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# THE INFLUENCE OF GRAIN GROWTH IN CIRCUMSTELLAR DUST ENVELOPES ON OBSERVED COLORS AND POLARIZATION OF SOME ERUPTIVE STARS

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The existence of gas and dust envelopes for many types of stars is well known. R CrB stars are classical examples of stars where dust envelope formation takes place. Dust envelope formation was detected around the Kuwano-Honda object (PU Vul) in 1980-1981 when the star's brightness fell to  $8^m$ . Such envelopes are also formed at nova outbursts. The process of dust envelope formation leads to appreciable variations in optical characteristics, which are seen in specific color and polarization variations in the course of light fading and the appearance of IR radiation.

The main features observed are 1) a light decrease of several magnitudes; 2) the asymmetric shapes of minima with a steep decrease and slow increase in light; 3) different amplitudes and durations of the minima; 4) the delay in minima at long wavelength with respect to the minima at short wavelength, as was observed at the time of deep minimum of PU Vul in 1980 by Kolotilov (1983); 5) the reddening of a star at the beginning and end of minima and the bluing at the centers of minima (typical of R CrB minima that were detected at the minimum of PU Vul in 1980); 6) rapid color variations at the "bottoms" of the minima; 7) exponential increase in the degree of polarization with decreasing light (as it was observed in R CrB in 1977); 8) coincidence of a polarization peak with a peak of bluing at the center of light minimum; 9) the rise of polarization up to 5-14% at the center of the minimum (observed on R CrB); 10) variation of the shape of wavelength dependence of polarization from a flat to a convex shape with the polarization maximum shifted toward long wavelengths at the time of decreasing light; 11) different values for the polarization maximum for the same amplitudes of photometric variations (observed on R CrB).

The explanation of all these features is difficult. One source of confusion may be due to the ignoring of change of optical parameters of dust particles as they grow during dust envelope formation from a thousandth part of a micrometer at the beginning to submicrometer size at the end of the process. In fact, all optical properties of dust grains are strongly dependent on the composition, shape, and size of the grains. Hence, for particles of any material and constant geometry, size variations lead to variations in the optical characteristics of particles. This implies that optical parameters of dust in the circumstellar envelope will change too.

For simplicity consider the case of a star with a thin dust circumstellar envelope of uniform density consisting of identical particles. At any wavelength  $\lambda$  the light decrease will be

$$\Delta m = 1.086\pi a^2 Q_\lambda^e n l ,$$

where  $a$  is the size of particles,  $Q_\lambda^e$  is the extinction factor,  $n$  is the number density, and  $l$  is the geometrical depth in the line of sight. The extinction factor  $Q_\lambda^e$  is the only parameter which is wavelength-dependent. For a given type of particle, the extinction factor depends on the ratio of the particle radius to the wavelength (figure 1). It is clear that for the same value of the extinction factor, in particular, its extrema will correspond to different sizes of particles. If we assume that the size of particles grows linearly with time, it follows that extinction factor extrema will come later than those in the short wavelength region. Just such a phenomenon was detected by Kolotilov (1983) in the deep minima of PU Vul in 1980.

It is known from the optics of small particles that the shape of the  $Q_{\lambda}^e$  curve may be very complex, with several local maxima with decreasing amplitudes and increasing separations. At various wavelengths the shapes of  $Q_{\lambda}^e$  curves are similar, but differ from each other in amplitude at the same radius. Thus, at each moment in time, a given particle's size corresponds to different values of extinction factors  $Q_{\lambda}^e$  at different wavelengths. This implies that variations in color index, for example, B-V, are determined by the variations of difference  $Q_B^e - Q_V^e$ . The color-index amplitude

$$\Delta(B-V) = 1.086\pi a^2(Q_B^e - Q_V^e)nl$$

may be variable as well, and its sign may be reversed several times depending on the composition of particles. For silicate-like particles with weak absorption, the sign reversals occur more often than for particles of material with high absorption like graphite or iron. This feature may be used as a rough diagnosis of dust composition (see figure 2).

