DETERMINATION OF DUST PARAMETERS AROUND SYMBIOTIC MIRAS

Tomislav Jurkić, Dubravka Kotnik-Karuza

Department of Physics, University of Rijeka, Croatia

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, as observed for at least 10 years at different epochs at SAAO, have been analyzed. The magnitudes have been corrected for interstellar reddening using visual extinctions A_v given in Table 1. In order to show only the long-term variations, the light curves were corrected for Mira pulsations by an approximate procedure. RR Tel, R Aqr and RX Pup give evidence of marked obscuration events.

We reconstructed spectral energy distribution (SED) for RR Tel at different time intervals when both JHKL magnitudes and ISO short wavelength spectra were available. Reconstructed SEDs cover the near- and mid-infrared spectral region in the periods with and without obscuration.

Modeling of circumstellar properties of the dust shell around the cool Mira component was carried out by use of the numerical code DUSTY, assuming spherical geometry, with Mira in the centre of the spherical dust shell. We used black body 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. Contrary to other Miras of the sample, o Cet stellar temperature was obtained by modeling because of its high spectral class variability. As the Mira component has strong stellar winds, envelope expansion is driven by radiation pressure on the dust grains. In the analytical approximation for radiatively driven winds the number density η is a function of the scaled radius $y = r/r_{in}$, of the initial v_i and final wind v_e velocity, while r_{in} is the inner dust shell radius (sublimation radius):

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

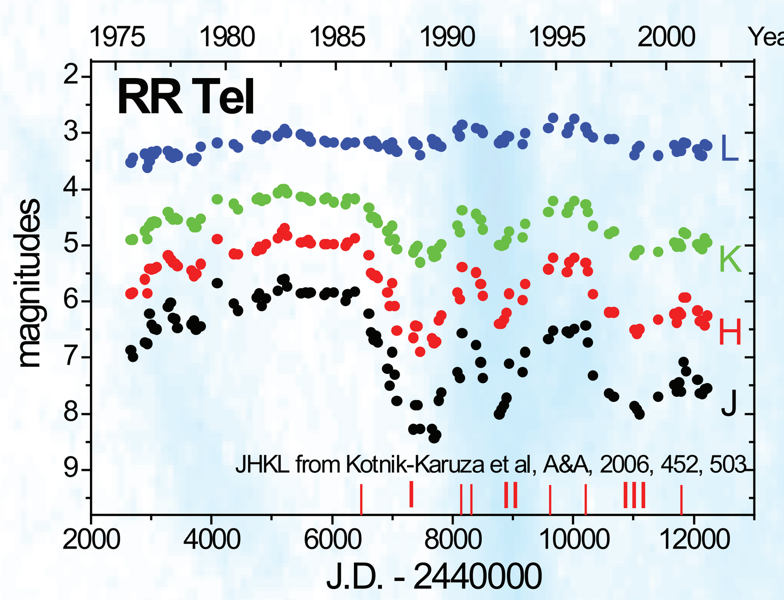
In the applied MRN dust grain size distribution $n(a) \propto a^{-q}$, ($a_{min} < a < a_{max}$), the minimum grain size of a = 0.005 μm and q = 3.5 are taken as fixed input parameters, while maximum grain size a_{max} is a free parameter determined by modeling. Dust composition typical for Mira stars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

