Multiwavelength Study of HAEBE Stars with Algol-like Minima

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Abstract. The properties of circumstellar dust shells around several HAEBE stars with Algol-like minima are discussed. A numerical radiative transfer modelling technique for a spherical shell is used to fit the observed IR energy distribution, the circumstellar extinction curves (UV) and the colour-magnitude diagrams in minima. Such a simultaneous multiwavelength study enables some of the model parameters (such as optical depth, size and density distribution law of the envelope) to be found with some degree of certainty.

1 Introduction

The existence of dust shells around Herbig Ae/Be (HAEBE) stars shows itself in intense infrared (IR) emission and extinction of stellar radiation. Hence for the properties of circumstellar dust to be studied, it is reasonable to construct infrared spectra of the stars (Hartmann et al. 1993; Hillenbrand et al. 1992; Natta et al. 1993) as well as circumstellar extinction curves in ultraviolet (Voshchinnikov et al. 1995) and to compare them with the observational data. However, simultaneous modelling the far-ultraviolet (UV) through far-IR observations for dust embedded stars provides a better chance to strengthen constraints on dust grain properties (see e.g. Sorrell 1990).

For the group of HAEBE stars with non-periodic Algol-like brightness minima (UX Ori, WW Vul, etc), the observations of the brightness variations may tell something about the circumstellar (CS) dust environments as well (Voshchinnikov 1989).

Here we report the results of a multiwavelength modelling for a few UX Ori-like stars taking into account their colour-indexes behaviour in minima. Note that in previous papers there were no attempts to fit IR spectrum, colour-magnitude diagrams, and CS extinction curve simultaneously.

2 Model

To model radiative transfer in a spherical dust envelope with a power-law dust density distribution the numerical code described by Chini et. al. (1986) with some modifications is used. Inner boundary of the shell is determined by evaporation of dust particles. It is assumed that non-periodic Algol-like minima are caused by circumstellar dust clouds, that move around the star and screen it from time to time inducing the "blueing" effect (Grinin, 1988). The diffuse dust in the envelope responsible for this effect is held to be as in MRN-mixture of graphite and silicate grains.

In such a manner we have modeled, for each star, the spectral energy distribution (SED) in IR region, the variation of the colour-indexes (U-B, B-V, V-R, V-I, V-J, V-H, and V-K) with the stellar brightness, and the circumstellar extinction curves with the following parameters — dust shell: inner R_i and outer R_o radii, exponent of the dust density distribution law α, optical depth τ; dust grains: minimum a_{min} and maximum a_{max} sizes, index of the size power-law distribution q, and graphite and silicate particles ratio n_C/n_{Si}. For more details about the approach and modelling technique see Krivova (1995).

3 Stars

We considered five HAEBE stars with non-periodic minima of the brightness — UX Ori, WW Vul, BF Ori, CQ Tau, and NX Pup. For each of them, we have collected from the literature the observed fluxes from UV to IR and the brightness variations with time in the U, B, V, R, I bands. The fluxes are reduced for interstellar extinction using the available distances and colour excesses E_{B-V}. For NX Pup the observations in the UV from the IUE and ANS satellites were also used (de Boer 1977; Tjin A Djie et al. 1989).

The main observational characteristics of the stars are listed in Table 1 (top part).

Table 1. Observational characteristics of the stars and parameters of the models

Star	UX Ori	WW Vul	BF Ori	CQ Tau	NX Pup
Maximum visual brightness, m_V	9.61	10.25	9.55	9.48	9.84
Max. brightness variation, Δm_V	2.73	2.37	2.88	1.77	1.32
Spectral type	A1-A4	A0-A2	A0-A2	A2-A8	A0-A2
Luminosity, $L/L_\odot$	55	80	50	25	70
Distance, pc	450	550	400	200	450
Colour excess E_{B-V}, total	0.15	0.35	0.11–0.16	0.6	0.5–0.6
E_{B-V}, interstellar	0.06	$\gtrsim$0.2	–	0.3	0
Density distribution, α	-1.4	-1.5	-1.5	-1.0	-1.3
Optical thickness, τ_V	0.3	0.3	0.2	0.8–0.9	1.0–1.2
Inner boundary R_i, AU	1.5	2	2.5	1	2
Outer boundary R_o, AU	$\sim 4 \times 10^4$	$\sim 2 \times 10^4$	$\sim 5 \times 10^4$	$\sim 3 \times 10^3$	$\sim 3 \times 10^4$

