THE Mg II h and k LINES IN A SAMPLE OF dMe AND dM STARS[1]

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ABSTRACT

We present observed Mg II h and k line fluxes for a sample of 4 dMe and 3 dM stars obtained with the IUE satellite in the long wavelength, low dispersion mode. The observed fluxes are converted to stellar surface flux units and the importance of chromospheric non-radiative heating in this sample of M dwarf stars is intercompared. In addition, we compare the net chromospheric radiative losses due to the Ca II H and K lines in those stars in the sample for which calibrated Ca II H and K line data exist. Moreover, we estimate active region filling factors which likely give rise to the observed optical and ultraviolet chromospheric emission. Finally, we briefly discuss the implications of the results for homogeneous, single-component stellar model chromospheres analyses.

INTRODUCTION

The resonance lines of Ca II and Mg II, designated as the H and K and h and k lines, respectively, are valuable diagnostics of stellar chromospheric properties. The dominant role of the H and K lines in model chromospheres analyses has been due to their accessibility to earth-based observation

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(ref. 1 and references therein). However, with the advent of the International Ultraviolet Explorer (IUE) satellite, the resonance lines of Mg II are now available for theoretical analysis. The height of formation of the h and k lines is somewhat greater than the height of formation of the Ca II H and K resonance lines. Furthermore, Mg II can be represented with a simple atomic model. Hence the radiative transfer can be solved more accurately to yield more reliable results. In the following we will offer a brief quantitative assessment of low dispersion Mg II h and k line observations of dMe and dM stars.

RESULTS

The stars observed, their spectral types and the Mg II (h + k) line fluxes at the earth are given in the first three columns of table I[4]. The spectral types are taken from reference 2 except for 61 Cyg B. The spectral type for this star is given in reference 3. The relations between stellar angular diameter and (V-R) color (refs. 4, 5) convert the observed flux to surface flux. The (V-R) color index for each star follows from reference 6 (the (V-R) color for AT Mic is not available). The ratio of the Mg II (h+k) stellar surface flux to the same quantity for the mean Sun is listed in column 4 of table I. This ratio is based upon the mean solar value of the Mg II h and k line flux given in reference 7. The importance of chromospheric non-radiative heating in this sample of M dwarf stars considered here can be readily intercompared through the ratio

$$R_{hk} = F(\text{Mg II h+k})/\sigma T_{eff}^4,$$

where R_{hk} represents the chromospheric radiative losses in the h and k lines normalized to the total stellar surface flux. We assume that the radiative equilibrium contribution to the h and k line fluxes is negligible in these cool dwarfs. The values of R_{hk} are listed in column 5 of table I. The effective temperatures for GL 380 and GL 411 are taken from reference 8. The values of T_{eff} for EQ Vir and YZ CMi are taken from reference 9. The effective temperature of 61 Cyg B is taken from reference 10 while that for UV Ceti is estimated from its spectral type and reference 11. Values of R_{HK}, the analogous quantity for the Ca II H and K lines, are taken from reference 8 and listed in column 6 of table I (the R_{HK} value for 61 Cyg B follows from reference 10 while the R_{HK} values for EQ Vir and YZ CMi given in reference 8 have been modified to reflect the new T_{eff} measurements presented in reference 9). Finally, we list in column 7 of table I the ratio of the Mg II (h+k) line fluxes to the Ca II (H+K) line fluxes. Omitted entries in table I indicate that the particular value is not available.

DISCUSSION

The values of the ratio $F(\text{Mg II h+k})/F_{\odot}(\text{Mg II h+k})$ are less than unity, with the exception of the most active star (as defined by the R_{hk} values), EQ Vir. The values of R_{hk} for the dMe stars are basically an order of magnitude greater than for the dM stars. Furthermore, $F(\text{Mg II h+k})/F_{\odot}(\text{Mg II h+k})$

[4]The observed Mg II fluxes for YZ CMi and UV Ceti have been kindly provided by K. G. Carpenter and R. F. Wing in advance of publication.

increases with increasing R_{hk}. In addition, the ratio F(Mg II h+k)/F(Ca II H+K) is greater than unity (with the exception of GL 380) for the sample considered here. Thus the Mg II resonance lines generally play a more important role in the overall chromospheric energy balance in dMe and dM stars than do the Ca II H and K resonance lines. However, there is an important caveat that must be noted: the Mg II data and the Ca II data discussed in this investigation were not acquired simultaneously. Thus the emergence and decay of stellar surface activity combined with the rotational modulation of these features are likely to cause variations in the observed net chromospheric radiative losses. Therefore data sets obtained at widely separated times of observation cannot be confidently compared on a star-by-star basis (with the possible exceptions of the "most active" and the "least active" stars). We can, however, partially circumvent this difficulty by comparing the mean values of physical quantities for a particular sample of stars. Since the degree of chromospheric activity among stars in a given sample is uncorrelated, the mean values of physical quantities will remain relatively constant. We thus find the mean value of the ratio F(Mg II)/F(Ca II) to be 2.85. This is similar to the mean solar value of 2.5 (ref. 10). The mean values of R_{hk} and R_{HK} are $\overline{R_{hk}}$ = 8.6 (-5) and $\overline{R_{HK}}$ = 3.3 (-5). The ratio $\overline{R_{hk}}/\overline{R_{HK}}$ is 2.6 which is even closer to the solar value of 2.5. Thus we conclude that the mechanism which determines the relative contributions of certain spectral lines to the energy balance in the chromosphere must be similar in the late-type, main sequence dwarf stars.

