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Stellar Magnetic Fields:

I. The Role of a Magnetic Field in the Peculiar M Giant, HD 4174

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STELLAR MAGNETIC FIELDS: I.

THE ROLE OF A MAGNETIC FIELD IN THE PECULIAR M GIANT, HD 4174.

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ABSTRACT

Principles of coronal heating via basic electrodynamic effects, viz., resonant absorption of Alfvenic surface waves (quiescent), and magnetic tearing instabilities (impulsive), are detailed to argue three principles which may have application to late-type evolved stars. First, if one observes $B^2/8\pi \gg \rho v^2$ in a stellar atmosphere, then the observed magnetic field must originate in an interior dynamo. Second, low mass loss rates could imply the presence of closed magnetic flux loops within the outer atmosphere which constrain hydrodynamic flows when the magnetic body forces exceed the driving forces. Third, given that such magnetic loops effect an enhancement of the local heating rate, we predict a positive correlation between the existence of a corona and low mass loss rates. Application of these principles is made in the case of the peculiar M giant star HD 4174, that is purported to have a kilogauss magnetic field. Several of its spectroscopic peculiarities are shown to be consistent with the above principles, and further observational checks are suggested. Possible application to dMe and RS CVn objects is sketched.

Key words: Magnetic fields, MHD coronal heating, M giant stars, mass loss.

I. INTRODUCTION

For many years, astro-physicists have appreciated the important role that magnetic fields play in various solar phenomena, such as flaring and coronal heating. Evidence is mounting that a wide variety of stars exhibit impulsive, high temperature events that are qualitatively similar to the flaring process (dMe, RS CVn stars, in optical and X-ray flux enhancements), as well as strong surface magnetic fields (classical Ap stars, possibly symbiotic stars). Very recent advances in solar flare and coronal heating theory and new observational parameters and understanding of late type stellar spectra make a re-evaluation of the observable effects of magnetic fields appropriate at this time. Useful previous work in this area can be reviewed in Mestel (1975), Mullan (1976) and Wdowiak (1977). In this paper we propose to discuss the manner in which such fields may assume important aspects in the atmospheric structure and dynamics of a star.

II. THE EFFECTS OF MAGNETIC FIELDS

Whenever the age of a star exceeds the magnetic diffusion time T_D, it follows that the existing field must be maintained by some form of velocity field (e.g., by coriolis forces associated with differential rotation). The diffusion timescale T_D is given by

$$T_D = \frac{4\pi R^2}{c^2 \eta} \qquad (1)$$

where R is the stellar or characteristic radius and where η(esu) is the electrical resistivity which, for Coulomb scattering processes is

$$\eta = 2.55 \times 10^{-7}\ T^{-3/2}\ (\text{esu}). \qquad (2)$$

In Equation (2), $T(^{o}K)$ is the temperature of a fully ionized plasma. Although the coupling between a velocity field and magnetic lines of force is not fully understood, we can generally describe such coupling by the following power densities, where ρ is the mass density and v the characteristic velocity:

(i) $\rho\, v^3/2R$ = the maximum rate at which a velocity field can supply energy;

(ii) $B^2 v/4\pi R$ = the rate at which the velocity field couples energy into the magnetic field;

(iii) $\rho\, v^2/2T_D$ = the rate at which the velocity field heats the plasma due to damping of induce magnetic fields.

From these power densities we can generate two dimensionless numbers, viz.,

$$\beta = 4\pi\rho v^2/B^2 = (i)/(ii) \tag{3}$$

and

$$Re_{mag} = vT_D/R = (i)/(iii) \tag{4}$$

where Re_{mag} is the magnetic Reynolds number. In this context, note that the energetics required to maintain stellar magnetic fields are achieved only when the kinetic energy associated with a velocity field is such that:

$$\beta \gtrsim 1 \tag{5}$$

and

$$Re_{mag} \gg 1. \tag{6}$$

Thus, if we observe a magnetic field embedded within a velocity field with $\beta \ll 1$, it follows that the majority of this magnetic field is generated elsewhere within the star, where $\beta > 1$, e.g. a central dynamo. Assuming that this is the case, how can we connect this magnetic field to the rate of mass loss from a star as well as the existence of a corona?

