INFRARED STUDIES OF SYMBIOTIC STARS

David A. Allen
Anglo-Australian Observatory

(read by J. P. Swings)

ABSTRACT

Infrared photometry and spectroscopy of symbiotic stars is reviewed. It is shown that at wavelengths beyond 1μm these systems are generally dominated by the cool star's photosphere and, indeed, are indistinguishable from ordinary late-type giants. About 25% of symbiotic stars exhibit additional emission due to circumstellar dust. Most of the dusty systems probably involve Mira variables, the dust forming in the atmospheres of the Miras. In a few cases the dust is much cooler and the cool component hotter; the dust must then form in distant gas shielded from the hot component, perhaps by an acccretion disk.

Spectroscopy at 2μm can be used to spectral type the cool components, even in the presence of some dust emission. Distances may thereby be estimated, though with some uncertainty.

Spectroscopy at longer wavelengths reveals information about the dust itself. In most cases this dust appears to include silicate grains, which form in the oxygen-rich envelope of an M star. In the case of HD 330036, however, different emission features are found which suggest a carbon-rich environment.

EARLY DAYS

It was Jean Pierre Swings who first suggested to me that symbiotic stars would merit study at infrared wavelengths. Our paper (Swings and Allen 1972) demonstrated that these systems are dominated in the 1-4μm region by the cool giant star, in most cases known to be present from optical work. The subject did not seem to merit further attention at the time, our interests then lying with stars shrouded in circumstellar dust. The only such object amongst the symbiotic stars was RX Pup, and this was soon shown by Sanduleak and Stephenson (1973) to be

M. Friedjung and R. Viotti (eds.), The Nature of Symbiotic Stars, 27–42.

in a low-excitation state. It seemed reasonable to argue that the high excitation of the classical symbiotic stars prevented the formation of dust, and that RX Pup was proof that dust was ready to form within such systems whenever the destructive ultraviolet source was (by some means) extinguished.

Within the year Swings was following up my infrared photometry in the southern hemisphere by optical spectroscopy of objects exhibiting dust emission between 1 and 4μm. We had confidently expected to find more low-excitation Fe II and [Fe II] emission stars by this means. However, he wrote "I haven't found [Fe II] yet, but [Fe VI]". Swings' spectra did not at the time reveal the symbiotic nature of the [Fe VI-VII] stars, so the fallacy of my argument remained unproved.

In the mean time, Glass and Webster (1973) were applying infrared photometry to some southern symbiotic stars, with results that differed from our (mostly northern) survey. In particular, they found a sizeable infrared excess in RR Tel. It was not at first clear how to explain the infrared data on RR Tel; it must be remembered that at that time no optical evidence had accrued to suggest the presence of a cool star in the system. We now know that a combination of an M giant and dust emission produces the energy distribution found by Glass and Webster.

From these beginnings it was but a small step for Webster and Allen (1975) to show that indeed symbiotic stars divide into two groups - those in which the 1-4μm continuum shows only the presence of a cool star (type S), and those in which dust emission dominates (type D).

THE TWO TYPES

This outwardly esoteric classification appears to be of some significance: several correlations exist between it and the optical and radio properties. Specifically, D-type symbiotic stars generally show evidence for more extended, ionized gaseous envelopes which provide weak radio emission together with an environment of low-enough electron density to allow a rich spectrum of forbidden lines to form. Additionally, where forbidden-line spectra are seen in S-type symbiotic stars, the lines tend to be only of high excitation, suggesting that many S-type objects are density bounded, whilst D-type objects are radiation bounded, at least in some parts.

Additionally, there seems to be a significant reduction in the proportion of D-type symbiotic stars near the galactic centre. This may, however, reflect observational selection. Most symbiotic stars in that part of the sky are near the limit of the objective-prism surveys by which they have been discovered. The additional effect of circumstellar absorption expected in the D-types may render such stars undetectable.

Finally, correlations with spectral type and variability will be discussed below.

https://doi.org/10.1017/S0252921100097396 Published online by Cambridge University Press

TWO-MICRON SPECTRA

In most of the D-type symbiotic stars the presence of an M star is not easily inferred from the optical data. Skeptics thus argued (and sometimes still do) that these systems might not after all be symbiotic. To overcome these arguments, two-micron spectroscopy has proved powerful. Within the 2.0-2.5μm atmospheric window lie not only the steam bands, which depress the continua of M giants towards both ends of the window, but also the CO band heads. The CO spectral break at 2.3μm is a certain indicator of the presence of a cool star. By spectroscopy at these wavelengths, cool giants were shown to be present in the D-type objects He 2-38 and RR Tel (Allen *et al* 1978), and RX Pup (Barton, Phillips and Allen 1979).

