Stellar X-ray and Radio Activities and Coronal Magnetic Field

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Abstract: Activities due to the magnetic effects in the stellar atmospheres are discussed with a special emphasis on the enhanced X-rays and radio activities in RS CVn binaries. Enhanced activities in these close binary systems are proposed to be due to an enhanced production of the twist of the subphotospheric magnetic flux tubes by the large differential rotation in radius, created between the inertially rotating core and more or less synchronously rotating envelope. The magnetic twist of the emerged flux tubes in the "active-longitude-belt" will be dynamically released into inter-star flux tubes together with the driven-out mass heated in the events of magnetic reconnections which are mediated by the magnetic fields of the companion star.

1. Introduction

It has been revealed by the solar flare research that the coronal part of the magnetic fields plays essential roles in causing drastic activities in the stellar atmospheres as observed in X-rays and radio emissions. In the case of the sun, both the hot corona and the flares were shown to have the form of loops or of arcade consisting of aggregate of loops (Vaiana *et al*. 1973, Sheeley *et al*. 1974). These loops coincide roughly with the calculated magnetic field, indicating the essential role of the magnetic field (Sakurai and Uchida 1977). It is believed that the coronal part of the magnetic field stores and then liberates energy drastically at the time of the flare events. Magnetic field is suitable in doing this since the free energy can be stored in the distortion of the field, and the stored energy can be released by the transition of this energized state to lower energy states through a variety of instabilities.

We here survey first the methods of calculating the basic (lowest energy) state of the magnetic field (namely, the "current-free" field) for a given boundary distribution of the sources and then discuss processes of storing energy, and of releasing it. The latter will give rise to super-hot plasmas through the sudden deposition of a considerable amount of energy in a rarefied plasma having a small heat

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capacity and a poor radiative cooling capability. We also add a new way of interpreting some of the sudden heatings by the thus-far unnoticed dynamical effect in the relaxation into the coronal loops of the magnetic twist produced in the high $\beta(\equiv p_g/p_m)$ subphotospheric layers.

2. Basic Structure of the Coronal Magnetic Field

As for the basic structure (lowest energy state) of the coronal magnetic field subject to the boundary condition at the photospheric level, several methods of calculation have been discussed. These include Schmidt's method (1964) for planar geometry in which the normal component of the photospheric field is convolved with the Green's function. Schatten *et al.* (1969) tried to extend it to the spherical geometry, but a legitimate method for this situation was given later by Sakurai (1982). Altshuler and Newkirk (1969), on the other hand, gave another approach for the spherical geometry by expanding the scalar magnetic potential in spherical harmonics and fixing the coefficients by fitting the model to the photospheric values of the magnetic field. These can reproduce the potential magnetic field if the complete set of boundary condition is provided, but the flux distribution outside the region (actually existing but neglected) could have profound influence on the result especially when a finite region is dealt with.

Sakurai-Uchida (1977) method of calculating the vector-potential in the corona by replacing the photospheric (and subphotospheric) flux tubes by a system of current loops may represent another category of approach. Their method concentrated attention to the strong field of active regions and plages and deals with the vector-potential due to these sources. Figure 1 shows an example of calculated field lines by Sakurai-Uchida method (Figure 1b) compared with the observed counterpart (Figure 1a). This shows that the observed bright loops are well reproduced by the calculated field lines related to strong field regions, and furhter observation showed that flarings occur mostly in relation to such strong field loops. The fact that the reproduction is reasonably good in the S-U model may indicate the pronounced importance of strong-field regions.

Uchida and Sakurai (1984, 1985) also tried to calculate the case of RS CVn type close binary system in the above-mentioned method, and suggested that the activities in them may be due to the interaction of magnetospheres of both stars. Since there is no direct information of the surface distribution of magnetic field of these stars yet, the model is, of course, of a tentative nature, awaiting the real measurement of the magnetic field of these stars. They, however, calculated it based on an argument that it is much more natural if the photometric wave (= PW) on the light curve is attributed to the stellar version of active-longitude-belt (= ALB) than when it is attributed to a gigantic starspot. In their picture, the spot pairs, born in the ALB, drifting across it, and disappearing as the edge of the ALB is approached, can have more reasonable size of the order of the depth of the convection