If the power density P associated with the driver of the stellar mass loss is less than the various energy sinks which result from induced magnetic body forces, then the flow associated with this mass loss is constrained to move along the field lines. That is, the constraining effects of a stellar magnetic field cannot be neglected if

$$P < (B^2 v/4\pi R)(1+(\beta/2Re_{mag})) \quad . \tag{7}$$

where the r.h.s of Equation (7) represents the sum of the two power densities described in (ii) and (iii) above. Thus, if the magnetic topology is closed and inequality (7) is satisfied it follows that mass could not readily leave the vicinity of the star. For example, if a fraction f of the stellar surface has closed magnetic flux loops then the rate of mass loss would be a factor f smaller than would be the case if the magnetic topology were open or if inequality (7) were not satisfied. This discussion assumes importance in light of recent observational work in the ultraviolet reported by Linsky and Haisch (1979). Using the IUE, they found a sharp division between G and early K type stars which exhibit high temperature UV lines, and late K and M stars which have only low excitation UV lines. This division, when considered in conjunction with optical studies by Reimers (1977) and Stencel (1978) leads to the idea that the latter group of stars, which have relatively large rates of mass loss (dM/dt), lack coronae possibly due to their large dM/dt. The stars with coronae have correspondingly much lower dm/dt. We will consider this in greater detail in what follows, as we investigate processes which may heat the solar corona and thereby deduce general expressions for the heating rates, Q, in ergs cm^{-3} s^{-1}. By requiring balance with radiative losses, equilibrium temperatures can be computed. A timescale for the impulsive (flaring) release of stored magnetic energy may also be found. This approach leads to predicted coronal fluxes and variation timescales which the observations may check.

As evidenced from solar studies, the existence of closed magnetic flux loops has extremely important implications in connection with establishing and maintaining a hot coronal plasma. This stems from the fact that magnetic flux loops can extract and in some cases store magnetic energy that is induced by a velocity field (e.g., thermal convection, differential rotation). This energy is then either quiescently or impulsively converted into thermal energy which is then available for balancing radiation losses, Q_{rad}[erg cm^{-3} s^{-1}], associated with a hot coronal plasma, viz.,

$$Q_{rad} = \begin{cases} 2.15 \times 10^{31} \rho^2/T & \text{for } 2 \times 10^5 \text{ K} < T < 10^7 \text{ K} \\ 5.63 \times 10^{20} \rho^2 \sqrt{T} & \text{for } T > 10^7 \text{ K} \end{cases} \qquad (8)$$

where T is the plasma temperature and where ρ(gm/cm^3) is the mass density (Cox and Tucker 1969). The various mechanisms which effect both a quiescent (Ionson 1978; Rosner et al 1978a) and impulsive (Spicer 1976; Spicer 1978a) conversion of magnetic energy into thermal energy are generally very dependent upon the detailed conditions of the magnetic loop and its interaction with the velocity field. In the solar case, there is a great deal of controversy (Wentzel 1978; Spicer 1978b). For the sake of illustration, however, we will assume that quiescent heating results from the resonant absorption of Alfvenic surface waves (Ionson 1978) and assume that impulsive heating is due to a current-driven tearing instability (Spicer, 1976) which occurs over a scale size r_t as defined below. The relevant heating rates: $Q_{quiescent}$ and $Q_{impulsive}$ are therefore given by:

$$Q_{quiescent} \simeq 2\pi\rho v^2 \nu \tag{9}$$

and

$$Q_{impulsive} \simeq \left(\frac{\beta^2 v_A}{8\pi r_t}\right)\left(\frac{r_t}{T_D V_A}\right)^{1/3} \tag{10}$$

In Equation (9) ν^{-1} is the timescale associated with the velocity field, viz.,

$$\nu^{-1} \simeq \pi R_L / V_A \tag{11}$$

where R_L is the major radius of the magnetic loop and where V_A is the Alfven speed defined by

$$V_A \equiv \frac{B}{\sqrt{4\pi\rho}} \tag{12}$$

In connection with Equation (11), the 300 sec solar atmospheric oscillations are very effective in heating coronal loops with $R_L = 6.6 \times 10^9$ cm, assuming $V_A = 7 \times 10^7$ cm/sec. One of the objectives of this study is to deduce the scale and frequency of the analogous velocity fields in other stars. By inverting the problem, armed with measured coronal fluxes and timescales, it may be possible to determine approximate R_L and ν^{-1}

values. Determination of total numbers of loops over a stellar surface is not tractable with the present technique.