Two-micron spectroscopy has since been used (Allen 1980a) to spectral type the cool components of symbiotic systems. In only the stars He 2-104, H1-36 and W16-312 is there doubt about the existence of a cool giant. The distribution of spectral types differs markedly from that in the field (Allen 1980a), in the sense that the symbiotic stars are biassed heavily towards the coolest M stars. If the symbiotic stars are interacting binaries, this observation is naturally accounted for by the greater propensity for mass loss (and hence mass transfer) amongst such late giants. Unfortunately, a precise luminosity classification cannot be established from the present data, so attempts to derive distances are somewhat at risk. Better results would probably be obtained by spectroscopy in the 0.7-1.0μm region. From the presently determined distances it would seem that we are sampling as far afield as the galactic centre in many cases. This allows a preliminary estimate that there are 10^3 symbiotic stars in the Galaxy.

Amongst stars of known spectral type, circumstellar dust is found primarily in those of type G or later than M6. There is no instance of a D-type system of spectral type from KO to M2.

VARIABILITY

Hyland has extensive but unpublished data on RX Pup which show the star to vary like a Mira. However, it was Feast, Robertson and Catchpole (1977) who first pointed out the variability by up to 2 magnitudes of the D-type symbiotics (including RX Pup) at infrared wavelengths. Before them, Harvey (1975) had suggested a periodicity of about 450 days in the D-type object V1016 Cygni, and subsequently variations in either the infrared or the optical red continuum have been seen in several other D-types. To date no corresponding change has been recorded in any S-type system, though intercomparison of various observers' data suggests changes of order 0.3 mag in some instances, and possibly more in AX Per.

It would be reasonable to infer that most D-type symbiotic stars involve Mira variables. Indeed, such stars possess a penchant for shrouding themselves in dust. However, it must be cautioned that the infrared observations are not yet so extensive as to allow an unequivocal classification of the type of variability. Perhaps the only convincing example is RR Tel, for which a pre-outburst period is known. A series of observations being accrued at the South African Astronomical Observatory (Feast, private communication) appears entirely consistent with the same period persisting, now almost 40 years after the outburst.

For the present it is sufficient to note that the D-type symbiotic stars appear (from the correlations already noted) to have shed more extensive circumstellar shells than the S types, and that the expulsion of material is more likely from variable (expecially Mira) stars.

DUST TEMPERATURES

There has been extraordinarily little work at longer infrared wavelengths. It must be admitted that the majority of symbiotic systems will be faint at, say, 10μm unless they possess thermal emission from dust. Nonetheless, there would be some interest in determining whether the simple classification scheme based on photometry at short wavelengths persists to 10μm. This is especially the case in view of the correlations between the infrared classification and other properties. At the time of my compilation of a catalogue of symbiotic stars (Allen 1979), about half had been classified only on the basis of their H-K (1.65-2.2μm) colours. The gradual accumulation of data at longer wavelengths has improved the situation, and in some cases the classification has been revised. I have secured deep 3.8μm photometry in a number of symbiotic stars, and longer-wavelength data on a few S-type systems have been presented by Bopp (1981) and, long ago, by Woolf (1973). For the present I discount Woolf's unconfirmed observation of a 20μm rise in Z And. Observations out to 10 or 20μm have been made by a number of authors of the more easily studied D-types.

The available photometry suggests the following range of dust temperatures:

(i) The classic D-type systems such as RR Tel, He 2-38 radiate a significant amount of energy (possibly over 50%) as thermal dust emission. The hottest dust is at about 800-1000K, but in most cases there appears to be some additional contribution from cooler material.

(ii) A small number of D-type systems is known in which the dust temperature is perhaps half as great. In these there is little or no indication of dust emission at 2.2μm, but a large colour index is seen from 2.2 to 3.8μm. Without exception these are the 'yellow symbiotic stars' defined by Glass and Webster (1973) - i.e. those which have cool components of type F-G. I propose that these be distinguished as type D'.

(iii) A very small amount of silicate-like dust may be present around some S-type objects. The only examples of this are R Aqr (Stein *et al* 1969), and CH Cygni in which Bopp (1981) found a weak silicate feature at 10 and 20μm. Both are very late-type stars with relatively low-excitation emission spectra. The temperature of the silicate dust in these stars is unknown. In CH Cyg it is superimposed on a continuum which is slightly too red for the 2800K star in the system, and which may represent a very weak black-body dust component.

We now see that not only is there a bimodal distribution of spectral types for which dust emission occurs, but that the dust emission is itself distinguished between the two ranges of spectral type. Apparently dust in the G-type stars is of a different nature, or lies in a different location relative to the system.

A COMPENDIUM OF OBSERVATIONS

Table 1 lists the available photometry of symbiotic stars at J, H, K, L, L' and N. The effective wavelengths of the first five filters are 1.20, 1.65, 2.20, 3.5 and 3.8μm. The data at N represent a broad 10μm filter, though in many cases the quoted value is derived somewhat loosely from narrow-band data. It should be noted that the present definition of the J filter is that used at the Anglo-Australian Observatory and the observatories in Hawaii: it appears to be indistinguishable from Johnson's originally defined J filter (Johnson 1965), despite the different quoted effective wavelengths. The following transformations have been applied to other J data:

$(J-H)_{AAO} = 1.09\ (J-H)$ for Cal Tech, Kitt Peak photometry
$(J-H)_{AAO} = 1.07\ (J-H)$ for South African photometry

The objects included in Table 1 are, in the main, listed in Allen (1979). A few have been added:

AS 289 and AS 316, inadvertently omitted from the original. The 1950 coordinates of these stars are, respectively, 18 09 34.7 -11 40 55, 18 39 33.4 -21 20 46;

BI Crucis (Henize and Carlson 1980);

An innominate object discussed by Carter and Feast (1979);

EG Andromedae, shown to be of high excitation by IUE spectroscopy (Stencel and Sahade 1980);

UV Aurigae, HD 149427, CH Cygni and R Aquarii, which are of lower excitation but are probably closely related objects.

