Magnetodynamical Processes in Interacting Magnetospheres of RS CVn Binaries

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Abstract : Magnetodynamical processes in RS CVn binaries are discussed in the scheme of Active-Longitude-Belt picture (Uchida and Sakurai, 1983) in which the "photometric wave" is due to a number of spot pairs which emerge, drift across, and submerge in the "active longitude belt" on the K-star. The formation of the corona and the origin of flares in these close binary systems having starspots are interpreted in terms of the reconnections of the magnetic flux tubes of the companion star with the emerging and submerging pairs of spots on the K star. The injection of the hot plasma into the large scale pole-to-spot connections is required to explain the extended corona with large emission measure, and we attribute this to the "sweeping-pinch" mechanism (Uchida and Shibata, 1984) associated with the relaxation of the toroidal component in the twisted magnetic flux tubes which emerge and reconnect with the flux tubes connecting pole and spots.

1. Introduction

The super starspot interpretation of the "photometric wave" (= PW) of RS CVn binaries seems to lead to some paradox. If the drift of PW along the light curve is attributed to the migration of starspots toward the equator on a differentially rotating star, the differential rotation derived from the drift rate of PW is rather small, of the order of $\Delta\Omega/\Omega \sim 10^{-3}$. On the contrary, the differential rotation law scaled from the sun (Durney and Robinson, 1982) suggests a much larger differential rotation in such rapid rotators like RS CVn's, even the tidal effect may tend to bring the stellar atmospheres into the synchronized rotation (Zahn, 1977). The drift curve of PW for SS Boo and V711 Tau, showing reversals of the direction of the migration during a cycle, may also be difficult to interpret in the framework of solar analogy. The very small differential rotation deduced from the almost static super starspot

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makes the picture of the system rather static because there is no very drastic occurrence expected if relative orientations of everything do not charge. Although it is not impossible that stars in such close binary systems may show rather peculiar behavior, the discrepancies seem to be too large between this and the G5 star, the sun.

Uchida and Sakurai (1983) proposed a different view that the PW is the stellar version of the active-longitude-belt (=ALB) in which individual spot-pairs appear, drift across, and disappear. This model, at a glance, seems to be similar to the multiple spot model of Eaton and Hall (1979) but the latter did not include the notion of such lively activities in the zone. The introduction of ALB picture relaxes the otherwise inevitable restrictions in the somewhat queer (though fascinating) super starspot model, and allows an activated picture in which many pairs of smaller spots appear and disappear after being carried across ALB by appreciable differential rotation.

2. Magnetic Field in ALB Model

It is known that RS CVn systems have coronae and produce flares in X-rays (Walter *et al.*,1981) and radio (Gibson *et al.*,1978, Feldman *et al.*,1978). The coronae have two temperature structure (Swank *et al.*,1981) and the hotter component might be extending to the size of the binary system. In AR Lac's case, the extended corona is found nonuniform and localized around the leading side (facing the direction of revolution) of the K-star (Walter *et al.*, 1983).

In the solar case, not only flares but also the corona turned out to be magnetic in origin (e.g. Sheeley *et al.*, 1974; Sakurai and Uchida,1977). The presence of radio and X-ray emissions in RS CVn system nicely fits in the situation of stars having starspots, and we discuss the origin of the corona and flares in terms of a magnetic field model.

In order to see what occurs in such a system, we try to visualize the magnetic fields in the binary by taking RS CVn itself as a typical case. In calculating the field configurations, we used Sakurai-Uchida method (1977). An aggregate of starspots whose magnetic field intensity is of the order of 10^3 G (Vogt,1981; Giampapa *et al.*,1983) are distributed on the K-star. The dipole-like general field is also assumed on the K-star ($\sim$ 10 G at the pole) as well as on the F-star ($\sim 10^2$ G at the pole). The computed magnetic field (Figure 1) shows usual active region loop systems as seen on the sun, and also *a loop system connecting the two stars*. These two classes of loop systems could be the reason for the two temperature structure of the corona found by Swank *et al.* (1981). As the spots are carried by the differential rotation, the geometry of the loop system changes drastically through magnetic field reconnection. For example in Figure 2, the spots moving toward the leading edge of ALB lose their connection with the companion star. The surplus flux of these spots must then be absorbed by the adjacent spots, and as a final consequence large scale pole-to-pole connections appear. This is an example of the "sequential reconnection" mediated by the magnetic field of the companion star. As the new spot pair emerges near the trailing side of ALB while the old pair submerges near the leading

