INFRARED OBSERVATIONS OF SYMBIOTIC MIRAS

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ABSTRACT. Symbiotic Miras are identified by their infrared characteristics. It is shown how an understanding of the evolutionary position of normal Mira variables together with the empirically established period luminosity relation can be used to derive various physical parameters for similar objects in symbiotic systems. The pulsation periods of symbiotic Miras measured so far fall between 280 and 580 days, their ages must be in the 5-10 Gyr range while main sequence masses of the order 1 to 1.5 $M_{\odot}$ are indicated. The obscuration events seen in the IR light curves of several symbiotic Miras are highlighted as potentially important and possible causes are discussed.

1. INTRODUCTION

A small subgroup of the symbiotic stars have the infrared variability and colours which identify their cool giant components as Mira variables. These are largely objects which have more usually been designated "D-type" symbiotics in the past (e.g. Allen 1984). Observational data for these objects and their interpretation have recently been reviewed in detail (Whitelock 1987, hereafter Paper I). Owing to restrictions in space it has not been possible to give full references in the present paper, they can however be found in paper I.

This paper is an updated summary of the IR observations of symbiotic Miras and their interpretation. It concentrates particularly on the application of our knowledge of normal (i.e. single) Miras to their symbiotic counterparts. o Cet (Mira) is included in the symbiotic Mira category as it appears to exhibit weak symbiotic activity and has a number of similarities with the other objects under discussion. Their relationship with o Cet is in fact probably closer than with the other, S-type, symbiotics.

The objects under discussion are listed in Table I together with other data which will be described below.

J. Mikolajewska et al. (eds.), The Symbiotic Phenomenon, 47–56.

TABLE I SYMBIOTIC MIRAS

Name	RA	(2000)		Dec		ℓ	b	P (day)	K (mag)	A_K (mag)	d (kpc)
o Cet	02	19	21	-02	58.5	167.8	-58.0	332	-2.5	0	0.12
RX Pup	08	14	12	-41	42.4	258.5	- 3.9	580	2.4	0.7	1.3
KM Vel	09	41	14	-49	22.7	274.2	+ 2.6	370	5.4	1.1	3.0
He2-38	09	54	43	-57	18.9	280.8	- 2.2	433	4.4	0.4	2.8
BI Cru	12	23	27	-62	38.2	299.7	+ 0.1	280	4.8	0.9	2.0
SS38	12	51	26	-65	00.0	302.9	- 2.1		6.1	1.2	(4.2)
V704 Cen	13	54	56	-58	27.3	311.2	+ 3.4		8.7	-	-
He2-104	14	11	52	-51	26.4	315.5	+ 9.5	400	6.7	1.7	4.3
V835 Cen	14	14	09	-63	25.7	312.0	- 2.0	450	4.7	0.9	2.8
He2-127	15	24	49	-51	49.9	325.5	+ 4.2		7.8	0.3	(14)
He2-139	15	54	45	-55	29.6	366.9	- 1.4		5.8	0.7	(5.0)
He2-147	16	14	01	-56	59.5	327.9	- 4.3	370-380	4.7	0.1	3.4
He2-171	16	34	04	-35	05.4	346.0	+ 8.6		6.5	1.3	(4.7)
AS210	16	51	21	-26	00.4	355.5	+11.6		6.5	1.2	(4.9)
V2110 Oph	17	43	32	-22	45.6	5.0	+ 3.6		7.6	-	-
H1-36	17	49	48	-37	01.5	353.5	- 4.9	450-500	7.4	1.5	7.6
W16-312	17	50	17	-30	57.6	358.8	- 1.9		7.6	1.3	(7.8)
AS245	17	50	58	-22	19.4	6.3	+ 2.4		7.5	0.2	(12)
SS122	18	04	41	-27	09.2	3.7	- 2.7		6.4	-	-
H2-38	18	06	01	-28	17.1	2.8	- 3.5		6.8	0.4	(8.1)
Hen 1591	18	07	32	-25	53.7	5.1	- 2.6		8.9	-	-
He2-390	18	20	59	-26	48.4	5.7	- 5.8		7.4	2.0	(5.2)
HM Sge	19	41	57	+16	44.7	53.6	- 3.2	540	4.2	1.2	2.1
V1016 Cyg	19	57	05	+39	49.8	75.2	+ 5.7	450	5.1	0.9	3.3
RR Tel	20	04	16	-55	43.3	342.2	-32.2	387	4.1	0.2	2.6
R Aqr	23	43	49	-15	17.0	66.5	-70.3	387	-1.1	0.1	0.25

