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An IR view of mass loss in Long Period Variables

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Abstract. We have investigated the mass loss processes in Long Period Variables, by combining radiative transfer modeling with mid-IR imaging and spectroscopic observations. We find a correlation between variability type and temporal variations in the mass loss rate. Mira variables are more likely to maintain constant mass loss rates over long period of time. Semiregular and Irregular variables are characterized by frequent interruptions in their mass loss rate, on timescales of $\sim$ 100 yr. High resolution imaging of individual Long Period Variable sources show departures from spherical symmetry. We present the case of *o* Cet (Mira), in which the presence of a low mass companion plays an active role in shaping the circumstellar environment.

Key words. circumstellar matter – stars: mass-loss - stars: variables: other – infrared: stars – stars: individual (*o* Ceti)

1. Introduction

Intense mass loss is an important factor in the late evolutionary phases of Long Period Variables (LPVs). Mass loss processes are responsible for the creation of circumstellar envelopes of gas and dust around these stars, which will later evolve into Planetary Nebulæ (PNs). HST images of PNs reveal a rich variety of bipolar structures, including jets, shell fragments and asymmetries, which are largely unexpected in objects evolved from spherically symmetric stars. Understanding the origin of such asymmetries is thus of a crucial interest for the comprehension of mass loss processes in the latest stages of stellar evolution, and specifically in the precursor stars of PNs. This analysis is best done at infrared wavelengths where dust thermal emission peaks, since the dynamics of LPV circumstellar envelopes is dominated by the dust grains ("dust driven winds").

With this in mind, we have started a long term study of LPVs, combining radiative transfer modeling with observations performed in the mid-IR. Our results show that temporal variations in the mass loss rate and deviations from spherical symmetry are in fact common in PN precursors.

2. Radiative transfer modeling

The spectral energy distribution and broad band colors at mid-IR wavelengths provide a reliable diagnostic tool for the spatial distribution and thermodynamical condi-

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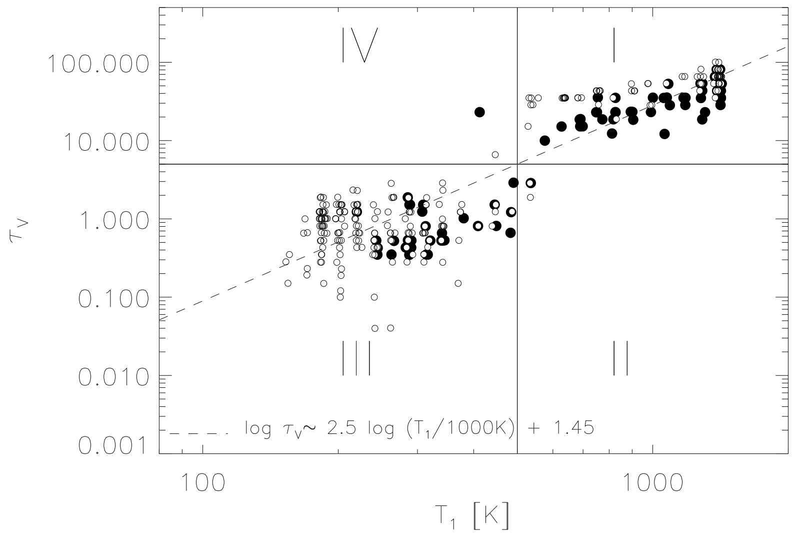

Fig. 1. Best fit parameters for our sources: Miras (filled circles) and non-Miras (open circles).

tions of LPV circumstellar dust (see e.g. Marengo et al. 1999). The two main parameters that can be derived with such analysis are the total optical depth τ_V and the temperature structure of the dust circumstellar envelope. The temperature T_1 at the inner edge of the envelope, in particular, is an indicator of either the dust condensation temperature T_{cond}, or the presence of an inner cavity depleted of hot dust. Since central cavities in circumstellar envelopes are generally associated with sudden interruption in the mass loss processes, the determination of T_1 for a large sample of LPVs would provide a method to study the temporal variations of the mass loss rate in the sample.

For these reasons we have selected a sample of 342 LPVs of which 96 Mira, 188 Semiregular and 58 Irregular variables. The sources were derived from a sample compiled by Kerschbaum & Hron (1996) with additional requirements including the availability of the IRAS Low Resolution Spectra (LRS) and O-rich chemistry. The last requirement was enforced in order to have a homogeneous sample, and because of the better diagnostics provided by the prominent 10 μm silicate feature. Following Ivezić & Elitzur (1997), we have modeled the shape of the dust emission features for all sources, deriving an estimate for τ_V and T_1. The details of our technique and a complete statistical analysis of the results are presented in Marengo, Ivezić & Knapp (2001, hereafter MIK) .

Figure 1 shows the main result of our analysis: there is a dichotomy between Mira and non-Mira variables, with 70% of the Miras having high optical depth and high dust temperature, and 70% of the non-Miras having low τ_V and temperature much below T_{cond}. This result can be interpreted as an evidence that Semiregulars and Irregulars are subjected to phases of reduced mass loss, in which the envelope detaches and expands at the stellar wind velocity. This hypothesis is supported by the best fit of the sources distribution, which is consistent with the theoretical prediction $\tau_V \sim T_1^{2.5}$ (MIK).

