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INFRA-RED PHOTOMETRY OF RR TELESCOPII AND OTHER EMISSION-LINE OBJECTS

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SUMMARY

Infra-red measurements at three or more wavelengths between 1·25 and 20 microns are presented for 16 emission-line objects in the later stages of their evolution. In the slow nova RR Tel, the infra-red energy distribution resembles that from free-free and free-bound processes, but is two orders of magnitude stronger than expected from the visible spectrum. A cool stellar component is detected for the first time in three objects and confirmed in eight known symbiotic stars. Radiation from dust is found to be characteristic of a small subclass of symbiotic stars and of two unusual planetary nebulae.

1. INTRODUCTION

It is believed that stars in the later stages of evolution may emit measurable infra-red radiation (a) if their photospheres are sufficiently cool and extensive, (b) if dust grains condense from their extended atmospheres as they expand, or (c) as the result of atomic processes in an associated hot plasma. In this paper we report infra-red measurements for 16 such stars at wavelengths between 1·2 and 20 μ. The infra-red energy distributions and, where available, the visible intensities and spectra are interpreted in terms of the above hypotheses. All the stars studied have emission-line spectra and most have at one time or another been classified as symbiotic stars or possible ones. Swings & Allen (1972) found that very few classical symbiotic stars contain detectable dust grains. We have, however, included several stars possessing symbiotic characteristics in order to detect any cool components which may be present and to try to determine which conditions cause the condensation of dust. Stars with similar visible properties are grouped together in the discussions.

2. OBSERVATIONS

The infra-red measurements were made using a photometer described by Glass (1973) attached to the 74-in. Radcliffe telescope and the 18-in. telescope of the South African Astronomical Observatory in Cape Town. The *J*, *H*, *K* and *L* bands (1·25, 1·65, 2·2 and 3·5 μ) were detected by means of a lead sulphide cell and the *N* and *Q* bands (10 and 20 μ) by a gallium-doped germanium bolometer cooled to the temperature of liquid helium. A sectored-mirror chopper was used at *JHKL* and replaced by an oscillating one for work at *NQ*.

Standard stars at *JHKL* were obtained from the lists of Johnson *et al.* (1966) with the addition of interpolated *H* magnitudes. At *NQ* extensive lists of standards are lacking in the Southern Hemisphere. Measurements from various different authors were employed in addition to the predicted long-wavelength fluxes from

TABLE I

Infra-red photometry

Object	Tel	JD 244000+	*J*	*H*	*K*	*L*	*N*	*Q*	Other photometry or comments
FR Sct	18	1440	3·92 ± 0·07 −24·32	2·66 ± 0·06 −24·05	2·16 ± 0·05 −24·05	1·69 ± 0·07 −24·21			SA
	74	1502	3·96 ± 0·07 −24·33	2·67 ± 0·06 −24·05	2·14 ± 0·05 −24·05	1·71 ± 0·05 −24·21			
	74	1499					1·54 ± 0·18 −24·98		
FN Sgr	74	1472	9·27 ± 0·10 −26·46	8·17 ± 0·08 −26·25	8·00 ± 0·09 −26·39				SA
	74	1498	9·01 ± 0·07 −26·36	8·17 ± 0·07 −26·25	7·85 ± 0·06 −26·33	8·02 ± 0·14 −26·74			
My 129	74	1471	6·75 ± 0·06 −25·45	5·72 ± 0·06 −25·27	5·55 ± 0·09 −25·41	5·38 ± 0·07 −25·68			
RR Tel	18	1426	5·10 ± 0·15 −24·79	4·04 ± 0·18 −24·60	3·73 ± 0·06 −24·68	2·69 ± 0·12 −24·61			GNBN
	74	1496	5·06 ± 0·07 −24·77	4·15 ± 0·06 −24·64	3·60 ± 0·05 −24·63	2·87 ± 0·05 −24·68			
	74	1497					0·41 ± 0·13 −24·53	−0·75 ± 0·54 −24·66	
AG Peg	74	1498	5·01 ± 0·07 −24·75	4·13 ± 0·06 −24·63	3·89 ± 0·05 −24·75	3·74 ± 0·06 −25·03			SA, M
	74	1499					>2·80 <−25·49		
VV80	74	1571	9·17 ± 0·12 −26·42	7·24 ± 0·07 −25·88	5·36 ± 0·06 −25·33	3·13 ± 0·05 −24·78			
H 172	74	1569	10·67 ± 0·27 −27·02	10·59 ± 0·37 −27·22	10·20 ± 0·37 −27·27	8·40 ± 0·72 −26·89			
RX Pup	18	1432	5·89 ± 0·08 −25·11	4·70 ± 0·07 −24·86	3·49 ± 0·06 −24·59	1·80 ± 0·08 −24·25			SA
SY Mus	18	1432	6·00 ± 0·09 −25·15	5·03 ± 0·08 −24·99	4·68 ± 0·07 −25·06	4·67 ± 0·44 −25·40			
	18	1440	6·08 ± 0·14 −25·18	5·04 ± 0·07 −25·00	4·66 ± 0·07 −25·06	>3·54 <−24·94			