In addition to the photometry, spectral types of the cool components have been listed. Those derived at 2μm are used only where no adequate optical determination exists.

https://doi.org/10.1017/S0252921100097396 Published online by Cambridge University Press

TABLE 1 INFRARED DATA ON SYMBIOTIC STARS

Object	IR Type	K	J–H	H–K	K–L	K–L'	N	Refs	Spectral Type	Refs
EG And	S	2.4 to 2.7		0.10	0.1		2.2	B, IRC, SA	M2	W2
SMC S18	D	11.09	0.36	1.00				U	G?	Fig.1
AX Per	S	5.6 to 6.5	0.87	0.25	0.42			Sz	M5	Bk
M1-2	D'	9.81		0.28	1.6		4.0	A1,CB,SA,GKS	G2	O
UV Aur	S	2.13			0.3		0	IRC,W	N	NB
LMC –	D	12.8	0.6	1.8				A6		
LMC S63	S	11.4		0.3				A6	R	A4
Wray 157	D'	9.40	0.73	0.35		1.19		U	G	A5
RX Pup	D	2.1 to 3.1	1.2	1.1	1.4	1.8		FRC,GW,SA,U	M5	A5
Hen 160	S	7.48	1.02	0.41		0.39		U	M7	A5
AS 201	D'	9.93	0.29	0.33		0.98	4.9	CB,U	G	A5
He 2-38	D	4.0 to 5.6	1.4	0.9	1.2	1.5		AG1,FRC,U	M	A4
SS 29	S	10.6 var	0.91	0.28		0.1		U	G	U
SY Mus	S	4.68	1.07	0.32	0.18			FRC,GW,U	M2	SS
BI Cru	D	4.7 to 5.2	1.6	1.4	1.4			A2,U	M	A2
He 2-87	S	5.98	1.60	0.70	0.32			A1,AG1	M7	A5
Hen 828	S	7.12	1.06	0.35		0.2		U	M6	A5
SS 38	D	5.7 to 6.5	2.0	1.6		2.3		U	M	A5
Hen 863	S	8.51	0.91	0.19				U	K4	A5
Hen 905	S	8.47	1.06	0.34				U	K4	A5
RW Hya	S	4.70	0.99	0.17	0.16			FRC,GW,SA	M2	M
Hen 916	S	7.86	1.17	0.32				U	M6	A5
He 2-104	D	6.80	2.04	1.76	2.06			A1,AG1,U		
He 2-106	D	5.5 var	3.6	1.9	2.1			A1,AG1	M	A4
BD-21°3873	S	7.20	0.83	0.19		0.18		U	G	A5

Object	IR Type	K	J–H	H–K	K–L	K–L'	N	Refs	Spectral Type	Refs
He 2–127	D	7.9 to 8.3	1.2	0.8		1.1		U	M7	A5
Hen 1092	S	7.67	1.09	0.29				AG1,GW	K5	A5
Hen 1103	S	8.36	0.97	0.31				U	MO	A5
HD 330036	D'	7.57	1.00	0.54	1.7		0.7	AG1,GW,U	F–G	U,We
T CrB	S	4.82	0.99	0.23	0.14		4.2	FG1,GKL	M3	K
AG Dra	S	6.4		0.08	0.2		6	B,SA	K1	Bk,R
He 2–147	D	4.3	1.32	0.72	0.9			A1,AG1,U	M8	A5
UKS-Ce 1	S	12.6		0.1:				U	R	LA
Wray 1470	S	7.81	0.98	0.34				U	M4	SS
He 2–171	D	6.3 to 7.2	1.8	1.5	1.8		2.2	AG1,U	M	A4
Hen 1213	S	6.72	1.08	0.29		·0.19		U	K4	A5
He 2–173	S	6.78	1.48	0.32				A1,AG1	M	A4
HD 149427	D'	10.33	0.10	0.40		1.23		AG1,GW,U	A–F	We
He 2–176	D	5.6 var	1.5	0.70	0.6			A1,AG1	M7	A5
Hen 1242	S	6.06	0.90	0.33	0.16			A1,AG1,AS,GW	M6	A5
AS 210	D	6.7	1.8	1.4				U	G?	A4
HK Sco	S	7.96	1.13	0.29				U	M1	A5
CL Sco	S	7.85	0.93	0.22				U	K5	A5
V455 Sco	S	5.92	1.19	0.45	0.33			AG1	M6	A5
Hen 1341	S	7.58	0.98	0.34				U	MO	A5
Hen 1342	S	8.43	1.01	0.31				U	M2	A5
AS 221	S	7.60	1.27	0.57				AG1,U	M4	A5
H2–5	confused								M	A4
Th 3–7	S	8.05		0.50				AG2	M	A5
Th 3–17	S	8.18		0.20				AG2	M3	A5
Th 3–18	S	8.03	1.3	0.35				AG1	M2	A5
Hen 1410	D?	8.41	0.8	0.67				AG1	M3	A5
V2116 Oph	S	8.10	1.66	0.75				GF	M6	A5,DMB
Th 3–30	S	8.30	1.34	0.51				U	K5	A5
Th 3–31	S	7.57	1.28	0.46				AG1	M5	A5