The heating rate given by Equation (10) is representative of a double tearing-mode instability (Drake and Lee 1977) where r_t is the thickness of the "tearing layer". The tearing thickness r_t is the characteristic scale size which should be used when evaluating T_D (Equation (1)) and is generally written as:

$$r_t/R_L = 0.01. \tag{13}$$

Using the Alfven velocity, Equation (12), the timescale $t_{impulsive}$ associated with an impulsive release of energy is given by

$$t_{impulsive} \simeq \frac{B^2}{8\pi Q_{impulsive}} \tag{14}$$

with $B^2/8\pi$ being the free energy density that is available for conversion into heat.

It remains an enigma that not all solar magnetic loops release energy impulsively (i.e., flare). We will not address this problem here but we do wish to point out that Skylab observations of solar magnetic loops suggest that small loops flare, whereas larger loops are heated quiescently (Priest 1978). According to the above physical principles, the temperatures of these two different classes of loops can be determined by equating Equations (8) and (9) and Equations (8) and (10) that gives:

$$T_{imp} = 1.1 \times 10^7 \left(\frac{\bar{V}_A^{8/3}}{\bar{\rho}^{imp} (\bar{R}_L^{imp})^{4/3}} \right) \quad {}^oK \tag{15}$$

$$T_{quies} = 2.7 \times 10^6 \left(\frac{\bar{\rho}^{quies} \bar{R}_L^{quies}}{\bar{v}^2 \bar{V}_A} \right) \ {}^oK \qquad (16)$$

where $\bar{V}_A = V_A/7 \times 10^7$ cm/sec, $\bar{v} = v/7 \times 10^5$, $\bar{R}_L^{imp} = R_L^{imp}/5 \times 10^8$ cm, $\bar{R}_L^{quies} = R_L^{quies}/6.6 \times 10^9$, $\bar{\rho}^{imp} = \rho^{imp}/2 \times 10^{-12}$ gm/cm^3, $\bar{\rho}^{quies} = \rho^{quies}/1.3 \times 10^{-15}$ which, for the solar case are ~ 1. Additionally, Equation (14) reduces to a timescale:

$$t_{impulsive} \simeq 322 \left(\frac{(\bar{R}_L^{imp})^{2/3} \bar{V}_A^{2/3}}{(\bar{\rho}^{imp})^{1/2}} \right) \text{sec} \qquad (17)$$

Note that the scalings described by Equations 15 through 17 have assumed that the mass density, ρ, is a free parameter. This is not strictly correct since conduction of thermal energy into the cool chromosphere "evaporates" chromospheric material until Q_{rad} balances Q_{cond} Thus, thermal conduction can buffer a temperature runaway by increasing the coronal mass density (cf., Krieger, 1977; Rosner, et al. 1978b). In addition, the above scalings assume that the electrical resistivity, η, is governed by a Coulomb rather than an anomalous scattering cross-section (e.g., that due to electrostatic ion cyclotron waves). In this regard, the physics and relevant parameters invoked in obtaining the above scalings are somewhat oversimplified and is the subject of our current research. For the present, however, we emphasize that both the qualitative and quantitative trend of Equations (15) through (17) is consistent with Skylab observations of both quiescent and flaring magnetic loops on the sun. As such, we stress the following points which will be relevant to our discussion of HD 4174:

(i) If one observes that $\beta \ll 1$ in a star's outer atmosphere, then the observed magnetic field must originate with the inner atmosphere, e.g., an interior dynamo.

(ii) Low mass loss rates could imply the presence of closed magnetic flux loops within the outer atmosphere which dramatically constrain hydrodynamic flows if the magnetic body force exceeds the driving force (see Equation (6)).

(iii) In light of the fact that such magnetic loops effect an enhancement in the local heating rate, we would also expect a positive correlation between the existence of a hot corona (consistent with the scalings given by Equations (15) through (17)) and low mass loss rates.

