RS CVn STARS: PHOTOSPHERIC PHENOMENA AND ROTATION

S. Catalano
Institute of Astronomy, University of Catania, Italy

ABSTRACT

This review presents a summary of observed photospheric phenomena on RS CVn stars: the amplitude, shape, evolution and migration rate of the photometric wave in relation to the rotational and orbital motion.

The main points considered are: 1) the activity level (maximum amplitude, short and long timescale variability) versus rotation period; 2) the activity cycles as inferred from changes in the wave migration rate and direction and from the variation of its amplitude; 3) the detection of differential rotation; 4) the connection between the orbital period variation and activity.

INTRODUCTION

This is just the twentieth year since we started observing RS CVn at Catania (Blanco et al 1982a) and, it is a great pleasure for me to have the opportunity of discussing the photometric peculiarity and properties of those stars that have since become a special group of binaries (Hall 1972).

Among the phenomena characterizing "Stellar Activity"like that we observe on the Sun are spots, flares, chromospheric emission, variable radio and X-ray emission, coronas, and so forth. Large-scale dark spots appear as the most conspicuous manifestation on RS CVn binaries compared with the Sun itself. The case for spots on the stellar surface is largely indirect. Direct evidence however has recently been provided by spectroscopic investigation of the TiO band (Ramsey and Nations, 1980).

It is generally believed now that photometric variability in the RS CVn binaries and in the BY Dra variables outside eclipse are due to an uneven distribution of large-scale spotted areas. The RS CVn binaries exhibit light variations with amplitudes typically 0.1-0.2 mag. of the combined light of the system, which may become as large as 0.7 mag

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when the variation is referred to the spotted star only, i.e. after the contribution of the unspotted companion has been taken into account (Catalano, Frisina and Rodonò 1980). This means spot areas up to 30-40% of the visible hemisphere, i.e. three to four order of magnitude more extended that the largest solar spotted areas.

It is now generally accepted that chromospheric and coronal activity on single and binary stars is essentially determined by the rotation speed (Skumanich 1972, Duncan 1981, Pallavicini et al 1981, Catalano and Marilli 1982). Many people are becoming convinced (Bopp and Espenak 1977, Walter and Bowyer 1981) that rapid rotations is of major importance in determining the high rate of occurrence of active stars in binary systems rather than the binary nature itself. There is however no definite evidence of photometric variability in single stars with similar rotation speed (Blanco et al 1979) and with definitely ascertained chromospheric variability (Wilson 1978, Vaughan et al 1981).

The general properties of chromospheric and coronal activity and theoretical problems on RS CVn binaries are being reviewed at this meeting by Bopp, Charles and Vogt. Therefore I will deal with photometric characteristics related to photospheric activity, spots, spot cycles and rotation.

Reviews on the general properties and problems have been recently published (Hall 1981, Milano 1981, Rodonò 1981 , 1982).

PHOTOMETRIC ACTIVITY LEVEL AND ROTATION

Many different parameters can be considered as defining the activity level from a photometric point of view, like the maximum wave amplitude, the time scale of amplitude changes, flare events, long-term variability of the median brightness.

If rotation is the main parameter in determining the level of activity we would expect some interdependence among these parameters or at least between some of them and the rotation period. However a number of complications arise from such a kind of analysis. The wave amplitude is not only determined by the total area and temperature of the spots but also from the asymmetric distribution of spots on the stellar surface, their latitude, and the inclination of the rotation axis to the line of sight. The detection of optical flares is strongly dependent on the spectral type of the star (Byrne 1982) and rotation periods may reflect evolutionary status.

Hall (1976) suggested that a distinction can be made between short-period ($P \leq 1$day), regular (i.e.intermediate), and long-period ($P \geq 15$ days) RS CVn binaries. Even if it is difficult to define a specific domain of P_{orb}, to segregate certain sets of physical properties and the evolutionary stage of the components, a broad subdivision can be made. Short-period group members have both components on the main sequence (Milano 1981) with primaries (hotter) of spectral type near GOV and smaller secondaries in the range G5 V to M2 V. Regular and long-period RS CVn's are post-main sequence binaries, in which one star is a subgiant or a giant evolved off the main sequence, but not yet filling its Roche lobe (Popper and Ulrich 1977, Morgan and Eggleton 1979).

A) The Maximum Wave Amplitude

Although the maximum observed wave amplitude is smaller in short-period systems than in the regular and long-period groups, the values, corrected for the dilution effect caused by the light contribution of the companion, turn out to be comparable (on the average 0.3 - 0.4 mag.) in all the groups. This is because in the short-period group the spotted stars are always the faintest in the system, sometimes by a factor of more than three (Table 1), and the correction factor is very large. In regular and long-period systems both components have comparable luminosity or the spotted, larger, giant component is more luminous than the smaller main-sequence companion so that the correction factor is generally small. There are few exceptions to this but RS CVn is one of them. Its maximum observed wave amplitude ΔV=0.22 mag. leads to a large value for the corrected amplitude of 0.67 mag.

