ON ACTIVE STARS, CORONAL LOOPS, MAGNETIC BRAKING AND ALL THAT

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ABSTRACT. Coronal scaling laws and magnetic braking are discussed. The importance of future EUV and X-ray spectroscopy missions is emphasized.

1. SCALING LAWS

From the observations one easily derives the impression that magnetic fields confine and heat the stellar coronae [1,2]. The nice dependences on the Rossby number also favors this interpretation (Figs. 1 and 2). A good guess may be: where X-rays -- there closed magnetic fields. The following scaling laws are frequently used in this context, for lack of better physical models:

$$p^2Hf = EM/4\pi R^2 \cdot k^2T^2 \equiv F_x/P(T) \cdot k^2T^2 \quad \text{(definition)} \qquad (1)$$

$$H = 5000\ T\ (g/g_\odot)^{-1} \quad \text{(pressure scale height)} \qquad (2)$$

$$pH = 3.64 \times 10^{-10}\ T^3 \quad \text{(loop-eq. [3])} \qquad (3)$$

$$pf \propto F_{TR} \quad \text{(from static loops [4])} \qquad (4)$$

$$B = 6.9 \times 10^{-7}\ T^2\ H^{-1/2} \quad \text{(loop-eq. and solar p vs. B [2])} \qquad (5)$$

$$B = 9.6 \times 10^{-5}\ T^{3/2}\ H^{-1/2} \quad \text{(loop-eq. and } B^2/8\pi = p) \;. \qquad (6)$$

The right-hand sides of these equations can in principle be derived from present observations, so that estimates for the pressure p, coronal height H, filling factor f and magnetic field B can be obtained. For the sequence, weakly active (Sun) -- very active (representatives ER Vul and σ^2CrB) G dwarfs, one observes [4,5] $EM/4\pi R^2 = 10^{27}$–10^{30} cm^{-5} and $T = 2 \times 10^6$–10^7 K. Using (1)-(3): $H = 10^{10}$–$5{\times}10^{10}$ cm, p = 0.3-7.2 dyn cm^{-2} and f = 0.09-2.1. The deduced field strengths are 28-300 G from (5), and 3-14 G from (6), respectively. The resulting

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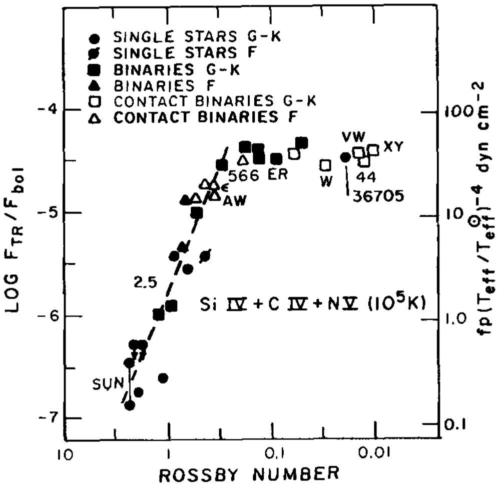

Fig. 1. Transition region activity of dwarfs versus the Rossby number [4].

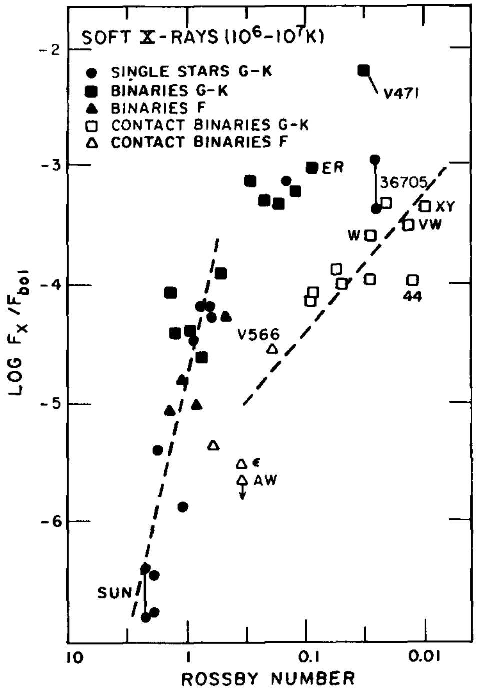

Fig. 2. Coronal activity of dwarfs [4].

pf-values follow qualitatively eq. (4) (and Fig. 1), although it has been suggested [4,6] that the increasing trend is mainly due to the increase in the filling factor ($f \propto Ro^{-2.5}$), resulting also from a simple flux-tube model.

2. NEED OF DENSITY-DIAGNOSTICS: AXAF/MMX AND FUSE/LYMAN

The above scaling laws give reasonable stellar-size numbers. However, very little useful physics will be gained if better temperature-, and most important, density-diagnostics do not become available. Single temperature and pressure values are clearly inadequate. Further difficulties arise from the complex geometries [7,8] (Fig. 3). For very active stars the loop-modeling becomes poor when an ensemble of overlapping loops makes the pressure-values in (1) and (3) inconsistent. This results often in large computed filling factors ($f > 1$). One alternative is to forget the filling factor and to write eqs. (1)-(2) in a more sophisticated form, including ultraviolet resonance lines, to derive mean structures with $f = 1$ [9].