Symbiotic Mira	*Other name*	*Spectral class*		A_v	*d (kpc)*	*P (days)*	
o Cet	HD 14386 MWC 35	Mira M2-7III	Karovska et al. 1997, ApJ, 482, L175 Whitelock et al. 1988, IAUC 103, p. 47	0.01	0.12	331-333	Whitelock et al. 2000, MNRAS, 319, 728 Kholopov et al, 1985, GCVS, Nauka Perryman et al. 1997, Hipp.Cat. ESA SP-1200
KM Vel	Hen 2-34	Mira M	Acker et al. 1988, A&AS, 73, 325 Whitelock et al. 1988, IAUC 103, p. 47	3.2	9.0	370	Feast et al. 1983a, MNRAS, 203, 373
V835 Cen	Hen 2-106	Mira M ≥ M5	Schulte-Ladbeck 1988, A&A, 189, 97	3.9	9.4	400	Feast et al. 1983a, MNRAS, 203, 373
V366 Car	Hen 2-38	Mira M6	Muerset & Schmid 1999, A&AS, 137, 473	2.8	3.8	433	Feast et al. 1983a, MNRAS, 203, 373
RR Tel	Hen 3-1811	Mira M6/M5	Allen 1980, MNRAS, 192, 521 Muerset & Schmid 1999, A&AS, 137, 473	0.3	2.5	387	Feast et al. 1983b, MNRAS, 202, 951 Penston et al. 1983, MNRAS, 202, 833 Kotnik-Karuza et al. 2006, A&A, 452, 503
R Aqr	HD 222800 MWC 400	Mira M7, M8, M4	Kenyon, 1986 Muerset & Schmid 1999, A&AS, 137, 473 Whitelock et al. 2000, MNRAS, 319, 728	0.01	0.27	383-386	Whitelock et al. 2000, MNRAS, 319, 728 Kholopov et al, 1985, GCVS, Nauka Perryman et al. 1997, Hipp.Cat. ESA SP-1200
RX Pup	HD 69190 Hen 3-138	Mira M5.5/M5	Allen 1980, MNRAS, 192, 521 Muerset & Schmid 1999, A&AS, 137, 473	2.0	3.0	580	Whitelock et al. 1983, MNRAS, 203, 363 Feast et al. 1977, MNRAS, 179, 499 Mikolajewska et al. 1999, MNRAS, 205, 190

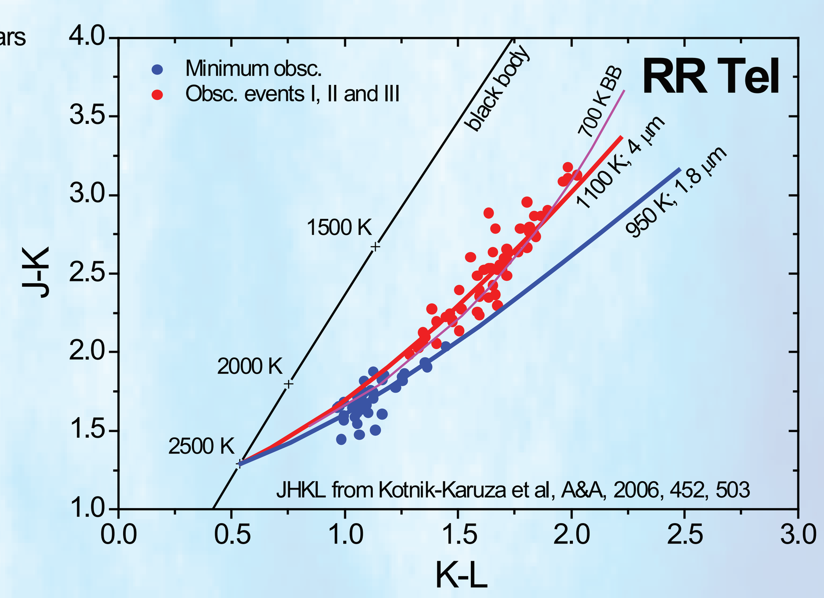
Results

RR Tel

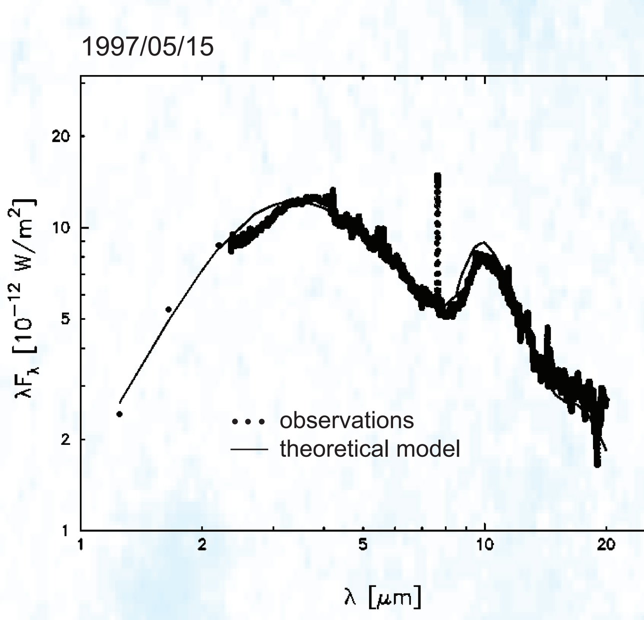
JHKL lightcurves of RR Tel corrected for Mira pulsations

