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Properties of Circumstellar Dust in Symbiotic Miras

D. Kotnik-Karuza[1], T. Jurkic[1], and M. Friedjung[2]

[1]Physics Department, University of Rijeka, Omladinska 14, Rijeka, Croatia
email: kotnik@ffri.hr, tjurkic@ffri.hr

[2]Institut d'Astrophysique de Paris, Universite Pierre & Marie Curie,
98bis, bd Arago, 75014 Paris, France
email: fried@iap.fr

Abstract. We present a study of the properties of circumstellar dust in symbiotic Miras during sufficiently long time intervals of minimal obscuration. The published $JHKL$ magnitudes of o Ceti, RX Pup, KM Vel, V366 Car, V835 Cen, RR Tel and R Aqr have been collected. In order to investigate their long-term variations, we removed the Mira pulsations to correct their light curves. Assuming spherical temperature distribution of the dust in the close neighbourhood of the Mira, the DUSTY code was used to solve the radiative transfer in order to determine the dust temperature and its properties in each particular case.

The preliminary results of this systematic study of dust envelopes in symbiotic stars with Miras as cool components provide information on nature of dust in these objects.

Keywords. stars: binaries: symbiotic, stars: circumstellar matter, stars: AGB and post-AGB, infrared: stars, radiative transfer

1. Introduction

Symbiotic stars are interacting binaries in which the cold component transfers material to the much hotter companion star, usually a white dwarf (Whitelock & Munari 1992). The cool component consists mainly of a late-type red giant star, although yellow giants are also found. Around 80% of symbiotic stars contain a normal giant and are classified as S-type symbiotics. The remainder show the presence of a reddened Mira and a dust envelope in the near-IR. Symbiotics with warm dust shells of around 1000 K are classified as D-type symbiotics (Mikolajewska *et al.* (1988); Kenyon 1986). The interaction between components results in the formation of a circumbinary nebula, which mostly acts as a line-emitting region.

Most attempts to describe physical properties of circumstellar dust shells around Mira components use a simple model of a thick dust shell with constant dust temperature, without determination of any physical dust properties such as grain sizes or sublimation temperatures. Only a few authors use radiative transfer to determine dust properties in single objects (Tuthill *et al.* (2000); Bryan & Kwok 1991).

2. Observational data and methods of analysis

$JHKL$ magnitudes of seven southern symbiotic stars, o Cet, KM Vel, V835 Cen, V366 Car, RR Tel, R Aqr and RX Pup, observed for at least 10 years at different epochs at SAAO, have been analysed. Magnitudes have been corrected for interstellar reddening using visual extinctions A_V given in Table 1. The light curves were corrected for Mira pulsations by an approximate procedure to show only the long-term variations. RR Tel, R Aqr and RX Pup give evidence of marked obscuration events (Figure 1).

Table 1. Selected sample of southern symbiotic Miras

Symbiotic Mira	Other name	Spectral class	Ref	A_V	d (kpc)	P (days)	Ref
o Cet	HD 14386, MWC 35	Mira M2-7III	1, 2	0.01	0.12	331-333	8, 9, 10
KM Vel	Hen 2-34	Mira M	2, 3	3.2	9.0	370	11
V835 Cen	Hen 2-106	Mira M $\geqslant$ M5	4	3.9	9.4	400	11
V366 Car	Hen 2-38	Mira M6	5	2.8	3.8	433	11
RR Tel	Hen 3-1811	Mira M6/M5	5, 6	0.3	2.5	387	12, 13, 14
R Aqr	HD 222800, MWC 400	Mira M7, M8, M4	5, 7, 8	0.01	0.27	383-386	8, 9, 10
RX Pup	HD 69190, Hen 3-138	Mira M5.5/M5	5, 6	2.0	3.0	580	15, 16, 17