TABLE 1. Maximum wave amplitude in short-period RS CVn binaries

System	Sp.Type	P(orb)	L_c/L_{SP}	$(\Delta V)_{max}$	$(\Delta V)_{cor}$
RT And	F8V+KOV	$0^d.629$	4.4	$0^m.06$	$0^m.37$
SV Cam	GOV+K4V	0.593	8.3	0.06	0.75
WY Cnc	G5V+M2V	0.829	0.005^	0.08	0.08
CG Cyg	G1 +G9V	0.631	2.4	0.11	0.43
UV Psc	G2V+KOV	0.861	3.0	0.08	0.36
XY UMa	G2V+G5V	0.479	< 0.4 ^	0.20	0.29
ER Vul	GOV+G5V	0.698	2.9	0.04	0.17

^Spots on the early type component.

Since the spotted stars are of different spectral types and luminosity classes, for system of different period any dependence of the maximum amplitude on the orbital period may not be obvious. In order to attempt to separate the two effects, distributions of the maximum wave amplitude for each spectral type have been considered.

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The distribution of the corrected maximum wave-amplitude in KO-K1 IV components does not show any dependence on the orbital period (Figure 1). The largest value in Figure 1 refers to the spotted component of RS CVn. For W UMa binaries Budding and Kadauri (1982) found evidence of a correlation of the wave amplitude and the orbital period. The shorter is the period, the larger is the wave amplitude. W UMa binaries may not be considered true RS CVn binaries, but spot characteristics have been detected (Binnendijk 1970, Eaton, Wu and Rucinski 1980). Hall (1976) discussed them in the context of stellar spots and Russo et al (1982) considered their evolutionary stage in relation to the short-period RS CVn binaries.

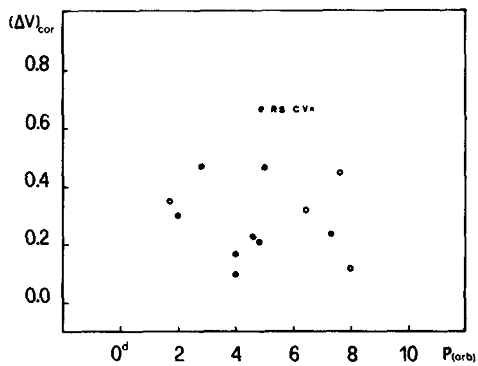

Figure 1. Maximum values of wave amplitude, for RS CVn stars of spectral types KO-K1 IV corrected for the light contribution of the unspotted component, versus the orbital period. Open circles (o) refer to systems for which the luminosity ratio of the two components has been deduced from their spectral types.

B) Time Scale for the Wave Amplitude and Median Luminosity Changes

Waves of a wide variety of shapes have been observed in RS CVn binaries. For any one system shape and amplitude changes can obviously result from changes in the spot sizes and temperatures or redistribution of the spots on the stellar surface (Bartolini et al 1982). Synopses of light-curve evolution based on many years of observation are being published now. Let me summarize some of the most important. RT And (P=0.629 days) (Milano et al 1981), in addition to wave-like distortions migrating towards increasing orbital phases on a timescale of 3.86 years (≈2250 P_{orb}) (Blanco et al 1982b), shows changes outside eclipses by as much as 0.1 mag. over a period of 1-2 months (Zeilik et al 1982a), variations in the depths of primary and secondary minima from night-to-night and a changing dip near the end of primary eclipse. UV Psc

(P=0.86 days) showed a nearly constant sinusoidal wave migrating toward decreasing orbital phase between 1976 and 1978 (Vivekananda Rao and Sarma 1981). The wave disappeared in 1979 and 1980 and reappared in 1981 (Zeilik et al 1981, 1982b). In SV Cam (P=0.593 days) the wave is not clearly visible due to the rounded maxima, which indicates a large proximity effect (Van Woerden 1957), but the large changes outside eclipse agree with a wave migrating toward decreasing orbital phases. Variation in the average light at maxima and the primary minimum occurred in SV Cam between 1969/70 and 1976/77, while the magnitude at the middle of the secondary eclipse remained unchanged. Hilditch et al (1979) found that the cooler K4 V star exhibits a BY Draconis variability, confirmed by the detection of flares (Patkos 1981). XY UMa (P=0.48 days), even if its inclusion in the RS CVn binaries is questionable, shows the most remarkable light curve changes of the short-period systems. Geyer (1980) has collected an extensive series of observations showing changes from symmetric to asymmetric light curves with a periodicity of 3.5-4 years, flickering and brightness spikes dominate the light curve for 1-2 weeks and variations of the average brightness of the system on a time scale of 25 years. For this binary as well as for WY Cnc (Awadalla and Budding 1979) the active spotted star appears to be the hotter component in the system. WY Cnc shows periodic variations in the median brightness in about ten years (Sarma 1976), while CG Cyg is undergoing a steady increase in the median light amounting to about 14% since 1965 (Milone et al 1979).