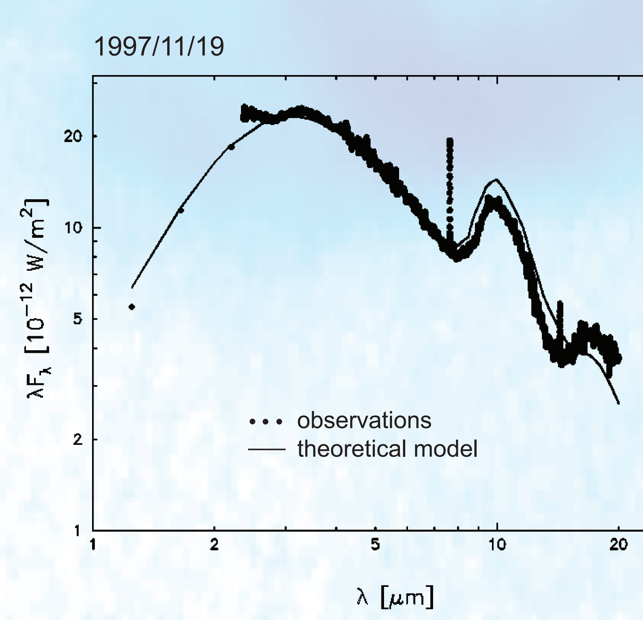


Two-colour diagram of RR Tel with theoretical models



ISO SWS spectra + SAAO JHKL during minimum obsucration
(phase difference: 0.49 - 188 days)





Obscuration	Parameters	**RR Tel**
Minimum Obscuration	T_{Mira} (K)	2500(4)
	T_{dust} (K)	950 ± 100
	a_{max} (μm)	1.8 ± 0.4
	τ_v	1.9 – 4.2
	A_K	0.23 – 0.52
	$\dot{M}$ (10^{-6} M_{Sun}/yr)	4.6 – 9.7
	v_e (km/s)	17 – 21
Obscuration Events	T_{Mira} (K)	2500
	T_{dust} (K)	1200 ± 100
	a_{max} (μm)	4.0 ± 0.5
	τ_v	4.6 – 9.5
	A_K	0.56 – 1.16
	$\dot{M}$ (10^{-6} M_{Sun}/yr)	9.7 – 17.3
	v_e (km/s)	12 – 16

RR Tel shows three distinct obscuration intervals. Single shell model with realistic physical dust properties can reproduce very well both long-term JHKL observations and ISO infrared spectra during periods with and without obscuration.

According to our results, obscuration events can be explained by the change in dust optical depth, accompanied by an increase in dust grain size and sublimation temperature. Higher dust optical depth means larger amount of dust present around Mira and hence, a higher mass loss.

Increase in dust grain size during the obscuration can be caused by grain growth as the mass loss and optical depth is increased. Sublimation temperature also rises as the larger grains can sustain higher temperatures.

Abstract

We determined circumstellar dust properties and modeled inner dust regions around the cool Mira component in a sample of symbiotic Miras which showed obscuration events during the observed time intervals. The published JHKL magnitudes of o Ceti, RX Pup, KM Vel, V366 Car, V835 Cen, RR Tel, R Aqr have been collected. In order to follow the evolution of their colours in time, their light curves were corrected by removing the Mira pulsations. Using the simultaneously available JHKL magnitudes and ISO spectra for different time intervals we obtained SEDs for RR Tel which cover the near- and mid-infrared spectral region in the periods with and without obscuration.

Assuming spherical temperature distribution of the dust in the close neighbourhood around the Mira component, the DUSTY code was used to solve the radiative transfer in order to determine the dust temperatureand its properties in each particular case. Dust temperature, grain size, density distribution and optical depth during intervals with and without obscuration have been obtained. Special attention was given to model circumstellar envelope around RR Tel.

