RS CANUM VENATICORUM BINARIES

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Abstract

Some properties of the RS CVn subtype of eclipsing binaries can be explained in terms of observational selection. Provided that the components of a binary are (a) the sameage, and (b) too small relative to their Roche lobes to have begun to undergo any mass transfer, then eclipses deep enough to be detected are most likely to be found in systems where (i) one star is a subgiant of spectral type late G to early K (ii) the other star is near the main sequence but above it, and (iii) the binary period is a few days. These conditions will only be satisfied if the more evo lved component is about 3 per cent more massive than the companion, in accordance with observations. Other features of RS CVn systems, such as emission lines, and secular changes in the light curve, are then to be interpreted as consequences of, but not causes of, the evolutionary status of these objects.

RS CVn type binaries were, about 20 years ago, a largely unrecognised subset of Algol (or "EA") binaries. EA's are eclipsing binaries which show nice sharp eclipses separated by intervals of near-constant light output, as in Figure 1a. The near-constancy between eclipses suggests that the stars are not strongly distorted by each other's presence, in contrast to or EB's or EW's (Figures 1b, 1c) where the components are close enough together to be strongly distorted. However, there is often a small degree of distortion in EA's indicated by the dotted line; the RS CVn group are partly distinguished by the fact that this distortion is asymmetric and time-dependent.

I will not dwell very long on the detailed behaviour of the distortion in the light curves of RS CVn stars interesting though it is. My main concern is with the evolutionary status of these objects, and I believe that this distortion is probably a consequence of, but not a cause of, the evolutionary status of RS CVn's, to the same extent that δ Cephei pulsations are a consequence rather than a cause of the evolutionary status of δ Cephei stars. In brief, superimposed on the simple eclipse curve of Figure 1a is a roughly sinusoidal variation of a character whch suggests that one sid e of the larger component is hotter than the other. Futhermore, there is slight difference in period, as if the asymmetric larger component

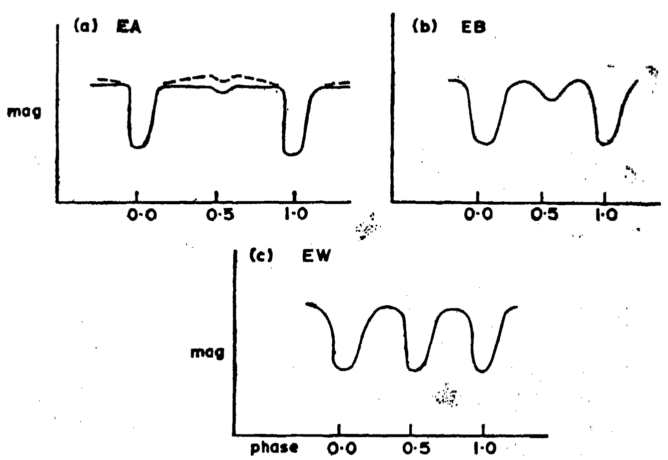

Fig. 1: Characteristics of light curves of eclipsing binaries.

