MODELLING OF CIRCUMSTELLAR DUST AROUND SYMBIOTIC MIRA HM SGE

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Observational data and methods of analysis

HM Sge is one of the best studied symbiotic Miras, a symbiotic interacting binary with a M7 Mira star and a hot compact white dwarf. Its nova eruption in 1975 was followed by a long-lasting decline. The properties of the dust in HM Sge were determined using different observation methods - **photometry, spectroscopy and interferometry**:

1. Near-IR RIJHKLM photometry, mainly from the Crimean observatory
2. Spectral energy distribution in the range 2.3 - 15 μm observed by ISO satellite (SWS spectra)
3. Interferometric visibilities from MIDI VLT interferometer in the range 7.5 - 13 μm.

Mira pulsation period was determined from RIJHKLM magnitudes observed in the period 1978-2008. Light curves corrected for Mira pulsations give evidence of obscuration events. The pulsation period was determined using "Phase dispersion minimization" (PDM) technique. Spectral energy distribution (SED) in the range 1-15 μm was reconstructed from JHKL magnitudes and ISO spectra.

Abstract

The Mira component of symbiotic binaries is characterized by a presence of substantial dust. Determination of the properties of circumstellar dust is an essential step in understanding the evolution of symbiotic Miras, mutual interactions between the components and the circumstellar matter, influence of stellar winds and mass transfer mechanism. HM Sge is one of the best studied symbiotic Miras which underwent a nova eruption in 1976. The spectral energy distribution in the near- and mid-IR spectral range (1-15 microns) was obtained from the available long-term ground-based near-IR photometry from the Crimean observatory and from mid-IR ISO spectra. In order to further constrain the properties and distribution geometry of the dust, interferometric measurements from MIDI VLTI have been included. The DUSTY code was used to solve the radiative transfer through the dust and to determine the circumstellar dust properties of the inner dust regions around the Mira component. The near- and mid-IR SEDs and interferometric visibilities were simultaneously fitted with the theoretical DUSTY spectra and visibilities. Dust temperature, maximum grain size, dust density distribution, mass-loss rate, terminal wind velocity and optical depth have been determined. We have shown that a single silicate dust shell with a sublimation temperature of around 1200 K can explain both spectra and interferometric visibilities. The near-IR obscuration can be fully understood by increased mass loss and by condensation of dust near sublimation radius, leading to observed increase in optical depth.

Results

The single spherically-symmetric dust shell model with realistic dust properties and dust distribution determined by radiatively driven dusty stellar wind can explain both the near- and mid-IR sprectra and mid-IR interferometric visibilities. The SEDs show a presence of silicate dust with condensation/sublimation temperature increasing from 900 to 1200 K as the Mira luminosity increases. The near-IR absorption could be fully explained by scattering on larger grains of up to 3 μm in the medium of modest optical depth between 3 and 6. This solves the problem of high optical depth (>15) claimed by other authors necessary to model the mid-IR sprectra and interferometry. The mid-IR spectra and interferometry are dominated by the dust emission.

A distance of 2.45 kpc was determined from the PL relation for single Miras and from bolometric IR luminosities determined from ISO spectra. This value agrees well with estimates from other authors. It shows that the influence of the hot component on heating of the circumstellar dust in the Mira must be small, which suggests existence of strong blocking mechanism of the UV flux.

Numerical modelling

The circumstellar dust properties of the shell around the Mira component were modelled from the SEDs and from interferometry by use of the **DUSTY numerical code**. The model of the spherical dust shell centred around the Mira was used. Mira flux was approximated by the black body radiation at a temperature 2600-3000 K. The DUSTY code takes advantage of the scale invariance and self-similarity to reduce the number of free parameters. The dust density distribution was determined by stellar wind driven by radiation pressure on 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 of the final wind velocity v_e:

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

The MRN dust grain size distribution $n(a) \propto a^{-q}$, ($a_{min} < a < a_{max}$) was assumed, with the minimum grain size of a = 0.005 μm and q = 3.5 taken as fixed input parameters, while the maximum grain size a_{max} was determined by modeling. The dust composition typical for Miras containing 100% warm silicates has been used. The inner dust shell radius determined by the dust sublimation/condensation process, together with dust sublimation temperature T_{dust} was obtained.

The near-IR photometry shows a long 20-year period of steadily decreasing and increasing obscuration, and another 8-years long obscuration period. We have explained these obscuration periods by dust absorption in which new dust is formed by condensation at the inner dust shell radius during the higher mass loss. The optical depth increases while the brightness decreases more in J than in the M band.

