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MASS LOSS FROM WARM GIANTS: MAGNETIC EFFECTS

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Abstract

Among warm giant stars, rapid mass loss sets in along a well-defined velocity dividing line (VDL) in the HR diagram. Hot coronae also disappear close to the VDL: hence, thermal pressure cannot drive the observed rapid mass loss in these stars. The VDL may be associated with magnetic fields changing from closed to open. Such a change was predicted (Mullan, 1978), and is consistent with the lack of X-rays from late-type giants. To refine this prediction, we derive a magnetic transition locus (MTL) based on Pneuman's (1968) work on helmet streamer stability. The MTL agrees well with the empirical VDL. We propose that the change from closed to open fields not only makes rapid mass loss possible, but also contributes to energizing the mass loss in the form of discrete "bubbles".

1. INTRODUCTION

"Warm" stars are those which do not have radiatively-driven winds: they are too hot to allow dust formation, and too cool to have strong UV fluxes. Here we point out that a Parker-type wind (driven by thermal pressure of a hot atmosphere) also cannot drive mass loss from these stars. We propose magnetic reconnection as an alternative possibility.

Rapid mass loss causes chromospheric emission lines to become asymmetric: the intensity ratio of shortward to longward emission peaks (S/L) becomes <1. Fig. 1 shows this ratio for the Mg h and k emission in giants (Stencel and Mullan, 1980; hereafter SM). Stars with rapid mass loss ($S/L < 1$) lie above and to the right of a well-defined velocity dividing line (VDL). The VDL is quite abrupt, a feature it shares with other mass loss indicators, such as circumstellar absorption (cf. Mullan (1978); hereafter MSTL). We stress that the dividing line occurs in velocity, but not in intensity. In crossing the VDL, chromospheric heating undergoes no significant change: this is apparently a coronal transition, and observational selection imposes no bias on these results.

Also shown in Fig. 1 is a temperature dividing line (TDL) (Linsky and Haisch, 1979) along which hot coronae disappear. The close coincidence between VDL and TDL suggests that there is a real boundary here. The same boundary also serves to separate (roughly) stars with detectable X-rays from those without (Linsky, 1980), and also to separate stars with and without variable He 10830 profiles (O'Brien, 1980). Since rapid mass loss sets in precisely where hot atmospheres disappear, and since mass loss is apparently highly variable when it is rapid, a Parker-type wind (i.e., thermally driven, spherically symmetric, steady in time) cannot drive the mass loss.

2. SUPERSONIC AND MAGNETIC TRANSITION LOCI (STL, MTL)

In MSTL, I argued that the onset of rapid mass loss may be associated with the coronal sonic point (at radius R_s) approaching close to the stellar surface ($R_\star$). (The boundary in the HR diagram where this happens was called the supersonic transition locus, STL.) However, my suggestion that when $R_s = R_\star$, the chromosphere would expand as a thermal wind is now known to be untenable (Holzer, 1980). The mass loss expression in MSTL is therefore invalid. Another explanation must be sought for the onset of rapid mass loss along the VDL.

An important corollary of the STL concept was pointed out in MSTL (§ IV): below the STL, magnetic fields in stellar atmospheres would be mainly closed, while they would be open in stars above the STL. Arguing from the solar analogy, this would suggest that stars below the STL would be bright in X-rays, while those above the STL would not be: the Einstein X-ray data are consistent with this. In order to define this magnetic transition more precisely, consider the stability of helmet streamers: these are solar coronal structures in which the field lines are closed at low altitudes ($R \leq R_h$), and open at $R > R_h$. Such structures can be in magnetohydrostatic equilibrium with $R_h = R_s/2$ (Pneuman, 1968). Hence if a star has a corona in which $R_s < 2\,R_\star$, closed coronal field lines cannot exist in static equilibrium: coronal fields must then become essentially dynamic. The original definition of the STL ($R_s = R_\star$) is sufficient, but not necessary, to cause the field to alter from static to dynamic.