Object	Tel	JD 244000+	J	H	K	L	N	Q	Other photometry or comments
RW Hya	18	1446	5·67 ± 0·19	4·83 ± 0·09	4·75 ± 0·07	3·70 ± 0·68			Poor night
			−25·02	−24·91	−25·09	−25·01			SA
H 134	74	1472	8·98 ± 0·07	7·96 ± 0·08	7·67 ± 0·06	7·97 ± 0·31			SA
			−26·34	−26·16	−26·26	−26·72			
HD 330036	18	1426	> 7·62	> 7·06	7·69 ± 0·41	5·35 ± 0·52			Poor night
			< −25·80	< −25·80	−26·27	−25·67			SA
	74	1473	8·96 ± 0·09	8·02 ± 0·06	7·47 ± 0·06	5·89 ± 0·07			
			−26·34	−26·19	−26·18	−25·89			
	74	1497					0·7 ± 0·1	−0·7 ± 0·6	
							−24·66	−24·70	
H 177	18	1426			6·01 ± 0·10	4·78 ± 0·38			Poor night
					−25·59	−25·44			SA
	74	1472	7·21 ± 0·07	6·25 ± 0·06	5·92 ± 0·05	5·76 ± 0·06			
			−25·63	−25·48	−25·56	−25·83			
M2–9	74	1502	10·86 ± 0·19	9·26 ± 0·10	6·91 ± 0·06	4·11 ± 0·05			AS
			−27·09	−26·69	−25·95	−25·17			
	74	1499					−0·04 ± 0·12	−1·75 ± 0·24	
							−24·36	−24·26	
KW Sgr	74	1473	2·72 ± 0·07	1·81 ± 0·06	1·36 ± 0·05	0·70 ± 0·05			
			−23·84	−23·71	−23·74	−23·81			
AR Pav	74	1471	8·35 ± 0·06	7·40 ± 0·06	7·17 ± 0·05	7·35 ± 0·35			
			−26·09	−25·94	−26·06	−26·47			
	74	1496	8·31 ± 0·07	7·41 ± 0·07	7·17 ± 0·06	6·98 ± 0·08			
			−26·07	−25·94	−26·06	−26·32			
	74	1502	8·28 ± 0·08	7·44 ± 0·07	7·14 ± 0·06	7·20 ± 0·12			
			−26·06	−25·96	−26·05	−26·41			
	74	1587	8·01 ± 0·07	7·26 ± 0·08	6·91 ± 0·09	6·74 ± 0·16			
			−25·96	−25·88	−25·95	−26·23			

(The upper numbers are magnitudes and the lower are fluxes in W m^{-2} Hz^{-1})

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SA, Swings & Allen (1972); AS, Allen & Swings (1972b); GNBN, Gehrz *et al.* (1973); M, Mendoza (1972).

certain hot stars. The internal agreement of these measures was found to be quite poor with the result that systematic errors may be larger than statistical ones at N and Q. A working estimate of the systematic errors in these bands is $0^{m}\cdot15$. The relation between magnitude and flux that has been used is that of Becklin, quoted by Glass & Feast (1973). The infra-red observations are given in Table I, together with references to previous photometry where it exists. In most cases our observations cover a greater wavelength range with smaller statistical errors. The identification letter H refers to Henize (1967).

Spectroscopic observations of five objects were made with the Radcliffe 74-in. telescope in order to measure specific quantities and to investigate their variability. The detector was an electronographic image tube which gave a linear relation between intensity and density on the spectrogram. Line ratios could be obtained with an accuracy of better than 10 per cent from a single measurement. The results are given as required in the discussions which follow.