The two histograms in Figure 2 show the distribution of T_1 and the mass loss rate dM/dt for all sources. Miras show a

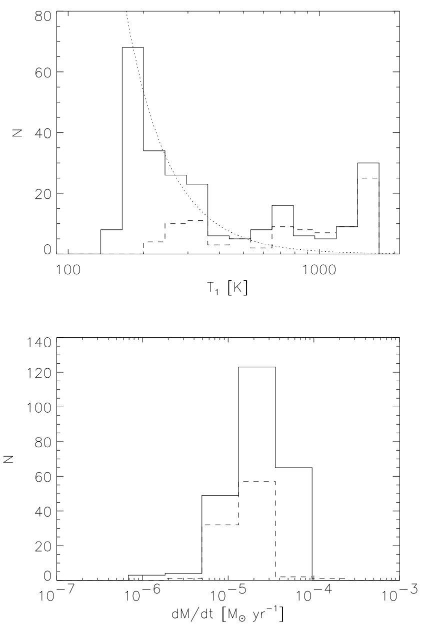

Fig. 2. Distribution of best fit T_1 and mass loss rates for our sources: Miras (dashed line) and non-Miras (solid line). The dotted line is the theoretical distribution for detached shell.

flattened distribution at the dust condensation temperature range. The distribution of non-Miras, instead, follows a $dN/dt \sim T_1^{-3.5}$ law, as expected for detached envelopes (MIK). The minimum temperature of $\sim$ 150 K for the coldest envelopes suggests a timescale of $\sim$ 100 yr as maximum duration of the reduced mass loss phase. The histogram of the source mass loss rate, on the contrary, does not show any difference between the two classes, suggesting a similar mass loss during the active phase of dust production.

In summary, this analysis suggests a different behavior in the mass loss of Mira and non-Mira type LPVs. Mira circumstellar envelopes are characterized by hotter dust which is an evidence of active dust production and mass loss. In many Semiregular and Irregular variables, on the contrary, cold dust prevails, and there are evidences of detached shells as a consequence of a temporal reduction in the mass loss rate, on timescales of $\sim$ 100 yr. These differences does not seem to be related to different mechanisms of dust production, but rather to the specific ability of maintaining a constant mass loss rate of the two classes of pulsators. Confirmation of this hypothesis can only be provided by a comprehensive theory of dust driven mass loss in LPVs, including dust condensation and two-fluid time-dependent hydrodynamics. Important steps in this directions have been made by J.M. Winters (private comm.) and Simis et al. (2001).

3. Mid-IR imaging

High resolution imaging can in principle provide a direct test for the existence of departures from "steady-state" and spherically symmetric mass loss in LPVs. Such structures can be investigated in the mid-IR by direct imaging of the thermal emission from circumstellar dust. For this reason we are carrying-on a long term campaign of mid-IR imaging of circumstellar envelopes around nearby LPVs. The project started with the cameras TIRCAM and CAMIRAS at the TIRGO (Switzerland) and San Pedro Martir (Mexico) observatories, and is continuing with the MIRAC camera at the IRTF (Mauna Kea), MMT (Arizona) and Magellan (Chile) telescopes.

Preliminary results of our observations have been published in Marengo et al. (2000). Of the MIRAC sources alone, 65% of the total show extended emission with total flux 20% above the level of a point source. Many sources have circumstellar envelopes with sizes as large as 4 arcsec, departing from spherical symmetry. In one case (W Hya) we have detected evidences of a detached envelope. In another (*o* Cet, Mira AB) we have documented the case of a binary system in which the companion star is playing an active role in shaping the common circumbinary environment.

Figure 3 shows the MIRAC/IRTF images of *o* Cet at 9.8 and 11.7 μm. The source

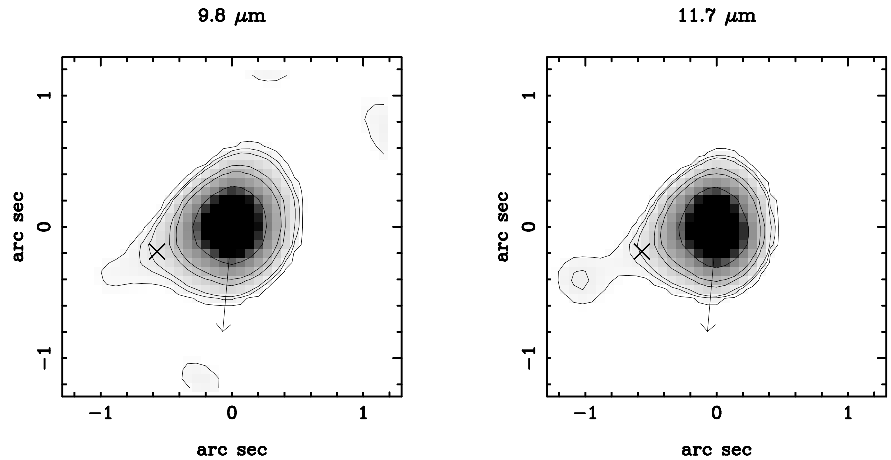

Fig. 3. 9.8 μm (left) and 11.7 μm (right) images of the Mira system. The arrow indicate the main asymmetry of Mira HST TiO images, and the cross shows the position of the companion.

appears dominated by an asymmetry in the N-S direction (PA $\sim$ 175 deg), which is consistent with the main asymmetry observed in the Mira A TiO envelope by HST (Karovska et al. 1997). The dusty envelope appears also extended in the direction of Mira B, with a separate clump at PA $\sim$ 110 deg, suggesting that Mira A envelope may be shaped by the interaction with the companion. These observations are described in detail in Marengo et al. (2001b).

4. Conclusions

Our analysis show that temporal changes in the mass loss rate of LPVs may be common, and correlated with the variability type. Mira variables show the ability to maintain constant mass loss, while non-Miras show the tendency to develop detached shells. Whenever the angular resolution is sufficient, we have been able to find indication that the dust formation in LPVs extended atmospheres produces departures from spherical symmetry. In some cases this asymmetries may be enhanced, or even determined, by the presence of a companion, as in the *o* Cet system.

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