Let us therefore define a "magnetic transition locus" by the criterion $R_s = 2\,R_\star$. We can locate the MTL in the HR diagram by a semi-empirical procedure analogous to that used in deriving the STL (cf. MSTL). We now assume that pressure at the top of the chromosphere equals the coronal base pressure, i.e. we assume $\Delta = 0$ (see MSTL for definition). Combining our results with evolutionary tracks (Paczynski, 1970), the MTL is defined by the circled Π's in Fig. 1. For comparison, circled P's show the location of STL derived earlier using the same tracks (with $\Delta = 0.8$). The shift between MTL and STL is partly due to different Δ values, but there is also a difference even for identical Δ values. The MTL seems to agree well with the empirical VDL, whereas the older derivation of the STL seems to have no counterpart in the Mg velocity data. The major conclusion of the present calculation therefore is that the velocity data (i.e. Mg h and k asymmetry data) are consistent with the hypothesis that the onset of deeply penetrating velocity fields in giant chromospheres occurs when the atmospheric magnetic fields change from static to dynamic structures.

3. MAGNETIC ACTIVITY AND MASS LOSS

Among subgiants, rapid mass loss sets in at spectral types K0-K1 (cf. SM). It can hardly be coincidental that subgiants of precisely this spectral class are the active secondary stars in most RS CVn systems (Popper, 1970). In the latter systems, rapid mass loss is also known to be occurring at the present time (Walter et al, 1978), although this mass loss cannot have been occurring at a high level for a long period of time (Popper and Ulrich, 1977). We propose that the onset of magnetic activity and the onset of rapid mass loss are both recent phenomena in the RS CVn stars, and that both are due to the alteration from static to dynamic magnetic fields in the coronae.

When magnetic flux emerges as active regions on a stellar surface, mass loss is inhibited because the field lines are closed. In the mass loss process, there are two important ingredients: opening of the field lines, and an energy source to drive the mass loss once the field permits it. Below, we will sketch a possible scenario in which dynamic field behavior supplies both ingredients.

However, before we claim that magnetically driven mass loss is viable for all late-type giants, it must be admitted that the RS CVn systems are clearly exceptional among giants for their strong magnetic fields. These fields are so strong that flaring activity is detectable at great distances from the stars. Direct measurements of field strengths in single giants are non-existent. However, since calcium emission is generally strong in giants, there are probably active regions on their surfaces, presumably created as a result of dynamo action in the deep convective envelopes (Wilson, 1973). Even if these fields are too weak to cause spectacular flaring activity, nevertheless, as far as mass loss is concerned, these fields can have important dynamic effects once the star crosses the MTL. For that reason, we propose that the following scenario may be applicable to the mass loss process in essentially all giants above the MTL, whether or not the giant has ever been seen to flare.

The scenario is shown in Fig. 2. At time $t = 0$, magnetic loops emerge from the photosphere (a) into a pre-existing corona in which $R_s < 2R_*$. Since no static equilibrium is possible (Pneuman, 1968), we propose that the loops balloon upwards, forming distended loop structures (b). (We note that very extended loop structures play an important role in the model of RS CVn activity proposed by Simon et al, 1980.) The upward motion of the loops sweeps coronal material ahead of it, leaving a cavity in the lower corona. Pressure imbalance in this region induces lateral collapse from both sides of the loop . As a result, field line reconnection begins at an X-type neutral line near the base of the loops. This causes disconnected flux loops to accumulate in the upper part of the loop structure (c). During this phase, the reconnection process itself generates a strong upward force (Pneuman, 1979), and so the upward ballooning is reinforced. Finally, at time $t = t_{rec}$ (which depends on conductivity, loop size, and Alfven speed V_A), the upper section of the loop severs its connection with the stellar surface, and a bubble of material is ejected upwards (d). In this way, reconnection solves the problem of magnetic inhibition of mass loss. Moreover, if the reconnection energy can be converted efficiently into upward bubble motion, a crude energetics argument suggests that the ejection speed V is of the order of V_A. Now, a giant with $M = 3\ M_{sun}$ lying on the MTL (at the location of the central circled II in Fig. 2) has a radius $R_* \gtrsim 18\ R_{sun}$, and an escape velocity of 250 km/sec. The MTL calculations for such a star indicate a coronal base density of $5 \times 10^7\ cm^{-3}$. Hence the Alfven speed exceeds escape speed if the field exceeds about 0.8 gauss in the active region.

