NAG 5-82

RS CVn BINARY SYSTEMS

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ABSTRACT

In this review I will attempt to place in context the vast amount of data obtained in the last few years as a result of X-ray, ultraviolet, optical, and microwave observations of RS CVn and similar spectroscopic binary systems. Since this topic is now very broad, I will concentrate on the RS CVn systems and their long-period analogs, and restrict the scope by attempting to answer on the basis of the recent data and theory the following questions: (1) Are the original defining characteristics still valid and still adequate? (2) What is the evidence for discrete active regions? (3) Have we derived any meaningful physical properties for the atmospheres of RS CVn systems? (4) What are the flare observations telling us about magnetic fields in RS CVn systems? (5) Is there evidence for systematic trends in RS CVn systems with spectral type?

I. INTRODUCTION

While the study of close binary systems that we now consider members of the RS Canum Venaticorum class goes back many decades in time, the recognition that these systems constitute a well defined class of objects with common characteristics began with Hall's (1976) review paper published only seven years ago. Subsequently, ultraviolet and X-ray observations with the Copernicus, IUE, HEAO-1, and HEAO-2 spacecraft, together with microwave and optical observations from the ground have revealed a vast range of fascinating phenomena that were not anticipated even seven years ago. Later reviews by Catalano, Frisina, and Rodono (1980), Dupree (1981), Hall (1981), Rodono (1983), Bopp (1983), and Catalano (1983) have summarized much of this complex phenomenology and have presented the generally accepted starspot model in which magnetic fields and their interactions with the ambient plasma are presumed to be responsible for the dark starspots in the photosphere and the greatly exaggerated but solarlike activity occurring in the chromosphere and corona.

In this review I propose to take a somewhat different approach. Instead of reviewing phenomena *per se*, I will ask a number of basic questions concerning the RS CVn systems and then attempt to answer these questions by describing the relevant

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(NASA-CR-174164) RS CV SUB n BINARY SYSTEMS (Joint Inst. for Lab. Astrophysics) 15 p HC A02/MF A01 CSCL 03A
N85-13704
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data and theoretical work on the topic. The purpose is to attempt to place in context the vast amount of data obtained in the past few years from the X-ray to the microwave regions of the spectrum. Of particular concern are the atmospheric structures of these stellar systems and the roles played by magnetic fields. I will also emphasize very recent observations, many of which are not yet published.

II. ARE THE ORIGINAL DEFINING CHARACTERISTICS STILL VALID AND STILL ADEQUATE?

a) Defining Characteristics

Close binary stars display a vast array of phenomena depending on the spectral types, mass ratios, and evolutionary status of the component stars, whether one or both stars fill their Roche lobes, and the proximity of the two stars. In order to bring some order out of this chaos and to define a relatively homogeneous class of systems with similar characteristics and phenomena observed in the visible, Hall (1976) proposed a working definition of RS CVn systems consisting of the three properties listed below. Are these three defining characteristics still valid?

1. Binaries with orbital periods of 1-14 days. Hall chose these upper and lower limits rather arbitrarily on the basis that for the 24 stars, which he felt have similar characteristics and thus should be members of the RS CVn class, the distribution of periods was such that there were no suspected candidates with periods of 0.9-1.9 days and 11-17 days. Since the list of known RS CVn binaries keeps growing (Hall [1981] lists 69 members), we should question this original definition and search for a definition that rests on a physical basis. Probably the main characteristic separating the more evolved (and in general more active) components in these systems from single stars of the same spectral type is rapid rotation, a direct consequence of tidally-induced synchronism of rotation and orbital periods.

Zahn (1977) has shown that for stars with convective envelopes, the synchronization time is

$$t_{synch} = 10^4\left[\frac{(1+q)}{2q}\right]^2 P^4 \text{ yr} \quad , \qquad (1)$$

where q is the mass ratio, which is generally close to unity for these systems, and P is the orbital periods in days. Thus $t_{synch} = 10^8$ yr for P = 10 days and 1.6 × 10^9 yr for P = 20 days when q = 1. Evolutionary considerations then suggest that subgiants with orbital periods less than 20 days should be tidally synchronous, and thus rapid rotators and active stars as is indeed the case. A well-known nonsynchronous system, λ And (G8 III-IV + ?), with P_{orb} = 20.5 days and P_{rot} = 54 days confirms this argument. Thus a natural division between RS CVn systems and the so-called long period RS CVn systems is about 20 days, not 14 days as originally suggested. The proper short period cutoff to the RS CVn class is unclear at this time, but it seems reasonable to exclude contact binaries such as the W UMa systems (Dupree 1983) on the basis that they exhibit somewhat different properties, such as a common coronal envelope.