Object	IR Type	K	J-H	H-K	K-L	K-L'	N	Refs	Spectral Type	Refs
M1-21	S	7.21	1.22	0.42				AG1	M2	A5
Pt-1	S	8.58	1.26	0.42				U	M1	TP
RT Ser	S	7.00	1.11	0.42	0.23			FG1,U	M6	A5
AE Ara	S	6.26	1.02	0.29	0.4			AG1	M2	A5
SS 96	S	6.39	1.35	0.46	0.55			AG2	M2	A5
UU Ser	S	9.12	1.04	0.39				U	M	A4
AS 239	D	7.5 to 8.2	1.6	0.9	1.0			FG2	M8	A5
(SSM)	S	8.28	1.34	0.51				CF	M	CF
Hen 1481	D	7.85	1.2	0.51				AG2	M7	A5
H1-36	D	8.06		2.2	2.53		0.6	AG2,U		
W16-312	D	8.02	2.4	1.8				U		
RS Oph	S	6.58	0.70	0.35	0.4		4.8	FG1,GKL,Sz,SA	MO	SS
AS 245	S	7.19		0.50	0.50			U	M6	A5
He 2-294	S	8.40	1.29	0.41				U	M3	A5
Bl 3-14	S	8.74	1.22	0.54				U	M6	A5
Bl L	S	7.81	1.46	0.38				AG2	M6	A5
AS 255	S	8.43	0.99	0.30				U	K3	A5
V2416 Sgr	S	4.55	1.49	0.57	0.35			A3	M5	A5
SS 117	S	7.07	1.18	0.50				AG2	M6	A5
Ap 1-8	S	7.9	1.4	0.4				AG2	MO	A5
SS 122	D?	6.63	1.29	0.69				U	M7	A5
AS 270	S	5.53	1.26	0.47				U	M1	A5
H2-38	D	6.67	0.89	0.90	1.02		3.5	AG2,U	M8	A5
SS 129	S	8.03	1.03	0.27				U	K	A4
V615 Sgr	S	7.58	1.03	0.30				U	M	A4
Hen 1591	D	8.96	0.86	0.72		1.54		AG2,U	G	A5
AS 276	S	8.05	0.97	0.29		0.35		U	M4	A5
Ap 1-9	S	8.8		0.3				AG1	K4	A5
AS 281	S	6.95	1.09	0.31				AG1	M5	A5
V2506 Sgr	S	8.42		0.5				AG1	M	A4

Object	IR Type	K	J-H	H-K	K-L	K-L'	N	Refs	Spectral Type	Refs
SS 141	S	8.97	0.99	0.29				U	M	A4
AS 289	S	5.03	1.23	0.54				U	M3	SS
Y CrA	S	6.54	0.98	0.35		0.42		U	M5	A5
V2756 Sgr	S	7.76	0.98	0.27				AG1	M2	A5
CnMy 17	S	7.50	1.14	0.28				AG1	M3	A5
YY Her	S	7.87		0.15				SA	M2	H
He 2-374	S	6.43	1.23	0.44				U	M	A4
AS 296	S	4.50		0.34	0.34			SA	M5	SS
AS 295B	confused							U	M	HH
AR Pav	S	7.16	0.99	0.25				GW	M3	TH
Hen 1674	S	7.67		0.27				U	M5	A5
He 2-390	D	7.66			2.2		2.2	AG1,U	M	A4
V3804 Sgr	S	7.30		0.45				U	M6	A5
V443 Her	S	5.34		0.29	0.14			SA	M3	TG
AS 304	S	7.60		0.33				U	M4	A5
V2601 Sgr	S	8.03		0.27				U	M5	SS
AS 316	S	7.76		0.31				U	M	U
MWC 960	S	7.84		0.19				U	M0	A5
AS 327	S	8.52		0.16				SA	M	A4
FN Sgr	S	7.85	1.06	0.24				GW,SA	M4	A5
Pe 2-16	S	8.09		0.50				AG1	M5	A5
V919 Sgr	S	7.20		0.24				U	M1	A5
CM Aql	S	7.64	1.10	0.45				U	Var	A4,A5,H2
AS 338	S	7.54	0.95	0.35	0.1			A3	M5	A5
BF Cyg	S	6.33	0.87	0.31	0.47			Sz,SA	M5	Bk
CH Cyg	S	-0.6 to -0.8	0.96	0.39	0.5		-2.6	B,GMS,IRC,LPV,Sz,SA	M6	W1
Hen 1761	S	5.55	1.10	0.17	0.17			GW	M3	A5,T
HM Sge	D	3.6 to 4.4	2.0	1.8	1.9		-1.5	B,DHM,M',P	M	DHM
AS 360	S	7.06	1.03	0.39				SA,U	M6	A5
CI Cyg	S	4.45	0.89	0.30	0.41			Sz,SA	M5	Bk