Collection of data for regular and long period systems can be summarized as follows. RS CVn appears to have the most stable wave, its shape has undergone very little changes during the last 20 years (Blanco et al 1982a). In 1976 (Ludington 1978), as in 1981, the wave showed two minima of different depths. Small cyclic variations on the wave amplitude have been detected with a period of 4.5 years (Rodonò 1981). Variations of the median brightness by 0.1 mag. occur on a time scale of 15-20 years (Reglero 1982). II Peg has the most variable light curve. The shape and amplitude of the wave both change within a few months. Generally the curve is strikingly asymmetric, the rise and decline having markedly different slopes, while the median brightness is now secularly decreasing (Rodonò et al 1982). A similar decline was observed between 1940 and 1950 (Hartmann et al 1979). UX Ari (P=6.438 days) in less than ten years (1972-1980) has shown alternate periods of small and large amplitudes of the wave (Guinan et al 1981). The largest amplitude values observed till now occurred when the system was at the maximum and the minimum of its median brightness. The last event took place between March and November 1980 leading to an amplitude increase from 0.06 to 0.17 mag. The light curve obtained during late 1978 and early 1979, appears to have two maxima and two minima of unequal brightness (Boyd et al 1981). A similar behaviour, but with a reversed temporal sequence was observed in the light curve of V711 Tau (Bartolini et al 1982). The large-amplitude single wave in late 1978-early 1979, developed in late 1980-early 1981 into a light curve showing two maxima and two minima (Figure 2). For V711 Tau the median brightness remained unchanged so that Bartolini et al (1982) reasonably supposed the total spotted area remained also unchanged. The wave amplitude variation results from a redistribution in longitude of the spotted area. The appearance of two distinct minima in the light curve and the decrease of the wave amplitude to a minimum both coincide with the maximum longitude separation of the spot groups. Light curve fitting of V711 Tau by Dorren et al (1981) required a theoretical model of two circular spot well separated in longitude before the two maxima and minima became visible in the light curve.

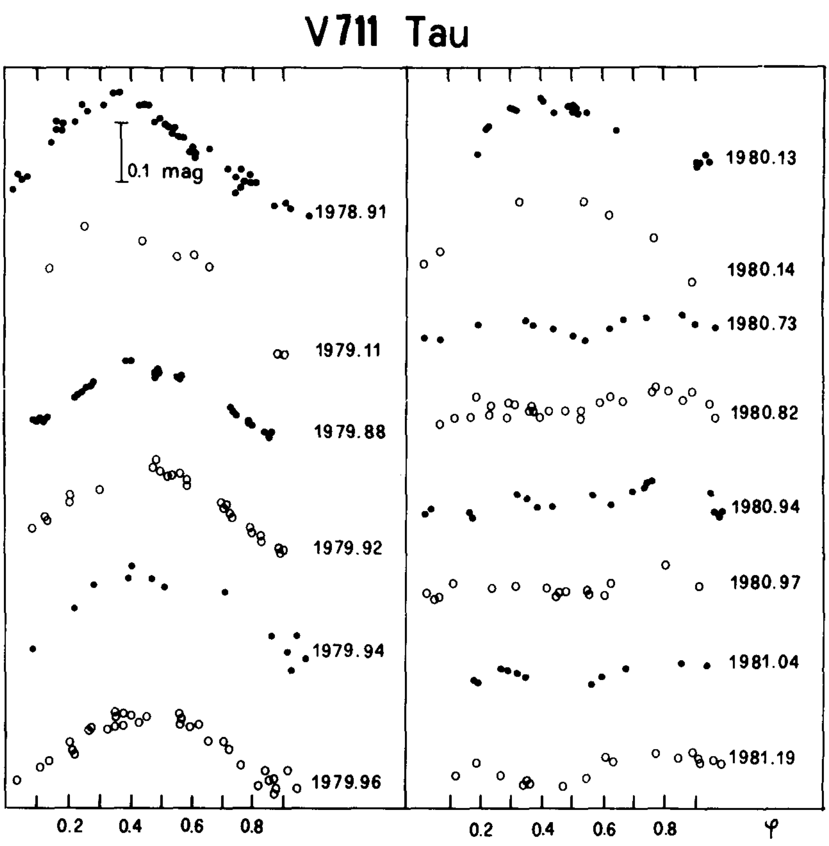

Figure 2. Synthesis of the observations of V711 Tau from 1978 to 1981 (Bartolini et al 1982), showing the evolution of the light curve and the double wave structure.