2. Strong Ca II H and K line emission outside of eclipse. Bright H and K emission historically has been used to identify new members of the RS CVn class because these emission features stand out against the relatively weak photospheric continuum and photospheric Ca II absorption line wings even at relatively low dispersion. Bopp (1983) has tabulated Ca II surface fluxes for 19 RS CVn systems, which are typically 2-20 times that of the quiet Sun. The Hα line is a pure emission feature in only the most active systems (e.g. HR 1099, UX Ari, II Peg, and DM UMa), and appears as a filled-in absorption feature in the other systems. While one can subtract the Hα profile of a standard single star to obtain a net Hα emission profile (e.g. Fraquelli 1982), this is not a simple technique; thus filled-in Hα absorption should not be a defining characteristic for these systems. Enhanced ultraviolet emission lines (e.g. Dupree 1981) and X-ray luminosity (Charles 1983) are common properties of these systems and could be used as defining spectral characteristics, but it is not yet feasible to search large numbers of stars for these features. On this basis, it seems reasonable to continue to use bright H and K line emission as a defining characteristic, but we should recognize that the strong Ca II line emission is only one indicator of the enhanced nonradiative heating rate, which is the physical basis responsible for this defining characteristic.

3. The hotter star is of spectral type F or G and luminosity class V or IV. If we adopt P_{orb} = 20 days as defining the long period cutoff of the RS CVn group, the only systems that are inconsistent with this definition (Hall 1981) are single line spectroscopic binaries for which the other component is unknown. Three are luminous systems with periods of 17-20 days (σ Gem, ζ And, and V350 Lac) and the other is II Peg (P_{orb} = 6.7 days). What are the secondary components in these systems? Are they less evolved stars close to the main sequence as is generally the case for RS CVn systems, or could they be white dwarfs as in V471 Tau, but cooler?

b) Nondefining Characteristics

Hall (1976) also lists 15 additional characteristics that appeared to be valid for most but not all of the systems for which he had data at that time, and thus were not suitable as defining characteristics. I would like to comment on several of these.

1. The Ca II H and K emission is from the cooler star (or both). This is generally true for the RS CVn systems, but it is important to recognize that the hotter star is often also quite active, and when the orbital velocity separation of a spectrum is large the contribution of the hotter star is often apparent in high resolution spectra. For example, Simon and Linsky (1980) detected Mg II h and k emission from the G5 V star in UX Ari about 1/5 as strong as that of the K0 IV star. But since the radius of the K0 IV star is about twice that of the G5 V star, the Mg II surface fluxes of the two stars, indicative of the general activity level, are similar. The long period Capella system (G6 III + F9 III, P_{orb} = 104 days) is a clear exception in that the earlier type star is the predominant emitter (Ayres and Linsky

1980; Ayres, Schiffer, and Linsky 1983), presumably because the F9 III star is a rapid rotator whereas the G6 III star is not. In some sense this exception proves the rule since for synchronous systems the more evolved (i.e. cooler) star has a larger radius and is thus the more rapid rotator.

2. A wave-like distortion in the optical light curve is detected outside of eclipse. This characteristic is now deemed fundamental as it indicates the presence of dark starspots (e.g. Eaton and Hall 1979) that migrate in phase (Catalano and Rodono 1974), are cool (Vogt 1979; Ramsey and Nations 1980), and are presumed to be magnetic in character by analogy with sunspots. This last point is critical because strong magnetic fields presumably underlie all of the interesting activity seen in RS CVn systems, yet rapid rotation makes it difficult to measure the magnetic fields directly by the Zeeman effect. To my knowledge the only direct measurement of a magnetic field is the measurement of a field of 1290 ± 320 Gauss covering half the visible surface of λ And (Giampapa, Golub, and Worden 1983). It is important that this work be extended.