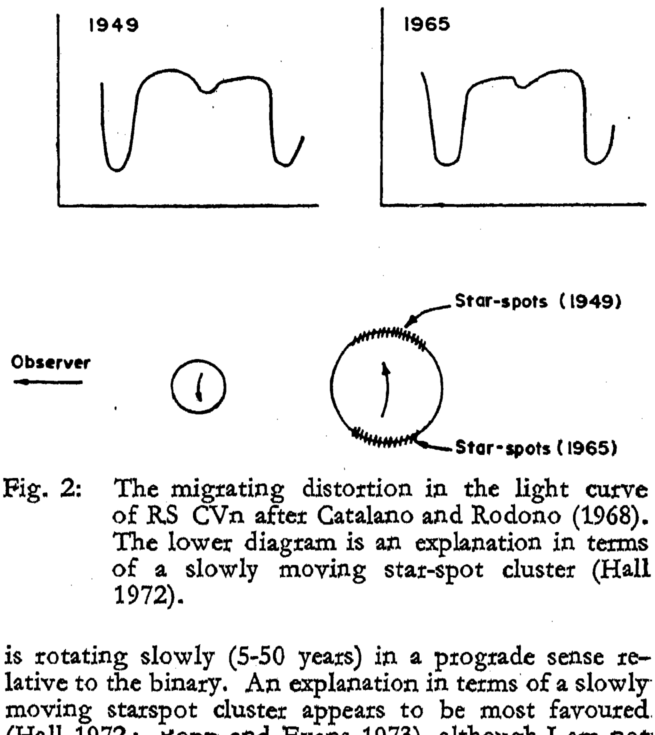

Fig. 2: The migrating distortion in the light curve of RS CVn after Catalano and Rodono (1968). The lower diagram is an explanation in terms of a slowly moving star-spot cluster (Hall 1972).

is rotating slowly (5-50 years) in a prograde sense relative to the binary. An explanation in terms of a slowly moving starspot cluster appears to be most favoured (Hall 1972; Bopp and Evans 1973), although I am not able to comment on the attractivenesss of this possibility (Figure 2).

The eclipses of RS CVn's occupy typically a somewhat smaller fraction of the orbital period than for normal Algols, suggeting that the stars are rather further apart relative to their radii, and so rather less interacting, than normal Algols (Plavec and Grygar 1965). This is borne out by more detailed observations on mass ratios: the larger component typically underfills its Roche lobe by $\sim 30\%$. Thus there is no reason to suppose that mass transfer is currently taking place, in contrast to typical Algols where one star is lobe-filling and losing mass. There is however some evidence of mass loss, in the shape of strong H and K emission, but this may be due simply to a stronger-than-normal stellar wind, perhaps indicative of unusually strong chromospheric activity, or of the possibility that stellar wind is enhanced by the presence of a close campanion.

Most Algols consist of a red or organge giant and a smaller but hotter companion of comparable or greater (even much greater) luminosity. However, there are several eclipsing binaries whose light curves resemble Figure 1a sufficiently to be called EA's (or Algols) but which are actually rather different, e.g., containing a white dwarf (RW Tri, V471 Tau). For the sake of argument, I shall use the following rough classification :

EA's:
- "true" Algols } giant star + near-MS star
- RS CVn's } giant star + near-MS star
- Various others

Hall (1976) has reviewed the properties of RS CVn stars very thoroughly, and all the observational information I refer to is taken from his paper. There are several different ways of defining the class, none of which is entirely satisfactory. There are several properties whicq are shared by most though not all candidates. Hall chooses three characteristics as definitions, and then notes that some further properties are shared by most members. His three defining characteristics are :

1. $P \in$ (1d, 14d); but all 24 known members have $P \in$ (2d, 11d)
2. Hotter component is F or G IV or V (compared with B or A for "true" Algols)
3. Strong H and K emission is seen outside eclipse.

The following further characteristics are shared by more than half of those of the 24 members for which they have been examined :

4. H and K emission is from the cooler star (or both) (22 out of 23 stars)
5. Cooler star is around KO IV (23/24)
6. $H\alpha$ emission seen outside eclipse (6/6)
7. Wave-like distortion of light curve outside eclipse (15/24)
8. IR excess in one or both components (5/6)
9. Mass ratio (cooler/hotter) is 1.03 $\pm$ 0.03(13/15)
10. Both components under fill their Roche lobes, i.e. the binary is detached (8/8).

A further point is that the component masses range from $\sim 0.9 M_\odot$ to $\sim 1.5 M_\odot$, with $\sim 1.3 M_\odot$ as a typical value.

To theorists, and certainly to me, the most mysterious of these characteristics is the near equality of masses, Generally, it is the cooler star which is more massive, though occasionally it is fractionally less massixe What possible evolutionary scenario could selecout such nearly equal masses? Before considering a possible explanation, there is at least one further point that ought to be emphasised.