III. APPLICATION TO HD 4174

A. Spectroscopic Peculiarities

Having outlined the general principles which may govern coronae, mass loss and related phenomena in stars, we now turn to a specific case to examine these ideas in application. The peculiar M giant HD 4174 was selected on the basis of its purported kilogauss magnetic field (Babcock, 1950, 1958) and spectroscopic peculiarities (Wilson, 1950). Whereas Preston (1977) and Slovak (1979) have commented on the difficulty of confirming Babcock's work, Anderson (1978) claims that the original spectrograms clearly exhibit a variable field. The observational difficulties are non-trivial and we await further results on this object.

Spectroscopically, HD 4174 is unusual for an M giant (gM2ep) in several respects. Wilson (1950) obtained 10 and 40 A/mm spectra in the blue and noted Hβ - H18 emission, along with [Ne III] at 3868 and 3967Å, a possibly weak [O III] at 4363Å, but no sign of [O II] 3727Å. Babcock (1950, 1958) first noted that the Hβ emission varied and possibly correlated with peak magnetic field strength. Re-examining the limited photometric and magnetic data, we find that the magnetic field does not clearly correlate with the known low amplitude ($0^m.07$) light variation of $40^d.5$ period (Jarzebowski, 1964). However, a cyclic variation of the magnetic field appears at one-fourth of the photometric period, a possibility noted by Jarzebowski (1965). The variations in Hβ strength occur roughly in anti-phase with the magnetic variation on a ten day period. This type of anti-phasing is often seen among Ap stars. Further observational verification of this is of course desirable.

We have obtained 2 and 8 A/mm spectra in the blue-violet at KPNO recently and can confirm the presence of the [Ne III] lines reported by Wilson, as well as the Balmer line emission. Other details of the observations are listed in Table 1. The new information we offer deals with the asymmetry sense of the Ca II H and K emission cores, I(K2V)/I(K2R), the so-called V/R ratio (Stencel, 1978). Normal M giants exhibit this ratio to be much less than unity, largely due to mass outflow and blue-shifted circumstellar absorption. HD 4174 is unusual in that V/R is virtually unity on our plate material (Figure 1). This ratio is considered to be an indicator of outer atmospheric differential motions. Stars with large rates of mass loss (dM/dt) generally show V/R < 1, as is typical of M giants (Mullan, 1978). In addition, normal M giants with large dM/dt exhibit marked circumstellar cores of zero eV lines (Ca I 4227, Al I

3944, 3961A). These are absent in the spectrum of HD 4174. Further, several H-K wing emission lines, while present in HD 4174, are very weak compared to the average M giant (Stencel, 1977). Since the strength of these features correlates with dM/dt, the above information suggests a weak stellar wind and low dM/dt rate for HD 4174. The width of the Ca II K-line emission is also somewhat narrower than other M giant stars, yielding $M_v = -0.4 \pm 0.5$ on the recent Lutz (1975) calibration of the Wilson-Bappu effect. This appears 0.5 to 1 magnitude less luminous than other normal early M giants measured from comparable plate material (Keenan, 1978).

HD 4174 differs from normal M giants and supergiants in additional respects. The spectrum of HD 4174 contains evidence for high temperature plasma: the [Ne III] lines are of width 1.15Å (FWHM), which if purely thermal, arise from a gas at 6.5×10^6 °K. The [Ne III] excitation levels are over 120 eV. On the other hand, most M giants and supergiants exhibit few coronal signatures in the UV or at radio wavelengths. IUE spectra by Linsky and Haisch (1979) and Wing (1978) of M giants and supergiants depict an outer atmosphere which is no hotter than 2×10^4 °K as judged by the absence of emission lines with excitations greater than Fe II or SI II. Radio fluxes for continuum emission from M supergiant coronae fall seriously below prediction (Seaquist, 1967; Kundu, 1978). The large dM/dt among normal M giants and supergiants may occur at the expense of coronal heating, in agreement with the theoretical picture developed by Mullan (1978). A comparison can be made between the radiative loss rate for a million degree corona (Equation 8, above) and the power involved in moving material through a circumstellar (CS) envelope. For typical CS densities ($\sim 10^{-16}$ gm/cm^3, Hagen, 1978) and expansion velocities of order 10 km/s, the associated power, $\rho v g$, is about $10^{-7.5}$ (erg cm^{-3} s^{-1}). Q_{rad} for this situation is $10^{-6.7}$, quite comparable to $\rho v g$. In consort with recent studies of late-type evolved stars (Linsky and Haisch, 1979), it seems one finds either a corona and low dM/dt, or no corona and a large dM/dt. HD 4174, which is unusual in having a kilogauss magnetic field and also unusual in having a low dM/dt, may be a case where the normally large dM/dt is constrained by the abnormally large magnetic field.