3. RR TEL AND THE SLOW NOVAE

The slow nova RR Tel has been monitored spectroscopically since its outburst in 1945 (Thackeray 1969). It developed a low excitation emission-line spectrum in

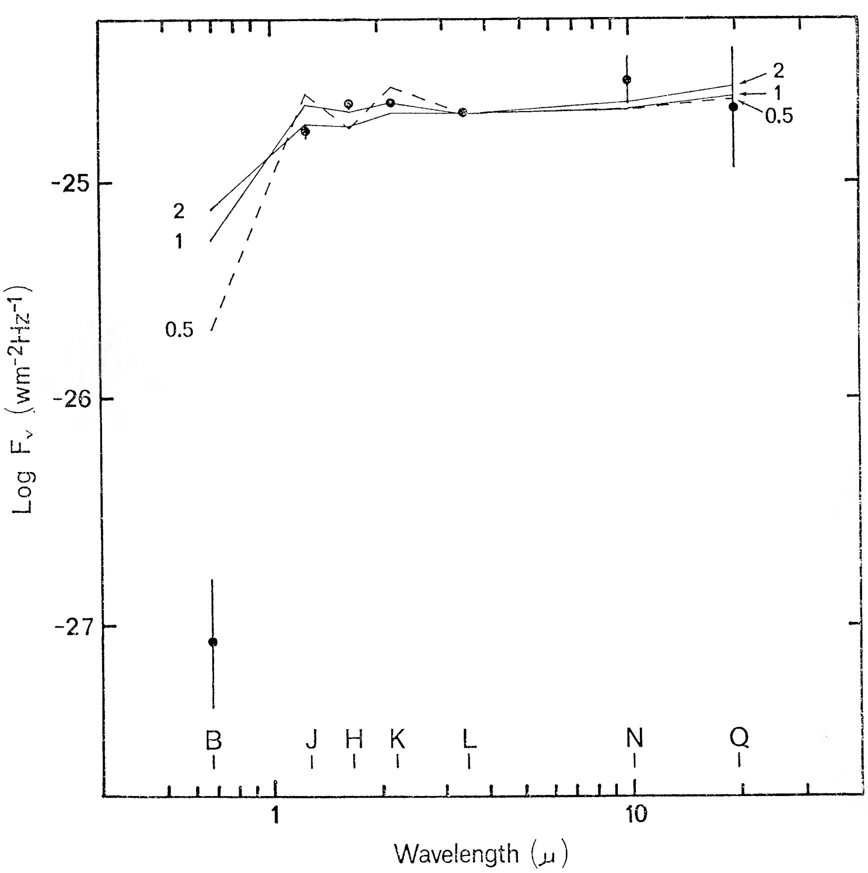

FIG. 1. *The energy distribution of RR Tel. The filled circles are the observed points with their errors marked by vertical lines when greater than the size of the circles. The B value is that of the true continuum. Theoretical free-free and free-bound points for each band are joined by lines numbered by* 10^{-4} T_e *and have been normalized to the L band.*

1949 and the ionization level subsequently increased slowly with time. In September 1972, our spectrograms showed a rich emission-line spectrum with both high and low ionization lines strong. There is considerable similarity between the spectroscopic behaviour of H 177 (Webster 1973, in preparation) and RR Tel and the massive star η Carinae. RR Tel is changing at a faster rate than the other two and η Car is at the earliest, lowest, ionization stage of the three (Thackeray 1955).

The infra-red energy distribution of RR Tel has been measured between 1·2 and 20 μ and is unlike that from the photosphere of any normal star or from thermal radiation from dust. Fig. 1 illustrates a comparison between the observed energy distribution and the theoretical radiation by free-free and free-bound processes in optically thin, ionized hydrogen ($Z = 1$) at temperatures between 5000 and 20 000 K. The calculations have been performed using nebular theory as given by Seaton (1960) and Karzas & Latter (1962) for the central wavelength of each band and have been normalized to fit the observed L. The observed distribution will have been somewhat smoothed in practice by the integration of the free-bound edges over the band (e.g. the K band is slightly overestimated). Reddening is assumed to be zero. The fit is within the errors between at least H and Q. With minor differences this spectral shape is characteristic of free-free and free-bound from electrons on any positive ions.

We can investigate whether the visible spectrum is consistent with the above interpretation with the following data. On JD 2441566·46, RR Tel had a photoelectric B magnitude of 10·6 (Hawarden, private communication). The rate of change of the star is such that the visible spectrum and brightness can be regarded as constant over the period in which all the 1972 observations were made (Thackeray 1969). Intensity tracings of our spectra, convolved with the B band response, show that the continuum contributes 30 per cent of the B intensity, the 12 strongest lines contribute 40 per cent and the remaining 30 per cent is from the numerous fainter lines. Thus the continuum is equivalent to $B = 11{\cdot}8$ mag or has a flux of $8{\cdot}3 \times 10^{-28}$ W m^{-2} Hz^{-1}. From the strength of the H lines relative to the continuum and each other we find:

$$\log F(\mathrm{H}_\gamma) = -10{\cdot}3, \quad \log F(\mathrm{H}_\beta) = -10{\cdot}0 \ \mathrm{erg\ cm^{-2}\ s^{-1}}.$$