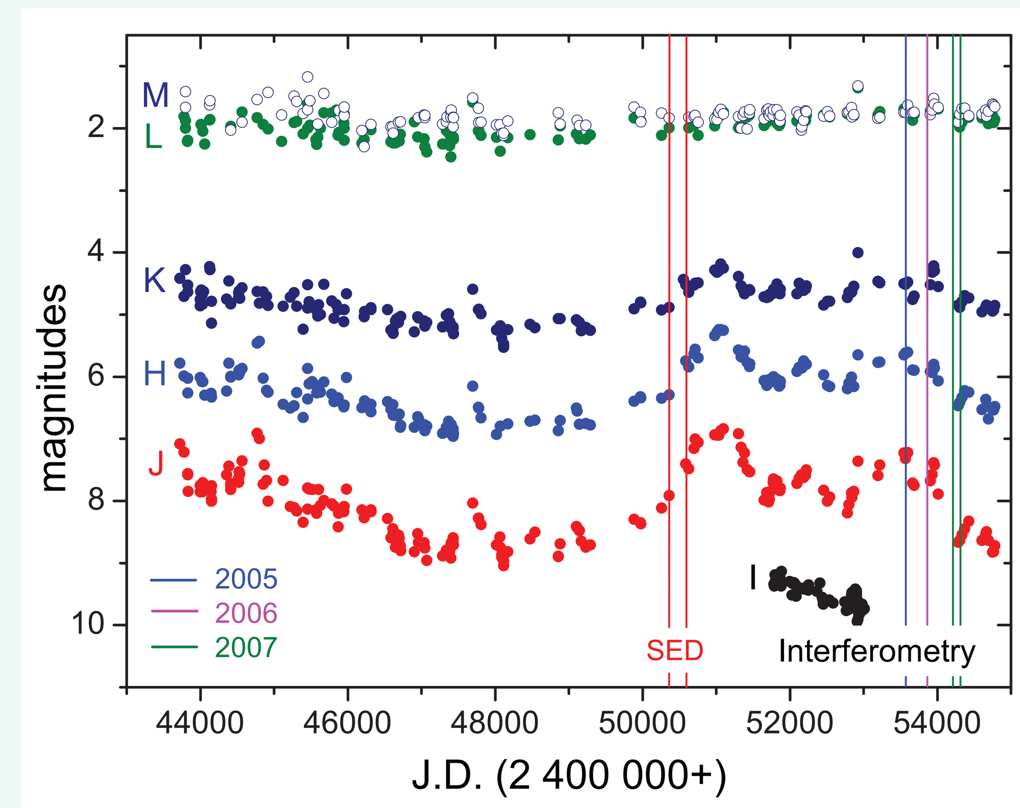
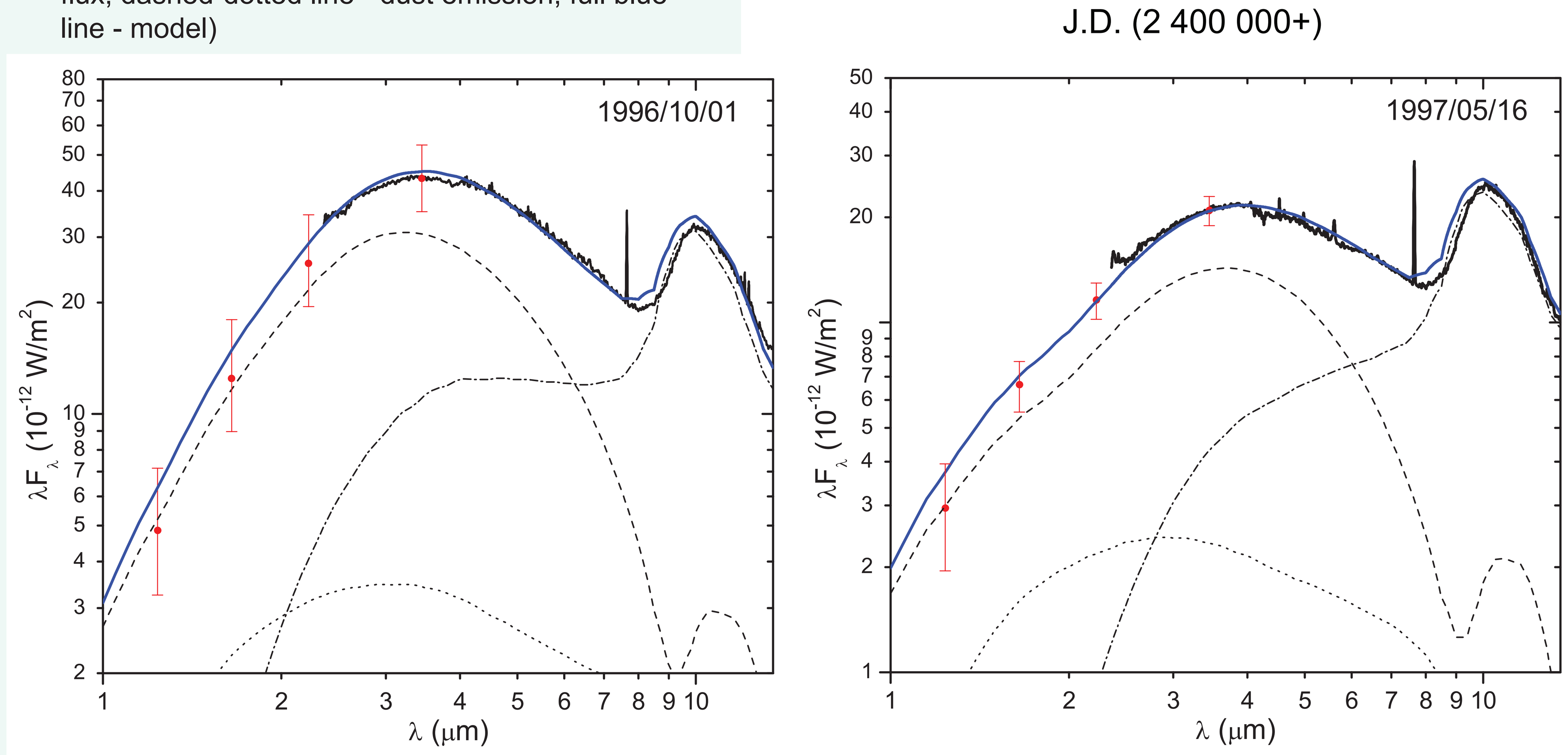


