CIRCUMSTELLAR DUST AROUND THE SYMBIOTIC MIRA RR TEL

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Observational data and methods of analysis

RR Tel JHKL magnitudes observed in the period 1975 - 2004 at SAAO have been analyzed. In order to show only the long-term variations, the Mira pulsation period was determined and the light curves were corrected for interstellar reddening and Mira pulsations. RR Tel gives evidence of obscuration events indicated in Fig. 1 (I, II and III).

The pulsation period was determined by fitting the JHKL light curves on a periodic function and in particular on a sinusoid, and by finally obtaining the residual light curve. The periodic function was fitted by dividing the light curve in bins for a chosen test period. By varying the number of bins and values of periods, the best fit was found using the least scattering method. Fitting on a sinusoid, the epochs of minima and maxima on the light curves were found by a fit on 3rd order Fourier polynomials, followed by determination of the initial pulsation epoch, pulsation period and amplitude.

By fitting JHKL magnitudes on 3rd order Fourier polynomials, we have reconstructed the spectral energy distribution (SED) of RR Tel at different time intervals when both JHKL magnitudes and ISO short wavelength spectra were available. The 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 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 2200 K and 2800 K. As the Mira component has strong stellar winds, we assumed that envelope expansion is driven by radiation pressure on the dust grains. In the analytical approximation for radiatively driven winds the number density h 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):

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

For other forms of density distribution, the power law $\eta \propto y^{-p}$ was used and power index p determined.
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 the maximum grain size a_{max} is a free parameter determined by modeling. The dust composition typical for Mira stars containing 100% warm silicates has been assumed. The 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}

Symbiotic Mira	*Other name*	*Spectral class*		A_v	*d (kpc)*	*P (days)*	
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

Results

Pulsation period

	PERIODIC FUNCTION	SINUSOID	
	Period (days)	Period (days)	JD_0
NO OBSCURATION	385.1 ± 4.8	384.3 ± 5.2	2 442 339 ± 7
OBSCURATION	386.4 ± 1.1	385.8 ± 2.3	2 442 344 ± 12
ALL INTERVALS	387.1 ± 0.8	386.8 ± 1.2	2 442 328 ± 11
Gromadzki et al, 2009		385 ± 4	2 442 303

The pulsation periods in epochs with and without obscuration have been determined using the two described methods and no statistically significant differences were found. This result suggests that there is no change in internal stellar properties which might cause obscuration influencing the dust properties. Periods obtained by two methods are almost undistinguishable, suggesting that the Mira light curve variation is mainly sinusoidal. The fitted values agree very well with recent results from other authors, but are obtained with lower uncertainty.

Conclusion

Single-shell dust model around Mira component with realistic grain sizes, chemical composition and radiatively driven winds can successfully explain near- and mid-infrared spectra of RR Tel symbiotic binary during obscuration events. Such events can be explained by dust condensed at distances beyond the inner dust shell radius and originating from the Mira component. Modeling of circumstellar dust during obscuration events gives evidence of an increase in optical depth as well as in grain size from 1.8 μm to 4.0 μm as a consequence of possible grain growth, related to the unobscured epochs.
The SED modeling in the epoch without obscuration represents quite a challenge as both almost unattanuated stellar black body and strong dust emission are present, leading to a model of thick dust region of particular non-spherical configuration.

References

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Abstract

Evolution of symbiotic Miras and interaction between the stellar environment and components of the binary system can be properly understood only by knowing the geometry and properties of the circumstellar dust. In order to find the properties and geometry of the dust surrounding the Mira component of the symbiotic binary RR Tel we used the DUSTY numerical code to model the near- and mid-IR spectra and colour indices of this star. The most prominent dust properties determined by this procedure were sublimation temperature, grain size, dust distribution, optical depth and mass loss rate. The spectral energy distribution was reconstructed from available observations during and outside obscuration epochs. Long-term changes in dust properties were determined by modelling temporal variations of colour indices. Pulsation properties and long-term periodic variability were found from the near-IR light curves. Our model of the circumstellar environment and its dynamical behaviour in RR Tel outside obscuration epochs gave evidence of an optically thin circumstellar dust envelope and an optically thick dust region outside the line of sight. Without significant obscuration by dust, the emission from the Mira can be observed almost unattenuated. Obscuration events in RR Tel are explained by an increase in optical depth caused by the newly condensed dust in the sublimation region and a higher mass loss. This leads to the formation of a compact silicate dust shell of about 1200 K sublimation temperature. The shell is shielded from the influence of the hot component.

