MORPHOLOGY OF CIRCUMSTELLAR ENVIRONMENT AND SOME CHARACTERISTICS OF CIRCUMSTELLAR SHELLS OF STARS WITH THE R CORONAE BOREALIS VARIABILITY

A. E. Rosenbush

Main Astronomical Observatory, NAS of Ukraine
27 Akademika Zabolotnoho, 03680 Kyiv, Ukraine
e-mail: mijush@mao.kiev.ua

The well-known light minima of stars with the R Coronae Borealis variability are caused by the formation of an additional circumstellar dust shell, the screening shell, inside the permanent shell. Under the assumption of uniform distribution of matter in the circumstellar environment we estimated the optical thickness of the permanent gas–and–dust shell at 0.2–0.7, and its geometrical thickness is no less than 0.4 of its own radius. The wavelength dependence of extinction is close to neutral.

From spectral observations of R CrB itself in the 1985 minimum we traced the transformation of the stellar linear and molecular absorption spectrum to the emission spectrum and established that the fast variation of the U–B colour index by –0.6 in the light decline was caused purely by a change of the spectrum type. The spectrum transformation causes an increase of star brightness in the U, B, and V bands of about 1.4, 0.75, and 0.75 mags, correspondingly.

It is suggested that a high–velocity (>200 km/s) matter stream through the circumstellar environment is the cause of the excitation of the emissions observed during light minima when the photospheric flux is weakening.

INTRODUCTION

The set of unique characteristics of the stars with the R Coronae Borealis (RCB) type variability keeps constantly the high interest to them from observers and theorists. For all this, side by side with the progress in observations, negligibility in the theory is noted.

The principal variability – deep light declines up to 8 mag which last hundreds of days and are caused by dust condensation on the line of sight – remains the phenomenon with many questions, including even the lack of a simple geometric model of the phenomenon [1, 2, 3, 4].

The basis of the modern model is the cloud structure of the circumstellar permanent dust shell [2, 3] when one of the dust clouds in this shell forms on the line of sight, and, as a result, a visual light minimum is observed. This explains the lack of anticorrelation between variations of visual and infrared brightness during a minimum [5]. The lack of clear influence of the permanent shell, in which up to 40 percent of the bolometric luminosity of star is transformed, on apparent characteristics of the star at a light maximum supports the idea of its cloud structure. The difficulties of this model in simulating light minima were well known [3, 4].

As the result of our studies, we concluded that it is necessary to investigate not variables of the R Coronae Borealis type but the R Coronae Borealis phenomenon observed in various objects, for instance, in novae. It is need the high mass loss rate and the enhanced abundance of carbon. The hydrogen is necessary for the phenomenon. Hydrogen deficiency is a consequence of the phenomenon, and its full exhaustion means the cessation of the variability. This view helps us to understand many sides of the phenomenon. At a time we concluded that the 1972 rejection of the model of a spherical dust shell for the interpretation of the R Coronae Borealis phenomenon [5] was not sufficiently justified: not all sides of the phenomenon were known and were taken into consideration. Below we consider some principal consequences from the assumption of the uniform distribution of a matter in the circumstellar environs.

STRUCTURE OF CIRCUMSTELLAR ENVIRONS

Three spherical shells can exist in the environs of a star: two constant shells, the permanent and the fossil (the latter is not connected directly with current light minima), and a temporal, screening one. Both shells are formed in the outflow of mass with a high loss rate estimated at about 10^{-6} mass of the Sun per year.

The radius of permanent shell was estimated at 26 radii of the star or 2340 radii of the Sun [1]. The formation of this shell can occur in the framework of the homogeneous dust nucleation theory by Fadeyev [6], which gives the dust condensation zone radius close to this value. The mass of the shell is of 10^{-6} mass of the Sun.

Sometimes conditions can arise for dust condensation very close to the star, *i.e.*, a screening shell with a radius of 4–10 radii of star is formed [1]. We estimated the full mass of this shell at about 10^{-7} mass of the Sun. The screening shell has its own infrared excess which compensates the weakening of the permanent shell luminosity. The effective temperature of screening shell during its maximum optical thickness drops down to 700–900 K, which is equal to the permanent shell temperature.

OPTICAL THICKNESS OF PERMANENT SHELL

It is known that the permanent shell re–radiates up to 42 percent of the bolometric luminosity of the star itself [5]. If we assume that the shell only re–radiates, we have an indirect estimate of optical thickness of this shell at about 0.7.

FG Sge allows a more direct estimation. Since 1992 it shows the RCB type variability that allows us to compare stellar parameters before and after 1992. Since 1992 FG Sge was at the state of maximal brightness, *i.e.*, it had only the permanent shell, in the end of 1997 – the beginning of 1998, in 1999 and 2000. The difference of average brightness in these periods from the level before 1992 may be due to the extinction in the permanent shell. Our estimate for this is of $0\overset{m}{.}26$. It means that the permanent shell absorbs nearly 20 percent of the bolometric luminosity of the star itself. From published data we estimated that the bolometric luminosity of shell is nearly 25 percent of the bolometric luminosity of the star itself.

SIZE OF DUST PARTICLES

RY Sgr has a number of observations in the UV, where dust particles primarily show an evidence of their existence after condensation.

From the graphic and tabulated data of [7], in addition to the author's results, we can obtain the following data.