References: (1) Karovska *et al.* (1997); (2) Whitelock (1988); (3) Acker, Lundstrom & Stenholm (1988); (4) Schulte-Ladbeck (1988); (5) Muerset & Schmid (1999); (6) Allen (1980); (7) Kenyon (1986); (8) Whitelock, Marang & Feast (2000); (9) Kholopov (1985); (10) Perryman *et al.* (1997); (11) Feast *et al.* (1983b); (12) Feast *et al.* (1983a); (13) Penston *et al.* (1983); (14) Kotnik-Karuza *et al.* (2006); (15) Whitelock *et al.* (1983); (16) Feast, Robertson & Catchpole (1977); (17) Mikolajewska *et al.* (1999)

Modeling the circumstellar properties of the dust shells around Mira components was carried out by use of the numerical code DUSTY (Ivezic, Nenkova & Elitzur 1999), assuming spherical geometry, with Mira in the centre of the spherical dust shell. We used blackbody input radiation from the Mira at a temperature between 2300 K and 2600 K, depending on spectral class and in agreement with data from the literature. Only o Cet stellar temperature was modeled due to its high spectral class variability. As Mira components have strong stellar winds, envelope expansion is driven by radiation pressure on the dust grains. In the analytical approximation for radiatively driven winds (Danchi *et al.* 1994) the number density η is a function of the scaled radius $y = r/r_{in}$, of the initial v_i and terminal wind v_e velocity, while r_{in} is the inner dust shell (sublimation) radius:

$$\eta \propto \frac{1}{y^2}\sqrt{\frac{y}{y-1+(v_i/v_e)^2}} \tag{2.1}$$

In the applied MRN dust grain size distribution (Mathis, Rumpl & Nordsieck 1977), $n(a) \propto a^{-q}$ ($a_{\min} \leqslant a \leqslant a_{\max}$), the minimum grain size of $a_{\min} = 0.005\ \mu m$ and q = 3.5 are taken as fixed input parameters, while maximum grain size $a_{\max}$ is a free parameter determined by modeling. Dust composition typical for Mira stars containing 100% warm silicates has been assumed (Ossenkopf, Henning & Mathis 1992). Outer dust shell radius is fixed to 20 $r_{\rm in}$, contrary to the inner dust shell radius $r_{\rm in}$ which is obtained by fitting, together with the dust sublimation temperature $T_{\rm dust}$ as a linked parameter.

3. Results and discussion

The results obtained by modeling the circumstellar dust around the cool Mira component during time intervals of minimal obscuration for six symbiotic stars are given in Table 2 and Figure 2. V835 Cen was not modeled as it appeared to show permanently decreasing dust obscuration without any evidence that the obscuration by dust reached its minimum. RX Pup was successfully modeled for the time period between 1980 and 1996, while the near-IR observations between 1975 and 1980 couldn't be explained by use of the radiative transfer dust shell model only, implying other mechanisms as well.

Sublimation dust temperatures of the sample stars range from 650 K to 1150 K and increase with increasing Mira temperature. Such behaviour is clear in view of the DUSTY

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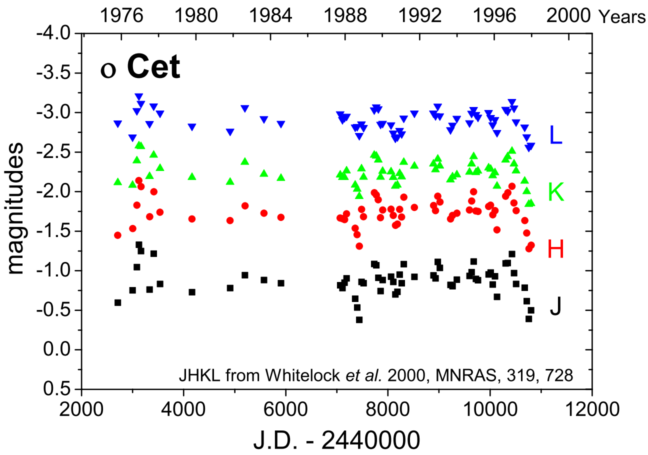