3. RS CVn systems are detached binaries with mass ratios close to unity. To my knowledge the only exceptions to this statement are RT Lac and SZ Psc, which are semidetached systems, and the single line spectroscopic systems for which the mass ratios are unknown. Popper and Ulrich (1977) have called attention to the interesting evolutionary status of the RS CVn systems. They point out that binaries develop RS CVn characteristics when one or both stars enter the Hertzsprung gap and develop convective envelopes. The tidal synchronism mechanism will halt the rapid loss of rotational velocity when $P_{rot} = P_{orb}$, so that the K0 IV and K0 III cool stars in these systems have equatorial rotational velocities of 40-60 km s^{-1} instead of 2-5 km s^{-1} (Gray 1982). This combination of rapid rotation and convection presumably is responsible for the efficient generation of strong magnetic fields by dynamo processes that results in the RS CVn phenomena. For most systems there is no evidence for streams, tidal distortions, or reflection effects, consistent with the detached geometry.

III. WHAT IS THE EVIDENCE FOR DISCRETE ACTIVE REGIONS?

a) Chromospheres and Transition Regions

RS CVn systems have been monitored extensively in the Hα line (see Bopp 1983 for a detailed review), but these data exhibit no evidence for active regions correlated with starspots. For example, Ramsey and Nations (1980) observed stronger Hα emission in HR 1099 at a phase near spot maximum (photometric minimum) than at spot minimum, but they did not monitor for flares at that time. In an extensive study of HR 1099 during 1977-79, Dorren et al. (1981) monitored the Hα line with narrow band photometry. They detected strong net emission in Hα with large nightly variations, but no correlation with photometric phase even though the photometric wave showed a large amplitude at that time. They concluded that the variable Hα net flux indi-

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cated flaring rather than the presence of active regions. Similarly, Fraquelli (1982) also detected variable Hα net flux from HR 1099 that correlated with the microwave radio flux, a good indicator of flaring. When she removed from the data set those observations taken during flares, she also found no correlation of Hα emission with photometric phase.

There are fewer observations of RS CVn systems in the Ca II H and K lines, but these data do provide some evidence for active regions correlated with the star spots. For example, Weiler (1978) observed six systems in the Ca II lines and Hα. The data are sparse, but the Ca II emission equivalent widths appear to strengthen at photometric minimum for RS CVn itself, consistent with the hypothesis that chromospheric active regions cluster above starspots. Weiler's observations of UX Ari and Z Her are also marginally consistent with the above hypothesis.

The connection between active regions and starspots became clear only with observations by IUE. The first such evidence by Rodono, Romeo, and Strazzula (1980) is based on low dispersion Mg II fluxes of II Peg (K2-3 V-IV + ?). Subsequently, Baliunas and Dupree (1982) observed λ And at photometric maximum and minimum with IUE. They detected transition region line (e.g. C II, C IV, Si IV) emission 30-50% brighter, and the Ca II lines brighter, at photometric minimum than at maximum, but for some unexplained reason the Mg II line fluxes were nearly unchanged. Also the Ca II lines have different asymmetries, suggesting that the flows are different on the two hemispheres. Walter, Gibson, and Basri (1983) observed Ar Lac (G2 IV + K0 IV) with IUE at egress (phase 0.053) from primary eclipse (K0 IV star in front) and at quadrature (phase 0.256). These data (see Figs. 1 and 2) show the Mg II flux

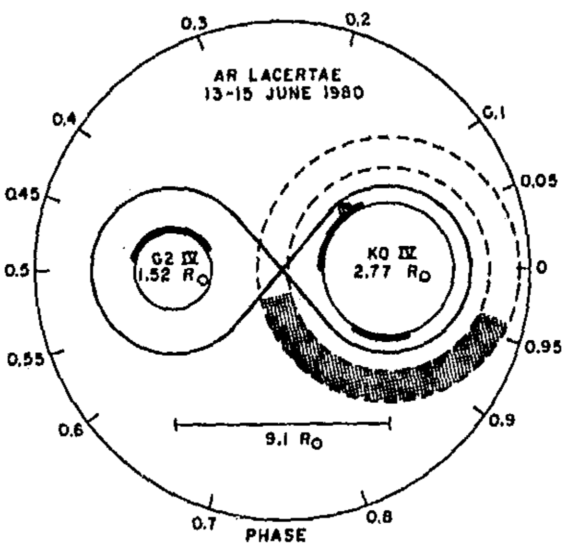

Fig. 1. A scale drawing of the AR Lacertae system. The line of sight at a given phase is found by lining up the phase indicated on the outer circle with the center of mass. The solid line is the Roche surface; the dashed lines surrounding the K star indicate the inner and outer radii (1.5 and 2.0 R_K) of the extended component of the K star corona. Crudely indicated are the location and extent of the observed chromospheres and coronae. Note that the extended component of the K star corona exceeds the Roche radius (from Walter, Gibson and Basri 1983).