B. Application of Principles

The power density associated with the driver of the stellar mass loss can be compared to the constraining induced magnetic body forces. To first order the driving power can be represented by a coupling efficiency, E, times the radiative flux (σT_e^4) over a characteristic distance, R_{cs}. The opposing induced magnetic body force is given by Equation 7 above as:

$$(B^2 v/4\pi R)(1 + (\beta/Re_{mag})).$$

As we will show below, since $\beta \ll 1$ and Re_{mag} is large in the present case, we can neglect the final term. Given a typical CS velocity, 10 km/s, B(phot) $\sim$ 1 kilogauss, $B(r) \propto r^{-3}$ and $R_{cs} \sim 2 - 10\ R_*$, we find:

$$E\ \sigma\ T_e^4/R_{cs} = 6.6 \times 10^{-4}\ E,\ @\ 2R_*$$

$$= 1.3 \times 10^{-4}\ E,\ @\ 10R_*,$$

while:

$$B^2 v/4\pi R_{cs} = 1.8 \times 10^{-4}\ @\ 2R_*$$

$$= 1.1 \times 10^{-8}\ @\ 10R_*.$$

For a weak coupling, E = 0.001, the constraining induced magnetic body force will dominate out to the inner CS envelope $10R_*$. A strong coupling, E = 0.1, will permit the induced magnetic body force to constrain material within the near-field of the star ($2R_*$) only. This latter situation may still strongly reduce the mass outflow since the primary acceleration probably occurs within the near star region (Weymann, 1977).

The magnetic energy density associated with a kilogauss magnetic field is considerably greater than the sum of thermal and turbulence energy densities in the case of this M giant. Photospheric motions of 5 - 10 km/s in the 3000 °K effective temperature atmosphere amount to only 0.0002 times $B^2/8\pi$, hence $\beta \ll 1$ (Equation 3). As concluded above, the field cannot originate in the atmosphere, but more likely arises from a rapidly rotating heavy core or from differential shearing in the extended convective envelope of this object. This fact seems to have been anticipated from stellar evolution studies and suggests that if this object evolved from a magnetic F dwarf, some small fraction of M giants might exhibit these peculiarities (Sweigart and Gross, 1978).

We next consider the previously outlined principles to obtain estimates for the coronal heating and flaring timescales in the case of HD 4174. Our model relies on a scaled solar analogy wherein energy storage and quiescent or impulsive release occur in magnetic flux loops. Evidence is emerging in the solar case that a continuum of loop sizes exists, perhaps correlated with the spatial size spectrum of turbulence elements. Among other stars where we lack spatial resolution, certain spectroscopic and photometric changes have been recorded on a variety of timescales including hours, months and years (Liller, 1968; present spectrograms). Presently, the details of the horizontal and vertical variations of density, velocities and magnetic fields are poorly known among M star atmospheres. Following the model developed for solar coronal heating, it is possible to invert the problem and deduce several characteristics of the atmosphere of HD 4174, since the thickness of the corona and the effective turbulence scale size and oscillation frequency are interdependent quantities. The consistency of the results argue for the validity of this approach.

Consider the two observational reference points: $v_o \lesssim 10$ km/s on all scales from photosphere to CS envelope (Reimers, 1977; Hagen, 1978), and, T_c([Ne III]) $\lesssim 6 \times 10^6$ °K. If photospheric oscillations perturb the quiescent loops and cause heating, as our model describes, then the foot-point motions, v_f, of the loops must be less than or of order v_o. Dimensionally, v_f is the footpoint radius, r_f, times the oscillation frequency, ν. Adopting the approximate solar ratio: $r_f = 0.1\ R_L$(quiescent), this limits $\nu_{max} = 10^7/R_L$.