2. MIRA VARIABLES

Mira variables are long-period ($P > 100$ d), large-amplitude ($\Delta V > 2.5$ mag), pulsating red giants with spectral types M, S or C. Single Miras can be distinguished from other red variables, usually without ambiguity, due to their relatively regular periods, large visual light amplitudes and at certain pulsation phases low excitation emission lines. Unfortunately in symbiotic Miras these distinguishing characteristics are often masked by the symbiotic phenomenon; frequently to the extent that there is no observational indication of the presence of a Mira in the visual spectral region. It is therefore of considerable importance that Miras have near-IR colours and spectral features which are distinct from those of other stars of the same spectral type.* This, together with the fact that their energy distribution peaks in the near-IR makes IR photometry a powerful way of identifying them in the presence of either a hot star or high extinction.

Before going on to discuss symbiotic systems it is useful to examine what we know about the evolutionary position and galactic distribution of Miras. This subject was recently reviewed by Feast & Whitelock (1987). Studies of Miras in globular clusters and the LMC have been crucial to our understanding of their evolutionary condition. Miras occur in the more metal-rich clusters where they are the coolest and brightest objects present. Their luminosities exceed that of core helium-flash, establishing that they are on the Asymptotic Giant Branch (AGB). Indeed, the available evidence points to Miras as the most luminous and terminal phase of AGB evolution. Their next evolutionary step must be the loss of the remaining hydrogen envelope to form a planetary nebula, which will be energised by the remnant stellar core.

Knowledge of the pulsation period of a Mira is important because it has been shown to be indicative of the stellar population group to which the star belongs. Evidence for this is provided by: (1) the good correlation between the value of [Fe/H] for a cluster and the period(s) of the Mira(s) it contains; (2) the fact that the kinematic properties of Miras in the solar neighbourhood are a function of their period. Stars with P ~ 200 d belong to an intermediate population II or thick disk population as do the metal-rich globular clusters. Longer period stars belong to kinematically younger populations, with an age of the order of 5 Gyr at a period of 350 d.

The existence of a period luminosity (PL) relation among Mira variables is now well established. Current evidence is consistent with the same PL relation applying to Miras in the rather different environments of the globular clusters, the LMC and the galactic bulge. It has also been suggested that the long-period (up to 2000 d) large-amplitude OH/IR sources fall on an extrapolation of the PL relation to higher luminosities. This would be consistent with their being younger (<1 Gyr), more massive (1.5-2.0 $M_\odot$) and more metal-rich analogues of the Mira variables. According to stellar evolution theory the maximum luminosity which a star reaches on the AGB is a function of the mass of the helium core which is in turn a function of the initial mass and metallicity. Although in general we have no direct information on the luminosity of a symbiotic Mira, if its pulsation period has been determined then its luminosity can be derived from the PL relation. A comparison of this luminosity with predictions of stellar evolution theory should provide some insight on the mass and metallicity of the red giant progenitor. This is discussed further in section 5.

Footnote: *Although there are certain, rare, supergiant variables which have similar colours to Miras, considerations of distance and height above the galactic plane make it exceedingly unlikely that any of the D-type symbiotics contain this type of object.

It seems likely that the symbiotic phenomena exhibited by Miras are a direct result of, among other factors, the high mass loss rates of these stars. The mechanism for mass loss in Miras and its relationship to the stellar parameters of mass, luminosity, composition etc. are very poorly understood. It is interesting that recent work has shown that the mass of circumstellar dust (m) around a Mira is a function both of its pulsation period (P) and pulsation amplitude (Δ M_{bol}):

$$\log (m/M_{\odot}) = 2.17 \log P + 1.32 \Delta M_{bol} - 12.36.$$

The dependence on amplitude clearly establishes pulsation as a major cause of mass loss. Presumably pulsation-driven shock waves move the outer atmosphere to a sufficiently large distance that conditions are suitable for dust grain formation. Mass loss will then be driven by radiation pressure (a function of luminosity and hence period) on the grains.