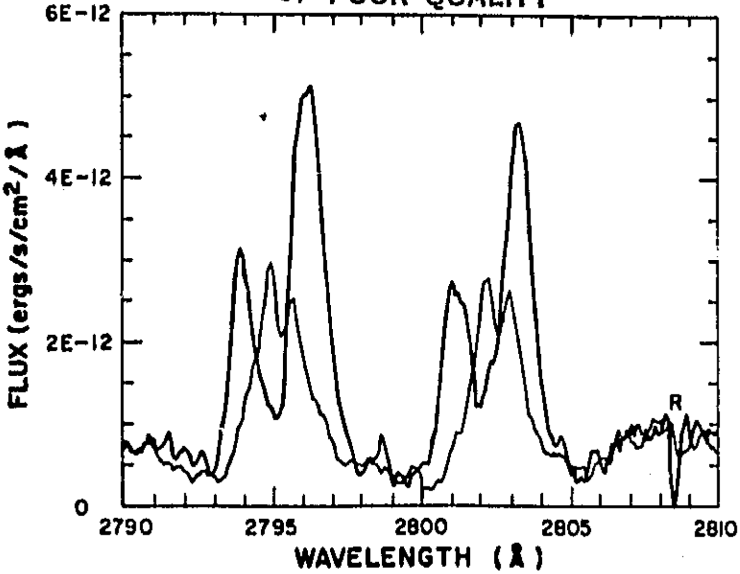

Fig. 2. High-resolution observations of the Mg II resonance lines for AR Lac during egress from primary minimum (thin lines) and at quadrature (thick lines). Approximately half of the G star is visible at this stage of egress. Note that although the G star is the one eclipsed, it produces the approximately constant blueward component while the K star shows a dramatic change (having remained unocculted). The flux ratio of K to G star is 2:1 at quadrature, indicating the G star actually has stronger surface flux here (from Walter, Gibson and Basri 1983).

attributable to the G2 IV star unchanged, but the Mg II flux attributable to the K0 IV star a factor of two larger at quadrature. They argued that the data are consistent with an active region (visible in both observations) above the spot group on the G2 IV star producing the photometric minimum at phase 0.25, and an active region on the K0 IV star in view only during the quadrature observation.

Two sets of IUE high resolution spectra with the short wavelength camera indicate the presence of compact active regions by changes in the line integrated fluxes and centroid velocities. In the first data set, Ayres and Linsky (1982) observed HR 1099 (G5 IV + K1 IV) at opposite quadratures (phases 0.21 and 0.76). They found that at phase 0.76 the transition region lines (e.g. C II 1336 Å and C IV 1548 Å) are brighter and displaced +40 km s^{-1} relative to the K1 IV star velocity, indicating an active region near the receding limb of the K0 IV star at this phase but on the back side of the star at phase 0.21. This would put the central meridian passage of the active region at phase 0.6 in June 1980, but photometric minimum in 1979 occurred near phase 0.95. Thus the connection between spot and active region is not clear for this observation.

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A better example is the high resolution spectra of σ Gem (K1 III + ?) obtained at phases 0.53 and 0.58 by Ayres, Simon, and Linsky (1984). They found that the transition region lines were both stronger and blue-shifted at phase 0.53 compared to phase 0.58, consistent with an active region on the receding limb at phase 0.53 but over the limb at phase 0.58. Since starspot group B (see Fried et al. 1983) was also on the receding limb at phase 0.53, the spatial connection of the active region and a spot group is indicated by these data.

The clearest example yet of the spot-active region connection is the October 1-7, 1981 IUE monitoring of II Peg. In this program, Marstad et al. (1982) found that the ultraviolet emission line flux is well correlated with photometric minimum (see Fig. 3). In particular, all the emission lines rise sharply at phase 0.45 and