Formulae for the color index and for the light amplitude also contain parameters  $n$  and  $l$  which are characteristic of stellar envelope. To eliminate or reduce these poorly known factors which depend on the envelope's composition one may consider the ratio  $\Delta(B-V)/\Delta V = Q_V^e/(Q_B^e - Q_V^e)$ . This ratio is a function only of dust properties. It is of interest to construct the  $Q_V^e, Q_B^e - Q_V^e$  diagram as shown in figure 3. The main features of such diagrams are 1) an approximately linear growth of  $Q_B^e - Q_V^e$  from zero to a maximum value which is followed by a sign reversal. The succeeding growth of particles leads to more negative values of the difference of  $Q_B^e - Q_V^e$  with minimal variations of  $Q_V^e$  near its maximum value. It is equivalent to the "bluing" observed in the minima of eruptive stars with dust envelopes. When the size of particles reaches 0.2 to 0.5  $\mu\text{m}$  for silicates or little more than 0.1  $\mu\text{m}$  for graphite-like particles, rapid sign reversals may be seen, as was observed at the time of deep minimum of PU Vul in 1980 (see figure 4). The continued growth of the particles leads to neutral absorption by dust envelope and the star's color returns to its initial value.

The increasing of dust particles' size also increases the radial pressure, however. This leads to the acceleration of particles to velocities at which large particles are destroyed by collision. Small particles are then again dominant in the expelled envelope. This may explain the reddening observed at the rising branch of the minima of R CrB stars (see figure 5). The similarity between the  $Q_V^e, Q_B^e - Q_V^e$  diagram and the color-magnitude diagram for PU Vul and R CrB is seen in figures 4-6. Comparison of corresponding parts of the diagrams can give a rough estimate of the mean size of the dust particles. Similar effects may also occur in optically thick envelopes as shown by Daniel (1978). Light scattering in the envelope limits the amplitude of minimum to a value which depends on the contribution of scattered radiation to total radiation and may lead to some compensation of reddening by the contribution of blue radiation from the scattered light.

Evidence of particle growth can be obtained from the shift of polarization maximum toward long wavelengths at the time of decreasing light. If particles are nonsymmetric, then any suitable alignment mechanism can lead to significant polarization. It is clear that in a system containing a star and a flattened envelope, the polarization may reach very high values (~33% in a disk-like electron envelope) if unpolarized light from a star is obscured by the dust screen. In such a case maximum polarization will occur at the time of light minimum and a nonlinear correlation between polarization and stellar brightness is expected. Such correlation was first observed at the time of the R CrB minimum in 1977 when polarization rose to 14% in the visual and the stellar magnitude fell to 8<sup>m</sup> (see figure 6).

Since the degree of polarization depends on the contribution of polarized light from the envelope and on the fraction of aligned particles in the line of sight, any reduction of the polarization factors leads to a rapid decrease of polarization without any effect on the total absorption. Consequently, there may be events when different polarization is observed at the same light amplitudes (as found in various minima of  $\delta$  CrB). The behaviour of the polarization angle will vary depending on the polarization mechanism.

Hence, the model of a circumstellar dust envelope with aligned particles of changing size can be successfully applied to explain most phenomena observed at the time of light minima for a number of eruptive stars. The polarization may arise in a nonspherical dust envelope or be produced by alignment of nonspherical particles. Such a model may be useful to study similar phenomena in other types of stars. These results will be published elsewhere (Efimov, 1988) in more detail.