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As in V711 Tau an amplitude increase from 0.07 to 0.13 mag. between 1977 and 1979 was followed in 1980 by the appearance of two maxima and two minima in the wave of AR Lac (Ertan et al 1982). This phenomenon which appears to be transient in many systems and develops on a time scale of one-two years seems to be characteristic of the light curve of some long-period system like λ And (Landis et al 1978), and HD 185151 (Bopp et al 1982).

Quasi-regular wave amplitude changes are observed in SS Boo (Blanco et al 1980) and in RT Lac (Shore and Hall, 1980) with periods of about 10 and 30 years. The matter of periodic variability will be discussed in more detail later on in the context of detection of stellar activity cycles.

No clear evidence has been gathered of optical flare detection in regular and long-period RS CVn systems. Guinan et al (1979) reported flare events on V711 Tau which are not confirmed by observations on the same nights by Bartolini et al (1982). On the other hand flare-like activity has been detected several times in V711 Tau at radio wavelength (Gibson et al 1975, Feldman et al 1978).

Sporadic events have been observed, at the primary eclipse of AR Lac, during totality. The V light at mid-eclipse changed by more than $0^{m}_{.}05$ between August 6th and August 28th 1979, while smaller changes were observed during the 1978 observations season.

From this short analysis on the best observed systems we can see that regular and long-period RS CVn binaries frequently show nearly cyclical variation of the wave amplitude, remarkable changes in the light curve shape on timescales of months to years, and in a very few cases long-term variation of the median brightness. Short-period systems exhibit, large variability from night to night, frequent optical flare events and well defined, in some cases cyclic variations of the median brightness.

All these latter symptoms are characteristic of the BY Dra stars. This, together with the fact that the components of the short-period RS CVn binaries are both main sequence stars, suggests that they be included in the BY Dra variables rather than in the RS CVn (i.e. if any distinction within the spotted stars must be done). In this context II Peg could be better classified as a BY Dra rather than as a RS CVn member.

It is interesting to recall that the active stars in the short-period systems WY Cnc and XY UMa appear to be the earlier-type components of spectral types G5 V and G2 V respectively, i.e. typical solar-type stars.

ACTIVITY CYCLES

Spot cycles a decade or so in duration are expected in RS CVn stars both on the basis of the solar analogy and of theoretical investigations. Stellar magnetic cycles have been estimated from a generalization of the dynamo mechanism (Shore and Hall 1980) and overlapping of successive cycles along the main sequence towards later spectral type have been predicted (Belvedere et al 1980a).

Observationally, the detection of cycles it is not an easy task, even if different approaches are possible. The most obvious are to study the variations in amplitude of the wave and or the median brightness of the star as a function of time. A third approach, based on the solar experience, is to study the periodicity in the wave migration direction relative to the orbital phase. If differential rotation and latitude drifts of spots operate on stellar surfaces, giving rise to a butterfly diagram, we would expect direction changes in the wave migration from increasing to decreasing orbital phase as the centre of the spotted area drifts from high latitudes (starting of a new cycle) to the equator (end of the cycle). Correlated amplitude variations would be expected (see the schematic diagramme in Figure 3). Various complications, (Hall 1981, Rodonò 1982) make a proper interpretation of the amplitude changes and of the migration direction variation non-trivial. The presence of two spot groups, which as we saw in the previous paragraph, is very frequent in RS CVn binaries, could cause the wave amplitude to diminish even though the area of those two groups remained the same. In addition the two groups may lead to minima in the light curve migrating in different directions

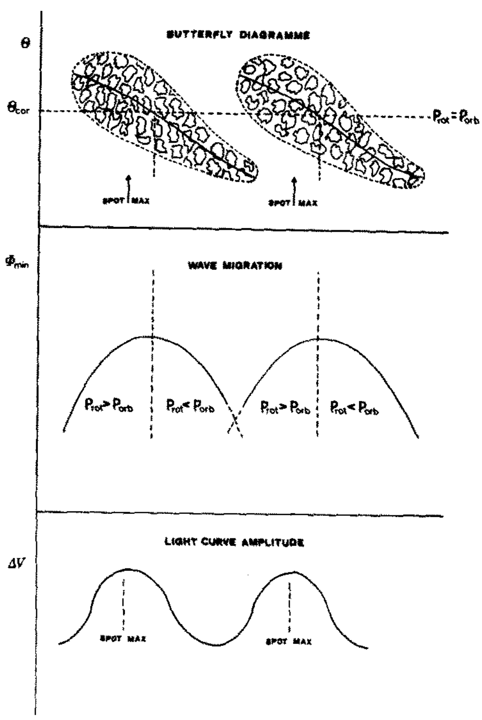

Figure 3. Schematic behaviour of the migration and amplitude variation of the wave in a solar-like cycle of activity.

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as in V711 Tau (Bartolini et al 1982). Furthermore, if reference is made to the minimum or to the maximum, the rate and direction of the migration may be completely different, as in II Peg (Rodonò et al 1982) and HK Lac (Percy and Welch 1982).