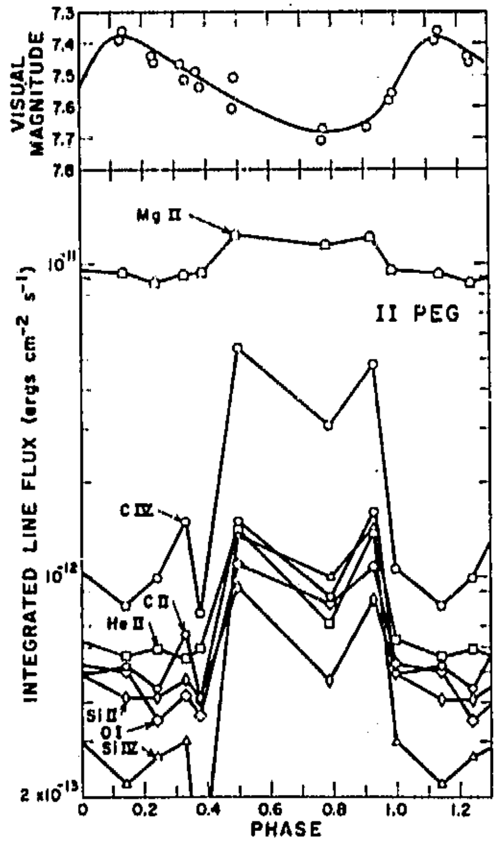

Fig. 3. Lower Panel: integrated emission line fluxes for II Peg obtained in October 1981 by Marstad et al. (1982). Note the rapid rise in flux near phase 0.45 and rapid fall near phase 0.95 indicating the rotational modulation of a compact active region across the disk. Upper Panel: photometric variation obtained with the FES simultaneously with the IUE spectra.

fall sharply at phase 0.95, indicating a rather compact active region. The much larger rise of the transition region lines (a factor of five) compared to the chromospheric lines (less than a factor of two) is consistent with the difference between the spectra of solar active and quiescent regions. Marstad (1983) used these data to locate the active region on the stellar surface and compared this active region with the location of the two spot groups he derived from the IUE optical light curve, which is similar to the 1976 light curve and spot group positions derived by Bopp and Noah (1980). Marstad placed the active region near the leading edge of the larger spot group (see Fig. 4), and concluded that its area is no larger than 6% of the visible hemisphere, compared to the spot area of 25-30% of the visible hemisphere.

This result is remarkable to say the least. Whereas solar active regions are much larger than the photospheric spots they overlie, the situation is reversed for II Peg. Second, the small active region size implies that the active region surface fluxes for the transition region lines must be very large as indicated by Table 1. For an assumed surface covering factor of 0.06, the maximum value indicated by Marstad, the C IV surface flux is 4200 times the quiet Sun value and the C IV 1550 Å lines carry 0.1% of the total stellar luminosity per unit area. These extreme

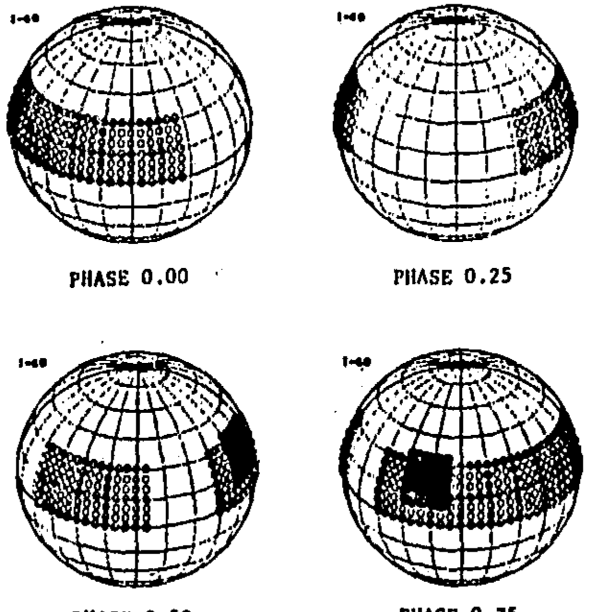

Fig. 4. The location of the two spot groups (small circles) and the active region (solid black) derived by Marstad (1983) from the optical photometry and emission line flux versus phase observations of II Peg in October 1981. Note that the active region overlies a small portion of the larger spot group.

Table 1. Active Region Surface Fluxes

Assumed Surface Covering Factor	$F_{C\ IV}$(active region) (ergs cm^{-2} s^{-1})	$\frac{F_{C\ IV}\text{(active region)}}{F_{C\ IV}\text{(quiet Sun)}}$	$\frac{F_{C\ IV}\text{(active region)}}{\ell_{bol}}$
1.00	1.7×10^6	2.6×10^2	7.3×10^{-5}
0.06	2.8×10^7	4.2×10^3	1.2×10^{-3}
0.02	8.3×10^7	1.3×10^4	3.6×10^{-3}

values point out the necessity for deriving active region areas and the folly of describing RS CVn chromospheres and transition regions by one-component theoretical models.

b) Coronae

I now consider the evidence for discrete active regions in the coronae of RS CVn systems based on observations with the *Einstein* X-ray observatory. The most important set of observations has been obtained by Walter, Gibson, and Basri (1983) of AR Lac during a total primary eclipse (K0 IV star in front at phase 0.0) and a annular secondary eclipse (G2 IV star in front). The geometry for these eclipses is shown in Figure 1. Eclipses are powerful probes of coronal X-ray brightness distributions and thus the location of active regions since each position in the corona is covered and uncovered during each eclipse.