RS CVn's are in actuality rather common, although only 24 (by Hall's definition) are known. This conclusion is based on the fact that they are intrinsically rather faint—typically $\sim 10L_\odot$ as against 10-100 times this for typical Algols. Furthermore, because both components are significantly smaller than their Roche lobes, the probability of eclipse is rather small, say about 10-20%. Montle (1973) and Dworak (1973) have found space densities of 1-2 x 10^{-6} pc^{-3}, without allowing for non-eclipsers, allowing for which the density is perhaps 0.5-2x10^{-5} pc^{-3}. This is a considerably greater space density than, say W UMa's ($\sim 10^{-6}$ pc^{-3}, Kraft 1967) which were once thought to be the most common type of eclipsing binary.

Several explanations have been attemptcd for RS CVn's; some of them are very contrived, but then one may feel driven to a contrived explanation since the properties of the class seem too odd for a simple explanation. However, I am going to outline a possible explanation which is currently being explored by J.G. Morgan and myself. Though not yet justified by hard calculation, it is at least simple. It is that the class owe its existence purely to a selection effect.

This possibility has been considered, and rejected, by several authors. I think their argument is roughly as follows. If you take two single stars at random from the field you have the greatest probability of a detectable eclipse if

(a) the period is such that the larger star just fills its Roche lobe, i.e. the separation is the least possible, subject to dynamical stability;

(b) the smaller star is at least as luminous as the larger and preferably more luminous (which also implies it is hotter).

Since in RS CVn's the larger star is smaller than in (a), and is only of comparable rather than much smaller luminosity, selection would work against, rather than in favour of, detecting RS CVn's. However, this argument (if I am givng it at all correctly) ignores the fact that the two components are unlikely to be chosen at random from single field stars.

Conditions (a) and (b) are staisfied by "true" Algols but this is really a fluke, which is due to the fact that mass transfer has taken place in the direction of making the initially less massive and fainter component into the more massive, and more luminous. Let us consider binaries in which

(i) no mass transfer has yet taken place ;
(ii) both components are of the same age, i.e. lie on the same isochrone;
(iii) helium burning has not yet been reached (which implies $P \lesssim 100$ days for stars less than 3 $M_\odot$).

In such binaries, the larger star will nearly always be the more massive and more luminous as well, so that eclipses will only be slight even for minimal separation. The only exception to this general rule is illustrated in Figure 3 : the larger star is the fainter when it is in the neighbourhood of A while its companion is at B. Because evolution gets very rapid after B, the mass difference between A and B is rather small, $\sim 3\%$. Even the mass diffeerence between A and C is only $\sim 10\%$. Although there are more stars at C, they are smaller and less luminous so the probability of finding EA's of type A and C is, we belive, smaller.

This interpretation can be embellished by the following points :

(i) for a wide range of masses (1 to 4 $M_\odot$ or more- the point A at the base of the giant branch has lo)g $T_c \sim 3.7$ corresponding to a narrow range of spec tral type G8-K2 III-IV;

(ii) we expect a long-period cut-off at $\sim$ 10 days, because a star at A in a longer-period binary would underfill its Roche lobe by such a factor that eclipses would be very improbable; alternatively, if the larger star nearly filled its Roche lobe in a longer-period binary, it would be much more luminous than its companion except for masses that were much more nearly equal, since evolution on the gianth branch becomes very rapid;

(iii) we expect a short period cut-off at $\backsim$ 2 days because a star cannot get as far as A without mass transfer unless the period is $\gtrsim$ 2 days

(iv) for masses above $\backsim 2.5\ M_\odot$ helium ignition is reached without the core's settling down in a degenerate state; consequently, evolution from B to A and beyond is on a thermal rather than a nuclear time-scale, and hence we expect to find a sharp cut-off in mass at about 2.5 $M_\odot$ for each component. Stars with masses $\gtrsim 1\ M_\odot$ cannot evolve to A in less than 10^{10} yr., though metal-deficiency could reduce this mass limit;

(v) mass loss driven by stellar wind may play an important role in both components, though more so for the more evolved component. This may explain the fact that in a few systems the more evolved component is slightly less massive.