Fig. 1. Near-IR light curves corrected for Mira pulsations. Epochs of SED and interferometric observations are marked with verical lines.

Fig. 2. ISO SWS spectra + SAAO JHKL during maximum (left) and minimum (right) Mira luminosity (dashed line - scattered flux; dotted line - Mira flux; dashed-dotted line - dust emission; full blue line - model)



Pulsation period

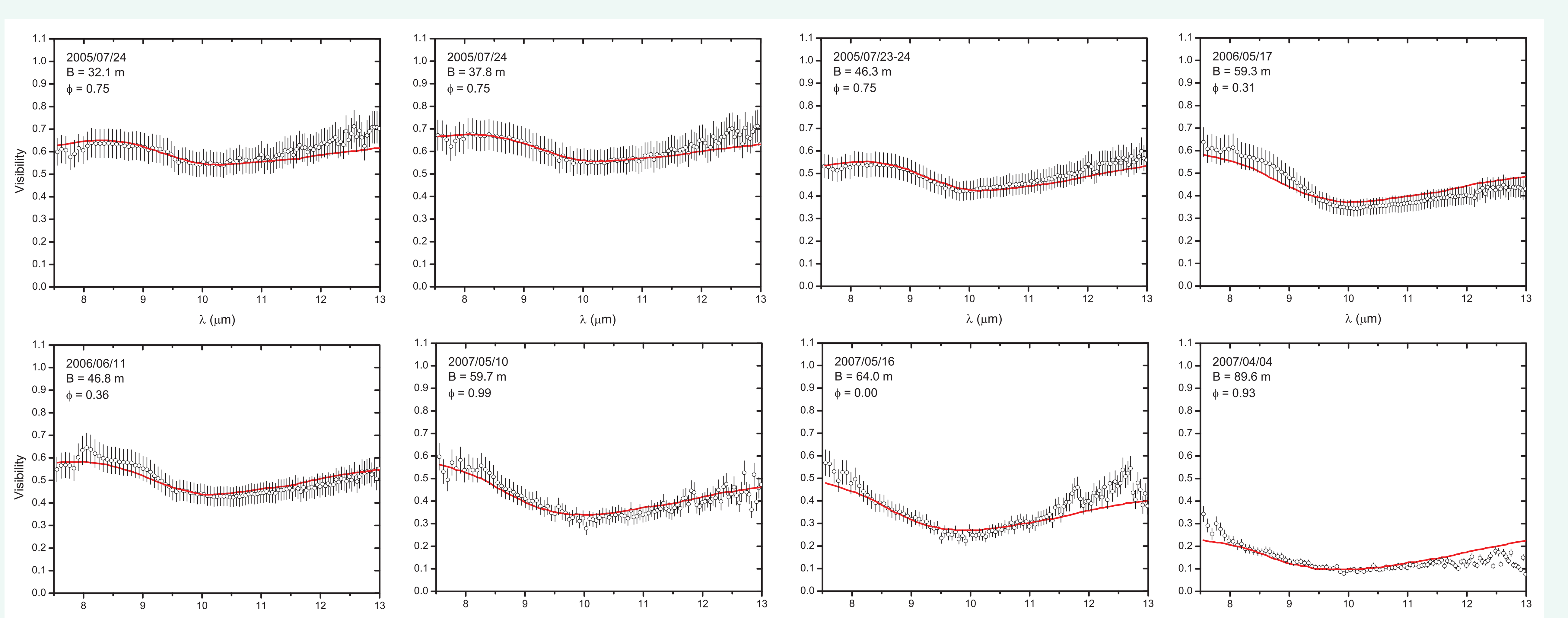
Author	Period (days)
This work	532.1 ± 0.8
Munari & Whitelock (1989)	527
Yudin et al. (1994)	
Taranova & Yudin (1983)	540
Lorenzetti et al. (1985)	

