Aspects of the Angular Momentum Loss Problem for Cool Close Binary Systems

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Abstract. We concentrate on the application of centimeter wavelength observational data to the coronae of rapidly rotating active dwarf stars. In particular we seek insight into coronal loop geometries, and their possible relevance to the magnetic braking mechanism, which must play a key role in binary evolution scenarios for such stars.

1. Introduction

Two of the physical variables associated with stellar activity are rotation and subsurface convection. For single dwarf stars subsurface convection is strongly related to spectral type or colour, switching on at about mid-F type and becoming progressively deeper in the outer envelope. The rotation rate may be relatively high at formation, but thereafter declines with age. Skumanich's (1972) $t^{-\frac{1}{2}}$ law is frequently cited as a well known approximation characterising this decline — at least for younger single cool dwarfs. The slowing down of rotation for such stars poses a problem for stellar physics; in particular to explain the pattern of angular momentum loss (AML) (cf. Vilhu and Moss, 1986). In the case of close binary systems, AML from the system speeds up the components as the tidally locked stars slowly spiral in towards each other. The mechanism is of relevance to the binary evolution of close systems: and it may play a critical role in the incidence of contact binaries (Van 't Veer, 1980; Vilhu, 1982; Rucinski, 1986).

A third important factor is magnetic field strength, though this is not generally independent of the other two in particular formulations for stellar activity. However, magnetic lines of force, 'frozen' into the high conductivity plasma shed as a stellar wind from the outer envelopes, stiffen such an eflux, thereby enhancing the associated AML by the process of 'magnetic braking'. A recent relevant account is that of Mestel and Spruit (1987).

The physical theatre, in which this action takes place, is the corona; consequently a good understanding of coronae of the involved stars is the key to understanding magnetic braking. We are currently engaged in a microwave survey of the nearest ($\lesssim$50 pc) southern contact binaries using the Compact Array of the Australia Telescope in an effort to bring more direct evidence to bear on this problem.

2. Observational pointers

Most interpretations of the microwave radiation from active cool stars refer to gyrosynchrotron emission from mildly relativistic electrons which have been accelerated along coronal magnetic loop structures. In analogy with the solar case,

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where microwave emission is known to be often closely associated with soft X-ray radiation (Dulk, 1985), the two types of radiation are regarded as originating in different regions of the structure and by a different mechanism. The X-ray radiation is associated with bremsstrahlung in the low corona, towards footpoint vicinities.

General observational indications are that contact binaries fail to come up to the expected scale of activity, based on a simple extrapolation of trends among rapidly rotating cool stars. Vilhu and Rucinski (1983) spoke of a 'saturation' effect. Budding (1983) pointed out another disparity relating to observed incidence and expectation, if one simply extrapolates up a power-law type magnetic braking behaviour in response to increasing rotation rate, which the Mestel theory applied to a single dwarf shows, and applies this to the statistics of cool dwarf close binary systems, detached and contact. The disparity might be resolved if the braking could be significantly reduced at very low binary separation.

The saturation effect, about which various interpretations are possible (Rucinski and Seaquist, 1988), is thus a potentially important aspect of the overall problem. Our aim is to seek information on coronal structures which will help resolve a clearer picture of it. In particular, we suspect there may be a systematic difference between field geometries in rapidly rotating single and close binary dwarfs.

3. Contact binaries compared with AB Dor

Gyrosynchrotron radiation emerges efficiently at a high inclination to the local loop axis, its line of sight emission preferredly originating from the tops of the magnetic arches. In this way, the broad correlation between X-rays and microwave data observed from cool 'active' dwarf stars (Rosner *et al.*, 1985; Stewart *et al.*, 1988) can be appreciated. Such a correlation takes a persuasive form with the 'double-humped' pattern seen for AB Dor in both X-ray and microwave regions contemporaneously (Vilhu *et al.*, 1991). The analogy of a greatly scaled up solar active region is also corroborated by the fact that this pattern anticorrelates with the optical light variation, associated with 'starspots'.

Unfortunately, there is insufficient information on the radio spectrum of AB Dor, to enable detailed modelling, such as that of White *et al.*, (1989). The available facts permit some general inferences, however, along similar lines to those of of Vilhu *et al.,* (1988). Thus the magnetic field B of the source region in the main peak of the 8.4 GHz 'light curve' for AB Dor (Budding *et al.*; 1990) is found to be around 40 gauss. Supporting evidence includes the relatively slow scale of time variation of the signal, and the low detections of circular polarization.