Bearing in mind these difficulties tentative cycles deduced from the median brightness variations, from amplitude variations of the wave and from wave migration curves, are given in Table 2. The cycles in Table 2 range between 5 and 100 years with values around 40 years. Some evidence of correlation between wave amplitude variation and migration direction seems to be detected in SS Boo and RT Lac (Figure 4).

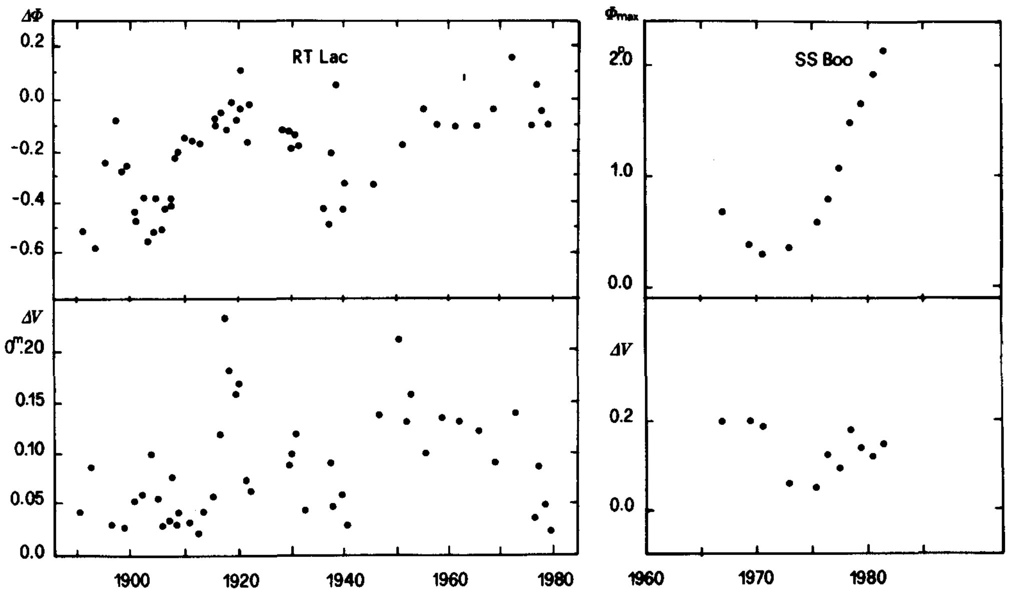

Figure 4. Observed migration and amplitude of the wave for RT Lac (adapted from Hall 1981) and SS Boo (Blanco et al 1982b) showing possible activity cycles.

DETECTION OF DIFFERENTIAL ROTATION

The wave migration with respect to orbital phases in RS CVn binaries indicates that the synchronization between rotation and orbital motion is not perfect. Among Algol binaries, cases of high asynchronism are well documented but, with very few exception, RS CVn binaries show a low degree of asynchronism. Typically their photometric and orbital periods differ by less than 1%. This asynchronism causes the minimum

TABLE 2. Activity Cycles for RS CVn Binaries, and BY Dra Stars

System	Sp Type	P(orb)	P_{cy} (Years)			References
			Bright.	Ampl.	Migrat.	
UX Ari	G5V+KOIV	$6^{d}.44$			16	Blanco et al.(1982b)
SS Boo	dG5+dG8	7.61		12	20	Blanco et al.(1982b)
WY Cnc	G5V+M2V	0.83	10			Sarma (1976)
RS CVn	F4IV+KOIV	4.78		4.5?	100	Blanco et al.(1982b)
RT Lac	G9IV+K1IV	5.07		30-35	35-40	Hall (1981)
AR Lac	GOIV+KOIV	1.98			30	Blanco et al.(1982b)
HK Lac	FIV+KOIII	24.43			22^	Blanco et al.(1982b)
II Peg	K2-3 V-IV	6.72	~ 40			Hartmann et al.(1979)
V711 Tau	G5V+G5V	2.84			5	Blanco et al.(1982b)
XY UMa	G2V+G5V	0.48	25			Geyer (1980)
BY Dra	dMOe+dMOe	5.97	50-60			Phillips & Hartmann (1978)
CC Eri	K7Ve	1.56	50-60			Phillips & Hartmann (1978)
BD 26°730	K5V	-	50			Hartmann (1981)

From the average photometric period of 24.96 days.

of the light curve outside-eclipse to migrate with respect to orbital phase. However changes in the migration rate (Figure 5) and reversal of the direction of migration (Figure 4) does suggest relative motions of the spotted areas on the stellar surface, which may be ascribed to a differential rotation and a latitude drift as on the Sun. Since migrations both toward increasing and decreasing orbital phases are observed (i.e. rotation period larger and smaller than the orbital period) an equatorial acceleration, as in the Sun, may explain the observation if there exists a latitude away from the equator which is rotating with the orbital period. Therefore the observed cyclic changes of the phase of wave minimum (ϕ_{min}) reflect the latitude drift of the spots toward the equator (advancing ϕ_{min} corresponds to spots at latitude larger than the co-rotating latitude $P_{rot}>P_{orb}$, regressing ϕ_{min} corresponds to spots at latitude smaller than the co-rotation latitude $P_{rot}<P_{orb}$).