We believe these to be correct to better than 0·3 in scale and 0·04 in relation to each other. The Balmer decrement is approximately equal to that of NGC 7009 (Aller & Kaler 1964), so is little reddened if Menzel's case B obtains. The helium lines lead to

$$N(\mathrm{He^+})/N(\mathrm{H^+}) = 0{\cdot}106, \ N(\mathrm{He^{++}})/N(\mathrm{H^+}) = 0{\cdot}086,$$
$$N(\mathrm{He^+ + He^{++}})/N(\mathrm{H^+}) = 0{\cdot}19.$$

Various inter-relations between the observed and theoretical H_β strength and optical and infra-red continua are presented in Table II, and the underlying B continuum has been added to Fig. 1. In addition, for reasonable values of the mass and electron density, the gas is calculated to be optically thin out to a wavelength greater than 20 μ. It is clear from the table that there is an extra component to the optical continuum, probably contributed mostly by two-photon emission from the hydrogen 2*s* level (e.g. Pagel 1969) and free-free and free-bound radiation from other ions. Alternatively, the electron temperature may be greater than 20 000 K.

TABLE II

Relations between H_β flux, B continuum and infra-red continuum in RR Tel

Input information	Electron temperature assumed	Theoretical prediction if continuum is f-f and f-b from He and He	Observed	Discrepancy: Observed/Calculated
1. $\log F(H_\beta) = -10\cdot0$ erg cm^{-2} s^{-1} $\frac{He^+}{H^+} = 0\cdot11$ $\frac{He^{++}}{H^+} = 0\cdot09$	10^4 K	$\log F(B$ continuum$) = -27\cdot7$ W m^{-2} Hz^{-1}	$-27\cdot1$ W m^{-2} Hz^{-1}	4
	2×10^4 K	$-27\cdot3$		$1\cdot6$
2. $\log F(H_\beta) = -10\cdot0$ erg cm^{-2} s^{-1} $\frac{He^+}{H^+} = 0\cdot11$ $\frac{He^{++}}{H^+} = 0\cdot09$	10^4 K	$\log F(L = 3\cdot5\ \mu) = -27\cdot0$ W m^{-2} Hz^{-1}	$-24\cdot7$ W m^{-2} Hz^{-1}	200
	2×10^4 K	$= -26\cdot8$		130
3. $\log F(B$ continuum$) = 27\cdot1$ W m^{-2} Hz^{-1} (f-f and f-b in $Z = 1$ ions)	10^4 K	$\log F(L = 3\cdot5\ \mu) = -26\cdot5$ W m^{-2} Hz^{-1}	$-24\cdot7$ W m^{-2} Hz^{-1}	60
	2×10^4 K	$= -26\cdot6$		80

A more striking feature of the calculations, which is also clear on the figure, is that the infra-red is two orders of magnitude brighter than expected. A rough infra-red maximum for free-free and bound-free radiation from all positive ions can be predicted from the observed B continuum, since all these ions have visible continua. The observations cannot all be fitted by any other choice of electron temperature. (At higher temperatures the B continuum would be expected to be even stronger; at lower temperatures the recombination line and continuum contributions are even more important and the free-free spectral distribution becomes redder.)

The most usual cause of dimming of visible radiation relative to infra-red emission from the same process is extinction by dust, but this can be eliminated in this case on the following grounds. RR Tel is at galactic latitude $b = -32°$, so the foreground absorption is expected to be small, and both the infra-red colours and the flat Balmer decrement support this. Although dust mixed with the gas could be responsible for extinction in the visible greater than predicted from the line ratios (Mathis 1970), a discontinuity between B and J would not be expected and, furthermore, the energy removed by absorption would be re-emitted in the infra-red as low temperature radiation stronger than observed.

No other well-known radiation mechanisms seem likely to be occurring in RR Tel, although artificial configurations could be set up to mimic its infra-red spectrum. Line radiation has been discussed in connection with other emission-line objects and seems inadequate (Holtz, Geballe & Rank 1971), as is synchrotron radiation.

The infra-red bears a resemblance to free-free radiation from an electron assembly which has a high energy cut-off in its velocity distribution. If the low J intensity is real then the cut-off is at about 600 km s^{-1}; otherwise it is slightly higher. Velocities of this order, presumed to be due to gas motions, have been detected in RR Tel at some epochs through emission wings in some lines (Thackeray 1955). An assembly such as is required has generally been assumed to be impossible because of the rapid thermalization of the electrons through electron–electron encounters. In view of the infra-red energy distribution of RR Tel this idea should perhaps be re-examined.