Recent investigation of photospheric field strengths in active young dwarfs like AB Dor (Saar, 1990) points to fluxes of order 10^3 gauss. Combining the X-ray flux of Vilhu *et al.*, (1990) with the mean relation between this parameter and active region field strength given by Saar, we expect that a field of order 5×10^3 gauss would characterise the surface region associated with the X-ray enhancement, which correlates with that of the microwave variation. Following the R^{-3} (dipole) scheme of Stewart *et al.*, (1989), the lateral extent of the magnetic loops giving rise to the microwave emission from AB Dor would thus reach out to $\lesssim \sqrt[3]{100}\times$ the size of the photospheric active region, ie. $\lesssim 5 \times 10^{10}$ cm, or comparable to the radius of

AB Dor itself. Utilising the rotational modulation of earlier data Slee *et al.*, (1986) argued for a source size of about $R_*/2$, a result supported in the statistical survey of Stewart *et al.*, (1988).

Vilhu *et al.*, (1988) reported an impulsive flare-type emission event from the contact binary VW Cep, of a similar peak intensity ($\sim$ 10 mJy) to the slowly varying level of AB Dor, which they attributed to gyrosynchrotron emission following a reconnection event, involving a plasma column of this order of size, or "of the order of the system separation" of this binary. However, any steady component of microwave emission in VW Cep was immeasurably small, and would have to be at least $\sim$ two orders of magnitude down on the present comparison of AB Dor, though the two stars are essentially of the same size and surface temperature (K0 IV-V), distance ($\sim$ 20pc), and with close rotational periods ($\lesssim$ 0.5d). Any long-lived ($\sim$ days) structures on VW Cep during the observation period would correspondingly be at least an order of magnitude scaled down in size (ie. $\lesssim 5\times10^9$ cm). The implied difference in geometry would be basically related to the binarity of VW Cep, but a different coronal density distribution is also a corollary of this, since field patterns are dependent on the gas to magnetic pressure ratio $8\pi p/B^2$.

This picture appears typical of observational evidence hitherto on contact binaries (cf. Rucinski and Seaquist, 1988), and suggests basic differences in the coronal field structures between contact binaries and rapidly rotating single cool dwarfs. It is borne out by our provisional upper limits for three recently observed contact binaries, integrated over ~3 h each, as follows: AE Phe $\leq$ 0.75 mJy, YY Eri $\leq$ 1.25 mJy, V757 Cen $\leq$ 0.75 mJy. A similar low value for RW Dor awaits a more precise positional confirmation.

4. Field geometry and magnetic braking

An overview of contact binary evolution was provided by Rucinski (1986). He recognized the very special actions which angular momentum loss via magnetic braking should perform in the context of the relative overabundance of the inherently unstable contact configuration (cf. Shu, 1980). Firstly, it helps introduce previously detached binaries into contact. Later, it prolongs the contact phase, when the natural tendency from the mass transferring close interaction would be towards a more unequal mass ratio, and thus increased separation. Somehow it has got to get this just right; avoiding the extremes of too heavy a braking, which would cause too frequent coalescences than are observed, and too light a braking, which does not produce enough contact binaries.

The effective results of various magnetic braking theories were summarized by Vilhu and Moss (1986). They showed that a power-law form for the dependence of braking ($-\dot{J}/J \propto P^{-n}$) could be reasonably inferred. Such a braking law would become *too* efficient for contact binary statistics when related to their low periods, however. Observations show that the scale of this 'friction' must stop increasing for contact binaries. This is relatable to the previously mentioned saturation effect. Explanations which have been offered about this were reviewed by Rucinski (1986).

Other AML formulae may be applicable (eg. Budding, 1983), but the main points which tend to emerge are the declining influence of field strength on magnetic braking in the purely dipole field distribution, as well as the increased effect of rotation for 'cool' as against 'hot' coronae. The increased effectiveness of a radial compared with a dipole field distribution also becomes apparent. Hence a possible approach to the observed form of braking dependence on binary period, for stars of a given type, as indicated eg. in Figure 2 of Vilhu and Moss (1986), is to regard such data as constraining field structure models.

There are indications that a less radial, more curl-free, magnetic structure characterises the envelopes of binaries, particularly the more influential primary components (Rucinski, 1986), as they move towards a contact configuration in such an AML scenario, though this should not be taken in isolation from probably concomitant reductions in coronal density, which will reinforce the effect.

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