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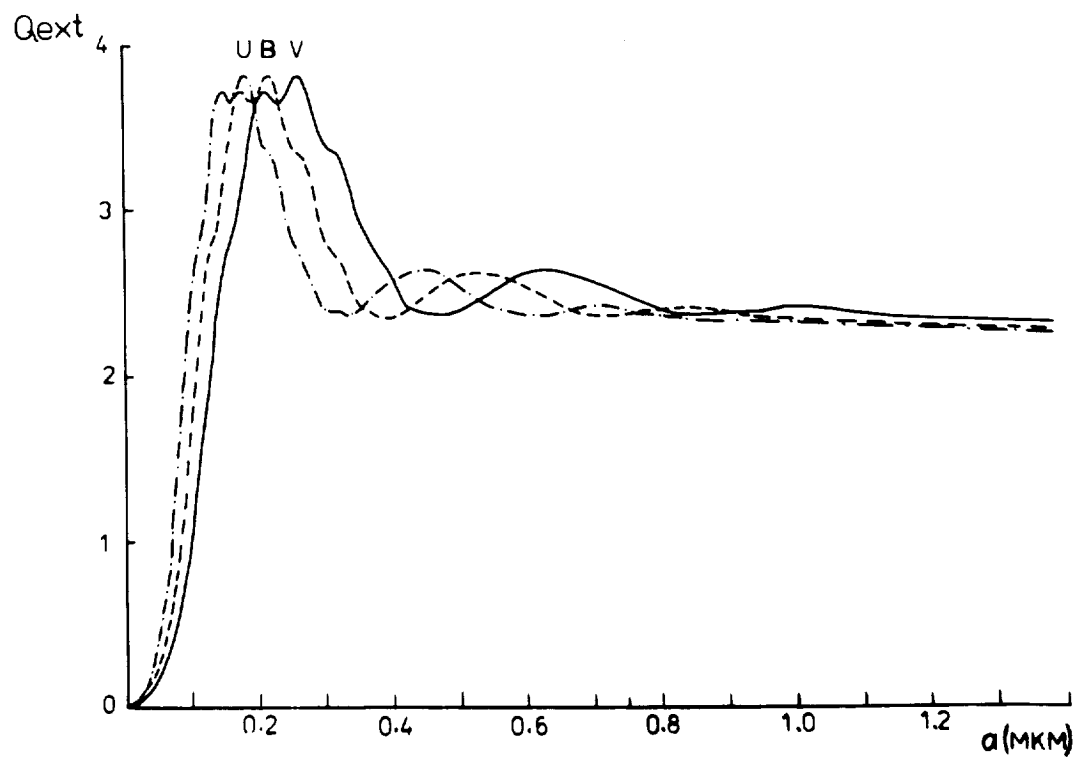


Figure 1.— The dependence of  $Q_{\lambda}^e$  on radius of particles  $a$  (micrometers) in the UVB system for silicate (Dorschner, 1970).