From these data Walter *et al.* found that the G2 IV star contributes 40% of the total X-ray flux. Its corona has a small scale height (~0.02 R_*) and is located primarily over the spot group, which is near phase 0.25 (see Fig. 1). The K0 IV star exhibits a more complicated coronal structure with a geometrically thin component (scale height ~0.02 R_*) located primarily at two longitudes and with an extended component (scale height ~R_*) located over one hemisphere. In addition, the IPC spectral height distribution indicates a two temperature coronal plasma, as does the SSS data (Swank *et al.* 1981), and Walter *et al.* argue that the hotter plasma is in the extended component. This data set thus points to a correlation of spots and coronal active regions at least for the G2 IV star, but the extended (hot?) component is not connected to any known spot region. Furthermore, the location of hot plasma far from the K0 IV star implies the existence of large loops extending beyond the Roche lobe of this star and perhaps interconnecting the two stars in the system.

IV. HAVE WE DERIVED ANY MEANINGFUL PHYSICAL PROPERTIES FOR THE ATMOSPHERES OF RS CVn SYSTEMS?

a) Chromospheres and Transition Regions

In the past few years there have been at least four major studies of RS CVn systems that purport to derive the run of temperature, pressures, and density with height using different spectroscopic diagnostics. In each case the authors solved the radiative transfer and statistical equilibrium equations for an assumed homogeneous, one component atmosphere in hydrostatic equilibrium so as to match computed and observed line fluxes and in some cases line profiles. For example, Baliunas *et al.* (1979) derived chromospheric models representative of λ And and Capella to match the observed Ca II, Mg II, and Hα profiles. Their best fit models are characterized by top pressures, appropriate for the base of the transition region, of 1-1.7 dynes cm^{-2}. Subsequently, Simon and Linsky (1980) derived models for HR 1099 and UX Ari to match the observed Mg II line profiles, fluxes of C II, Si II, and Si III lines, and three density sensitive line ratios. Their best fit models have a top pressure of roughly 0.5 dynes cm^{-2} and are inconsistent with a transition region that is conductively heated. On the basis of models constructed to match the Hα profile of λ And, Mullan and Cram (1982) derived transition region pressures of 0.06 or 0.4 dynes cm^{-2} depending on the assumed macroturbulence. Finally, Baliunas and Dupree (1982) proposed transition region pressures of 1.3 dynes cm^{-2} for the unspotted hemisphere and 1.9 dynes cm^{-2} for the spotted hemisphere transition region of λ And, based on observed C I and C II line fluxes.

These models, based on a range of spectroscopic diagnostics, different RS CVn systems, and computed by different groups, are in reasonable agreement with each other, but are they realistic representations of the mean atmospheric properties of RS CVn systems? It seems to me that they are not, because they ignore what is likely a fundamental property of the atmospheres of these systems -- extreme inhomogeneity. If the results for II Peg described above are representative, then most of the observed chromospheric and transition region emission originates in one or a few active regions covering a small portion of the observed hemisphere of the star. Thus the active region line surface fluxes could be 10-100 times that of the spatial average, and the transition region pressures and densities for the active region correspondingly larger. I suspect, but cannot prove, that the same is true for those systems that show little rotational modulation of the UV emission line fluxes, except that in these systems there are several active regions widely distributed in longitude observed at all phases. It seems vitally important, therefore, that future studies concentrate on determining the active region filling factor and then on computing models of the active and quiescent regions separately. One way of deriving active region filling factors is by rotational modulation studies of systems with simple photometric waves of large amplitude, as was the case for II Peg in October 1981. The second way involves deriving the densities of active regions from density-sensitive line ratios when the active regions dominate the observed flux.