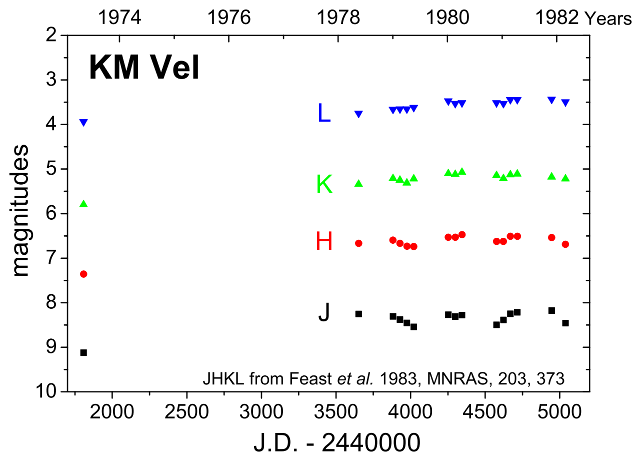

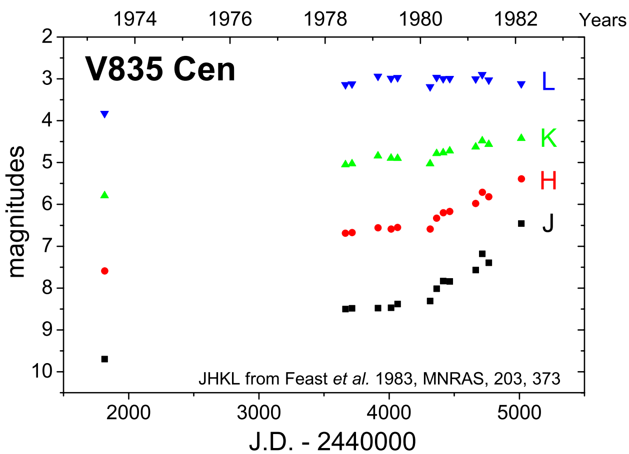

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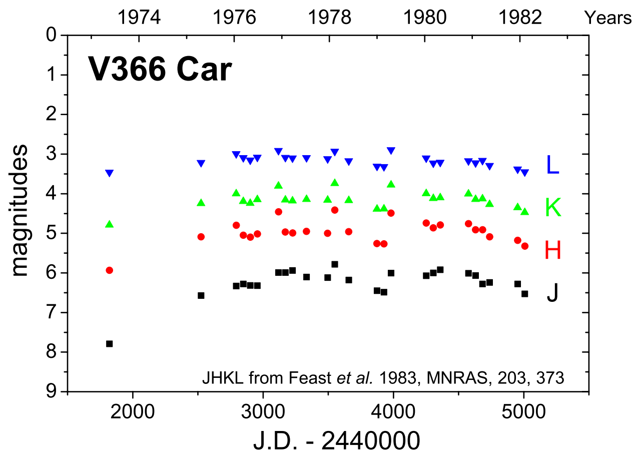