3. NEAR-INFRARED

Early JHKL photometry of Mira symbiotics showed an apparent excess over the flux expected from a normal stellar atmosphere. This was attributed to thermal emission from dust (hence the D-type classification). More recently it has become clear that the colours of certain Miras and of most symbiotics are at least as much a function of circumstellar reddening as of circumstellar emission. This realisation has significantly changed our view of these objects.

The presence of Mira variables in a few of the objects under discussion has been established from their large amplitude ($\Delta J \sim 1$ mag), long period ($P > 250$ d) IR variability. The Mira identification is supported in some cases by the detection of strong H_2O absorption

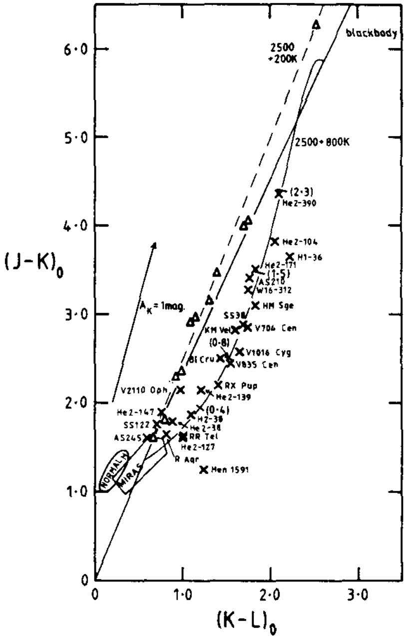


Fig. 1. Near IR two-colour diagram. Crosses: normal mean colours of symbiotic Miras; triangles: extreme Miras. The numbers in parenthesis are the extinction at K for a 2500K Mira with an 800K dust shell. Most observations are SAAO unpublished data, others are referenced in paper I, Fig. 3.

features in the 1-3 µm spectra. It is then tempting to assume that all symbiotics with similar IR colours contain Miras. However this may not prove to be the case and further observations are important.

The characteristic colours of the D-type symbiotics are illustrated in the near-IR two-colour diagram (Fig. 1). Mean points (excluding the obscuration phases discussed below), are shown for objects which have been measured repeatedly. An approximate correction has been applied for interstellar reddening. Shown for comparison are some of the extreme Miras discovered from the IRAS survey. They are single stars with thick dust shells and pulsation periods between 350 and 600 d.

Most of the symbiotic Miras fall close to the locus representing the combination of a 2500K Mira with an 800K dust shell. This locus is calculated on the assumption that a silicate dust shell surrounds the Mira whose light it absorbs and re-emits at the given temperature. The further up the locus the thicker is the dust shell (approximate values of the extinction at K (A_K) are noted along the line). This is unlikely to be a very realistic model of the dust shell around a symbiotic Mira given the presence of a second star and the complexity of the interaction between the two stars. However, it serves to illustrate the difference between the symbiotic Miras and the extreme Miras whose dust shells are predominantly at much lower temperatures and therefore produce very little emission in the near-IR even at L(3.45µm). It also indicates that reddening as well as dust emission has a strong influence on the observed colours of symbiotic Miras. The "extra" heating for the symbiotic dust, over that of the dust around the extreme Miras, is almost certainly provided by the hot star and/or an accretion disk. Hen 1591 has distinctly unusual colours which require further investigation.

One of the most interesting and potentially important characteristics of the symbiotic Miras is their tendency to undergo faint phases in addition to the modulation associated with Mira pulsation. These phases typically last between a year and several years and involve a decrease in brightness at J of 1 to 2 mag from the normal mean (see Fig. 4, Paper I). The change at longer wavelengths is less. A point representing the colours of the symbiotic during the faint phase falls higher up the star plus dust shell locus in Fig. 1 (see also Fig. 3, Paper I). Thus it appears that the most reasonable explanation of this phase is obscuration due to dust. It should be emphasised that no comparable effect is seen in single M-type Miras. *The obscuration must be a consequence of the symbiotic nature of the Miras.*