b) Coronae

Numerous RS CVn systems were detected as X-ray sources by HEAO-1 because they are intrinsically bright ($29.4 \lesssim \log L_x \lesssim 31.5$) and are quite numerous. Walter *et al.* (1980) listed 15 sources, and Charles (1983) listed 45 sources detected by HEAO-1 and *Einstein* and reviewed their properties. The HEAO-1 data suggested coronal temperatures of 10^7 K. Assuming this temperature and the Rosner, Tucker and Vaiana (1978) scaling law for static loops smaller than a pressure scale height,

$$T = 1400\ (PL)^{1/3} \quad , \qquad (2)$$

Walter et al. (1980) estimated values of loop heights (L), fractional filling factors (f), and number of loops (N) for different stars. Clearly these quantities depend on the pressure (P) in the loops, but assuming that for Capella $P = 1.5$ dynes cm^{-2}, the mean transition region pressure, then $f = 0.2$, $N = 100$, and $L = 2 \times 10^{11}$ cm $\approx 0.3\ R_*$. These loops are large but still only about 0.05 of the coronal pressure scale height.

Since the RS CVn systems are bright X-ray sources, Swank et al. (1981) were able to observe seven systems and Algol with the Einstein Solid State Spectrometer. These low resolution spectra indicate that all of the systems have coronae characterized by at least two temperatures: a low temperature component with $T = 4\text{-}8 \times 10^6$ K and $\log L_x = 30\text{-}31$, and a high temperature component with $T = 20\text{-}200 \times 10^6$ K and $\log L_x = 29.1\text{-}31.1$. Furthermore, the high temperature components appear to be more variable than the low temperature components, and the most widely separated system (Capella) has the smallest ratio of high to low temperature component luminosity. I will return to this important point later. They also applied the Rosner-Tucker-Vaiana scaling law [Eq. (2)] with the conclusion that if $P \lesssim 10$ dynes cm^{-2}, then L/R_* for the hot coronal component is similar to the binary separation and L/R_* for the cool coronal component is $\lesssim 1\ R_*$. However, if $P \gtrsim 100$ dynes cm^{-2} then both components are relatively compact geometrically. They could not decide between these two scenarios.

The Einstein IPC observations of AR Lac during eclipses provided Walter et al. (1983) with the critical data on the coronal emitting region volumes and locations needed to derive the loop pressures directly from Eq. (2). Their only assumption was that the extended component of the K0 IV star corona (see Fig. 1) consists primarily of the hot gas detected in earlier SSS observations. Their results, summarized in Table 2, indicate that the coronal loop pressures are large (25-140 dynes cm^{-2}), two orders of magnitude larger than the average transition region pressures previously discussed. This result provides further evidence for the inadequacies of one component models. It is interesting that the II Peg data imply that the active region surface fluxes are 10-100 times larger than quiescent, which may be consistent with the AR Lac coronal loop pressures if pressures scale proportionally to the surface flux. This point needs further consideration.

Table 2. Coronal Loop Parameters for AR Lac

Parameter	G2 IV Star	K0 IV Star (extended component)	K0 IV Star (inner component)	Flaring Sun
P	100	25	70	140
L/R_*	0.02	2	0.01	0.01
N	10^6	10	10^6	10^6

V. WHAT ARE THE FLARE OBSERVATIONS TELLING US ABOUT MAGNETIC FIELDS IN RS CVn SYSTEMS?

Flares are highly energetic events in RS CVn systems with time scales of hours to weeks, much longer than for flares on M dwarf stars like UV Ceti. Reviews of flare phenomena include discussions of the Hα data (Bopp 1983), X-ray data (Charles 1983), and radio observations (Gibson 1980, Feldman 1983). Also there are a number of important papers on the very long-lived flare on HR 1099 in February-March 1978 that are included in the December 1978 issue of the Astronomical Journal. From this wealth of data, I would like to call attention to those data that provide information on the geometry, flows, and magnetic field topology of the flaring plasma.

First, Bopp (1983) pointed out that while the Hα line brightens significantly during flares, this emission is not modulated at the orbital or rotational period. In other words, the emitting volume is either large compared to a stellar radius or the emission occurs in the binary system well away from either star and perhaps between the two stars. The VLBI microwave observations (cf. Feldman 1983) also point to emission from a large volume, several times the binary separation for the specific case of the April 1981 flare on HR 5110.