It is of interest to see whether other objects which are similar in the visible region to RR Tel show the same type of infra-red emission. η Car has been extensively observed in the infra-red and was found to have a behaviour characteristic of silicate dust, rising steeply towards longer wavelengths in its energy distribution and with peaks near 10 and 20 μ (Gehrz *et al.* 1973). However, H177, which we have observed, has an infra-red distribution which corresponds to a cool star or to a blackbody at 3000 K. While it is possible that RR Tel contained dust during its 'η Car' stage, the difference between it and H177 appears to be more fundamental.

4. YELLOW SYMBIOTIC STARS

There is a small subgroup (YSS) within the symbiotic stars in which the cool component is apparently a yellow supergiant rather than a red giant. The members are VV8 (O'Dell 1966), HD 330036 and Henize 172 (Webster 1966) and the recently discovered star AS 201 (Sanduleak & Stephenson 1972). The eclipsing symbiotic star, AR Pav, shows both a variable yellow supergiant shell and a red component (Thackeray 1959).

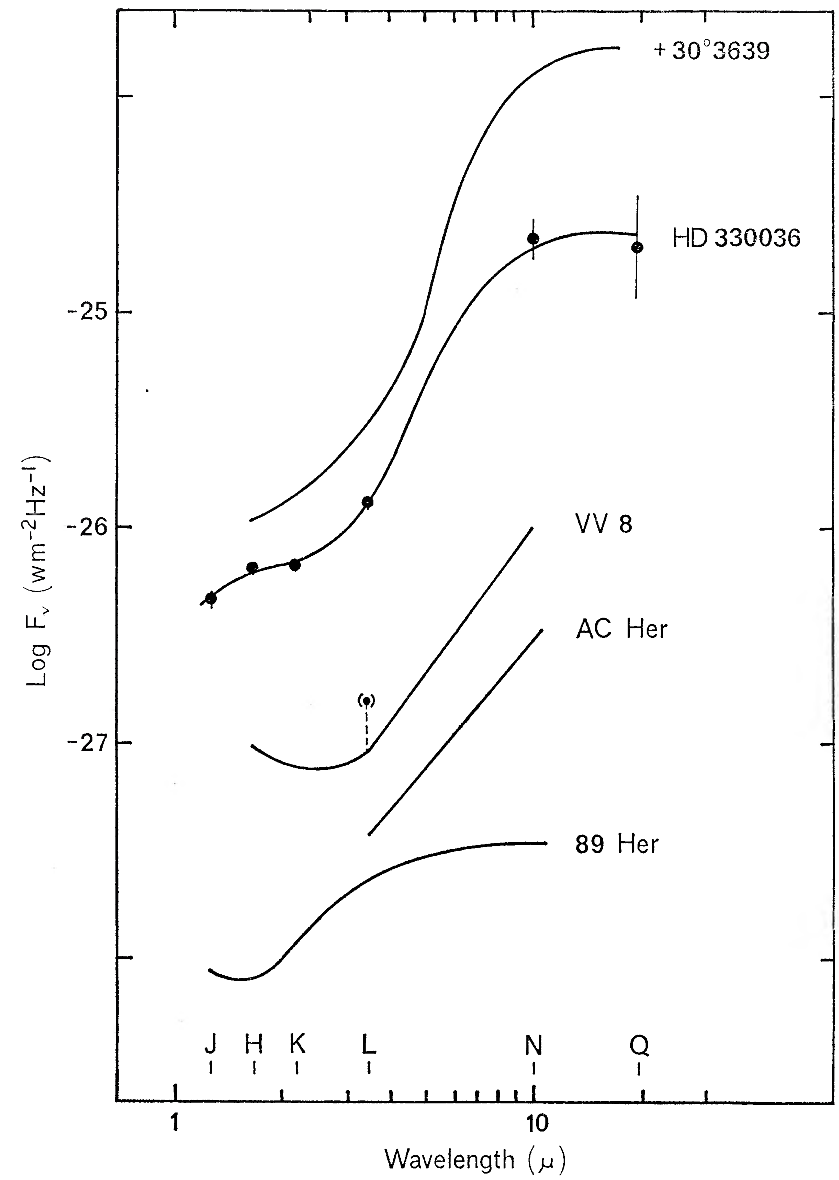

FIG. 2. *The energy distribution of the yellow symbiotic stars, HD* 330036 *and VV*8. *Curves for the comparison objects, BD*+30° 3639, *AC Her and* 89 *Her are on the same scale but with an arbitrary vertical displacement. Observational errors are marked by a vertical line when greater than the filled circles.*

Infra-red observations by us and others now exist for all of these except AS 201. AR Pav is dominated in this spectral region by radiation from a cool star (Fig. 3) with an intensity consistent with the red component seen in the optical region. From Mayall's (1937) ephemeris, the phases of our four sets of observations in *J*, *H*, *K* and *L* are, in order of JD, 0·94, 0·99, 0·00 and 0·14 ± 0·04 (where 0 is the phase of minimum). The B magnitude changes by 2 mag between phases about 0·93 and 0·07. We find the infra-red to change by no more than 0·2 mag through the minimum, as might be expected from the optical result that the M star is seen only during eclipse (Thackeray 1959).