Second, Cox and Tucker (1969) provide values of Q_{rad}/n^2 for each temperature, T_c, where Q_{rad} is the radiative energy loss rate [erg cm^{-3} s^{-1}] and n is the particle number density. By equating the radiative and quiescent rates, we find:

$$Q_{rad}/n^2 = C(T_c),$$

$$n^2\ C(T_c) = Q_{quies.} = 2\pi m_H n v_o^2\ \nu_{max}, \text{ or,}$$

$$n = 2\pi \times 10^7\ m_H v_o^2/(R_L\ C(T_c)).$$

For the loop radii, we will adopt solar proportions as given in the previous section: R_L(quiescent) = 0.3 R_*, which in the present case gives $R_L = 1 \times 10^{12}$ cm. This suggests a coronal density of:

$$n_c = 4 \times 10^6 \text{ cm}^{-3}$$

$$\rho_c = 7 \times 10^{-18} \text{ gm cm}^{-3}.$$

This result is palatable for several reasons: this density compared to the solar coronal density is roughly the same factor as the ratio of the effective gravities ($10^{-2.5}$); this density does not exceed the critical density which would collisionally quench the forbidden lines of Ne (Osterbrock, 1976); the spectral evidence for a suppressed dM/dt is consistent with an upper atmosphere density lower than the $n_{cs} = 10^8$ cm^{-3} found among M giants with larger dM/dt (Hagen, 1978), and, this lower density also concurs with a reduced R_* suggested by the lower than average Wilson-Bappu magnitude, derived above.

An Alfven speed, and hence field strength, can be deduced by use of Equations (11) and (16) separately. The first approach yields:

$$\nu = V_A/\pi R_L = 10^7/R_L;\ V_A = 3 \times 10^7 \text{ cm s}^{-1}.$$

The second approach leads to:

$$T_q = T(V_A, R_L, \rho, \dot{v}_o)\ ;\ V_A = 1 \times 10^7 \text{ cm s}^{-1},$$

which is in reasonable agreement. The magnetic field implied by these density and Alfven speeds is 0.3 gauss at the top of the quiescent coronal loop. Assuming an r^{-3} dilution of the field, we obtain the photospheric scale size, r_p, of the spatially averaged kilogauss photospheric field:

$$(r_p/R_L)^{-3} = B_{phot}/B_{cor}.$$

Since $R_L = 10^{12}$ cm, $r_p = 10^{11}$ cm = 0.1 R_L, which is also the adopted scale size for the loop footpoints, r_f.

This model leads us to consider the origin of the photospheric field in the upper convective envelope as due to shearing from differential rotation with an effective depth scale of 10^{11} cm. The differential rotation rate can be estimated by comparing rotational and magnetic energy densities, assuming full coupling efficiency:

$$E_{rot.} = 0.5Mv^2/\text{Vol.} = B^2/8\pi.$$

The effective volume is the shell of thickness r_p at R_*, which is $R_*^2\ r_p$. Thus the implied differential rotation rate, given $R_* = 3 \times 10^{12}$ cm and B = 1000 gauss, is 8×10^3 cm/s, which certainly does not exceed our v_o constraint, unless the efficiency falls below 5×10^{-4} for this dynamo.

We can develop this model one step further by considering the impulsive physics detailed in Section II, above. The heating occurs rapidly in a double tearing mode instability in a flaring loop. Adopting the solar proportions, the instability occurs in a thickness r_t which is approximately 0.01 times the loop size, R_L(impulsive). The solar proportions dictate that R_L(impulsive) = 7.6×10^{-2} R_L(quiescent), so $R_{L,i} = 7.6 \times 10^{10}$ cm and $r_t = 7.6 \times 10^8$ cm. Similarly, the quiescent and impulsive region densities are scaled by 6.5×10^{-4} (see Section II), which implies that $\rho_i = 1 \times 10^{-14}$ gm cm^{-3}. The magnetic field in the impulsive loop will be scaled from the photospheric value by the cube of the ratio of $R_{L,i}$ and $r_p = r_f$. This field value is approximately 350 gauss (B_i), and the resulting Alfven speed is: $V_A = 9.5 \times 10^8$ cm/s. Using Equations 10, 14 and 15 above, we find for the impulsive heating rate:

$$Q_i = 2.8 \times 10^{-3} \text{ erg cm}^{-3} \text{ s}^{-1}.$$

The impulsive heating timescale is interesting:

$$t_i = 1.7 \times 10^6 \text{ sec},$$

since it corresponds to a month long flare! The associated flaring temperature when impulsive heating and radiative losses are balanced is:

$$T_i = 1.4 \times 10^7 \text{ }^oK.$$

Since the flares occur over less than 0.001 of the stellar surface at some unknown frequency, the opportunity for detection may occur in the X-ray region during sudden onset intervals. Certainly flare related events on the Sun are known to persist in the visible and even in the soft X ray regions for multi-hour timescales (Neupert, 1979 private communication). The various parameters developed for this model of the upper atmosphere of HD 4174 are collected in Table 2.