4 Results

In an attempt to understand the parameter dependences of the results, numerous calculations have been made. We have drawn the following conclusions:

- fitting the IR SEDs has a potential for yielding information about the density distribution (α), optical depth (τ), and inner radius (R_i) of the shell;
- fitting the colour-magnitude diagrams enables to strengthen constraints on the optical depth and give an insight into albedo of grains;
- to clear up a point of the dust mixture one has also to take a look at the modelling of CS extinction curves.

Figure 1 presents two models of the dust envelope of NX Pup. The models differ by the grain mixture used. The parameters of the shell are identical to those listed in Table 1.

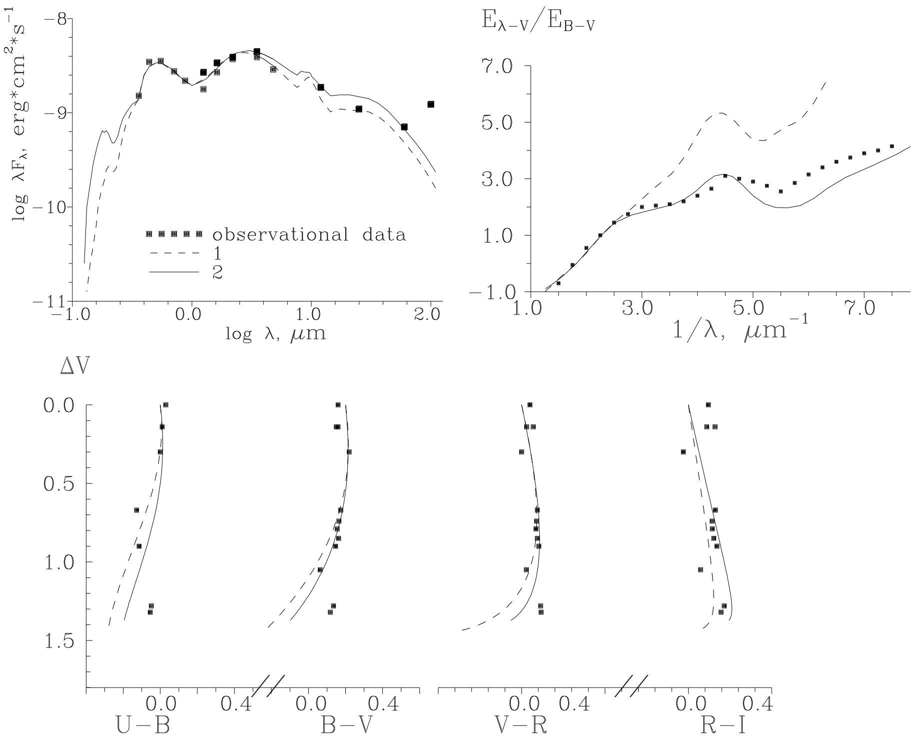

Fig. 1. IR spectra, CS curves, and colour-magnitude diagrams for shell models of NX Pup. Shell parameters: see Table 1. Dust mixture parameters: model 1 — $a_{min} = 0.06\mu m, a_{max} = 0.24\mu m, q = 5.0$ (obtained by Voshchinnikov and Grinin, 1991 for WW Vul); model 2 — $a_{min} = 0.0075\mu m, a_{max} = 0.96\mu m, q = 1.0$, without grains with $a = 0.03 - 0.2\mu m$

The results of the modelling for other stars are also presented in Table 1. In the same manner as in the case of NX Pup, the shell parameters were obtained using more that one grain mixture. It should be noticed that our objects fell into two groups — dust density in the deeper shells seems to have slower decrease to the outside.

Unfortunately, lack of reliable UV data as well as of information about the interstellar extinction in front of the stars makes it difficult to discuss the grain mixture properties.

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