In the other stars the yellow component is more prominent relative to the nebula than in AR Pav and, if normal, contributes some, but not all, of the *J* magnitude. The colours, not corrected for reddening and where *V* refers to the supergiant, are H 172 (sgA, $V\text{–}J = 1{\cdot}9$), HD 330036 (sgF, $V\text{–}J = 2{\cdot}2$), VV8 (sgG, $V\text{–}J = 3{\cdot}4$) compared with unreddened standard values A5I ($V\text{–}J = 0{\cdot}23$), F5I ($V\text{–}J = 0{\cdot}67$), G5I ($V\text{–}J = 1{\cdot}43$) (Johnson 1966). The measurements of H 172 have high errors and cannot be used reliably to identify the infra-red emission mechanism, although there is a suggestion of a brightening at L which would indicate a dust contribution. The longer wavelength infra-red of VV8 and HD 330036 corresponds to low temperature radiation from dust. The question arises whether all the YSS contain a red giant star, a yellow supergiant component and dust, as well as a nebula. This cannot be answered completely, since the relative brightnesses of the components could vary, but crudely speaking, if the brightness of the yellow supergiant is used as a standard, then the dust radiation would be weak in AR Pav and any red giant star would be relatively faint in the other objects.

In Fig. 2, the fluxes of VV8 (Swings & Allen 1972; Gillett, Knacke & Stein 1971) and HD 330036 are compared with the fluxes of the F2Ia supergiant 89 Her (Gillett, Hyland & Stein 1970) and the carbon-rich (F2Ib to K4e) RV Tauri star AC Her (Gehrz & Woolf 1970), each of which has the most extreme infra-red excess of its class. The infra-red of BD+30°3639, a high density, low excitation planetary nebula, is shown (Gillett & Stein 1970; Willner, Becklin & Visvanathan 1972). From the comparison with BD+30°3639 it is clear that the dust may be associated with the nebular component of the system. Not only is the temperature distribution of the dust similar, but the ratio of the total infra-red energy to the H_β flux is the same. However, neither VV8 nor HD 330036 shows the low excitation lines characteristic of dust in emission-line stars (Geisel 1960; Allen & Swings 1972a). Since dust emission is an apparent characteristic of the YSS subgroup, unlike most symbiotic stars, it alternatively seems possible that the dust is connected with the yellow component. If this component is a star, then conditions in its atmosphere are clearly unlike the Population I supergiants (represented by 89 Her) and the nearest relations seem to be among the RV Tauris, which is more understandable from an evolutionary standpoint. The only RV Tauris with comparably extreme excesses to those of the YSS are the carbon-rich AC Her and the probable carbon-rich RU Cen (Gehrz & Ney 1972), so there is a possibility (which could be checked through the more detailed shape of the infra-red spectrum) that carbon is enhanced in the yellow symbiotic stars.

5. THE SYMBIOTIC STARS

Seven of the stars (including AR Pav) are ‘ classical ’ symbiotic stars, exhibiting in the optical region both M giant and high excitation nebular components. In each case, the infra-red energy distribution corresponds to that of an M star (Fig. 3), as expected. Of the seven, RW Hya and FR Sct were measured in 1971 by Swings & Allen (1972) and AG Peg in 1971 by Swings & Allen (1972) and Mendoza (1972); their observations and ours all agree within 0·1 mag. There is therefore no evidence yet from this rather meagre data for variability in the M component. In SY Mus, KW Sgr, AR Pav and My 129, the existence of an M component was known from the optical spectrum and has been confirmed by the infra-red measurements.