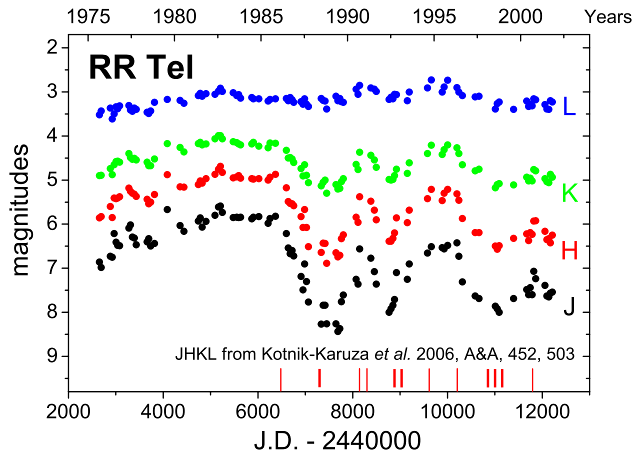

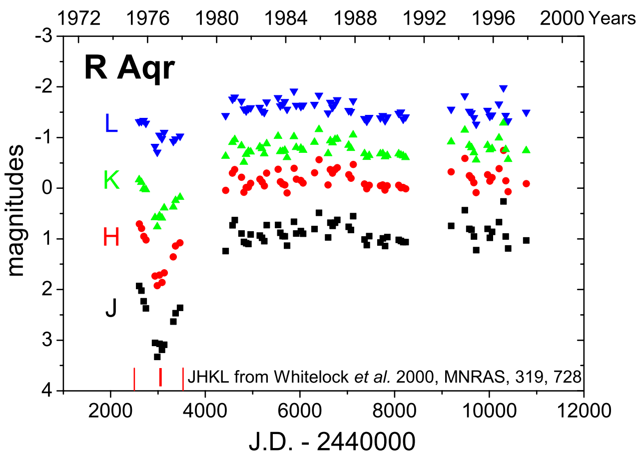

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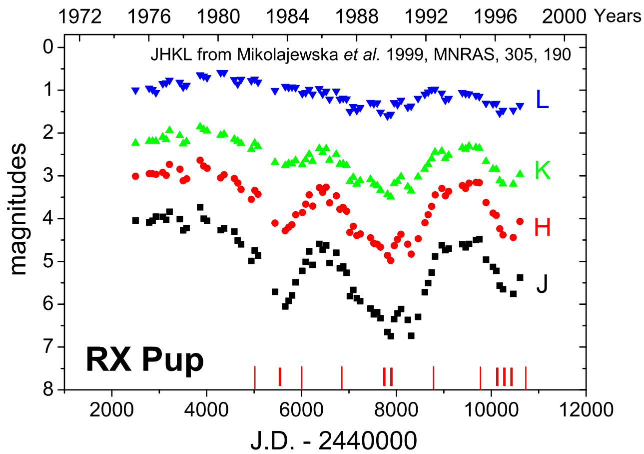

Figure 1. Light curves of seven southern symbiotics corrected for Mira pulsations. Obscuration events are marked at the bottom of each star's figure.

Table 2. Modeled physical parameters of circumstellar dust around southern symbiotic Miras (T_{Mira} = Mira temperature; T_{dust} = dust sublimation temperature; a_{max} = maximum grain size; τ_V = visual optical depth; A_K = extinction at K wavelength; $\dot{M}$ = mass-loss rate; v_e = terminal wind velocity).

			Symbiotic Miras			
Parameters	o Cet	KM Vel	V366 Car	RR Tel	R Aqr	RX Pup
T_{Mira} (K)	2600$^{(1)}$	2500$^{(2)}$	2500$^{(2)}$	2500$^{(3)}$	2300$^{(4)}$	2300$^{(5)}$
T_{dust} (K)	1100^{+50}_{-100}	1150^{+50}_{-100}	1000^{+100}_{-100}	800^{+50}_{-200}	650^{+20}_{-20}	700^{+100}_{-50}
a_{max} (μm)	$0.15^{+0.05}_{-0.05}$	$0.10^{+0.05}_{-0.05}$	$0.15^{+0.05}_{-0.05}$	$1.40^{+0.40}_{-0.20}$	$0.15^{+0.02}_{-0.02}$	$1.70^{+0.20}_{-0.15}$
τ_V	0.4–3.4	8.3–12.6	1.3–5.4	1.9 –4.2	0.6–8.8	3.2–5.3
A_K	0.04–0.4	0.9–1.4	0.2–0.7	0.2–0.5	0.1–1.1	0.4–0.6
$\dot{M}$ ($10^{-6} M_\odot$/yr)	2.7–3.3	9.1–13.6	4.6–9.7	4.6–9.7	0.7–10.1	8.7–13.8
v_e (km/s)	14.4–16.1	11.0–12.1	17.4–20.9	17.4–20.9	7.8–10.3	13.9–16.0

Notes: $^{(1)}$ fitted by the model; $^{(2)}$ fixed parameter defined by its spectral class and from Feast *et al.* (1983b); $^{(3)}$ fixed parameter defined by its spectral class and from Feast *et al.* (1983a); $^{(4)}$ fixed parameter defined by its spectral class and from Whitelock, Marang & Feast (2000) and Danchi *et al.* (1994); $^{(5)}$ fixed parameter defined by its spectral class and from Mikolajewska (1999)

code assumption that Mira is the only dust heating source. We find this assumption justified in our case, since the influence of the hot component on the near-IR radiation might be neglected. Namely, the hot component is too far from the inner dust shell where dust density is highest and thus it cannot warm the dust efficiently. Besides, irradiation of the dust shell from the hot component is strongly reduced by the gas nebula between the two components. The dust which is closer to the hot component is much thinner and cannot be expected to contribute significantly to the overall near-IR emission.