So both advancing and regressing ϕ_{min} have been observed, but in general the migration rate proves to be variable in almost all systems,

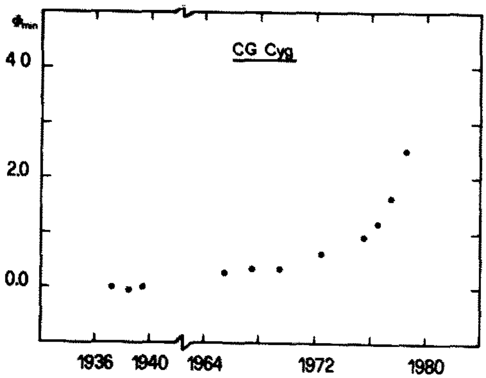

Figure 5. The phase of the minimum of the wave for CG Cygni (data from Blanco et al 1982, and sources referenced therein).

provided enough observational material is available (Blanco et al 1982a). On 30 systems for which reliable information are available, 6 show advancing ϕ_{min}, 16 regressing ϕ_{min} and 8 are variable.

This highly non-uniform distribution of the frequency of advancing (27%) compared to regressing (73%) migration(if the systems of variable migration direction are excluded) may result from different life-times of the migration in the two directions during a cycle. The frequency ratio therefore may give information on the co-rotating latitude relative to the maximum latitude of spot appearence for a new cycle.

Actually a completely repeated cycle has been observed to date only for RT Lac (Hall 1981) so it is not known how smooth the change in ϕ_{min} is from one cycle to the next and if the ϕ_{min} curve has a degree of asymmetry consistent with the distribution of migration directions.

In this interpretation the difference of the maximum values of the direct-to-reverse migration rate would be a measure of the differential rotation. Typical values of $\Delta\Omega/\Omega$ are $1.4\text{x}10^{-3}$ for short-period and $8.2\text{x}10^{-3}$ for long-period RS CVn binaries. $\Delta P/P$ values plotted versus the orbital period in Figure 6 show a power law dependence on the rotation period with exponent nearly equal to 1, i.e. $\Delta P/P \propto P$ (Blanco et al 1982b). Expressing this in terms of the rotational frequency one obtains $\Delta\Omega \propto (-\Omega^2/\Omega^2)$=const., while theoretical models of differential rotation predict $\Delta\Omega \propto \Omega$ (Belvedere et al 1980b). This is a puzzling result that can be understood in terms of forced synchronization of the stars by tidal action or by the braking effect of interacting magnetic loops (Simon et al 1980). The Sun appears to have a larger differential rotation (values for two different latitudes are given in Figure 6). An alternative possibility is that the interaction of the companion forces the spots to form closer to the co-rotating latitude where the strongest interaction is.

ORBITAL PERIOD VARIATION AND ACTIVITY

Many eclipsing binaries are known to have orbital period variations

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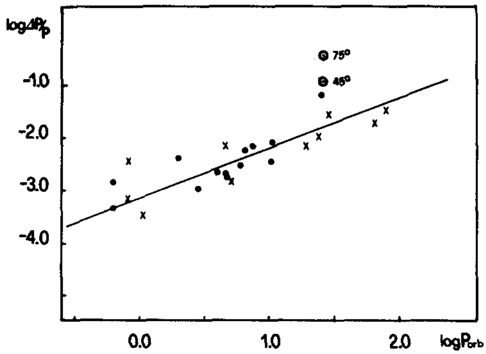

Figure 6. Maximum rate of the wave migration $\Delta P/P$ plotted against the orbital period of the system. Crosses (X) refer to systems for which only the difference ΔP between the photometric and the orbital period is known. Values for the rotation of the Sun at two different latitudes with respect to the equator are indicated. The solid line represents the power law relation $\log(\Delta P/P) = \log P + C$.

not due to apsidal motion or to a third companion. This phenomenon which appears to be fairly well understood in semidetached Algol binaries in terms of mass transfer, is difficult to explain in the RS CVn binaries, virtually all of which are clearly detached. The most comprehensive discussions of the period variation of RS CVn systems are those of Hall, Kreiner and Shore (1980) and Hall and Kreiner (1980). They found that of the known eclipsing RS CVn binaries around 40% have variable orbital periods. The observed long-term period changes are period decreases, while short-term alternating periodic changes (Hall, 1972) have been revealed to be spurious, the O-C residuals being due to a light curve asymmetry during the eclipses produced by the photometric distortion wave outside eclipses (Catalano and Rodonò 1974). Hall and Kreiner (1980) explained the long-term period changes with a model in which the active star loses mass in a convectively driven stellar wind which co-rotates with the star out to the Alfvèn radius. Average magnetic fields of about 1 k Gauss and mass losses of about 10^{-9} $M_\odot$/year are required. Due to the strong longitudinally asymmetric spot activity, they allow a possible anisotropy in the wind. De Campli and Baliunas (1979) found that mass loss rates of 10^{-6} $M_\odot$/year and high velocity ejection are required for the rocket effect to explain the apparent alternating short-term period changes. Magnetic braking can lower this required rate if the surface magnetic fields are $\geq$ 1 k Gauss. This could imply a different spin-orbit coupling which involves the interaction of the magnetic fields of the two components. De Campli and Baliunas have made an important first step computing the