Dust properties

Results

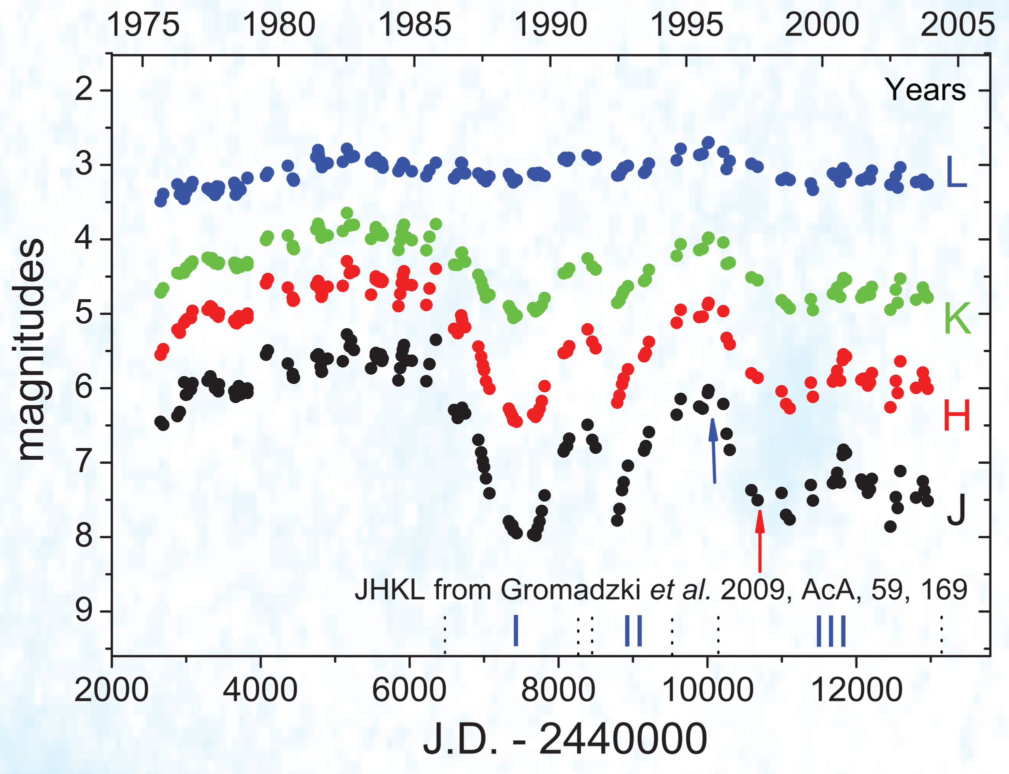

Fig.1. JHKL lightcurves of RR Tel corrected for Mira pulsations

RR Tel shows three distinct obscuration events. The single spherically-symmetric shell model with realistic physical dust properties can reproduce very well both long-term JHKL observations and ISO infrared spectra during these periods with obscuration.

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

An increase in dust grain size during obscuration can be caused by grain growth which agrees with an increase in mass loss as well as in optical depth.