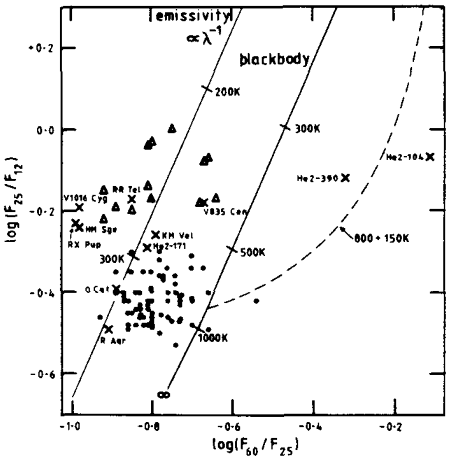
4. IRAS OBSERVATIONS

The IRAS observations of symbiotics have been discussed by Whitelock (1985), Kenyon *et al.* (1986) and in Paper I. As one might predict from their near-IR characteristics the symbiotic Miras are as a group stronger far-IR emitters than are the S-type objects. IRAS fluxes are reproduced in Table II for those Miras which appear in version 2 of the point source catalogue. Upper limits are indicated by an L. Most of the 100 µm and some of the 60 µm observations of the objects near the galactic plane were overwhelmed by background emission.

TABLE II IRAS DATA FOR SYMBIOTIC MIRAS

Name	IRAS No	Flux (Jy)			
		12 μm	25 μm	60 μm	100 μm
o Cet	02168-0312	4881.	2261.	301.	884.
RX Pup	08124-4133	182.	132.	150.	7.49
KM Vel	09394-4909	11.8	7.81	1.36	9.5L
He2-38	09530-5704	9.26	4.28	3.8L	38L
BI Cru	12206-6221	17.3	15.3	12L	119L
SS38	12483-6443	7.71	3.29	1.9L	19L
V704 Cen	13515-5812	1.43	1.16	0.5L	19L
He2-104	14085-5112	8.56	9.09	6.83	9.8L
V835 Cen	14103-6311	32.5	26.1	5.95	29.8:
He2-127	15210-5139	0.49	0.29	0.7L	9.2L
He2-139	15508-5520	5.87	2.99	10.3L	140L
He2-147	16099-5651	4.04	2.84	0.5L	31L
He2-171	16307-3459	7.47	4.58	0.75	5.0L
AS210	16482-2555	3.93	1.21	0.4L	2.1L
H1-36	17463-3700	18.1L	28.2	5.75	36L
W16-312	17470-3056	5.86	3.34	22L	291L
AS245	17479-2218	1.67	0.62	2.3L	34L
SS122	18015-2709	1.44	1.00	13L	212L
H2-38	18028-2817	3.39	2.06	4.0L	41L
He2-390	18178-2649	4.68	4.37	2.10	6.8:
HM Sge	19396+1637	119	82.6	9.45	15L
V1016 Cyg	19553+3941	42.9	34.2	4.03	5.8L
RR Tel	20003-5552	19.9	16.4	2.62	1.0L
R Aqr	23412-1533	1577.	544.	66.6	16.6

Fig. 2 is an IRAS two-colour diagram on which are marked the symbiotic and extreme Miras as well as the region occupied by normal Miras with P > 300 d. Fig. 3 is a composite IRAS/near-IR two-colour diagram for the same groups of objects. These figures indicate that the majority of the symbiotic Miras have similar far-IR flux distributions to those of normal or extreme Miras. For normal Miras the 12 μm emission arises from the combination of photosphere and dust while at longer wavelengths it is predominantly from dust. Dust completely dominates the far-IR emission at all wavelengths for most of the symbiotic Miras. The objects, He2-390 and He2-104, which fall on the right hand side of Fig. 2, seem to show distinctly different dust shell characteristics from Miras or the other symbiotics. It is possible to explain their IRAS colours as arising from a combination of blackbodies of various temperatures. They do not appear to contain a significant quantity of material with the strongly wavelength dependent emissivity characteristic of normal Mira dust shells (Paper I).