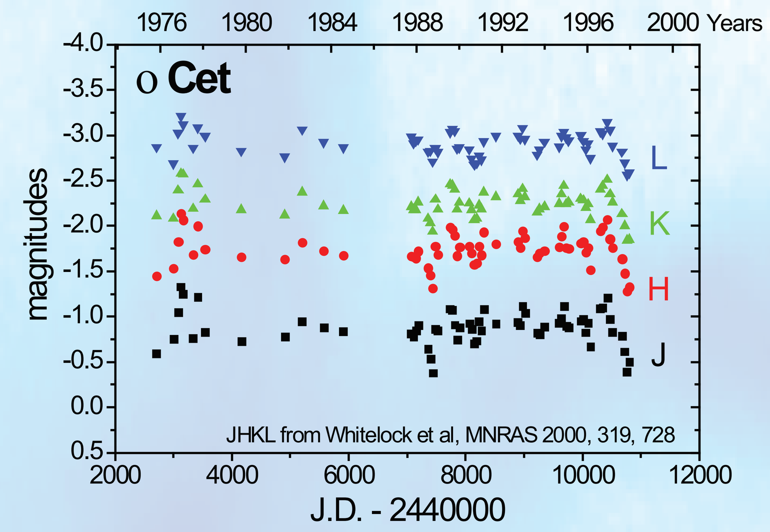
Results

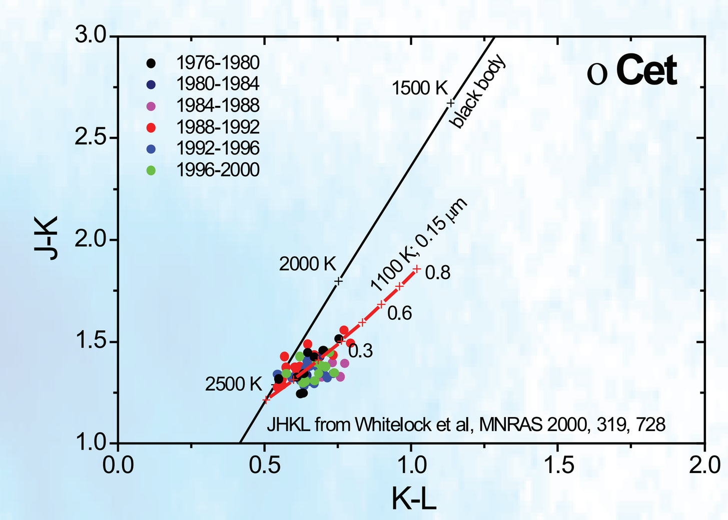
Six other southern symbiotic Miras

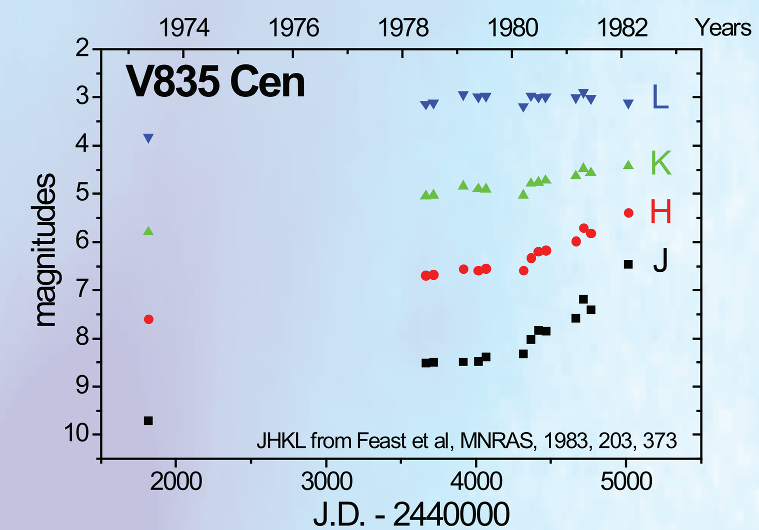
In search for possible common properties of circumstellar dust around symbiotic Miras, we have modelled six other symbiotic Miras beside RR Tel using only the long-term JHKL observations. To fully remove possible degeneracy among the dust models, near- and mid-infrared spectra are needed. Four out of six sample stars have ISO infrared spectra taken in the same period of time as the near-IR ones, so we plan to reconstruct infrared SEDs using both long-term JHKL observations and ISO spectra.