Four other stars possess emission-line spectra resembling that of the hot component of a symbiotic star and it is of interest to look for a cool star in the infra-red (Fig. 3). Cool components have been found in H 134 (a star with strong

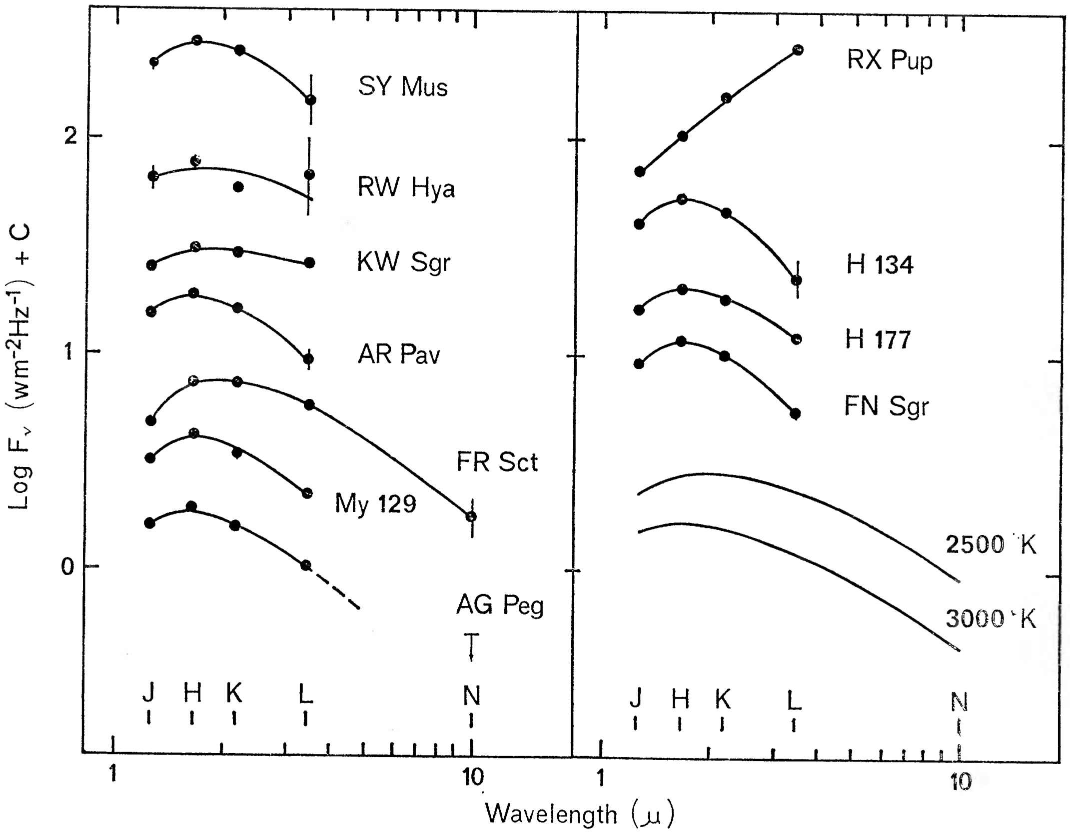

FIG. 3. *The energy distributions of some classical symbiotic stars (LHS) and some suspected symbiotic stars (RHS). The vertical zero points are arbitrary and observational errors are marked by a vertical line when greater than the filled circles. Two blackbody distributions are shown for comparison.*

H and He II emission), in H 177 (Section 3(a)) and FN Sgr (which resembles an old nova). All these can therefore be classed either with the symbiotic stars or with the nova-like binaries. The fourth star, RX Pup, radiates in the infra-red by dust emission and this has already been found and discussed by Swings & Allen (1972).

VV80 AND M2-9

VV80 (PK 331–1°1) and M2–9 (PK10+18°) are morphologically similar planetary nebulae, each with two concentrations of ionized gas situated on opposite sides of a central condensation. The spectra of VV80 (Evans 1959) and M2–9 (Allen & Swings 1972b (AS)) contain normal low excitation nebular lines and in addition numerous lines of [Fe II], [Fe III] and Fe II which are much stronger than is usual for planetary nebulae. Although the central core is the main contributor to the measured spectrum, spectrograms taken by us at Mount Stromlo Observatory and Kitt Peak National Observatory show that the outer concentrations also exhibit the same unusual set of lines, though with some differences from the core in relative intensity. The expelled gas therefore either has similar physical conditions to those in the core or else contains dust which reflects some of its light.