In order to successfully model interferometric visibilities in different epochs, it is important to determine more precisely the Mira pulsation period and the initial epoch of maximum brightness. The Mira pulsation period of 532.1 ± 0.8 days was found. Despite a long observational history, the Mira pulsation period fell in the large interval of 527-540 days. A statistically significant difference between the pulsation paremeters determined during the period of increasing obscuration and in subsequent period of mostly decreasing obscuration was not detected.

Interferometric visibilities

	SED		Interferometric visibilities		
Date	1996/10/01	1997/05/16	2005	2006	2007
ϕ	0.58	0.02	0.75	0.34	0.98
L (L_{Sun})	14 000	8 000	12 000	13 000	8 000
T_{dust} (K)	1200 ± 100	900 ± 100	1230 ± 80	1300 ± 100	1090 ± 50
a_{max} (μm)	3.0 ± 0.5	2.5 ± 0.5	2.8 ± 0.3	1.9 ± 0.4	1.5 ± 0.5
τ_V	6.0 ± 0.5	5.6 ± 0.5	5.7 ± 0.5	4.8 ± 1.5	3.4 ± 1.5
r_1/r_c	6.5	9.1	5.6	4.9	5.5
$\dot{M}$ (10^{-6} M_{Sun}/yr)	14.4 ± 1.5	11.1 ± 1.5	11.8 ± 1.2	8.2 ± 2.8	5.7 ± 3.8
v_e (km/s)	27 ± 3	17 ± 3	10 ± 1	12 ± 2	25 ± 6

T_{dust} dust sublimation temperature
a_{max} maximum grain size
τ_V visual optical depth
$\dot{M}$ mass-loss rate
v_e terminal wind velocity
r_1/r_c inner dust shell radius r_1 expressed in stellar radius r_c for 10 000 L_{Sun} luminosity
L Mira luminosity
ϕ Mira pulsation phase (0 for min., 0.5 for max.)



The dust properties obtained from interferometric visibilities are in agreement with values obtained from the IR SEDs. Visibilities show an increase of the inner dust shell temperature from 1000 to 1300 K with increasing Mira luminosity. Increased grain size with increasing Mira luminosity can be explained by grain growth in conditions of enhanced mass loss rate and higher dust temperature. Although sublimation temperature changes during the pulsation phase, the radius of the inner dust shell remains almost the same. It means that the distance from Mira at which the dust is formed does not change with its luminosity. An increase in the dust optical depth suggests larger amount of dust present around Mira, a higher mass loss and a stronger dusty stellar wind.

Successfull modelling of both IR spectra and mid-IR visibilities by a single dust shell heated by Mira flux only, gives evidence of small influence of the hot companion on the dust. So, an effective UV blocking mechanism must exist somewhere in the nebular region.

Conclusion

Single, compact and almost spherical stellar dust shell around Mira with radiatively driven winds can successfully explain the near- and mid-IR spectra as well as the mid-IR interferometry of HM Sge. The dust temperature at the inner dust shell radius is in the range 1100-1300 K, typical for silicate dust. A larger maximum grain size of 5 μm is needed to explain the near-IR part of the spectra and interferometric visibilities under moderate optical depths. This suggests a possible grain growth in the regime of the derived enhanced mass loss rate. Higher Mira luminosity leads to higher inner dust shell temperatures, followed by increased mass loss. Thus, favorable conditions of dust formation are met at higher dust density and higher temperature. The radius of the inner dust shell does not change significantly during the Mira pulsation, and dust is formed at approximately the same distance from the Mira, inspite of a change of the dust temperature. Our results show that an effective UV shielding mechanism must exist between the components, which allows neither significant geometrical distortions nor remarkable heating of the inner parts of the Mira dust shell.

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