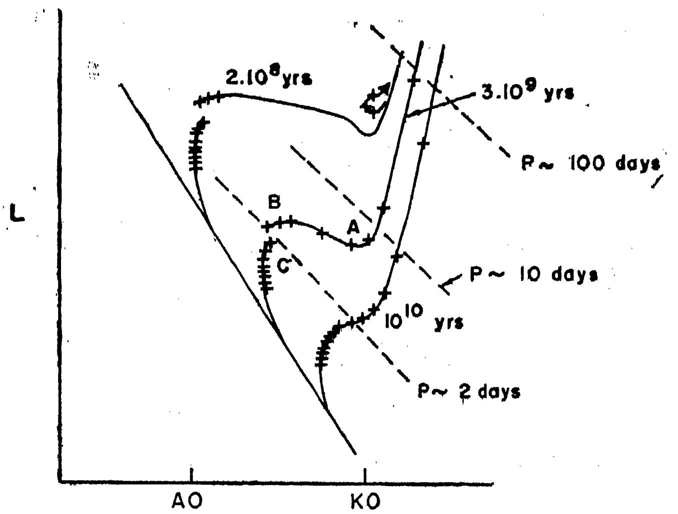

Fig. 3: Freehand sketch of isochrones for three ages. Crosses are intended to represent increments of about 1% in mass along each isochrone. The dashed loci indicate where the more evolved star would reach its Roche lobe at given periods.

This interpretation is clearly capable of being tested by a Monte Carlo procedure, and J. G. Morgan is currently exploring this. If it turns out to be satisfactory, it will mean that RS CVn's, far from being odd objects, arein fact the most normal eclipsing binaries around. This would be in accordance with Hall's (1976) conclusion that they are actually very common. Of course, we do not account in this way for the other oddities of RS CVn's, e.g., the strong H and K emission, and the slowly migrating distortion of the light curve. Our explanation has to be on the lines that any late G or early K star, if its radius is 50-90% of its Roche lobe radius, is likely to exhibit the following properties :

(1) the magnetic field is concentrated in one hemisphere, but does not quite corotate with the star (or the star does not quite corotate with the binary). We know from the Sun that the sunspot (equatorial) belt rotates faster than the poles;

(2) either because of this, or independently, mass loss by stellar wind is enhanced.

This seems to be in accordance with Hall's remarks that H and K emission, and secular changes in light curves are found in late G to early M components of :

(a) a group of short period EB binaries ($P < 1d$) where both stars are probably near-MS;

(b) a long period group ($P > 17d$), where typically only the K giant component is visible;

(c) some W UMa binaries ($P \lesssim 0.5d$);

(d) some binaries including flare stars (d Ke or d Me for the hotter component) (P $\backsim$ a few days);

(e) V471 Tau (white dwarf + KO V) ($P = 0.5d$).

I should emphasise that there may be several possible explanations of the complicated behaviour of the perturbations to the light curves, and of the emission lines, the IR excess, ete. But stellar evolution effects alone, in binary systems which have not yet undergone mass transfer, would readily explain a quite well-defined group of Algol-type eclipsing binaries with the characteristics that

(a) the mass ratio is within a few per cent of unity;

(b) the larger star is near KO IV-III; and

(c) periods lie in the range 2-10 days.

The author is indebted to the Cambridge Society of Bombay for financing a visit to the Tata Institute of Fundamental Research, Bombay, where part of this work was undertaken.

References :

Bopp, B. W, and Evans, D. S. 1973, *Mon. Not. R. astr. Soc.*, **164**, 343.

Catalano, S., and Rodono, M. 1968, in "*Non-Periodic Phenomena in Variable Stars*", ed. L. Detre (Dordrecht : D. Reidel Pub. Co.).

Dworak, T. Z. 1973, *IAU Inf. Bull. Var. Stars* no. 945.

Hall, D. S. 1972, *Publ.astr. Soc. Pacific*, **84**, 323.

Hall, D. S. 1976, in "*Multiply Periodic Phenomena in Variable Stars*", ed. W.S, Fitch (Dordrecht : D. Reidel Pub. Co.).

Kraft, R. P. 1967, *Publ. astr. Soc. Pacific*, **79**, 395.

Montle, R. E. 1973, M. A. Thesis, Vanderbilt University, Nashvill, Tennessee, U. S. A.

Plavec, M., and Grygar, J. 1965, *Kleine Veroff. Remeis Sternw Bamberg*, **4**, no. 40, 213.