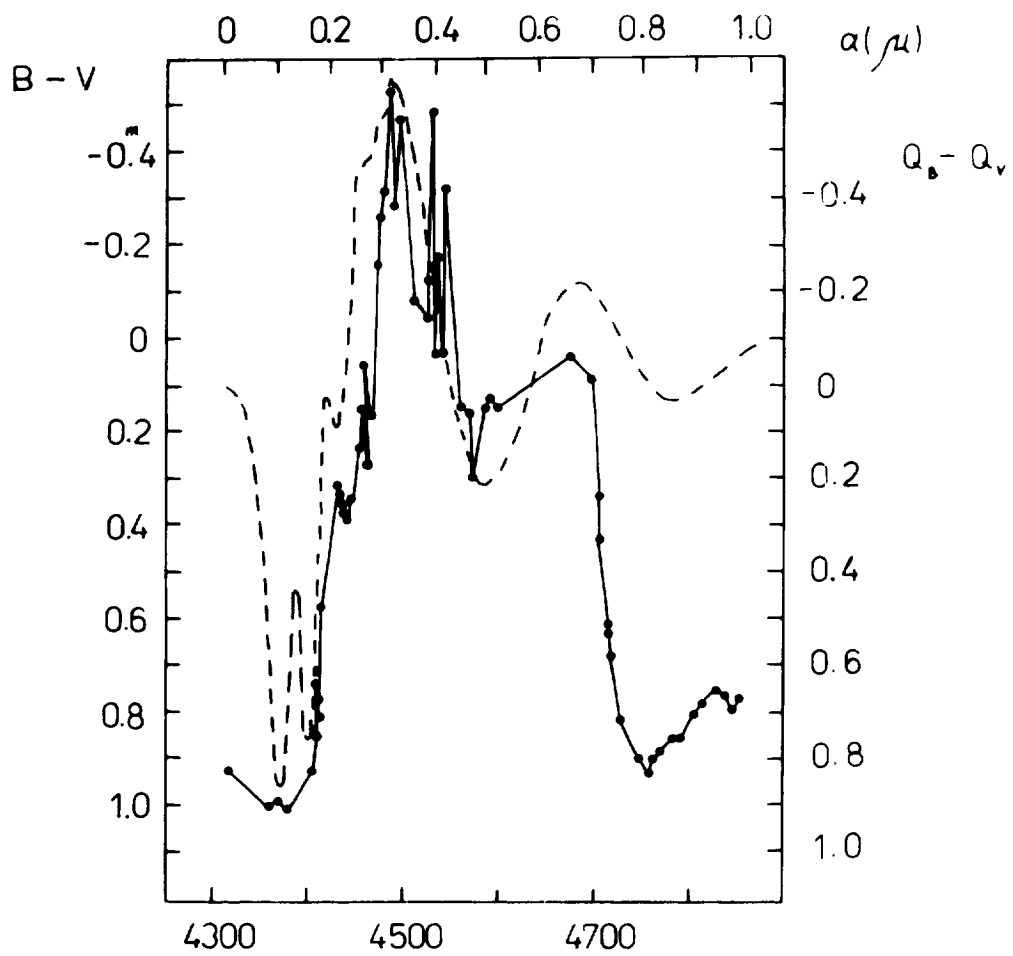


Figure 2.— The dependence of the difference  $Q_B^e - Q_V^e$  for silicate (dashed line) and color  $B - V$  for PU Vul in 1980 (continuous line).

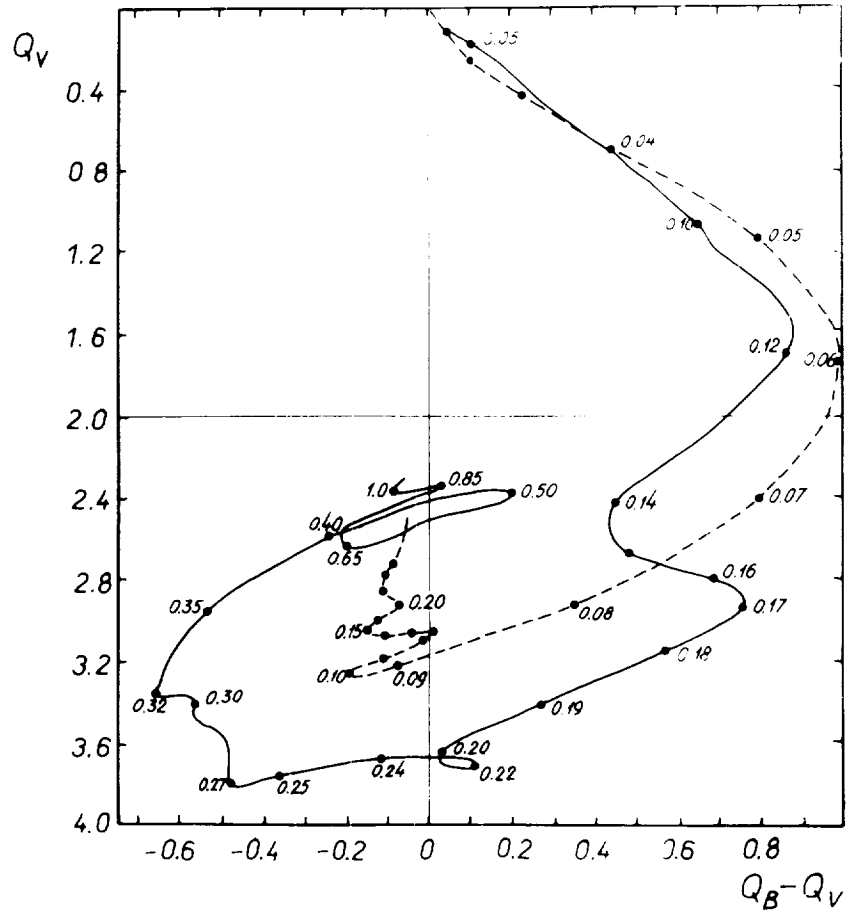


Figure 3.— The  $Q_V^e, Q_B^e - Q_V^e$  diagram for silicate (continuous line) and for graphite (dashed line). The figures near the curves indicate radii of grains in mcm.