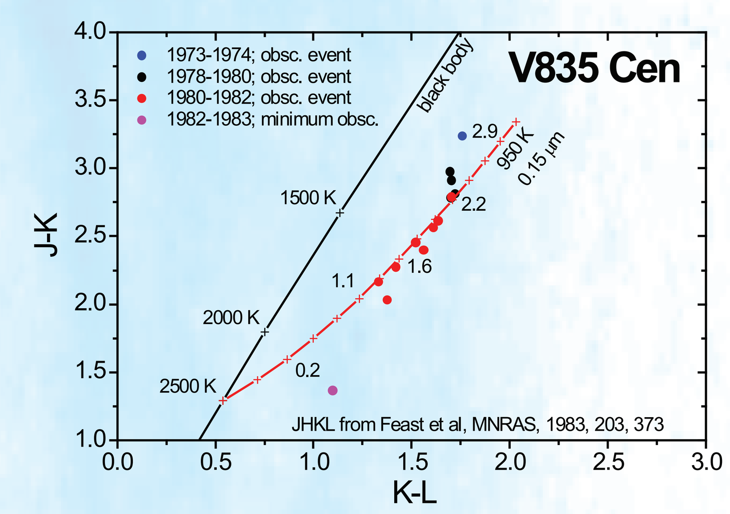
Models which use only JHKL observations but represent a good starting point for further numerical modeling of fully reconstructed SEDs are given below. We have also tested the difference between single shell model with the central heating source (Mira) and the model with two central sources (Mira and white dwarf) as the most extreme possibility. No significant differences were found.

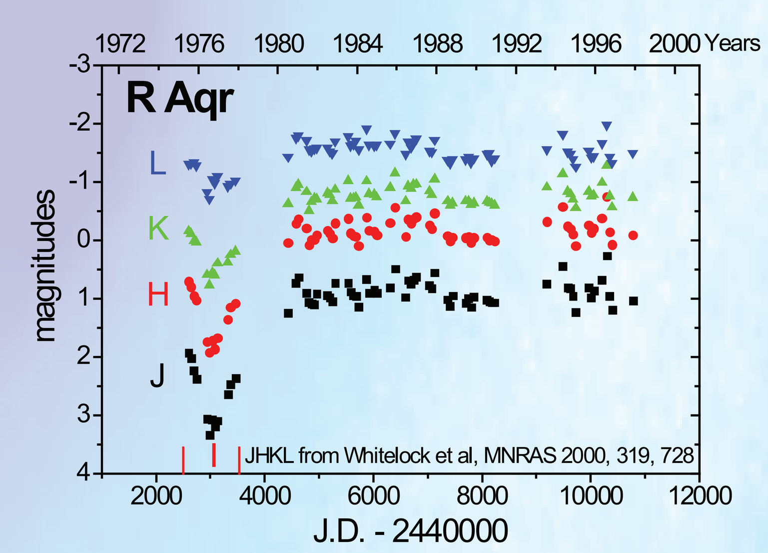
JHKL light curves corrected for Mira pulsations and two-colour diagrams with theoretical models and extinctions at K (A_K) of 4 chosen southern symbiotic Miras