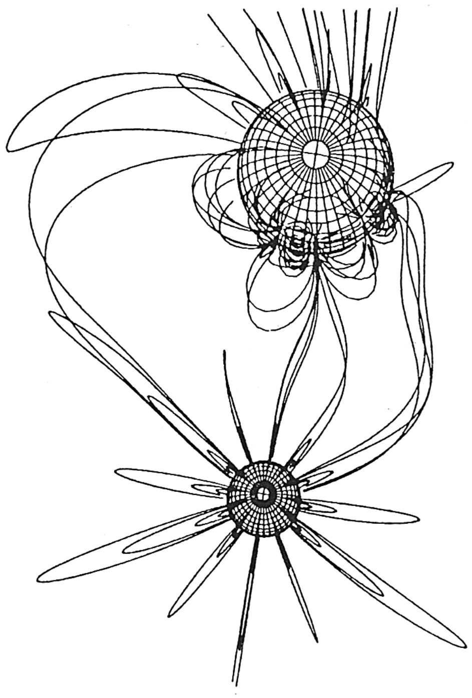

Fig. 1. Magnetic field structure calculated for RS CVn (Uchida and Sakurai, 1983, Fig.1).

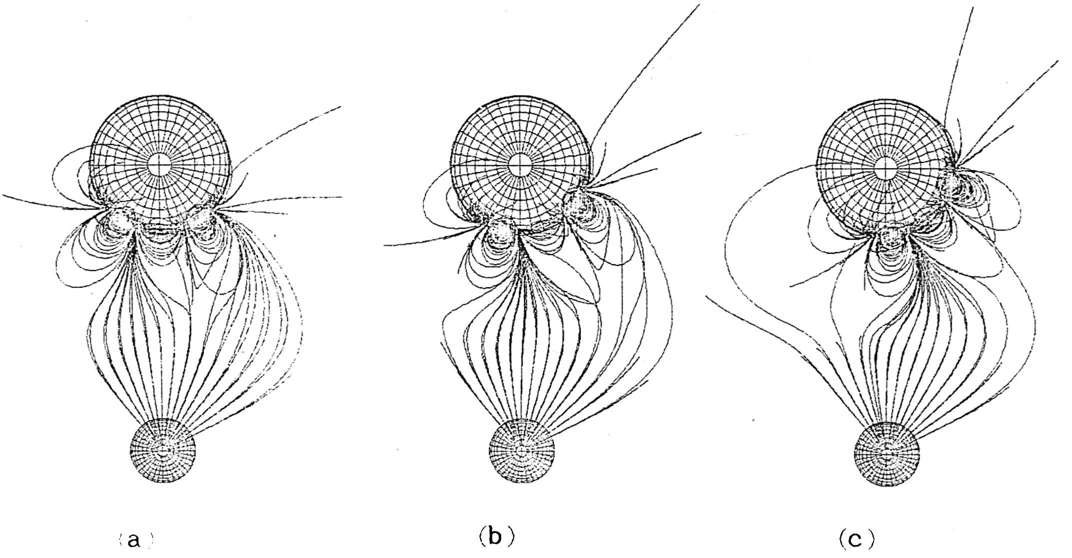

Fig. 2. Changes in the magnetic field structure as the active regions are carried by the differential rotation. The rotation and the revolution of the stars are supposed to be counterclockwise.

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side of ALB, the reverse process from Figure 2c→2a can also take place, creating a new pole-to-spot connection.