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synchronization time (about 10^3 years for RS CVn and AR Lac) on the basis of the effect of magnetic reconnection in non-synchronously rotating binaries suggested by Bahcall et al (1973). Since this synchronizing magnetic torque may be stronger than the de-synchronizing magnetic braking torque, large orbital period changes may be allowed on that time scale.

Scharlemann (1981, 1982) considering tidal coupling in differentially rotating binary stars, found that the coupling torque is sufficient to explain the nearly synchronous rotation, but may not be able to explain the very long observed periods for the migration of the photometric wave. Better agreement is found on the hypothesis of angular momentum loss directly from the orbit.

It would be very interesting to tackle further this complex problem in order to try to explain the period changes of those systems like SS Boo, SV Cam, RS CVn, CG Cyg, RT Lac and AR Lac which exhibit both period increases and decreases. Anyway in this context a much closer analysis would be welcome in order to see if there exists any relation between the period changes and the activity parameters of RS CVn binaries.

Now I would like to mention two cases for which both the wave migration and the period variation seem to show correlated cyclic variation. These are AR Lac (Figure 7) and RS CVn (Blanco et al 1982a). In both systems rotation periods smaller than the orbital period (wave migrating toward decreasing phases) correspond to an orbital period decrease and viceversa.

RT Lac, for which data on the wave migration and period variation are available for about 80 years, does not seem to show such a behaviour. Unfortunately there are not enough observations on the wave migration for the other systems exhibiting cyclic period changes. Therefore let me call for new continuous observations on this group of RS CVn systems.

Finally let me emphasize a number of facts arguing against the hypothesis that the migration of the wave with respect to the orbital period may represent a differential rotation of the spotted star. They can be summarized as follows:

1) The relation between the wave migration rate $\Delta P/P$ and the orbital period can result from a forced synchronization.
2) The excess of migration of the waves toward decreasing phases and the corresponding excess of decreasing periods.
3) The correspondence on the cyclic variation of the orbital period and the wave migration cycle.
4) The discordance between the latitude drift of the spotted areas deduced from light curve modelling and from the wave migration curve.

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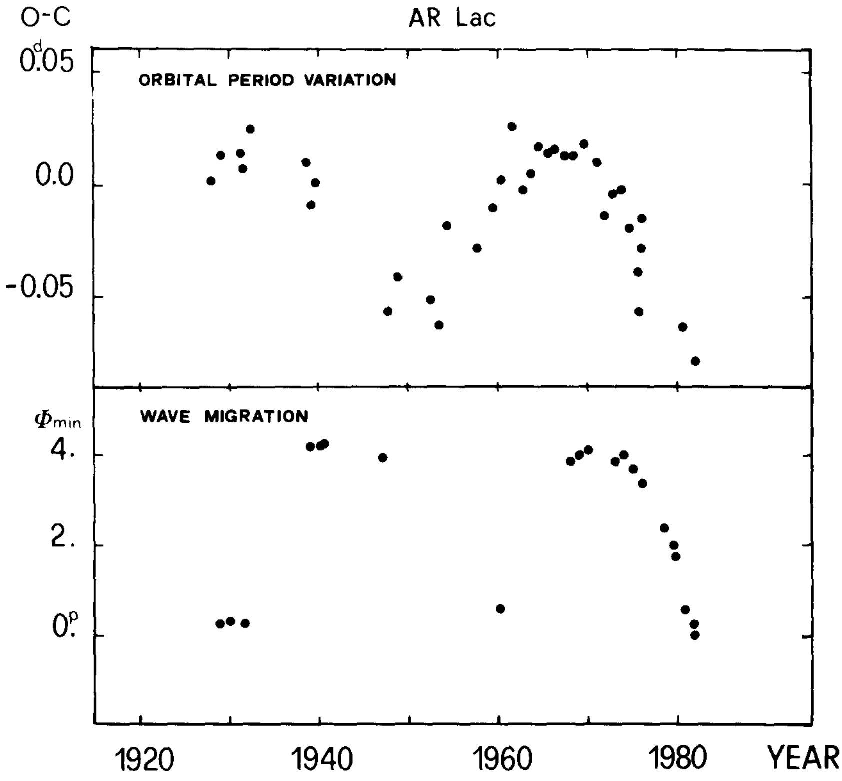

Figure 7. O-C residuals of the orbital period variations (Top) and the observed phases of the wave minimum ϕ_{min} (Bottom) for AR Lac (Blanco et al 1982b) . O-C residuals are averaged values from Hall and Kreiner (1980).