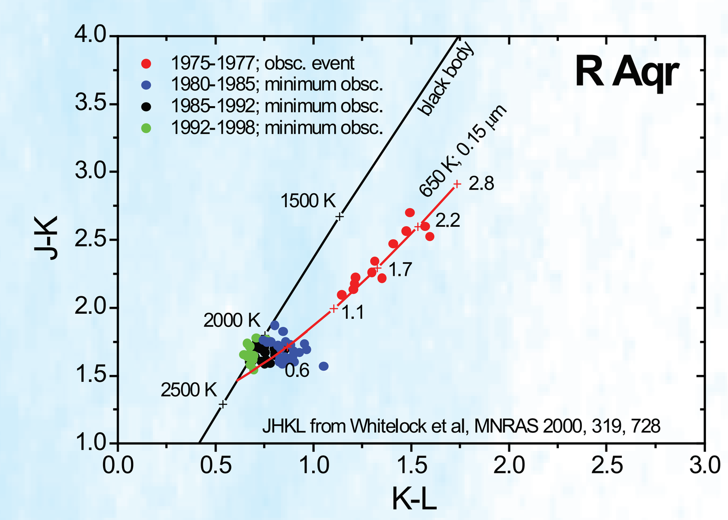


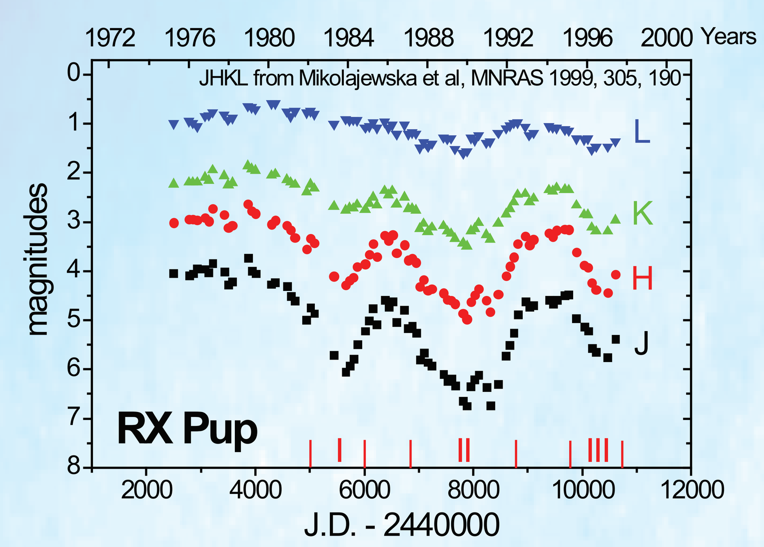


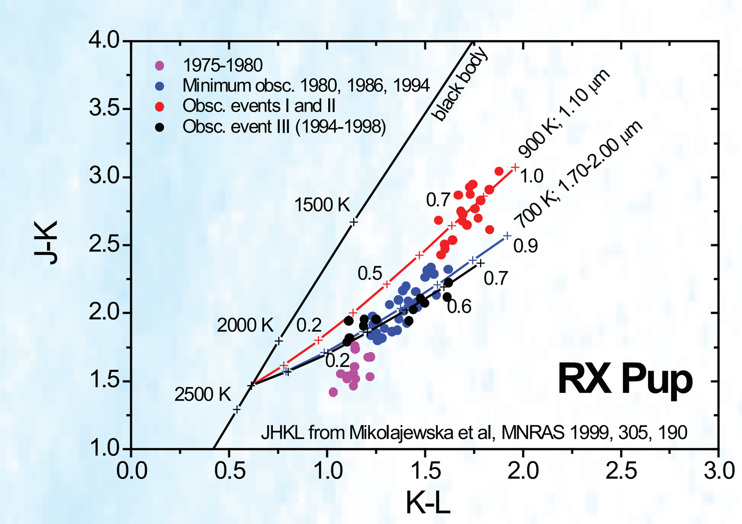












Obscuration	Parameters	Symbiotic Miras					
		o Cet	KM Vel	V835 Cen	V366 Car	R Aqr	RX Pup**
Minimum	T_{Mira} (K)	2600 (1)	2500 (2)	2500 (2)	2500 (2)	2300 (4)	2300 (5)
	T_{dust} (K)	1100 ± 100	1150 ± 100		1000 ± 100	650 ± 20	700 ± 100
	a_{max} (μm)	0.15 ± 0.05	0.10 ± 0.05		0.15 ± 0.05	0.15 ± 0.02	1.70 ±0.20
	τ_v	0.4 – 3.4	8.3 – 12.6		1.3 – 5.4	0.55 – 8.80	3.2 – 5.3
	A_K	0.05 – 0.40	0.9 – 1.4		0.2 – 0.7	0.07 – 1.07	0.4 – 0.6
	$\dot{M}$ (10^{-6} M_{Sun}/yr)	2.7 – 3.3	9 – 14		5 – 10	0.7 – 10	9 – 14
	v_e (km/s)	14 – 16	11 – 12		17 – 21	8 – 10	14 – 16
Obscuration event(s)	T_{Mira} (K)			2500	2500	2300	2300
	T_{dust} (K)			950 ± 50	1000 ± 100	650 ± 100	900 ± 50
	a_{max} (μm)			0.15 ± 0.05	0.15 ± 0.05	0.15 ± 0.05	1.10 ± 0.05
	τ_v			11.9 – 20.3	15.3	10.9 – 21.4	5.6 – 7.5
	A_K			1.3 – 2.3	1.9	1.3 – 2.6	0.6 – 0.8
	$\dot{M}$ (10^{-6} M_{Sun}/yr)			10 – 15	11	12 – 23	10 – 13
	v_e (km/s)			9 – 11	11	6 – 7	17 – 19
Obscuration event 1994 – 1998	T_{Mira} (K)		T_{Mira}	Mira temperature			2300
	T_{dust} (K)		T_{dust}	dust sublimation temperature			700 ±50
	a_{max} (μm)		a_{max}	maximum grain size			2.00 ± 0.20
	τ_v		τ_v	visual optical depth			2.5 – 5.1
	A_K		A_K	extinction at K			0.3 – 0.6
	$\dot{M}$ (10^{-6} M_{Sun}/yr)		$\dot{M}$	mass-loss rate			7 – 14
	v_e (km/s)		v_e	terminal wind velocity			14 – 17

All objects except RX Pup and RR Tel show similar dust properties – rather small grain size of up to 0.15 microns and sublimation temperature of around 1000 K, except in R Aqr where sublimation temperature is much lower. The latter agrees with interferometric studies of Danchi (1994). The only differences among symbiotic Miras come from different optical depth and mass loss rate, suggesting different amounts of dust present around Mira. Obscuration events in all Miras except in RX Pup and RR Tel show no change in sublimation temperature and grain size. These obscurations can be fully understood as a result of the change in dust optical depth. RX Pup is rather complicated object where both dust grain size and sublimation temperature change, while RR Tel shows grain growth and increase of sublimation temperature during the obscuration.