IV. CONCLUSION

The available observational data, combined with our analysis of the hydromagnetic effects, leads us to the following ideas about the peculiar M giant, HD 4174:

a. Since $B^2 \gg \rho v_o^2$, the major portion of the observed field must be generated in a sub-photospheric location, either via differential rotation within the upper convective envelope, or possibly in a core dynamo;

b. the low mass loss rate of HD 4174 implies the existence of closed magnetic flux loops in the outer atmosphere constraining the mass outflow;

c. the closed flux loops store and release magnetic energy via resonant absorption of Alfvenic surface waves, which increase the upper atmosphere heating rate and can maintain coronal temperatures.

Several useful observational efforts would be useful to help clarify the validity of our model concerning HD 4174 as well as its predictions. Continued high-dispersion spectroscopic monitoring would improve the suggested correlations among magnetic field strength, Ca II V/R, Hβ emission and other diagnostics of the upper atmosphere. Although this star has only few similarities to the symbiotic variables, a long term search for radial velocity variations, especially in the red, would be useful to help rule out binarity (Cowley and Stencel, 1973). Our present spectrograms do not show any radial velocity variations over the three month interval covered. Careful photometric observations to verify the 40.5 day period and to establish the variations in color would be useful. The present opportunity to obtain UV and X ray observations of this object should be utilized. Ultraviolet observations to verify the anticipated presence of high excitation emission lines and Lyman-alpha from a transition region between chromosphere and corona should be obtained with the IUE, if possible. Soft X ray observations could be made with HEAO-2 to detect the expected coronal flux and possible flare flux and timescales, as predicted. Evidence for mass loss could be checked with infrared observations at 10 and 20 microns.

Finally, the behavior of additional classes of late-type stars may make them amenable to this type of analysis. Sudden onset intense flare-like phenomena in the visible and X ray spectra of dMe and RS CVn stars is now well established. Although specific magnetic field strengths have not been clearly established, analogies to solar flaring processes have been elaborated (Mullan 1976a,b). The RS CVn variables, which are binary systems containing G or K subgiants with exceedingly strong chromospheric emission, also show evidence for prominence-like material (Weiler, 1979 private communication). In these cases, flaring timescales and fluxes are known, which may make it possible to repeat the analysis performed above to describe conditions in the stellar atmosphere which would obtain under the assumed physical processes.

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TABLE 1

Recent KPNO Spectra of HD 4174

Date	Instruments	Plate	Dispersion	Observer
15 Oct 78	4meter+echelle	IIa0,BI2314	2 A mm^{-1}	W.H.
22 Dec 78	CoudeFeed + I.T.	IIIaJ, 8394	8 A mm^{-1}	R.S.
23 Dec 78	CoudeFeed + I.T.	IIIaJ, 8404	8 A mm^{-1}	R.S.