Object	IR Type	K	J-H	H-K	K-L	K-L'	N	Refs	Spectral Type	Refs
V1016 Cyg	D	4.8 to 6.0		1.8	2.3		-0.2	A1,B,H,SA,U	M3	Bk
RR Tel	D	3.7 to 4.7	1.0	0.8	1.2		0.4	FRC,G,GW,U	M5	A5
He 2-467	S	9.41	0.82	0.23		0.11		A3,U	G	L
V1329 Cyg	S	6.88	1.17	0.48	0.3			A3	M4	AH
CD-43° 14304	S	7.60	0.88	0.19	0.0:			U	K3	A5
V407 Cyg									M	Bk
AG Peg	S	3.91	0.96	0.25	0.23			FRC,GW,Mz,Sz,SA	M3	Bk,CS
Z And	S	5.00	0.91	0.24	0.3			Sz,SA,W	M2	Bk
R Aqr	D	-1.2			0.5		-3.8	IRC	M7	M

References in table

A1 Allen (1973)
A2 Allen (1974a)
A3 Allen (1974b)
A4 Allen (1979)
A5 Allen (1980a)
A6 Allen (1980b)
AG1 Allen and Glass (1974)
AG2 Allen and Glass (1975)
AH Andrillat and Houziaux (1976)
B Bopp (1981)
Bk Boyarchuk (1970)
CB Cohen and Barlow (1974)
CF Carter and Feast (1979)
CS Cowley and Stencel (1973)
DHM Davidson, Humphreys and Merrill (1978)
DMB Davidsen, Malina and Bowyer (1977)
FG1 Feast and Glass (1974)
FG2 Feast and Glass (1980)
FRC Feast, Robertson and Catchpole (1977)
G Gehrz *et al* (1973)

GF	Glass and Feast (1973)
GKL	Geisel, Kleinmann and Low (1970)
GKS	Gillett, Knacke and Stein (1971)
GMS	Gillett, Merrill and Stein (1971)
GW	Glass and Webster (1973)
H	Harvey (1975)
H1	Herbig (1950)
H2	Herbig (1960)
HH	Herbig and Hoffleit (1975)
IRC	Neugebauer and Leighton (1969)
K	Kraft (1958)
L	Lutz *et al* (1976)
LA	Longmore and Allen (1977)
LVP	Luud, Vennik and Pehk (1978)
M1	Merrill (1950a)
M2	Merrill (1950b)
M'	Merrill (1977)
Mz	Mendoza (1972)
NB	Nassau and Blanco (1954)
O	O'Dell (1966)
P	Puetter *et al* (1978)
R	Roman (1953)
S	Stein *et al* (1969)
SA	Swings and Allen (1972)
SS	Sanduleak and Stephenson (1973)
Sz	Szkody (1977)
T	Thackeray (1954)
TG	Tifft and Greenstein (1958)
TH	Thackeray and Hutchings (1974)
TP	Torres-Peimbert, Recillas-Cruz and Peimbert (1980)
U	Unpublished data, D.A. Allen
W	Woolf (1973)
W1	Wilson (1942)
W2	Wilson (1950)
We	Webster (1966)

DISCUSSION OF THE PHOTOMETRY

The following emission mechanisms might be expected to be active in this spectral region:

(i) The photosphere of the cool giant

(ii) Any dust at temperatures of a few hundred Kelvin

(iii) Free-free emission

(iv) Such esoterica as cyclotron radiation from a magnetic accretion column.

The last of these is ignored: there is no evidence for a contribution from any such mechanisms. The possibility of such effects in an interacting binary environment should, however, be borne in mind. Free-free emission is also unlikely to be a significant contributor, as may be estimated from the intensity of Hβ or from the radio flux and spectrum (by a gross extrapolation). However, optically thin free-free emission may contribute a little at 10μm (e.g. in CH Cyg ?), for its intensity relative to the cool star increases roughly as the square of wavelength.

Figure 1 is a plot of the J-H/H-K colour indices for symbiotic stars, together with various diagnostic lines for cool giants with and without dust. It can be seen that the observations agree well with expectations. Note, however, that the Magellanic Cloud stars have colours suggestive of hotter stars with cooler dust than their galactic equivalents.

In theory the JHK photometry, used in conjunction with a good spectral type, could yield an estimate of the interstellar extinction for S-type systems. It is likely, however, that the derived value is too unreliable to be of value.