Even crude estimates for the coronal pressures would be valuable. So far we have no clear idea whether the density, or the filling factor,

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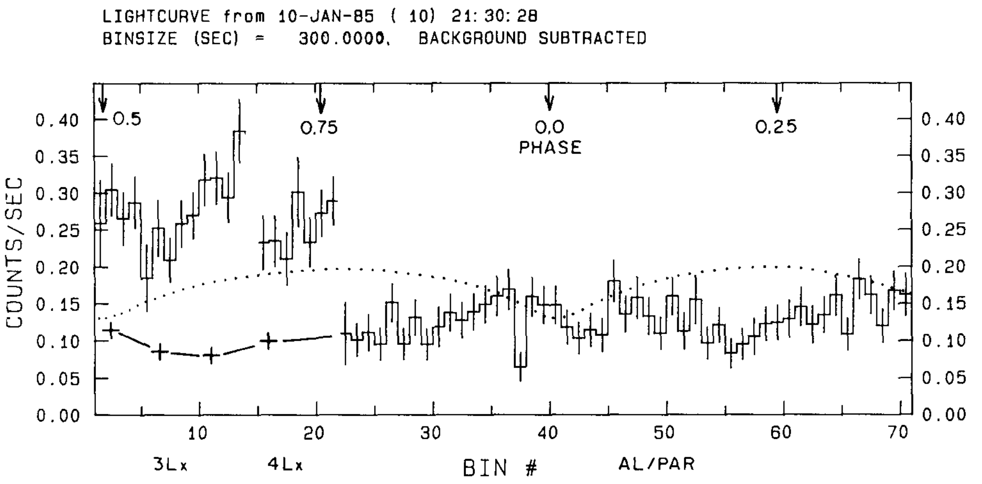

Fig. 3. EXOSAT-light curve of 44ι Boo (Aℓ/P-filter). The dashed line gives the projected visible surface area [8]. The fragmentary observations are with thin and thick Lexan filters.

or both increase along the activity sequence (Figs. 1, 2). However, the average coronal temperature seems to increase with the activity level [5]. For the pressure-diagnostics high-resolution EUV- and X-ray spectroscopy is needed, while lower resolution is sufficient for the temperature-diagnostics. NASA's AXAF, European Space Agency's planned cornerstone MMX and the joint NASA/ESA mission FUSE/Lyman are all capable of fulfilling part of this need. While awaiting them we are perhaps left to play with eqs. (1)-(6), and with qualitative remarks about complex structures of stellar coronae.

3. MAGNETIC BRAKING

Magnetic braking is one of the most important global aspects related to coronal physics. In contact binaries it may be the factor that controls the evolution. In cataclysmic and low-mass X-ray binaries the braking wind of the cool star probably drives the mass transfer onto the compact star. For slowly rotating dwarfs it has been suggested [6] that the braking timescale depends on the Rossby number. Figure 4 shows this relationship with expectations from binary star modelings [10,13,14]. Estimates for ER Vul and UV Leo are from the O-C diagrams.

The X-ray coronae are not linked in a trivial way to magnetic braking, which operates with open "lever arms" at large Alfvenic distances (several tens of stellar radii). The studies of X-ray coronae cannot be expected to give direct answers for the braking problem. However, X-rays may give the necessary boundary conditions close to the stellar surface, which every good wind theory needs (temperatures,

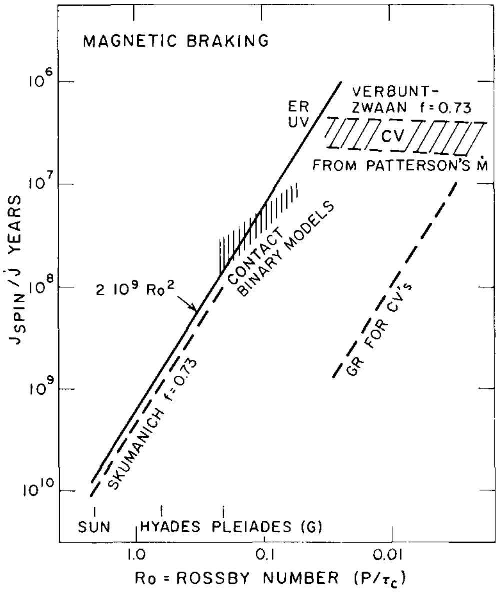

Fig. 4. The spin angular momentum-loss timescale versus the Rossby number.

densities, filling factors for open and closed field lines). In the thermo-centrifugal wind theory [11,12] the coronal temperature seems to be the key factor. At present too many wind models can be matched with the Ro^2-law of Fig. 4 ($V_{rot} \propto t^{-1/2}$), with suitable choices of the parameters [12].

It is a great challenge for the future to see what useful information can be extracted from the X-ray observations for the braking theory, which works with mass flux and magnetic geometry at much larger distances.

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