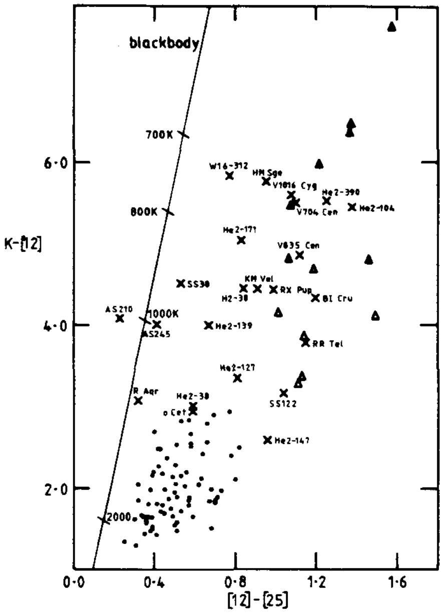


Fig. 2. IRAS 2-colour diagram. Closed circles: normal Miras with P > 300 d, other symbols as Fig. 1. Shown for comparison are the blackbody locus and the locus of dust with emissivity $\propto \lambda^{-1}$. The dashed line represents the combination of blackbodies with temperatures of 800 and 150 K.

Fig. 3. Combined IRAS-near-IR 2-colour diagram. Symbols as for Fig. 1 and 2. Note that some of the scatter in the diagram will be due to the lack of simultaneity of the IRAS and K observations.

Further insight into the nature of the dust emission from these stars may be gained from the 10μm spectroscopy performed by Roche et al. (1983). They found that the spectra of the majority of symbiotic Miras arises from two components: First the normal silicate particles and secondly an unknown material which exhibits a featureless 10 μm spectrum. However, four objects, He2-390, He2-104, BI Cru and AS210, showed a featureless spectrum only, with no sign of silicate emission or absorption. Note that although BI Cru was not detected at 60 μm by IRAS its [12]-[25] colour is consistent with it having the same shell characteristics as He2-390 and He2-104. AS210 has quite different colours which might indicate that its Mira is carbon-rich (paper I).

It is interesting that He2-390 and He2-104 have extremely red near-IR colours (Fig. 1) which are more typical of the other symbiotics during an obscuration phase. We have very little data on He2-390, but He2-104 has been monitored for several years and it shows no gross changes in its magnitude or colours beyond those associated with pulsation. Perhaps the peculiar IRAS colours and featureless 10 μm spectrum are associated with the obscuration phase and He2-104 may be undergoing a prolonged event of this kind.

5. DISCUSSION

Pulsation periods are given in Table 1 for the 13 objects for which they have been determined. They range from 280 to 580 d with a mean value of 420 ± 23 d. Following the procedure described by Feast & Whitelock (1987) we can use this period to establish an estimate of the age, initial mass (M_i), final white dwarf mass (M_F), present mass (M_P) and planetary nebula mass (M_{PN}) as given in Table III.

TABLE III

P (d)	M_{Bol} (mag)	Age (Gyr)	M_i	M_F	M_P ($M_\odot$)	M_{PN}
280	-4.36	10	1.07	0.59	0.75	0.16
580	-5.07	5	1.29	0.63	1.01	0.38

Obviously these estimates are model dependent and in particular are a function of the very uncertain assumed mass-loss rates. The initial mass estimates are somewhat lower than are sometimes derived for symbiotics. Lund and Leedyarv (1986) recently estimated $M_i \sim 3M_\odot$ for a group of symbiotics including o Cet, R Aqr, RR Tel and RX Pup. Such high masses are not consistent with the parameters of normal Miras discussed in section 2. Also, given that several of the symbiotic Miras lie in the galactic bulge, masses much higher than those listed here would seem inappropriate.

Miras or OH/IR sources with periods in excess of 580 d are very rare among single stars, so it is not surprising to find them unrepresented among the symbiotics. The absence of short-period symbiotics however requires some explanation. It may be that binary systems are rare among older stars; alternatively, if the binaries do exist then they may not be obviously symbiotic. This latter condition might arise because short-period Miras lose mass at a slower rate than their long-period counterparts. We might therefore expect a lower, possibly unobservable, level of symbiotic activity in such systems except for relatively close binary pairs.

The PL relation discussed in section 2 should provide one of the best methods for determining distances to symbiotic Miras. However severe problems arise due to uncertainties in the circumstellar extinction, including the possibility that significant quantities of neutral extinction are present (paper I). Table I contains distance estimates for the objects with known periods derived from the PL relation using the K magnitude after correcting for extinction (A_K). The corrections are derived from the simple dust shell model described earlier and are very uncertain for the redder objects. Distance estimates are given in brackets for objects without measured periods but with sufficient IR measurements to confirm their Mira nature. For the purpose of this estimate they are all assumed to have P = 400 d. The error on a distance determined from the PL relation excluding the extinction uncertainties is less than 10%. The distances derived for objects such as o Cet and R Aqr for which there is little uncertainty in the extinction are therefore probably the best currently available (they should be superseded by parallax measurements in due course). It must however be emphasised that the distance estimate for objects such as He2-390 and He2-104 are highly uncertain.