SPECTRA AT 3 AND 10 MICRONS

The best-known infrared spectral feature in cool stars is the 'silicate bump', a broad emission band centred near 10μm and common in oxygen-rich systems. This is most reliably identified at spectral resolutions of 50 or more, and has been recorded in R Aquarii (Stein *et al* 1969), HM Sagittae (Puetter *et al* 1978) and V1016 Cygni (Aitken *et al* 1980). Photometry through narrow-band filters can also suggest the presence of the silicate band, as in the case of CH Cygni by Bopp (1981). A recent spectroscopic survey by Allen, Aitken and Roche (in preparation) shows most D-type symbiotic stars to have silicate emission, and thus to be oxygen-rich.

In carbon-rich systems the silicate feature is not expected to form. Rather, emission due to silicon carbide is expected around 11μm.

https://doi.org/10.1017/S0252921100097396 Published online by Cambridge University Press

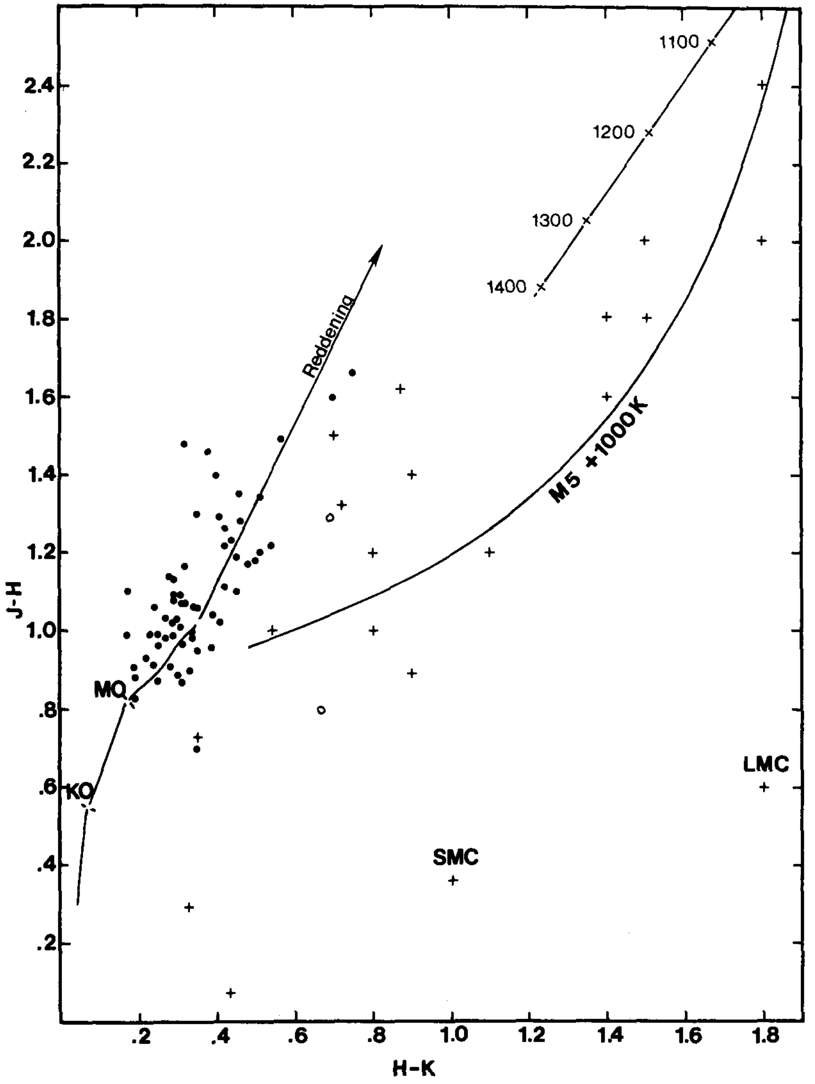

Figure 1. The J-H,H-K colour-colour diagram for symbiotic stars. The S-type systems (dots) are readily explained by M giants with a range of interstellar reddening. The giant sequence is represented by the irregular curve. Crosses indicate D-type systems. If the dust were the dominant emission mechanism, the data should fall on the black-body line, which is marked with temperatures in Kelvin. Combinations of cool star and dust map out a range of locations on the diagram; the combination of an M5 giant with a 1000K dust shell is shown. The four D-type stars near the foot of the diagram must have cool components hotter than 5000K. The Magellanic Cloud symbiotic stars are included in this group. Open circles are probable D-types for which longer-wavelength photometry is needed.

https://doi.org/10.1017/S0252921100097396 Published online by Cambridge University Press

This material probably accounts for the structure in Woolf's (1973) energy distribution for UV Aur.

Distinguishing itself from all others studied, the star HD 330036 was reported by Allen (1981) to have emission in the 3.3-3.5μm region. The emission resembles that in NGC 7027 and other H II regions, and is believed to originate in carbon-rich dust grains lying at the interface of ionized and neutral gas (Aitken *et al* 1979; Dwek *et al* 1980; Sellgren 1981). The emission bands at 7.7 and 11.3μm which usually accompany 3.3μm features are also seen (Allen, Aitken and Roche).