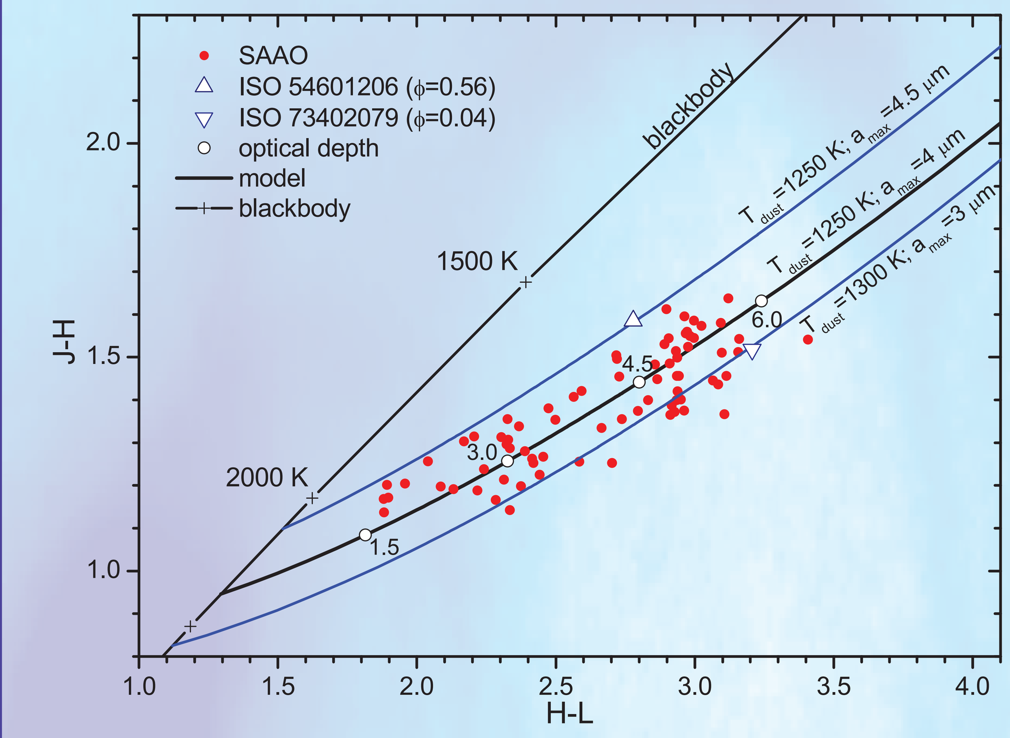

Fig.2. Two-colour diagram of RR Tel with theoretical models

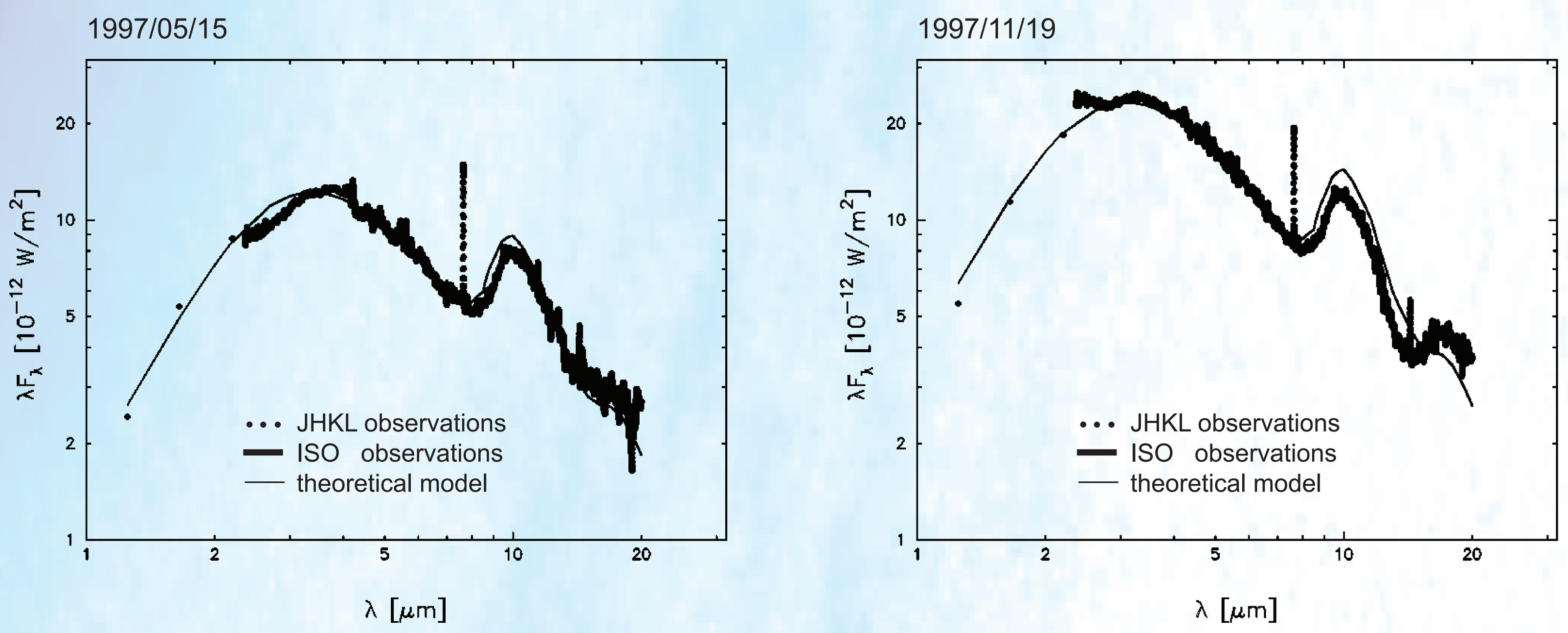

Fig.3. ISO SWS spectra + SAAO JHKL during maximum obscuration (red arrow in Fig.1) (phase difference between epochs of two SEDs: 0.49 = 188 days)

Circumstellar dust modeling of the near-infrared JHKL magnitudes in epochs without obscuration results in a very thin dust shell and in low optical depth. The SED in the epoch without obscuration clearly shows almost unattenuated Mira black body and strong dust emission. Such behaviour cannot be explained by a single dust shell, except in case of some other unknown mechanism or dust configuration which lead to a decrease of flux at wavelengths of about 3 μm. In order to explain such behaviour, we have adopted a model in which Mira is embedded in a thin dust shell and surrounded with thick probably thoroidally configured emitting dust located outside our line of sight. Our results show that the dust region does not have a disk geometry, but is rather radially distributed by a steady-state wind, though radiatively driven winds cannot be discarded.