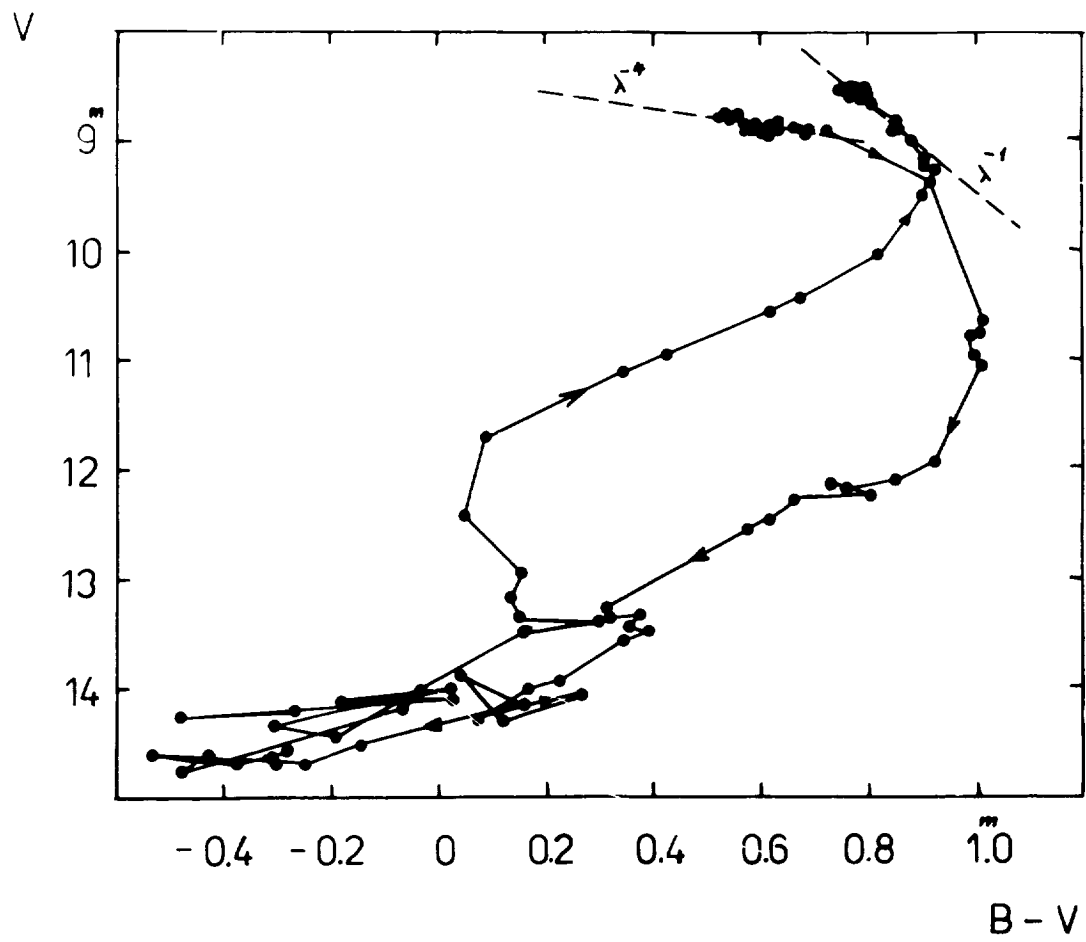


Figure 4.— The diagram  $V, B-V$  for the hot component of PU Vul in the deep minimum of 1980 (Efimov, 1988).