This is the first indication that any of the G-type (yellow) symbiotic stars might have an oxygen/carbon ratio less than unity. It also suggests the presence of neutral material in the HD 330036 system.

In the symbiotic stars which have M giant components, the high black-body temperatures are consistent with the formation of dust in the extended atmosphere, where it may be shielded from the destructive radiation of the hot component. The coolness of the dust in the G-type symbiotics (infrared type D'), where the star itself is hotter, indicates that the dust lies at greater distances from the cool component. Believing these to be mass-loss systems implies that the dust <u>forms</u> in these more remote corners. It is hard to envisage the <u>formation</u> of dust in the hostile radiation field of the hot component. Moreover, in HD 330036 the infrared emission bands imply that neutral, dust-laden gas exists. Perhaps the most attractive way to provide the necessary shielding from the hot star is for the latter to be enveloped in an optically thick disk. If this is the case, one cannot discount the possibility that the G-type spectrum is produced by the disk itself. It should be noted that in some cases the G star has been given a supergiant luminosity classification. One is reminded, too, of the B supergiant spectrum in RX Puppis which was mimicked by an optically thick disk or wind (Barton, Phillips and Allen 1979; Klutz, Simonetto and Swings 1978). If in this interpretation one argues that an M giant is still present, as for RX Puppis, the absence of dust as hot as 1000K must also be explained.

CONCLUSIONS

At wavelengths beyond 1μm, symbiotic stars do not appear symbiotic. They are seen to be normal cool giant stars. If these giants are of very late spectral type, and especially if they are Mira variables, they (like giants in the field) usually enshroud themselves in silicate-rich circumstellar dust, and consequently become extremely rubescent. It is difficult to escape the conclusion that symbiotic systems contain normal cool giants, and indeed that the giants are unaffected by even the thousandfold optical brightening of a slow-nova outburst.

One subset of the symbiotic stars, those containing G-type cool components, are distinguished from the remainder by having cooler dust, sometimes carbon rich, which must lie quite remote from the G star.

ACKNOWLEDGEMENTS

I'd like to thank June Holt for typing this, and all the staff of the AAO who have directly or indirectly contributed to the many observations noted herein which were made with the 3.9 m Anglo-Australian Telescope.

REFERENCES

Aitken, D.K., Roche, P.F., and Spenser, P.M.: 1980, Monthly Notices Roy. Astron. Soc. 193, pp.207-212.
Aitken, D.K., Roche, P.F., Spenser, P.M., and Jones, B.: 1979, Astron. Astrophys. 76, pp.60-64.
Allen, D.A.: 1973, Monthly Notices Roy. Astron. Soc. 161, pp.145-166.
Allen, D.A.: 1974a, Inf. Bull. Var. Stars, 911.
Allen, D.A.: 1974b, Monthly Notices Roy. Astron. Soc. 168, pp.1-13.
Allen, D.A.: 1979, Int. Astron. Union. Colloq. 46, pp.125-149.
Allen, D.A.: 1980a, Monthly Notices Roy. Astron. Soc. 192, pp.521-530.
Allen, D.A.: 1980b, Astrophys. Letters 20, pp.131-133.
Allen, D.A.: 1981, Proc. N. Amer. Workshop Symbiotic Stars, in press.
Allen, D.A., Beattie, D.H., Lee, T.J., Stewart, J.M., and Williams, P.M.: 1978, Monthly Notices Roy. Astron. Soc. 182, pp.57P-60P.
Allen, D.A., and Glass, I.S.: 1974, Monthly Notices Roy. Astron. Soc. 167, pp.337-350.
Allen, D.A., and Glass, I.S.: 1975, Monthly Notices Roy. Astron. Soc. 170, pp.579-587.
Andrillat, Y., and Houziaux, L.: 1976, Astron. Astrophys. 52, pp.119-121.
Barton, J.R., Phillips, B.A., and Allen, D.A.: 1979, Monthly Notices Roy. Astron. Soc. 187, pp.813-816.
Bopp, B.W.: 1981, Proc. N. Amer. Workshop Symbiotic Stars, in press.
Boyarchuk, A.A.: 1970, Chapter 3 in "Eruptive Stars", Eds. Boyarchuk, A.A., and Gershberg, R.E., Academy of Sciences, Moscow.
Carter, B.S., and Feast, M.W.: 1979, Inf. Bull. Var. Stars, 1714.
Cohen, M., and Barlow, M.J.: 1974, Astrophys. J. 193, pp.401-418.
Cowley, A.P., and Stencel, R.E.: 1973, Astrophys. J. 184, pp.687-692.
Davidsen, A., Malina, R., and Bowyer, S.: 1977, Astrophys. J. 211, pp.866-871.
Davidson, K., Humphreys, R.M., and Merrill, K.M.: 1978, Astrophys. J. 220, pp.239-244.
Dwek, E., Sellgren, K., Soifer, B.T., and Werner, M.W.: 1980, Astrophys. J. 238, pp.140-147.
Feast, M.W., and Glass, I.S.: 1974, Monthly Notices Roy. Astron. Soc. 167, pp.81-85.
Feast, M.W., and Glass, I.S.: 1980, Observatory, 100, p.208.
Feast, M.W., Robertson, B.S.C., and Catchpole, R.M.: 1977, Monthly Notices Roy. Astron. Soc. 179, pp.499-508.
Gehrz, R.D., Ney, E.P., Becklin, E.E., and Neugebauer, G.: 1973, Astrophys. Letters 13, pp.89-93.
Geisel, S.L., Kleinmann, D.E., and Low, F.J.: 1970, Astrophys. J. 161, pp.L101-L104.
Gillett, F.C., Knacke, R.F., and Stein, W.A.: 1971, Astrophys. J. 163, pp.L57-L59.