I would like to stress particularly the importance of the light level changes, described in section 3, for the understanding of this type of symbiotic system. Willson et al. (1981) have suggested that the obscuration seen in R Aqr around 1977 and similar effects seen in the optical light curve at earlier epochs are eclipses by an accretion disk or cloud associated with the companion star. They thereby infer a binary period of 44 yr. If this interpretation is correct and comparable events in other symbiotics are similarly caused then we have been provided with a relatively simple method of measuring orbital periods. It is hardly necessary in a meeting such as this to stress the importance of establishing the binary periods of these objects. However if the effect is due to material confined in the orbital plane it is perhaps surprising that it has been seen in such a large fraction of those symbiotic Miras which have been monitored over long time periods.

An alternative explanation for these events may be that they represent spontaneous large-scale mass loss from the Mira. Such mass loss might be caused by an effective reduction in surface gravity of the Mira due to the proximity of the second star. If the orbits of these systems are elliptical then periastron passage could trigger the increased mass loss; thus timing the events is still potentially a measure of the orbital period. Strong support for the spontaneous mass loss mechanism is provided by the recent work of Seaquist & Taylor (1987). They interpret increased radio emission from RX Pup during 1985, when the IR was faint, to indicate enhanced mass loss over that in the mid-1970's, when the IR was bright. Within a few months of the time the IR started to fade in RX Pup the re-appearance of high excitation emission lines was noted by Klutz & Swings (1981). The appearance of such lines is very probably symptomatic of increased mass accretion associated with the hot star. In that case we can make some estimate of the separation of the two stars from the fact that the material made the transition in a time not significantly exceeding 6 months. Thus if the material was travelling at the 60 km s^{-1} estimated by Seaquist and Taylor, the orbital period cannot be in excess of 20 yr. It is obviously well worth monitoring in detail the IR-photometric and optical spectroscopic development of the other symbiotic Miras.

Despite the above discussion one of the biggest gaps in our knowledge of symbiotic Miras is the lack of any definite information on the orbital parameters of these systems. Various analyses, including radial velocities, of S-type, i.e. non-Mira, symbiotics have yielded orbital periods in the range 0.5 to 4 yrs. In marked contrast, the suggested periods for symbiotic Miras are much longer - over 20 yr.

Given reasonable assumptions about the masses of the component stars (say, $M_1 + M_2 = 2\ M_\odot$ or slightly less), the Mira will fill its Roche lobe if the orbital period is less than about 20 yr. The low mass-transfer rates thought to be necessary to produce the observed phenomena in these systems suggest Roche-lobe overflow to be unlikely. However the stellar wind of the Mira, which to some extent behaves as an extension of its atmosphere, may well be channelled onto the other component via the inner Lagrangian point.

Observations indicate that the mildly symbiotic star o Cet transfers mass to a white dwarf via an accretion disk. The difference between it and those stars normally called symbiotic probably lies only in the larger separation (> 45 AU) of the o Cet binary components resulting in a lower level of interaction. The period of this system must be over 200 yr.

An important consequence of the suggested difference between the orbital periods of Mira and non-Mira (S-type) symbiotics is to highlight the fundamental difference between these two types of objects. It seems very unlikely that those containing Miras would have been recognised as symbiotic prior to onset of the high mass-loss rates associated with Mira variability. The mass transfer at the suggested binary separation would be too small. Equally it is not clear what a typical S-type symbiotic with an orbital period < 5 yrs will evolve into. As the giant component nears the Mira stage, i.e. approaches the top of the AGB, it will overfill its Roche lobe and the subsequent evolution will probably be extremely rapid. It therefore seems very unlikely that there is any evolutionary relationship between Mira and non-Mira symbiotics.

ACKNOWLEDGEMENTS

I am grateful to M W Feast and J W Menzies for helpful discussions and to all my colleagues in the SAAO IR-group for permission to use data in advance of publication.

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