R CORONAE BOREALIS VARIABLES. I

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Abstract

The light curves, spectra, and space distributions of these peculiar variable stars are reviewed.

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1. Introduction

Piggot discovered the variability of R Coronae Borealis in 1795, and this star has become the prototype of one of the least populated but most interesting classes of variables. The *General Catalog of Variable Stars* and its two Supplements list only 40 examples (and it is clear that a significant fraction of these are misclassified) out of a total of over 25,000 named variables. Table I (based on Orlov, 1975 and GCVS) lists the ten brightest known R CrB stars.

Table I

Star		Mag. at max.	Spectrum
002725	DZ And	10.3V	R
040053	XX Cam	7.3V	cGle
054319	SU Tau	9.8V	GOep
1237<u>53</u>	UW Cen	9.2V	K
1459<u>71</u>	S Aps	9.8V	R3
154428a	R CrB	5.8v	cFpep
1811<u>46</u>	RS Tel	9.3pg	R8
1840<u>38</u>	V CrA	8.3v	RO
1910<u>33</u>	RY Sgr	6.5v	GOep
234956	Rho Cas?	4.1v	F8p

Notes to Table I:

DZ And: Orlov and Rodriguez (1975) report a spectral type of KO, but with no carbon lines. Probably not an R CrB star.

UW Cen: C_2 bands have not been positively identified in the spectrum.

Rho Cas: The spectrum does not support an R CrB classification. (e.g. Beardsley 1961).

These unusual objects are characterised by spectra showing them to be hydrogen deficient carbon stars (HdC), and by abrupt drops in brightness. In this article we summarize the observational data gleaned from photographic and visual studies, while in a subsequent article we describe infra-red observations and outline a possible interpretation.

2. Light Curves

The "normal" state of these stars is maximum brightness, and the duration of maximum varies from a few days to many years. Figure 1 illustrates the light curve of the best-studied R CrB star in the Northern Hemisphere: R CrB (Andrews 1962a, b). Note the abrupt declines followed by more gradual recoveries. In general there is no pattern to the amplitudes and frequencies of these variations, and, for example, XX Cam has had only one short minimum observed since 1890 (Yuin 1948, Brun 1971).

In 1972, Fernie *et al*. reported a semi-regular oscillation of the maximum light of R CrB with an amplitude of about $0^m.15$ in the visual. Such oscillations are also present in other members of this class, although the amplitudes differ from star to star, and the oscillations themselves are not always present. Table II summarizes known data on these oscillations at maximum light. Fernie *et al*. (1972) suggest that all R CrB stars may have small periodic variations at maximum light, an idea supported by the work of Sherwood (1975).

Table II

Variations in Maximum Light of R CrB Stars

Star	Average Amplitude	Period (Days)	Reference
R CrB	$0^m.15$	45	Fernie *et al*. 1972
RY Sgr	0.5	40	Jacchia 1933
UW Cen	0.5	42	Bateson & Jones 1972a
GU Sgr	0.4	38	Bateson & Jones 1972b
S Aps	0.3	120	Waters 1966

At maximum, these stars also show variations of color (Δ(B-V) $\simeq 0^m.3$, Δ(U-B) $\simeq 0^m.5$ for RY Sgr) and radial velocity (amplitudes up to ca. 30 km sec^{-1}). The velocity variations provide a clue to the source of the light variations, viz., pulsation of the stars' outer layers. The light amplitudes are smaller than those of other pulsating variables of similar period and luminosity (Cepheid variables), but this may be understood as a consequence of the peculiar chemical composition of the R CrB stars. Alexander *et al*. (1972) have concluded that RY Sgr pulsates as a helium star of $M = 2M_{\odot}$, in agreement with the mass determinations by Fernie *et al*. (1972).

The times of minima of R CrB stars are irregular and completely unpredictable at present; indeed, an analysis of the minima of R CrB itself has shown the star to be "a perfect irregular" (Sterne 1935). Moreover, the depth and duration of the minima are irregular. They typically last a year or so, although HV 5637 in the Large Magellanic Cloud has had a single minimum lasting more then 8000 days (Hodge & Wright 1968), and, during the 1860's, R CrB had a series of minima, without full maximum ever being reached, lasting a decade (Mayall 1960).

A "normal" minimum comprises a comparatively rapid fade, when $dm/dt \simeq 0.1$ mag. day^{-1}, followed by a period of extreme faintness (up to 9^m below maximum) and a gradual and irregular rise to maximum. (The 1974 minimum of R CrB [Howarth 1975] is illustrated in Figure 2.) This outline, however, should not be accepted too rigidly, as many deviations from it occur. For example, a star may rise halfway to maximum, only to fall again to an even deeper minimum.

Pulsational variations have also been observed in certain R CrB stars during the rise to maximum. R CrB occasionally exhibits oscillations whose amplitude decreases as the star brightens (Isles 1973), according to the relation: Amplitude = $0^m.14 \times (m - 5.0)$. RY Sgr has shown fluctuations which closely correspond to those at maximum light, and in phase with the pulsations observed immediately prior to the minimum (Alexander *et al*. 1972). The pulsations of UW Cen seem to have their greatest amplitude when the star is brightening (Bateson & Jones 1972a).