Second, there is evidence for mass flows during flares. Bopp (1983) pointed out that during flares the Hα line becomes very broad (~400 km s^{-1} during the February-March 1978 flare on HR 1099) with occasional redward asymmetries. A very important observation in this regard is a high resolution spectrum of the Mg II lines obtained by Simon, Linsky and Schiffer (1980) during the New Year's Day 1979 flare on UX Ari. They found the Mg II lines to be very asymmetric with wings extending out to +475 km s^{-1}, roughly the escape velocity from either star, and interpreted these profiles as indicating a mass flow from the K0 IV to the G5 V star that could occur if the large flux tubes of the two stars interact. This hypothesis suggests that RS CVn flares are powered by magnetic field annihilation of interacting flux tubes as in solar flares, except that the scale is vastly larger because it is the flux tubes of two separate stars that are responsible. The long time scales of RS CVn flares could be a consequence of the large geometrical scales. Furthermore, the large circular polarization of flare microwave emission (e.g., Brown and Crane 1978) indicates that the emission process is magnetic in character.

Third, Uchida and Sakurai (1983), in their theoretical calculations, have shown that the magnetic flux tubes of active regions on both stars in RS CVn systems will interact and often interconnect the two stars. In particular, the strong coronal heating and flares could result from magnetic reconnection as individual starspots drift across the active longitudes of both stars. They interpreted the low temperature coronal component as plasma confined in small loops and the high temperature component as plasma confined to loops interconnecting the two stars. This picture is consistent with that proposed by Walter et al. (1983) for AR Lac on purely observational grounds.

VI. IS THERE EVIDENCE FOR SYSTEMATIC TRENDS IN RS CVn SYSTEMS WITH SPECTRAL TYPE?

I would like to conclude this rather selective review by calling attention to what appears to be a significant difference between the F9 III active star in Capella and the K0 IV active stars in typical RS CVn systems like HR 1099, UX Ari, and II Peg. Ayres, Schiffer and Linsky (1983) obtained high dispersion IUE short wavelength spectra of Capella at three quadratures and one conjunction. These data confirm earlier work (Ayres and Linsky 1980) that the F9 III component has transition region surface fluxes about 25 times brighter than the G6 III primary, presumably because the F9 III star is a rapid rotator ($P_{rot} \approx 8$ days) whereas the G6 III star is a slow rotator. Ayres et al. (1983) also found that Capella is a remarkably steady ultraviolet emission line source (to the few percent accuracy of the IUE photometry) on time scales of hours to 9 months. In a further study involving 22 observations over half an orbital period, Ayres (1983) also found no ultraviolet flux changes at a sensitivity level of <5%.

This remarkably steady flux from the F9 III star in Capella implies either uniform emission across the stellar surface or, more likely, a large number of active regions well distributed in longitude. By contrast, the K0 IV stars in typical RS CVn systems exhibit highly variable emission line flux indicative of only a few active regions or only one active region in the previously discussed case of II Peg in October 1981. I summarize these differences in Table 3.

I believe that these very different properties are not due to different rotational velocities since the rotational period of the F9 III star in Capella is comparable to the periods of the K0 IV synchronously rotating stars. Instead, I believe that these differences can be explained by two effects:

Table 3. Comparison of Active Stars in Capella and Shorter Period RS CVn Systems

Property	Capella	HR 1099, UX Ari, II Peg
Active star	F9 III	K0 IV - K2 IV
Orbital period	104^d	$2.8\text{-}6.7^d$
Rotational period	8^d	$2.8\text{-}6.7^d$
UV flux variations	<5%	large
Number of active regions	large	few
Radio emission (6 cm)	<0.2 mJy	up to 1000 mJy
$L_x(hot)/L_x(cool)$	0.1	1-3
a/R_{active}	23	4-7
Flaring	never detected	common

(1) The Capella F9 III star has a shallower convective zone and thus a much larger number of convective cells. Also the dynamo and convective zone velocity field together appear to generate many rather than few magnetic active regions.

(2) The separation of the stars in the Capella system is much larger than in the shorter period systems. Thus it is difficult for the magnetic fields of the two Capella stars to interact. According to the previous discussion there should be few flares, weak radio emission, and little hot plasma in the corona, as is observed. The difference between Capella and the short period systems thus strengthens our conclusion that interacting magnetic fields are fundamental to explaining much of the fascinating phenomenology of the RS CVn systems.

I would like to acknowledge partial support of the National Aeronautics and Space Administration through grants NGL-06-003-057 and NAG5-82 to the University of Colorado. It is a pleasure to thank my colleagues Drs. T. Ayres, A. Brown, K. Carpenter, S. Drake, D. Gibson, T. Simon, and F. Walter for stimulating discussions that clarified my thinking on RS CVn systems.

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