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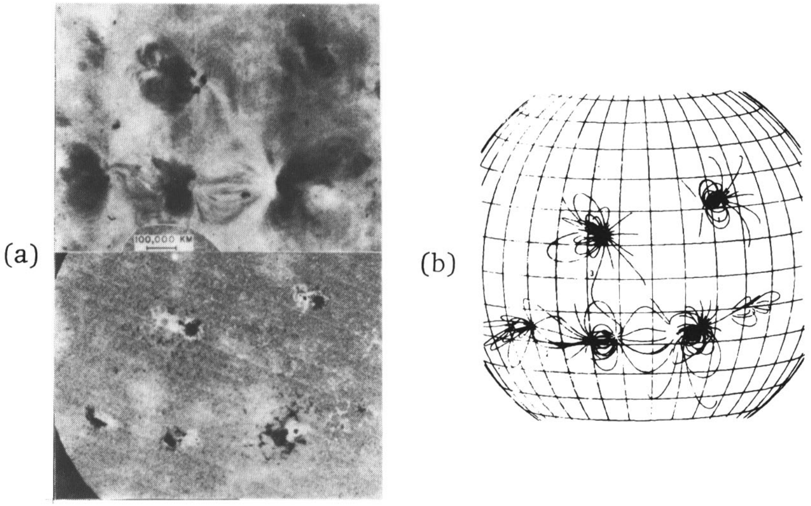

Figure 1. (a) Skylab EUV coronal loops of Sep 5, 1973 (Sheeley *et al.* 1974) together with the Kitt Peak magnetogram. (b) Calculated magnetic field lines for the same day (Sakurai and Uchida 1977).

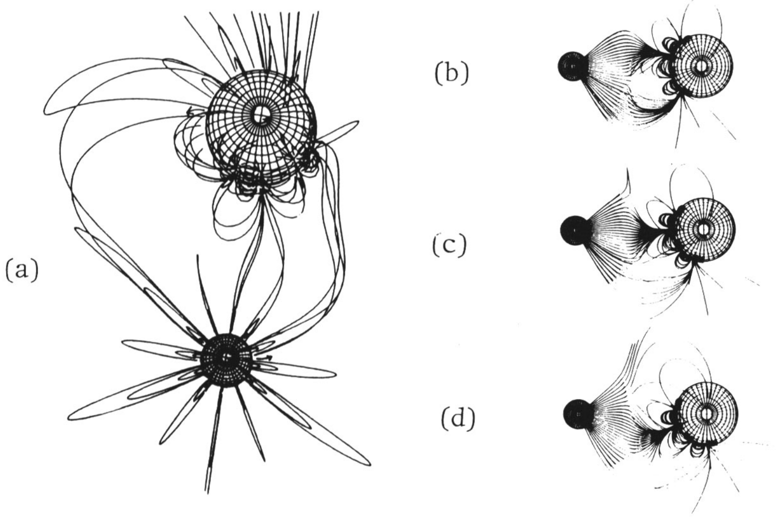

Figure 2. (a) Magnetic field in the magnetosphere of RS CVn (Uchida and Sakurai 1984, see text). (b)-(d) Reconnecting magnetic field lines with the drift of spot pairs in the ALB (Uchida and Sakurai 1985).

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zone, and the rather artificially stringent prohibition of the latitudinal differential rotation of the star by tidal interaction, derived by identifying the PW with the gigantic spot, will be relaxed to a more reasonable value. One of the important byproduct of this will be the introduction of high magnetic activity in the magnetosphere of the binary system (Figure 2, Uchida and Sakurai 1985).