3. Spectra

Surprisingly, apart from early studies by Joy and Humason (1923) and Herbig (1949), little was known about the spectra of R CrB variables until Payne-Gaposchkin's work (1963). Since then, Danziger (1965) and Alexander *et al*. (1972) have carried out highdispersion spectroscopic studies of RY Sgr, but no other stars have been examined in such detail.

At maximum light, their spectra typically range from F to K and R, and are characterized by absorption lines due to metals and very strong C_2 and CN bands. There is a marked deficiency of hydrogen, and this distinguishes the R CrB stars from ordinary carbon stars not showing light variations (Bidelman 1956). The spectra are so distinctive that XX Cam was identified as a possible R CrB star by its spectrum before its changes in brightness were observed.

MV Sgr, also classed as an R CrB star, is an exception in that its spectrum is much "earlier", or hotter, about type B, and it resembles the spectra of carbon-rich helium stars. Not surprisingly, in view of its higher temperature, MV Sgr does not display molecular bands, although it is hydrogen deficient and carbon rich.

During minima, these spectra change markedly. As the star fades, a rich emission spectrum of broad lines is observed. The H & K lines of ionized calcium, the D lines of neutral sodium, and lines of ionized iron and neutral helium, as well as CN molecular bands, show in emission, but hydrogen remains very weak. Feast (1969) notes a correspondence with the lines seen in absorption at maximum.

As the continuous spectrum in the visible and the red fades, the spectrum shortward of 4000 Å fades much less, and the color indices become bluer, with (U-B) decreasing more than (B-V) in general. The source of the anomalous blue continuum cannot be explained in terms of normal thermal emission from a stellar atmosphere, and Feast (1969) attributes it to the electron attachment spectrum of molecular CN.

As the light fades, the absorption lines of calcium, normally broad at maximum, become narrow and acquire a structure that is reminiscent of multiple lines produced by interstellar gas clouds. However, the Doppler shifts of these lines indicate velocities associated with the star itself.

As the star fades further and approaches minimum light, the continuum falls relative to the emission, and its intensity distribution more closely resembles that of a normal star. All this time, the emission spectrum changes, the strength of the lines decreases and their relative intensities change; for example, ionized iron becomes weak.

The recovery to maximum is accompanied by a continued fading of the emission lines and a gradual return of the absorption spectrum, which may resemble the maximal spectrum when the star is still two magnitudes below full brightness.

4. Miscellaneous

The distribution of known galactic R CrB stars on the sky is shown in Figure 3, plotted in galactic co-ordinates. The apparent concentration towards the galactic plane is partly the result of selection effects; the distribution, and what little is known of the space motions, is consistent with the idea that these evolved stars belong to an old disk population.

Three R CrB stars have been positively identified in the Large Magellanic Cloud (Feast 1972), and using the well-determined distance modulus for the LMC reliable absolute magnitudes can be derived for these stars at maximum. The values turn out to be $M_V = -5.1$ (for W Men) and $M_V \simeq -4$ (for HV 5637 and HV 12842). Eggen (1965) has obtained $M_V = -3.1$ for R CrB, from its assumed membership of the Wolf 630 group. Finally, Andrews _et al_. (1967) have discovered a close companion to RY Sgr, which, _if_ physically related to it, indicates $M_V \sim -4$ for the latter star.

In view of their intrinsic brightness, characteristic spectra, and generally large amplitude it is clear that the apparent scarcity of R CrB stars is real. A simple calculation suggests that there are $\sim 10^3$ of these variables in the Galaxy, and while this is at best a very rough approximation it indicates that the R CrB phenomenon occurs either in stars with very particular properties, or for a (comparatively) short time in the life of a star. The work of Paczynski and Trimble (e.g. Trimble 1972) supports the former idea, but probably both are true to some extent.

Recent measures of infra-red radiation and of the polarization at various wavelengths have given some important clues to the cause of these stars' peculiar drops in brightness. These will be discussed in a forthcoming article.

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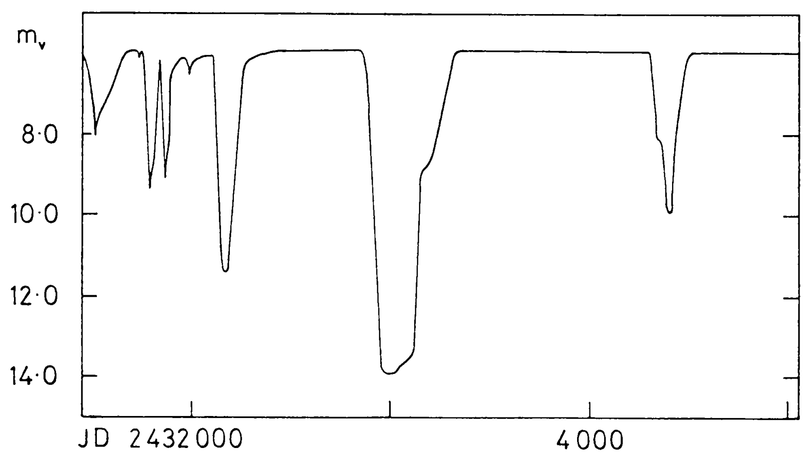

Figure 1. Light curve of R Coronae Borealis (Andrews 1962a,b).

