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R CORONAE BOREALIS VARIABLES, II*

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Abstract

Infrared and polarimetric observations are described and a model for the light variability of these stars is outlined.

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5. Infrared and Polarimetric Observations

The first observations of an infrared excess for R CrB occurred in the late 1960's, and the amount of data has become considerable. Stein et al. (1969) found R CrB to be much brighter in the infrared than would be expected for the normal emission from a star of its spectral type; indeed, they found about 40% of this star's luminosity output was in the IR. At about the same time, Lee and Feast (1969) found a similar large IR excess for RY Sgr. At the time of their observations the star was recovering from a deep minimum, and as it brightened in the visible region the intensity in the 2 - 3.4μ region fell. However, Forrest et al. (1971) found the IR flux from R CrB did not increase significantly during a minimum, but did rise at a time when the star was steady at maximum in the visible. In further observations, Lee (1973) also found no change in the IR flux from RY Sgr at a minimum.

Feast and Glass (1973) have reported extensive infrared photometry of a number of R CrB variables and related objects. They found most, if not all, R CrB stars to show permanent IR excesses, whereas the otherwise-similar hydrogen deficient carbon stars do not. This clearly indicates that the infrared excess is closely connected to the R CrB phenomenon.

An important discovery was that of intrinsic polarization in R CrB during its active phases (Serkowski and Kruszewski 1969). As yet the amount of published material is meagre, but it seems that the polarization at maximum (∿0.1%) is attributable to interstellar effects, from comparison with a neighboring normal star (Orlov and Rodriguez 1972). Coyne and Shawl (1973) found no polarization at maximum (it being below their detection limit), but during a minimum variable polarization was observed. The wavelength dependence of the polarization also varied, in agreement with the findings of Serkowski and Kruszewski.

6. Interpretation

The more important observed characteristics of R CrB stars have now been presented. Can we draw these into a coherent picture of the R CrB phenomenon? What is now regarded as the correct interpretation evolved from the proposition by Loreta (1934) and O'Keefe (1939) that the minima are due to the ejection of gas clouds from the stellar surface, which on receding from the photospheric region expand and cool, causing graphitic carbon to condense out. Particles of this element are particularly efficient absorbers in the visible region. As the cloud expands its density drops and the star is observed to brighten.

The initial condensation may be due to the stars' having envelopes in turbulent motion; a settling and contraction of the envelope could lead to increased local density and deposition of carbon particles. Orlov and Rodriguez (1974) find a microturbulent velocity of 8.9 km s^{-1} in XX Cam, compared with 1.1 km s^{-1} for the Sun (Allen 1973). It is noteworthy that the 1967 minimum of RY Sgr

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commenced at the time of minimum of the pulsational variations, when the star's outer layers would be near their coolest.

As the carbon shell is formed, the light from the photosphere is obscured, and the chromosphere (which will be more extensive for a giant or supergiant R CrB star than a main-sequence star like our Sun) is the obvious source of the observed emission spectrum. The development of this emission spectrum can be explained by the gradual variation of the height of the cloud above the star. Feast (1969) notes, however, that quite rapid variations are observed in the bright lines, which indicates that the physical conditions in the chromosphere are unlikely to correspond exactly to those at maximum light. According to him, the decay of an emission region (i.e. the chromosphere), suddenly cut off from its source of excitation, would be an ideal place for the production of an electron attachment spectrum, such as that of CN suggested earlier to explain the anomalous continuum.

As the cloud dissipates we would expect the photospheric spectrum to become increasingly prominent, as is observed. We have already noted that the cyclic fluctuations observed in RY Sgr as the star rose from minimum corresponded closely to those at maximum, supporting the idea that no major physical changes took place in the star itself.

The infrared observations enable us to build a more detailed picture of the form of the cloud. Krishna Swamy (1972) has shown that the observed IR emission from R CrB stars can be explained in terms of thermal emission from the shell of dust grains around the star. Such grains would absorb part of the light in the visible region and re-radiate it at longer wavelengths. The black-body temperatures of the shells are found to be about 800 - 900°K, in general, although MV Sgr has a hotter shell, ∿1300°K (Feast and Glass 1973).

If the dust formed a spherically symmetric cloud, then we would expect the infrared flux to be anticorrelated with the visible flux, and it seemed that this was in fact the case from the earliest observations (Lee and Feast 1969). However, as we have seen, subsequent work has given opposite results, and this, together with the finding that R CrB variables have circumstellar shells which give rise to the IR excesses at most, if not all, times suggests a permanent shell, in which 'blobs' of varying density occur. If these are not exactly in the line of sight, then the apparent magnitude will not change, but the IR flux may; the converse is also true.

Changes in the wavelength dependence of the polarization of R CrB at minimum are interpreted as scattering from graphite particles of varying size, 0.05 - 0.10μ (Coyne and Shawl 1973). At different times clouds with particles of different mean size dominate the observed polarization, agreeing with the 'blob' model.

It is clear that the geometry of the 'blobs' must be remarkably peculiar to explain the rapid decline and slower recovery which characterize the minima of R CrB variables. Moreover, some difficulties arise in reconciling this model with the spectroscopic observations, which are more easily explained in terms of an outward-flowing shell of gas (e.g., the shell lines mentioned earlier). The conclusion drawn from the material presented here is that occasionally, as the star's envelope settles, a cloud of condensed graphite particles is ejected in a particular direction (as opposed to the circumstellar cloud postulated earlier).

The form of the observed variations will depend on the orientation of the cloud with respect to the line of sight. There also exists a permanent circumstellar shell, possibly of irregular density, which is periodically replenished by the ejecta at minima, together with the steady outgassing of carbon/oxygen enriched helium reported by Strohmeier (1972). The total mass loss must be fairly small, since the pulsation period of RY Sgr, which is a function of mass, has not varied appreciably in the half-century since discovery.

Recently Maron (1974) has suggested an alternative mechanism for the infrared emission. The ejected material may be in the form of 'Platt' particles, with dimensions $\sim$3 - 30A, which act like non-saturated molecules. These particles cause extinction of about two orders of magnitude greater than classical grains, but will not re-radiate in the IR. However, subsequent growth by accretion, etc., to a size between 2×10^{-6} and 2×10^{-5}cm leads to classical grain nuclei, and the observed IR (re-)emission. There will be a time lapse from the visual minimum depending on the growth period, which in turn is a function of physical conditions in the shell; in particular, the growth period varies with local density and velocity of escape, and so may vary from minimum to minimum.

7. Conclusion

Practically all the detailed spectroscopic, infrared and polarimetric observations of R CrB variables are of RY Sgr and R CrB itself. In order that the conclusions outlined here may be examined in the light of more comprehensive data it is important that visual observers continue to follow these and other R CrB's, so that professional astronomers can be alerted when minima occur, and to enable comparison between visual light curves and other types of observations.

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