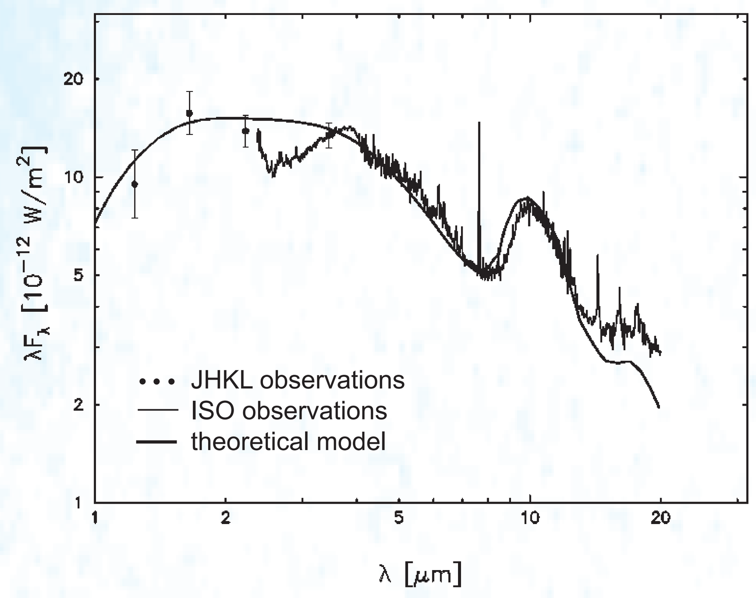

Fig.4. ISO SWS spectra + SAAO JHKL during minimum obscuration (blue arrow in Fig.1)

	OBSCURATION	NO OBSCURATION	
T_{mira} (K)	2500 ± 300	2200	
		thin shell	*'thick dust'*
T_{dust} (K)	1200 ± 100	1000 – 1200	*1200*
a_{max} (μm)	4.0 ± 1.0	0.5 – 1.0	*1.5 ± 0.5*
τ_v	5.2 – 5.8	0.4	*12.5 ± 2.5*
A_K	0.58 – 0.64	0.04	*1.38 ± 0.28*
p	rdw	rdw	*2.0 or rdw*
$\dot{M}$ (10^{-6} M_{Sun}/yr)	11 ± 1	0.4	
v_e (km/s)	26 ± 2	28	

T_{mira} Mira temperature
a_{max} maximum grain size
A_K extinction at K
$\dot{M}$ mass-loss rate
v_e terminal wind velocity
rdw radiatevely driven winds
T_{dust} dust sublimation temperature
τ_V visual optical depth
p power index in density distribution

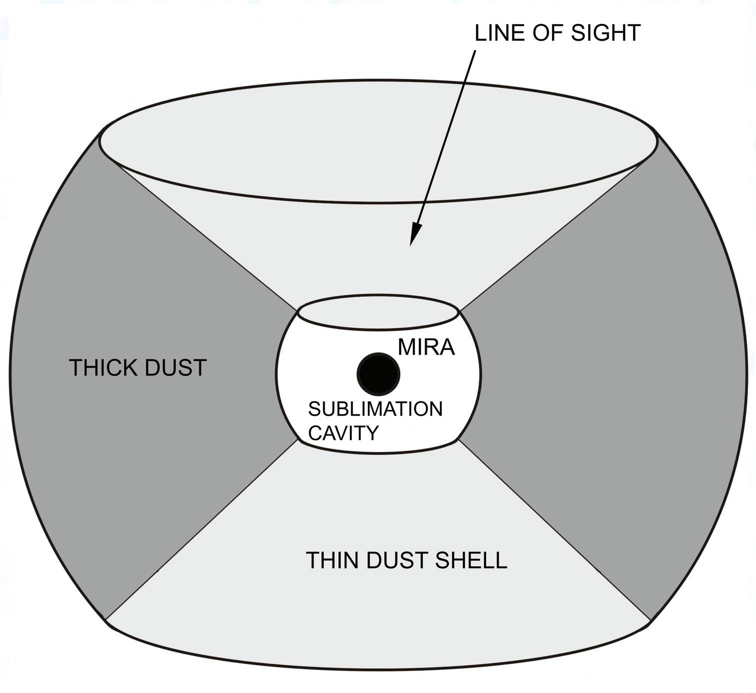

Fig.5. Two component model of circumstellar dust in RR Tel during minimum obscuration