(1) fitted by the model
(2) fixed parameter defined by its spectral class and from Feast (1983a)
(3) fixed parameter defined by its spectral class and from Feast (1983b)
(4) fixed parameter defined by its spectral class and from Whitelock (2000) and Danchi (1994)
(5) fixed parameter defined by its spectral class and from Mikolajewska (1999)

** Minimum obscuration 1980, 1986 and 1994; Obscuration events I and II

Conclusion

Single-shell dust model around cold Mira with realistic grain sizes, chemical composition and radiatively driven winds can successfully explain near-infrared spectra of symbiotic binaries with Mira component. Obscuration events can be explained by dust condensed around inner dust shell radius originating from the Mira component. Modeling of RR Tel in the near- and mid-infrared gives evidence that obscuration events show change not only in dust optical depth, but also increase maximum grain size from 1.8 μm to 4.0 μm, which also affects dust sublimation temperature.

References

Danchi W. C. et al. 1994, AJ, 107, 1469
Ivezic Z., Elitzur M. 1997, MNRAS 287, 799
Ivezic Z. et al. 1999, User Manual for DUSTY, University of Kentucky Internal Report, www.pa.uky.edu/ ~ moshe/dusty
Jurkić T., Kotnik-Karuza D. 2007, Balt.Astr., 16, 76
Kotnik-Karuza D., Jurkić T., Friedjung M. 2007, Balt.Astr., 16, 98
Kotnik-Karuza D. et al. 2006, A&A, 452, 503
Mathis J.S., Rumpl W., Nordsieck K.H. 1977, ApJ, 217, 425
Mikolajewska J. 1999, in Optical and Infrared Spectroscopy of Circumstellar Matter, eds. E. W. Guenther, B. Stecklum, S. Klose, ASP Conf. Ser. 188, 291
Ossenkopf V., Henning, Th., Mathis J.S. 1992, A&A, 261, 567
Whitelock P. A. 2002, in Symbiotic stars probing stellar evolution, eds. R. L. M. Corradi, J. Mikolajewska, T. J. Mahoney, ASP Conf. Ser. 303, 41