Gillett, F.C., Merrill, K.M., and Stein, W.A.: 1971, Astrophys. J. 164, pp.83-90.
Glass, I.S., and Feast, M.W.: 1973, Nature Phys. Sci. 245, pp.39-40.
Glass, I.S., and Webster, B.L.: 1973, Monthly Notices Roy. Astron. Soc. 165, pp.77-89.
Harvey, P.M.: 1975, Astrophys. J. 188, pp.95-96.
Henize, K.G., and Carlson, E.D.: 1980, Publ. Astron. Soc. Pacific 92, pp.479-483.
Herbig, G.H.: 1950, Publ. Astron. Soc. Pacific 62, pp.211-215.
Herbig, G.H.: 1960, Astrophys. J. 131, pp.632-637.
Herbig, G.H., and Hoffleit, D.: 1975, Astrophys. J. 202, pp.L41-L45.
Johnson, H.L.: 1965, Comm. Lunar Planet. Lab. 3, pp.73-77.
Klutz, M., Simonetto, O., and Swings, J.P.: 1978, Astron. Astrophys. 66, pp.283-288.
Kraft, R.P.: 1958, Astrophys. J. 127, pp.625-641.
Longmore, A.J., and Allen, D.A.: 1977, Astrophys. Letters 18, pp.159-162.
Lutz, J.H., Lutz, T.E., Kaler, J.B., Osterbrock, D.E., and Gregory, S.A.: 1976, Astrophys. J. 203, pp.481-484.
Luud, L., Vennik, J., and Pehk, M.: 1978, Soviet Astron. Letters 4, pp.46-48.
Mendoza, E.E.: 1972, Bol. Obs. Tonantzintla Tacubaya, 38, pp.211-214.
Merrill, K.M.: 1977, Int. Astron. Union Circ., 3088.
Merrill, P.W.: 1950a, Astrophys. J. 111, pp.484-494.
Merrill, P.W.: 1950b, Astrophys. J. 112, pp.514-519.
Nassau, J.J., and Blanco, V.M.: 1954, Astrophys. J. 120, pp.129-138.
Neugebauer, G., and Leighton, R.B.: 1969, "Two micron sky survey", NASA SP-3047.
O'Dell, C.R.: 1966, Astrophys. J. 145, pp.487-495.
Puetter, R.C., Russell, R.W., Soifer, B.T., and Willner, S.P.: 1978, Astrophys. J. 223, pp.L93-L95.
Roman, N.G.: 1953, Astrophys. J. 117, pp.467-468.
Sanduleak, N., and Stephenson, C.B.: 1973, Astrophys. J. 185, pp.899-913.
Sellgren, K.: 1981, Astrophys. J. 245, pp.138-147.
Stein, W.A., Gaustad, J.E., Gillett, F.C., and Knacke, R.F.: 1969, Astrophys. J. 155, pp.L3-L7.
Stencel, R.E., and Sahade, J.: 1980, Astrophys. J. 238, pp.929-934.
Swings, J.P., and Allen, D.A.: 1972, Publ. Astron. Soc. Pacific, 84, pp.523-527.
Szkody, P.: 1977, Astrophys. J. 217, pp.140-150.
Thackeray, A.D.: 1954, Observatory, 74, pp.258-259.
Thackeray, A.D., and Hutchings, J.B.: 1974, Monthly Notices Roy. Astron. Soc. 167, pp.319-336.
Tifft, W.G., and Greenstein, J.L.: 1958, Astrophys. J. 127, pp.160-171.
Torres-Peimbert, S., Recillas-Cruz, E., and Peimbert, M.: 1980, Rev. Mexicana Astron. Astrof. 5, pp.51-58.
Webster, B.L.: 1966, Publ. Astron. Soc. Pacific, 78, pp.136-142.
Webster, B.L., and Allen, D.A.: 1975, Monthly Notices Roy. Astron. Soc. 171, pp.171-180.
Wilson, R.E.: 1942, Astrophys. J. 96, pp.371-381.
Wilson, R.E.: 1950, Publ. Astron. Soc. Pacific, 62, pp.14-15.
Woolf, N.J.: 1973, Astrophys. J. 185, pp.229-237.