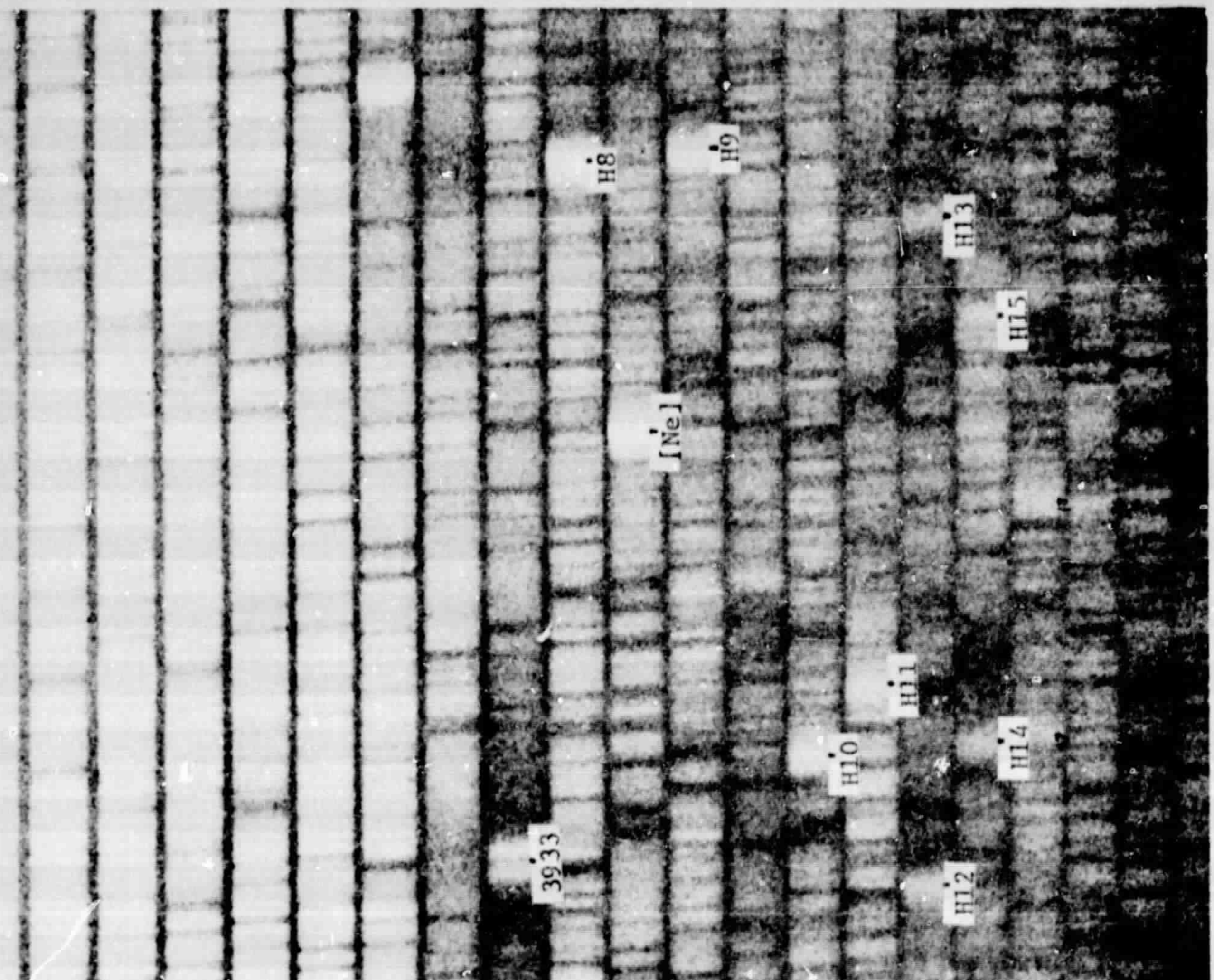
TABLE 2

HD 4174 Model Parameters

R_*	3.5×10^{12} cm
log g	2.0 - 2.5 [cm s^{-2}]
Photospheric region:	
ρ_p	1. $\times 10^{-9}$ gm cm^{-3}
B_p	1000 gauss, variable
T_p	3500 ^oK
Flaring region: (mid-chromosphere)	
ρ_i	1.1×10^{-14} gm cm^{-3}
B_i	350 gauss
T_i	1.4×10^7 ^oK
t_i	$\sim 10^6$ sec
$R_{L,i}$	7.6×10^{10} cm
Quiescent corona:	
ρ_q	7×10^{-18} gm cm^{-3}
B_q	$\sim$ 1 gauss
T_q	$\sim 10^6$ ^oK
$R_{L,q}$	1×10^{12} cm

FIGURE CAPTION

Figure 1. Portion of the echellegram of HD 4174 in the Ca II H & K region. Prominent emission lines are labeled. Note the symmetric character of the self-reverse Ca II emission cores at 3933 and 3968Å.


H8
H9
H13
H15
[Ne]
H11
H10
H14
3933
H12
Hε 3968 [Ne]
H8
H9