We propose that stars above the MTL lose mass in the form of discrete bubbles which form as often as new flux loops appear on the stellar surface, i.e. mass loss in essentially spherically non-symmetric and non-steady in time. Highly variable He 10830 profiles (O'Brien, 1980) are consistent with this concept. Not all, however, of the reconnection energy goes into outward flow: some appears as heat in the surrounding corona. This hot material sets the stage for the cycle in Fig. 2 to be re-initiated when the next loop of flux breaks up through the surface.

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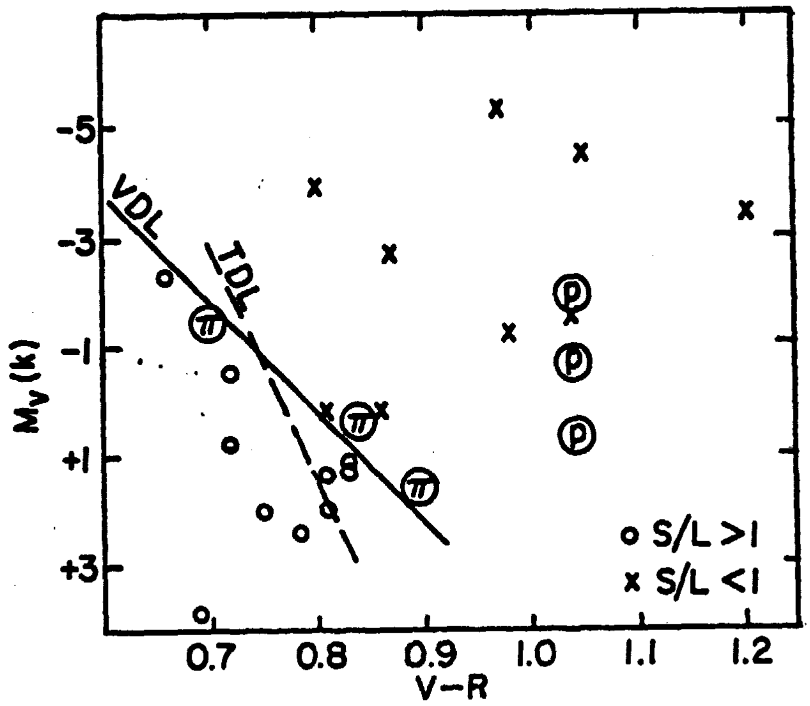

Fig. 1. Survey of Mg asymmetry in HR diagram: S/L is ratio of intensities in short and long peaks of emission core of Mg h and k. VDL = velocity dividing line derived from Mg data. TDL = temperature dividing line: note that cool coronae are correlated with rapid mass loss. Circled Π's and P's denote MTL and STL respectively.

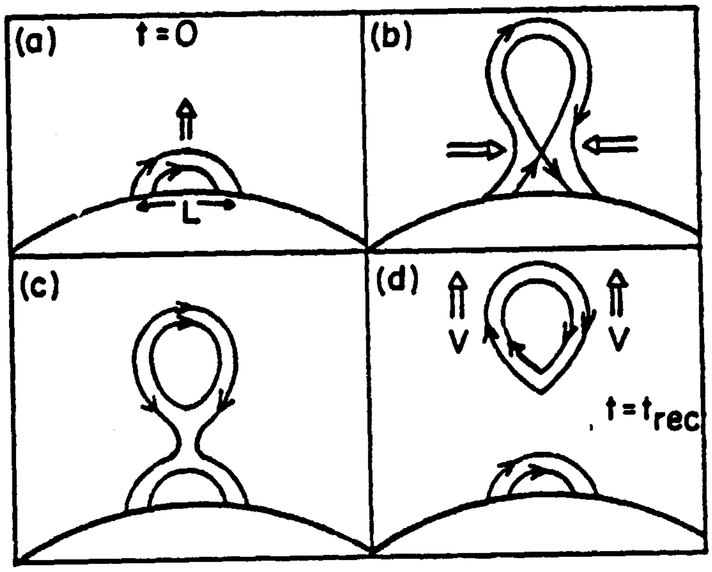

Fig. 2. Scenario for magnetically-driven mass loss.