Firstly, the light minima were not seen in the UV. The decline of the 240 nm flux during a minimum occurs probably only up to the weakening of visual brightness by nearly 2^m. The following rise of extinction in the visual is not accompainied by a rise of extinction in the UV. According to [8], this may occur by the change of a dust particle size from 0.01 micron to 0.3 micron. The particle density does not increase, otherwise the extinction should continue to increase. From this we can draw the unexpected and interesting conclusion that the light minimum may be considered only as a consequence of a change of the dust particle sizes but not their density, and the dust nuclei are constantly present in the stellar atmosphere.

Secondly, the amplitude of the UV brightness pulsations outside minima is a factor of 1.8 higher, on the average, than in the visual pulsations. The higher amplitude of the UV pulsations can be interpreted as the consequence of condensation of dust particles, their growth up to radii of 0.003 micron and disruption in every pulsation.

The dust particles move away from the star, dragging the gas of the stellar atmosphere.

OUTFLOW VELOCITY AND ORIGIN OF EMISSION LINES

The kinetic energy of helium atoms which are the main gas component of the stellar atmosphere is as high as 800 eV and more at a 200 km/s velocity. This energy is sufficient to excite emission by the interaction with low–velocity atoms. It is known that emissions of C IV] 155.0 nm, C II 133.5 nm, *etc.* are observed beyond minima, *i.e.*, we have a clear indication on their origin in the permanent shell. If there is no dust, there are no UV emissions mentioned above. This is observed in XX Cam and HD 182040.

This transformation of energy occurs on the inner boundary of permanent shell on a level of 10–26 star radii at a density of about 10^{-14}–10^{-15} g/cm or a helium density of about 10^9 cm^{-3}.

Thus, we can identify the region of the origin of sharp emission lines or the "chromosphere" of the star with the zone of dust condensation or with the permanent and screening dust shells.

During light minima the absorption spectrum disappears and the emission spectrum appears. Such transformation determines almost completely the behaviour of U–B and B–V indices observed during a visual minimum.

VARIATIONS OF COLOUR INDICES AND SPECTRUM IN A LIGHT MINIMUM

Based on the R CrB minimum in 1985, for which our extensive spectral observations are available and a detailed photometry is published, we studied the effect of the disappearance of absorption lines and appearance of emission lines on the colour indices of the broad–band photometric U, B, and V system.

We obtained that the key points of spectral changes are three levels of brightness weakening.

I – $1\overset{m}{.}4 - 1\overset{m}{.}6$ – no considerable changes;

II – $2\overset{m}{.}9 - 3\overset{m}{.}4$ – the disappearance of absorptions and the appearance of emissions;

III – $4\overset{m}{.}3$ – the maximum of emission intensity and its following sharp drop.

It is necessary to compare these levels with the light and colour curves. After the light fading to the first level a sharp decrease of U–B began. At the second level, a sharp increase of B–V occurred. At the third level, the brightness is minimal, it is the reverse point of the light curve and a sharp extremum of U–B; the B–V behaviour did not change.

Thus, we make the opposite conclusion that the colour change is due mainly to the change from the absorption spectrum to the emission, and all variations in U–B from $+0\overset{m}{.}3$ to $-0\overset{m}{.}3$ in 1985 were related to this cause only. The B–V variation did not exceed $-0\overset{m}{.}1$. The estimation of spectral transformation on our spectrograms for the 1985 minimum in the B band gives a value of line contribution of about $0\overset{m}{.}75$. Thus, one can say that the lines contribute of about $0\overset{m}{.}75$ in the B band, and their contribution in the V band was slightly smaller. The contribution in the U band was well above, and it reached $1\overset{m}{.}4$. The light minima are distinguished by the intensity of emission lines. Therefore, the colour variations were dissimilar but the cause of variations is the same.

This moves away one of the principal objections against the uniform distribution of a dust in the circumstellar shells.

The well–known loops of a star on the "colour–brightness" diagram during its light minimum should be interpreted with this circumstance taken into consideration.

CONCLUSION

As an addition to the above, we present a possible version of the development of the RCB type variability in FG Sge as a consequence of formation of an uniform circumstellar dust shell.

Years before 1992 FG Sge had a small infrared excess appropriate to of a low dust mass of 4×10^{-10} mass of the Sun. The IR excess was constantly rising, and at some stage of its increase the first RCB minimum occurred. This behaviour is very similar to the RCB phenomenon in the DQ Her novae [1], when the IR excess appeared well before the beginning of the RCB–like visual decline at the transition stage of a nova outburst. *I.e.*, in FG Sge the first RCB minimum was also connected with the formation of a screening shell. At the same time there was no permanent gas–and–dust shell, as no characteristic emissions were observed during the first minimum, but only the blue-shifted circumstellar absorption D Na I lines. It is unlikely that the first dust cloud as a cause of a light fading is formed at once on the line of sight. If there had been so, the "chromospheric" emissions might have been observed in the 1992 minimum as they were observed in the following ones. This supports our assumption about the origin of emissions in the permanent shell.

Since 1972 we have again all grounds to use the dust shell model to interpret the R Coronae Borealis phenomenon. The lack of obvious progress in the theory is caused by the one–sided approach to this "unique" variability. It is a widespread phenomenon, and it is more correct to study the RCB phenomenon, observing various objects, including novae at the transition stage of outburst.

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