The model assumes a fixed outer dust shell radius 20 times larger than the inner value. In fact, the choice of any $r_{out} > 5r_{in}$ is practically irrelevant. As most of the near-IR radiation up to 5 μm originates from the warmest part of the dust shell inside a few

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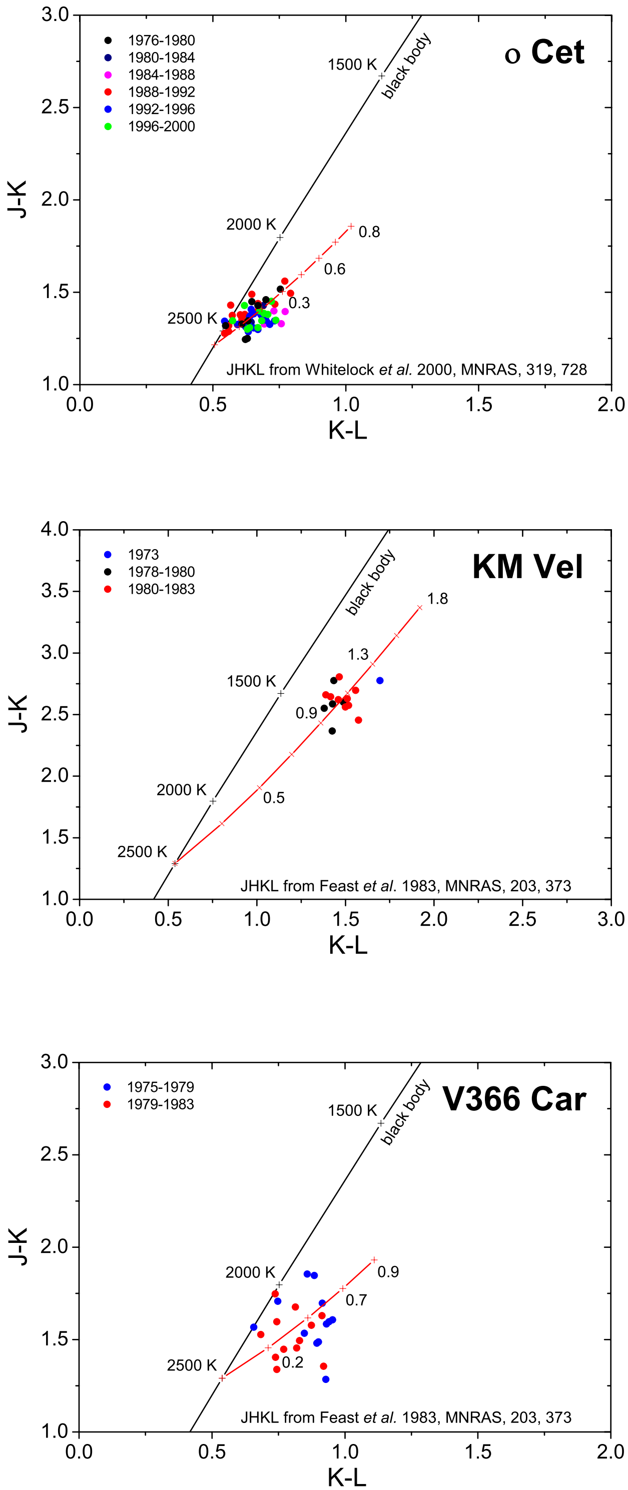

