6·82	6·37	>5·8
Hen 664	13		8·78	7·61	6·5
Hen 794	11		8·69	8·7	
Hen 938	13	9·5	7·64	6·10	4·34
Hen 1191	12		8·27	6·32	4·10
MWC 922	14	8·88	7·35	5·56	2·91

9. CONCLUSIONS

Approximately half of the compact planetary nebulae of the southern galactic plane have measurable continua in the 2-μm region. These fall into two groups distinguished by their infrared colours and to a lesser degree by their galactic distribution; we tentatively identify the two groups as (i) faint symbiotic stars, and (ii) emission-line stars probably of Population I. The remainder may be mostly conventional planetary nebulae. Infrared photometry is no substitute for spectroscopy, but can be of value in a first attempt at the classification of emission-line stars; by this means we have selected a number of objects with spectra probably resembling the peculiar objects in the Mount Wilson Catalogue of Be stars. If this can be regarded as a representative sample of the objects currently catalogued as planetary nebulae, it suggests that about 15 per cent of them should more properly be classified as emission-line stars.

Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, Sussex

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NOTE ADDED IN PROOF

Low-dispersion spectroscopic observations of several of the objects discussed here have been made by Sanduleak & Stephenson (*Astrophys. J.*, **185**, 899). Agreement is excellent between the classifications based on their spectra and on the infrared photometry.