5) The difficulty in explaining traveling times of the wave on the light curve as long as 10 years (Uchida and Sakurai 1982).

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DISCUSSION

Belvedere: I can add a theoretical argument in favour of your different interpretation of the migration of the minimum. If we accept an interpretation based on differential rotation then the rates of differential rotation implied are too small to give rise to an adequate dynamo action. This would not be in keeping with the levels of activity observed.

van Leeuwen: I would like to make a few remarks. These are with respect to the measurements presented by Torres on AU Mic, which showed that the minimum of that star stays at the same place. On your interpretation this would mean that spots would always arise on the same side of the star. Is that right?

Catalano: This would mean that this star is very highly synchronous.

van Leeuwen: But AU Mic is a single star!

Catalano: Can I ask to what you refer the positions of the maxima or the minima? If you measure periods using the maxima and the minima you get different results. One is considered constant and the other changing. This is similar to what we see in the case of II Peg.

van Leeuwen: If one calculates a period from the minima of AU Mic one gets a very good period fit while using the maxima the fit is very poor. So I wonder what keeps the minima at the same place in the spot model?

Catalano: I don't know. The problem for those modelling the RS CVn and

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BY Dra stars is why there is this preferred longitude like the Red Spot on Jupiter. On the Sun there are symmetries in the longitude distribution of the spots which are not so strong as in the case of these stars. This is a general problem and perhaps the answer can come from this meeting.

van Leeuwen: There is one other thing I would like to mention. You found no correlation between amplitude and period whereas such a relationship is obviously present in the observations of the Pleiades K-type stars. I believe that the reason that you do not see it is the spread in the ages and the masses of the stars that you took as your sample. If you take stars of the same age and mass then you find a very clear relation between amplitude and period.

Catalano: This may be a statistical problem. We have only about 6 known RS CVn stars. Of those only a few have been observed for a long enough time to see changes in their light curves. Such relationship may also be hidden by other effects. The approach we have adopted is a photometric one. Perhaps spectroscopic observations for instance can give us a better view.

van Leeuwen: Have you considered the possibility of precession of the stars' rotational axis as being the cause of the amplitude changes?

Catalano: No. It would be very difficult to have this effect. You need to have the rotational axis inclined with respect to the normal to the orbital plane. This is a complication which I did not consider.

Vogt: The spots we see appear relatively stable over long periods of time, longer than you would expect if you consider the kind of differential rotation which we see in the Sun. They show the same kind of stability as solar complexes. This would suggest that we are seeing the effect of one internal, radial dependence of rotation rate rather than the latitudinal shear which we observe on the Sun. The other thing I wish to say is that the mass loss rates from these regions derived by Hall is too large to be believable. The analysis of Baliunas and De Campli involving magnetic fields suggest a much lower mass loss rate and still provide the observed period changes. Is not this what you would expect if these spots were large-scale unipolar regions showing the same kind of mass loss that occurs in solar unipolar regions? Does not this provide evidence that these large spots are just filled-in analogues of solar complexes rather than something similar to sunspots?

Catalano: Baliunas considered two case of period change. One is on a short timescale. Their result is that the required mass loss is as great as Hall and Kreiner's model . They conclude that these short period changes are due to a rocket effect and may not be real. The longer period changes they treat very briefly. They just try to calculate the synchro-

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nization times for systems like RS CVn or AR Lac. They found a 1000 year timescale for synchronization. If we have the two effects, i.e. the braking effect on the spotted star and the reaction on the other star, then period change would be expected. So on this view we would expect some relation between the change of the period and the rotation of the star that we deduce from the periodic light variation.

Feldman: In superimposing your data on the diagram of Vogt (this volume, Fig.6) I noticed that there were a few points that had activity cycles of order 10 years for rotation periods less than 7 days. Could you comment on those particular systems?

Catalano: It was already pointed out by Vogt in his paper that there appeared to be some kind of relationship between the cycle period and the rotation periods less than about 7 days. You must ask Vogt for details of these. I believe the cycles were observed in variation of the K-line for rotation period larger than 7 days. But as I showed in Table 2 cycles deduced from median brightness, amplitude and wave migration variations in some case are different one another. Some os the systems you are referring to is the same plotted by Vogt, but the cycle is deduced from a different parameter.

Rucinski: I would like to point out that we have an interesting problem here. With regard to the changes in the migration rate, the short period systems seem to be better synchronized. On the other hand we have heard that from a theoretical point of view that these stars cannot generate enough magnetic field to account for the observed activity. This is important, since your period dependencies looked most impressive.