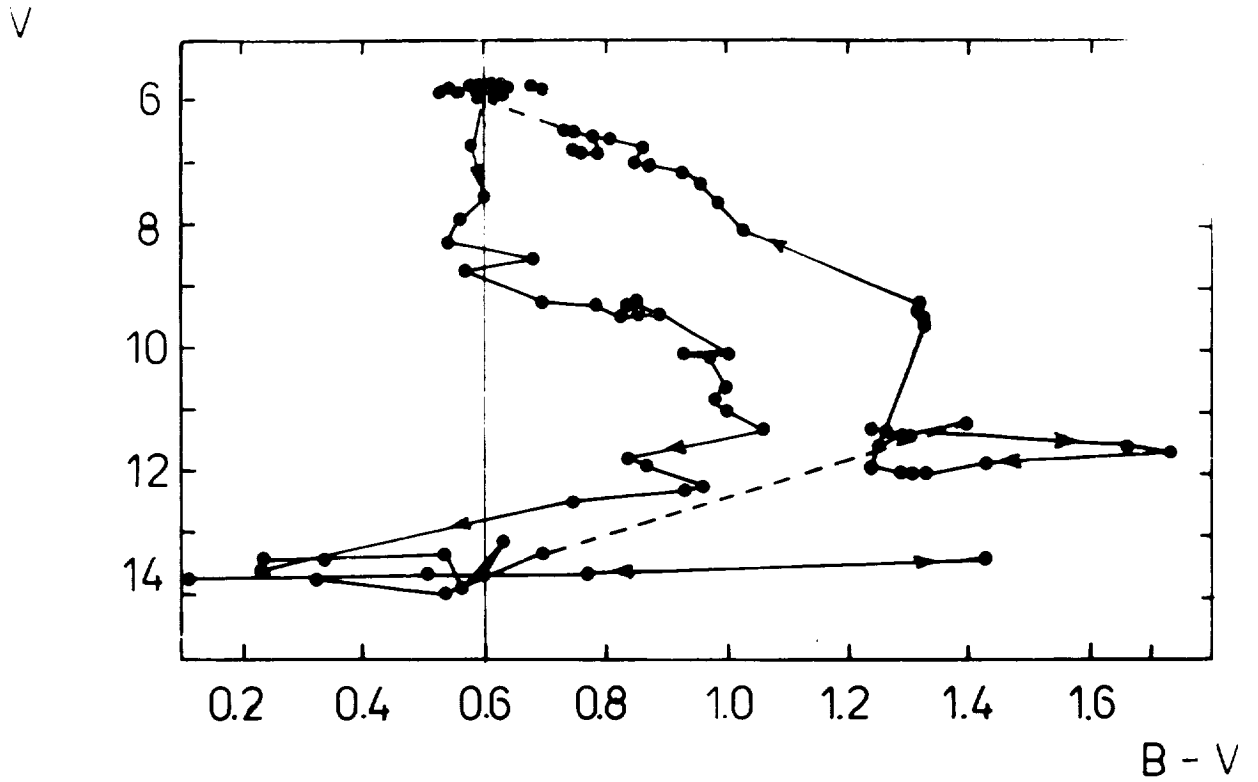


Figure 5.— The diagram  $V, B-V$  for R CrB in minimum in 1983 (Goncharova, 1985; Rosenbuch, 1986). The motion of the star in the diagram is shown by arrows.

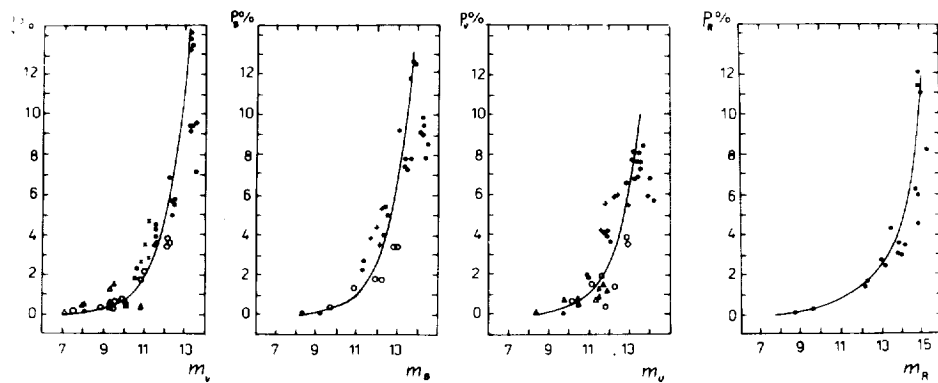


Figure 6.— The correlation between polarization and magnitude for different minima of R CrB in UBVR. Different symbols are used for different minima (Efimov, 1986).