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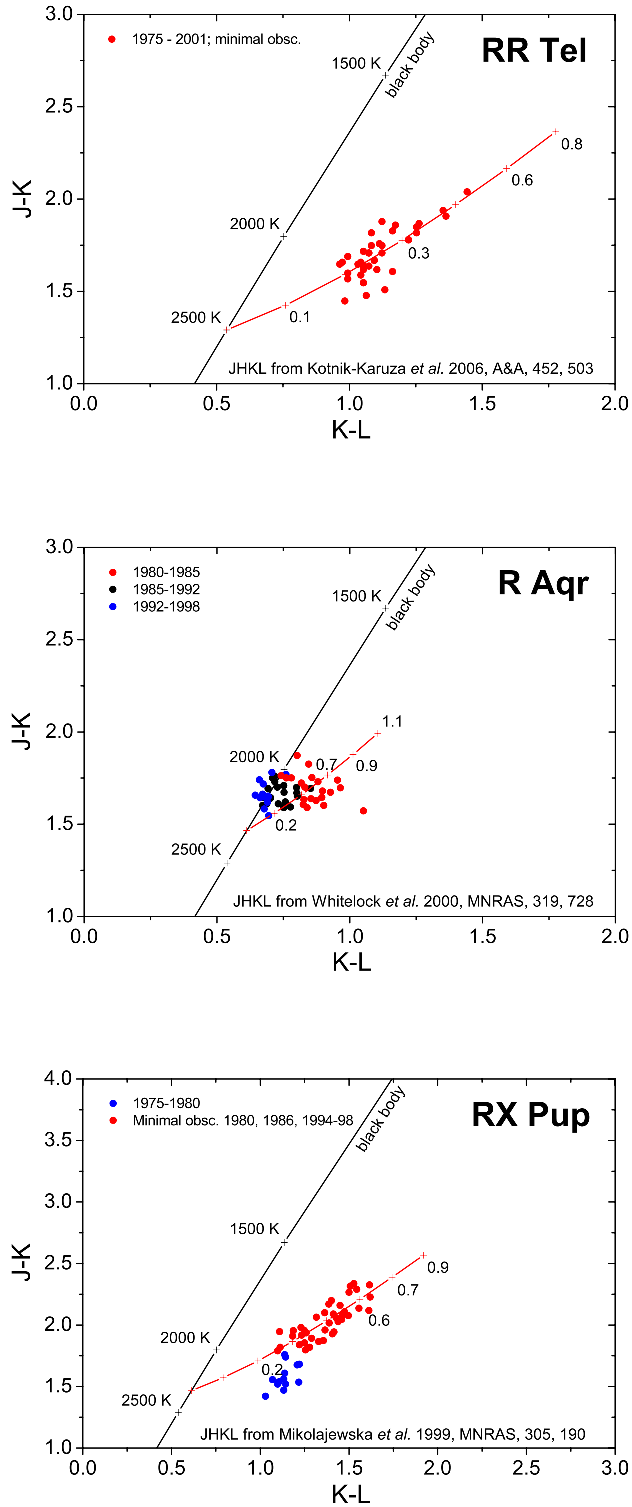

Figure 2. Two-colour diagrams of southern symbiotic Miras with theoretical models and extinctions at K (A_K) during time-intervals of minimal dust obscuration.

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tenths of the dust inner radius r_{in}, the dust far from the inner dust shell and nearer to the hot component would have a minor contribution to the near-IR emission. Also, major dust condensation takes place near the inner dust shell where dust density is highest and more enhanced by stellar wind, which means that major extinction contribution in the near-IR will come mainly from dust very near the condensation radius.

Maximum grain size varies between 0.15 and 1.70 μm. No correspondence with other parameters could be established.

Modeled mass loss rates in the interval 10^{-6} to 10^{-5} $M_{\odot}$/yr agree very well with other authors (Seaquist & Taylor 1990; Seaquist *et al.* 1993) and show increased values for symbiotic Miras relative to their normal counterparts (Loup *et al.* 1993).

An increase of optical depth and extinction with mass loss rate for different stars gives evidence that a star with higher mass outflow has more circumstellar dust which causes higher extinction.

The results published in this paper are only preliminary. Future research will also include modeling of observations in the extended near- and mid-IR wavelengths obtained from satellites and space telescopes (ISO, Spitzer Space Telescope) which will enable us to determine chemical dust composition and further constrain physical dust properties.

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