3. Coronal Heating and Flares in RS CVn Binaries

Keeping in mind the behavior of the magnetic field discussed above, we may consider possible mechanisms of coronal heating in these systems. The two temperature structure of the coronae could result from the existence of two classes of loop systems. The cooler component might be explained by simply scaling up the solar corona. The hotter (and presumably very extended) component, as we believe, may be trapped in the large scale loop system connecting the two stars. Since it has a high temperature ($\sim 10^8$ K) and a large emission measure ($\sim 10^{54}\mathrm{cm}^{-3}$), not only the heating but also a very powerful mechanism of mass supply would be needed. It is possible, for example, that the emergence of a twisted flux tube at the footpoint of the pole-to-spot connection may feed its twist into the large scale connection through reconnection process. The propagation of the twist, which pinches the flux tube and heat the plasma, sweeps up the hot mass along the flux tube and results in the injection of hot and dense plasma into the large scale connections. This process, the sweeping-pinch mechanism, will be discussed elsewhere (Uchida and Shibata, 1984). It is interesting in this context that the extended corona in AR Lac is found above the trailing side of ALB (Walter *et al.*, 1983) where the flux emergence is expected to be most frequent.

The amount of energy and mass provided in this mechanism may be roughly estimated as

$$\dot{W} = 2\times 10^{33} \times \left(\frac{B}{1000\mathrm{G}}\right)^2 \left(\frac{a}{10^5\mathrm{km}}\right) \frac{\Delta\Omega}{\Omega} f \qquad \mathrm{ergs/sec}$$

and

$$\dot{M} = 1\times 10^{18} \times \left(\frac{n}{10^{13}\mathrm{cm}^{-3}}\right) \left(\frac{a}{10^5\mathrm{km}}\right) \frac{\Delta\Omega}{\Omega} f \qquad \mathrm{g/sec}$$

where a is the radius, B is the field strength, n is the density in the emerging flux tube, respectively, and f is the filling factor of the spots in ALB. It is also assumed that the drift of the spots by the differential rotation in ALB makes a steady flow with the emergence (and submergence). $\dot{W}$ is sufficient to explain the observed X-ray luminosity, and $\dot{M}$ accumulated for a day or so would provide enough mass to account for the observed X-ray emission measure.

The emergence of new magnetic flux may or may not lead to the catastrophic change in the magnetic configuration, depending on the environment of the emerging flux region. Flares can be identified with the drastic liberation of magnetic energy associated with the global reconfiguration of the magnetic field, probably triggered by the flux emergence. Therefore flares are expected to occur above the leading side of ALB where the magnetic field may be most stressed due to the differential rotation. A flare eventually observed on AR Lac (Walter *et*

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al.,1983) seems to lie in this region. Mass flow from the K-star to its companion observed in a flare on UX Ari (Simon *et al.*,1980) also support this interpretation.

In conclusion, our model predicts that the location of the hot corona and the site of flares are closely related to the relative position of ALB in the binary system, which can be checked by observations.

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DISCUSSION

Henriksen: [After the computer-animated movie of mass injection into the coronal loop by Uchida and Shibata was shown]. What was the geometry of the initial configuration? What jet velocity was attained? How long does the field continue to drive the jet?

Uchida: As shown in the paper by Uchida and Shibata, the field at t=0 is a potential field with sources at large distances, namely, diverges moderately and converges at large distance again (see Figure 1 in Uchida and Shibata in these Proceedings). The jet velocity attained is roughly the Alfvén velocity. The length of time in which the drive is effective depends on the assumption of $B_\phi(r,z,0)$, and in the calculated case, the drive gradually loses strength with the expansion.

Bratenahl: I am very much interested in your mass ejection mechanism. Have you thought of applying this to spicules on the sun? Don't forget, the usual statement that the base of spicules is the middle chomosphere simply means that observational evidence for them ends there. The base of spicules could well be below the photosphere.

Uchida: Yes. We are thinking of applying this also to the jets of radio galaxies, etc.