3. Activation of the Coronal Magnetic Field and Its Relaxation Leading to Stellar Activities

The build-up of a local coronal current system may be resulted and maintained, if the motions in the high $\beta (\equiv p_g/p_m)$ region in the subphotosphere cause a distortion in the coronal part of the magnetic field in a way in which the distortion can not be disentangled by any motion in the corona alone. Such a distortion may in general correspond to a production and maintenance of a complicated electric current system in the coronal field, but in its essence, it may be composed of current having either a sheet geometry or a tube geometry. An example is a sheet current produced on the boundary between the region of a newly emerged pair of spots and that of the pre-existing one (Sakurai and Uchida 1977). The relaxation to a lowest energy state, in which the closer pairs are connected, is prohibited if reconnection is not allowed (in $\sigma = \infty$ plasma). The system is in a high energy state, and the difference of the energy is liberated into kinetic energy and heat *if* the reconnection becomes possible due to some instability. Such a stressed state will always appear, for example, between Figures 2b and 2c, or 2c and 2d (these themselves are potential fields which correspond to the states in which such stressed states have been artificially relaxed continuously), and a drastic energy liberation is expected to occur if such a relaxation is prohibited for certain period of time and then allowed by the onset of the current sheet instability (see eg. Priest 1981). It is readily understood from the Figure that the presence of the magnetic field of the companion star mediates magnetic reconnections (Uchida and Sakurai 1985).

Another type of distortion of the field lines which can not be disentangled by the motion in the corona alone is due to the rotation of the footpoints of a closed magnetic flux tube. This corresponds to a biuld up of a current along a flux tube, or to the filling up of a flux tube with magnetic twist, and the relaxation will also occur in the loop itself, for example, by tearing mode resistive instability or by other mechanisms (Priest 1981). The energization in this case is due to the winding up of the coronal part of the flux tubes by the rotational component of motions in the subphotospheric layers. A new point of view is recently suggested by Uchida (1985) in which the transient building up, rather than the destruction, of the magnetic twist in a flux tube may also contribute to the heating and flaring. Packets of magnetic twist released from the subphotospheric reservoir into the loop carrying mass will heat up the loop through collisions with each other.

4. RS CVn's Case

We here describe our view on why the activities of RS CVn stars are enhanced, or more energetic than those in normal stars. The enhancement of activities indeed seems to be related to the stellar duplicity itself (Feldman 1985, private communication). In our picture, the special situation with close binaries is the presence of a large differential rotation in radial direction, $\partial\Omega/\partial r$, because the surface layers tend to rotate more or less in synchronization with the revolution in the mean while the cores may rotate inertially. $\partial\Omega/\partial r$ rolls up the subphotospheric flux tube which is stretched by $\partial\Omega/\partial\theta$ (latitudinal differential rotation) in Babcock's mechanism (eg., Yoshimura 1976), and the active region loops which are the floated-up part of it may be filled up with the magnetic twist. These magnetic twist stored in the strong field of the coronal loops in the ALB will be transferred to the loops of binary scale in the events of magnetic reconnection by being mediated by the magnetic field of the companion star, and the dynamical mass injection into inter-star flux tubes will take place with shock heating. Detailed argument may be found in Uchida *et al.* (1986).

References

Altschuler, M.D., and Newkirk, G., 1969, Solar Phys., 4, 131.
Feldman, P.A., 1985, private communications.
Priest, E.R., 1981, Solar Flare Magnetohydrodynamics (Gordon and Breach), p139.
Sakurai, T., 1982, Solar Phys., 76, 301.
Sakurai, T., and Uchida, Y., 1977, Solar Phys., 52, 397.
Schatten, K.H., Wilcox, J.M., and Ness, N.F., 1969, Solar Phys., 6, 442.
Schmidt, H.U., 1964, in Physics of Solar Flare, ed. Hess, W.N., (NASA), p107.
Sheeley, N.R., Bohlin, J.D., Brueckner, G.E., Purcell, J.D., Scherrer, V. and Tousey, R., 1974, Solar Phys., 40, 103.
Uchida, Y., 1985, presented at Joint Commission 10 + 11 Meeting, IAU General Assembly, New Delhi.
Uchida, Y. and Sakurai, T., 1984, in Activity of Red Dwarf Stars, eds. P.B. Byrne and M. Rodono (D.Reidel), p629.
Uchida, Y. and Sakurai, T., 1985, in Unstable Current Systems and Plasma Instabilities in Astrophysics, eds. M.R. Kundu and G. Holman (D. Reidel) p287.
Uchida, Y. Sakurai, T., and Shibata, K., 1986, in preparation.
Vaiana, G.S., Krieger, A.S., and Timothy, A.F., 1973, Solar Phys., 32, 81.
Yoshimura, H.,1976, Solar Phys., 50, 3.