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Voshchinnikov, N.V.; Molster, F.J.; The, P.S.

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CIRCUMSTELLAR DUST AND CIRCUMSTELLAR EXTINCTION CURVES

N.V. VOSHCHINNIKOV

Astronomical Institute, St. Petersburg University, St. Petersburg, 198904 Russia

and

F.J. MOLSTER and P.S. THÉ

*Astronomical Institute "Anton Pannekoek", University of Amsterdam, Amsterdam,
The Netherlands*

Abstract. We have calculated the circumstellar extinction curves produced by dust grains which absorb and scatter the stellar radiation in the shells of pre-main-sequence stars. A Monte Carlo method was used to model the radiative transfer in non-spherical shells. The dependence on the particle size distribution and the dust shell parameters has been examined.

The application of the theoretical results to explain the extinction and polarization of the Herbig Be star HD 45677 shows that the dust shell is not disk-like and that very small grains are absent in it.

Key words: circumstellar matter – stars: pre-main-sequence – dust – extinction

1. Introduction

Many stars are surrounded by dust shells. They are primarily revealed by the IR excesses and variable intrinsic polarization. Another observational feature detected from the UV observations is the significant deviation of the extinction curves for hot young stars from the average interstellar extinction law which was treated as anomalous extinction (Steenman & Thé, 1991). It was observed for many Herbig Ae/Be stars (*e.g.* Sitko *et al.* 1981 and Thé *et al.* 1985) which are sufficiently bright in the UV and do not have numerous molecular bands as in late-type stars.

We consider the circumstellar (CS) extinction taking into account not only the obscured stellar radiation but also the light scattered by dust in the shell. A more detailed analysis will be published elsewhere (Voshchinnikov *et al.* 1994).

2. Model

We assume that the star lies in the center of a homogeneous oblate spheroidal shell with a central cavity free of dust and calculate the Stokes vector of the produced radiation. Its first parameter $[I(\lambda)]$ is the sum of the stellar brightness obscured by dust in the line of sight $[I_*(\lambda) \cdot e^{-\tau^{\text{ext}}(\lambda)}]$ and the scattered radiation $[I_{\text{sca}}(\lambda)]$. It may be used to define the curves of “the

Fig. 1. Wavelength dependencies of the normalized intensity (Mie scattering, standard MRN mixture: $a_- = 0.005 \mu\text{m}$, $a_+ = 0.25 \mu\text{m}$, $q = 3.5$, $n_{\text{Si}}/n_{\text{C}} = 1.07$, $\tau_{90}^{\text{ext}}(0.55 \mu\text{m}) = 0.3$). Solid lines: total radiation, short-dashed lines: scattered radiation, dot-dashed lines: obscured stellar radiation.

circumstellar extinction”

$$A^{\text{cs}}(\lambda) = -2.5 \log [I(\lambda)/I_*(\lambda)] = -2.5 \log \left[e^{-\tau_i^{\text{ext}}(\lambda)} + I_{\text{sca}}(\lambda)/I_*(\lambda) \right]. \quad (1)$$

Here, $\tau_i^{\text{ext}}(\lambda)$ is the optical path of the stellar radiation inside the shell in the direction of an observer.

We considered shells with various aspect ratios (A/B), viewing angles (i), and the optical thicknesses along the main axis [$\tau_{90}^{\text{ext}}(\lambda_0)$]. The properties of the CS dust were modeled by changing the parameters of the silicate-graphite mixtures of grains (MRN mixture; Mathis *et al.* 1977): the lower (a_-) and upper (a_+) size cutoffs, the index of the power-law size distribution (q), and the ratio of the number densities of silicate and graphite grains ($n_{\text{Si}}/n_{\text{C}}$).

The detailed description of the model is presented in the paper of Voshchinnikov & Karjukin (1994).

3. Some Results

Numerous calculations have been made to understand how the scattered radiation alters the CS extinction. Fig. 1 – 3 show the intensity and extinc-

Fig. 2. Wavelength dependencies of the non-normalized extinction for the same model as in Fig. 1. Solid lines: "circumstellar" extinction (with the scattered radiation), dashed lines: "interstellar" extinction (without the scattered radiation).

Fig. 3. The same as in Fig. 2, but now for the normalized extinction.

tion curves for four different cases of the shell shape and viewing angle. It is seen (Fig. 2) that the scattered radiation always dilutes the non-normalized extinction. Its influence on the normalized circumstellar extinction curves $A^{\text{CS}}(\lambda)/A^{\text{CS}}(V)$ (see Fig. 3) is maximal for shells seen pole-on.

It should be noted that the observations of the extinction in the UV (especially at $\lambda < 1600 \text{ \AA}$) as well as of the intrinsic polarization are very important to constrain the parameters of dust grain models.

We used the results of our modelling to interpret the observations of the pre-main-sequence star HD 45677 (B2: IV [e]) possessing a circumstellar dust shell (Grady *et al.* 1994). Its extinction curve shows a small 2200 $\text{\AA}$ -feature and a flat extinction in the far-UV (Sitko *et al.* 1981). Besides this, polarization reversal was discovered near $\lambda \approx 2400 \text{ \AA}$ (Schulte-Ladbeck *et al.* 1992). The main observational features can be explained if we choose a model with the following parameters — dust grains: $a_- = 0.05 \text{ \mu m}$, $a_+ = 0.25 \text{ \mu m}$, $q = 5.0$, $n_{\text{Si}}/n_{\text{C}} = 1.07$; dust shell: $A/B = 2$, $\tau_{90}^{\text{ext}}(0.15 \text{ \mu m}) = 2.1$, $i = 90^\circ$, i.e. oriented edge-on. The main discrepancy found between theory and observations concerns the polarization at $\lambda < 2000 \text{ \AA}$. Apparently, it may be reduced by varying the grain size distribution.

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