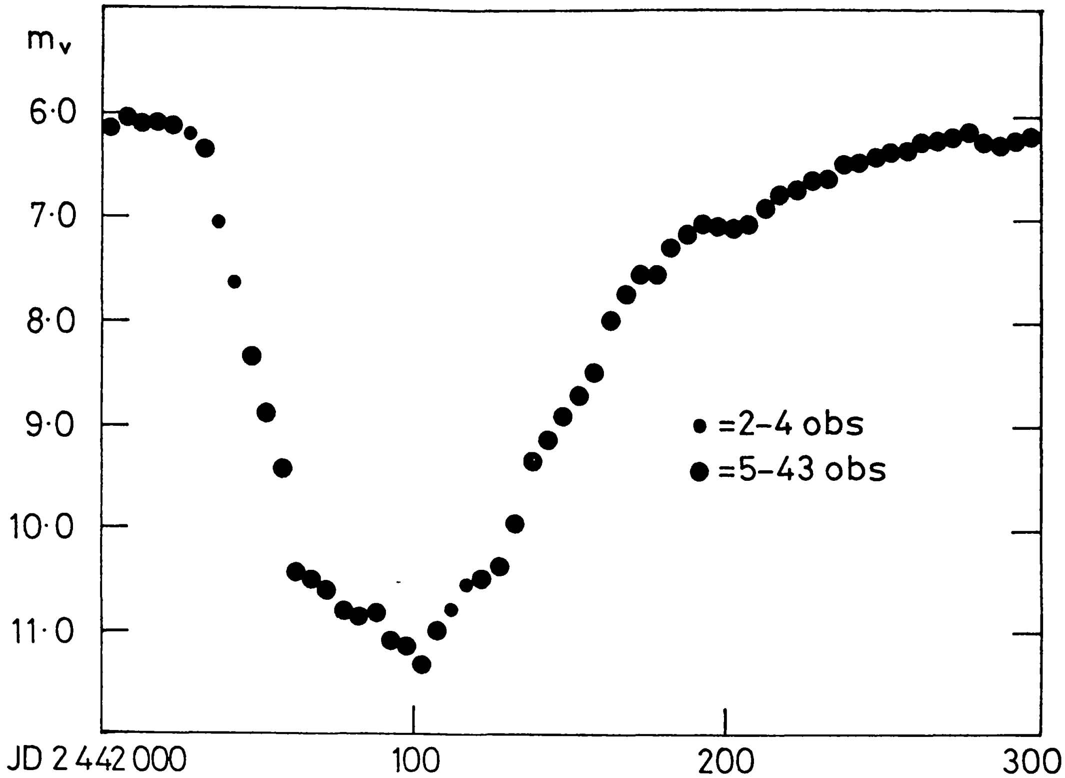

Figure 2. The 1974 minimum of R Coronae Borealis (Howarth 1975).

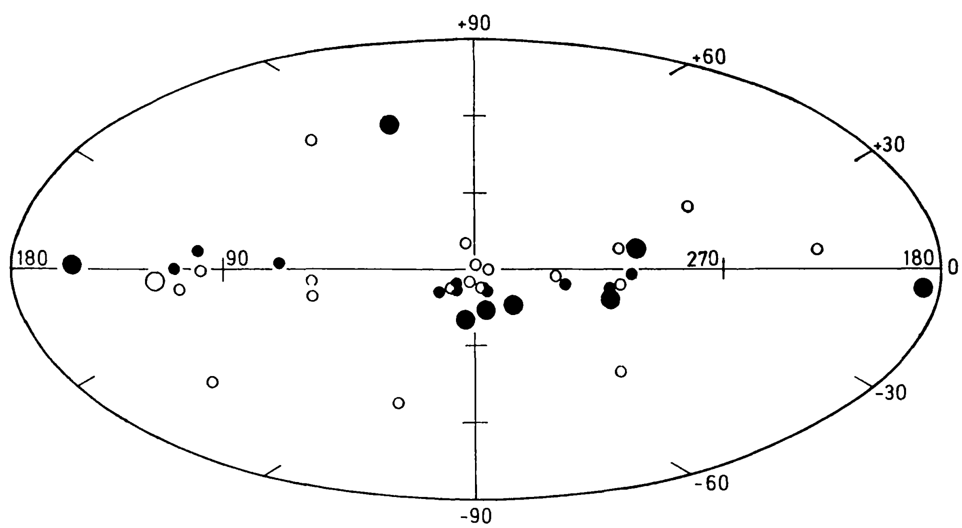

Figure 3. Distribution of R CrB variables on the sky. Plotted in galactic coordinates. Large dots: m_V brighter than 10.0 at maximum; small dots: fainter. Open circles mark questionable members of the class.