The infra-red fluxes from the central condensations of these two objects are illustrated in Fig. 4. M2–9 has been measured between 1·6 and 3·5 μ by AS with results consistent with ours. For VV80, previous photometry (Webster 1969) and 1972 spectra yield $\log F(H_\beta) = -11{\cdot}07$ and $\log F(H_\beta)/F(H_\gamma) = +0{\cdot}61$, so the

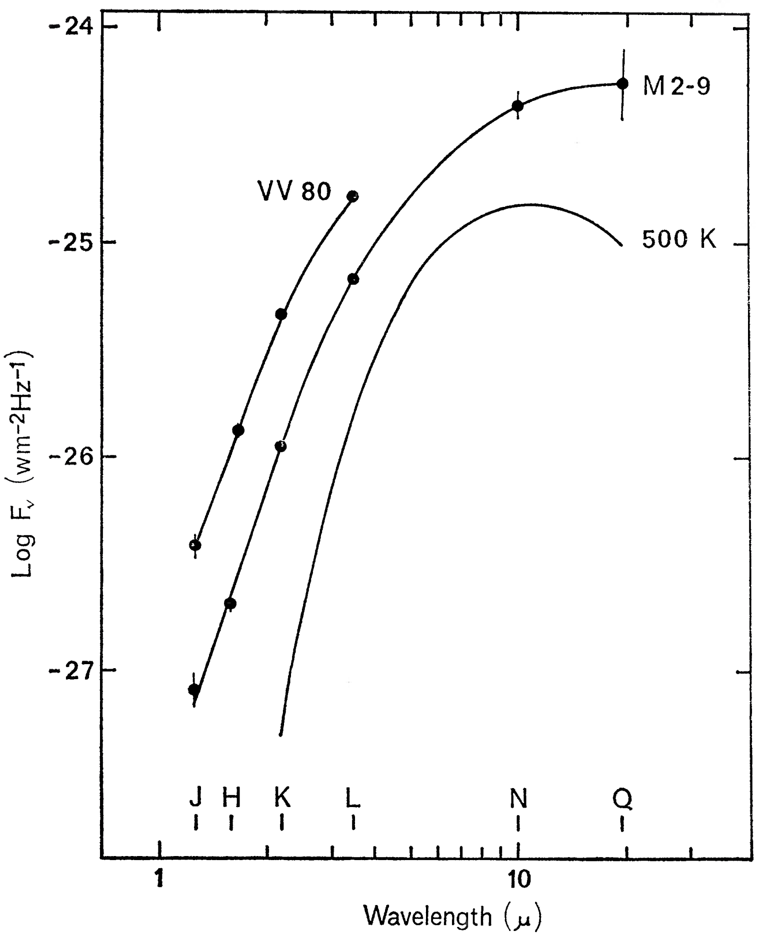

FIG. 4. *The energy distributions of VV80 and M2–9. A 500 K blackbody, with arbitrary vertical zero point, is shown for comparison. Observational errors are marked by a vertical line when greater than the filled circles.*

Balmer decrement is apparently reddened, presumably by the dust we are seeing in the infra-red. A rough calculation of the free-free and bound-free radiation expected from the H_β flux predicts $\mathcal{J}$(observed) $= -26.4\ \mathrm{W\,m^{-2}\,Hz^{-1}}$ for an electron temperature of 10^4 K, so atomic processes probably contribute at J, but not much further into the infra-red. The *HKL* radiation appears to come from dust at a temperature of 1000 K, though the general similarity to M2–9 suggests that longer wavelength measurements might reveal some lower temperature radiation.

In the case of M2–9, we do not have the optical data required for a similar discussion. The 3·5- to 10-μ flux can be fitted by dust emitting at a blackbody temperature of around 500 K. Additional dust at temperatures both higher and lower is clearly present.

These two objects are not the only planetary nebulae known to contain dust, but their infra-red radiation is stronger in relation to their H_β flux than in the others. Furthermore, their spectra are (so far) unique and contain just those lines known to be correlated with the presence of dust in emission-line stars (Geisel 1970). Their most intriguing parameter is their morphological type. In M2–9 the radial velocity data of AS is best fitted by mass flow outwards from the centre along an axis. The occurrence of bipolar symmetry in both nebulae, if significant, may suggest that the form of mass ejection bears an intimate relationship to the unusual physical conditions. Mass may be able to escape most easily through the poles of the parent star leaving behind an equatorial ring of dense material. Alternatively, there may be a uniform gas cloud around the system which is only ionized in certain directions because of the dust close to the central star. This latter suggestion receives some support from the changes in M2–9 discussed by AS.

CONCLUSION

The most significant result reported in this paper is that the slow nova, RR Tel, emits strong infra-red radiation which cannot be simply explained in terms of any of the well-known infra-red-producing mechanisms. Other objects with similar spectroscopic behaviour do not resemble it in this respect.

Infra-red emission from cool stellar-like components or from dust grains has been detected in all the other objects reported on here. The presence of low temperature dust has been found to be characteristic of the two symbiotic stars in which the cool star has an F or G supergiant spectrum and also of the two bipolar planetary nebulae with strong [Fe II] and [Fe III] lines in their visible spectra.

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