An approach to account for the degree of chromospheric emission in M dwarf stars is to assume that the dM and dMe stars fundamentally differ from each other in terms of the fractional area of their surface which is covered by active (plage) regions. The active region filling factor can be crudely estimated according to the following expression (ref. 12)

$$F = A\, F_a + (1-A)\, F_Q, \qquad (1)$$

where A is the dimensionless ratio of the area of the active region to the area of the visible quiet stellar surface. The symbols F_a and F_Q represent the Mg II h and k line surface flux for an active and quiet region, respectively. The underlying assumptions which lead to equation (1) are given in reference 12. The values of A based upon the Mg II h and k fluxes presented in this investigation are given in column 2 of table II. We also list in column 3 of table II the values of A given in reference 12. These filling factors are based upon the Ca II H and K line data presented in reference 8. In order to compute the relative active region filling factors it was necessary to arbitrarily define $A \equiv 1$ for EQ Vir and $A \equiv 0$ for GL 411 (ref. 12). Excluding these extreme values, we find the mean values $\overline{A}$ (Mg II) = 0.15 and $\overline{A}$ (Ca II) = 0.07. Of course the small size of the sample renders a comparison of these two estimates of active region filling factors less meaningful. However, it is interesting to note that model chromospheres deduced from the Ca II K-line profiles of reference 8 underpredict the Mg II k-line flux by an order of magnitude or more for a subset of the dMe and dM stars discussed in this investigation (ref. 13). In summary, the apparently discrepant mean active region filling factors derived from the Ca II H and K and the Mg II h and k lines combined with the failure of model chromospheres to reconcile two overlapping chromospheric spectral features suggest that single-component, homogeneous model atmospheres are not physically realistic representations of

M dwarf stars.

The stellar chromospheric emission features probably arise from plage regions which are, in turn, composed of magnetic flux tubes. A schematic model of a magnetic flux tube is presented in figure 1. The levels h_1 and h_2 represent the heights of formation of the Ca II K-line and the Mg II k-line, respectively. We consider a flux tube in hydrostatic equilibrium. Therefore

$$P_{ext}(h) = P_g(h) + [B(h)]^2/8\pi,$$

where $P_{ext}(h)$ is the external (field-free) gas pressure at height h, $P_g(h)$ is the internal gas pressure and B(h) is the internal magnetic field strength, also at height h. We ignore turbulent pressure in this preliminary analysis. At the levels h_1 and h_2 we have

$$P_1^{ext} = P_1^{g} + B_1^{2}/8\pi,$$

$$P_2^{ext} = P_2^{g} + B_2^{2}/8\pi.$$

Now $P_2^{ext} < P_1^{ext}$ by the constraint of hydrostatic equilibrium. But $B_2 < B_1$ in a flux tube characterized by diverging field lines (see fig. 1). Thus it is possible for $P_2^g > P_1^g$, which would lead to enhanced Mg II k-line emission. The condition $P_2^g > P_1^g$ occurs if the inequality

$$B_1^{2} - B_2^{2} > 8\pi\ (P_1^{ext} - P_2^{ext})$$

is fulfilled. An alternative way to conceptualize the problem is to note that the emission area (filling factor) for the k line, A_2, is greater than the emission area for the Ca II K line, A_1, as shown schematically in figure 1. Of course a proper analysis of the chromospheric line spectrum in a magnetic flux tube requires a two-dimensional radiative transfer calculation since the flux tube is in radiative exchange with its surroundings. Moreover, the importance of lateral turbulent heat exchange will change along a flux tube as the field decreases with height (refs. 14, 15).

CONCLUSIONS

The Mg II h and k line data and the transition region line data from IUE combined with Balmer line and H and K line data for the dMe and dM stars offer us the unique opportunity to construct self-consistent stellar model chromospheres. We further suggest that multi-component model atmospheres are more realistic physical representations of stellar chromospheres. In particular, we hypothesize that a detailed consideration of the line spectrum arising from magnetic flux tubes is required in order to reconcile various chromospheric spectral line diagnostics.

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TABLE I. - SUMMARY OF IUE Mg II (h+k) OBSERVATIONS

Star	Spectral Type	f*(Mg II)	F*(Mg II)	$\frac{F}{F_{\odot}}$(Mg II)	R_{hk}	R_{HK}	F(Mg II)/F(Ca II)
EQ Vir	dK5e	1.36 (-12)	2.67 (6)	2.12	1.71 (-4)	1.2 (-4)	1.43
61 Cyg B	dM0	6.52 (-12)	3.10 (5)	0.25	2.92 (-5)	8.2 (-6)	2.67
GL 380	dM0	8.19 (-13)	4.95 (4)	0.04	3.97 (-6)	1.0 (-5)	0.38
GL 411	dM2	5.79 (-13)	3.33 (4)	0.03	4.39 (-6)	1.4 (-6)	3.06
AT Mic	dM4.5e	3.94 (-12)	----	----	----	----	----
YZ CMi	dM5.5e	1.26 (-12)	9.37 (5)	0.75	1.68 (-4)	2.5 (-5)	6.72
UV Ceti	dM6e	6.41 (-13)	4.00 (5)	0.32	1.40 (-4)	----	----

* Units: ergs - cm^{-2} - s^{-1}

TABLE II. - ACTIVE REGION FILLING FACTORS

STAR	A (Mg II)	A (Ca II)
EQ Vir	≡ 1.0	≡ 1.0
61 Cyg B	0.10	0.065
GL 380	0.01	0.07
GL 411	≡ 0.0	≡ 0.0
AT Mic	---	---
YZ CMi	0.34	0.07
UV Ceti	0.14	---

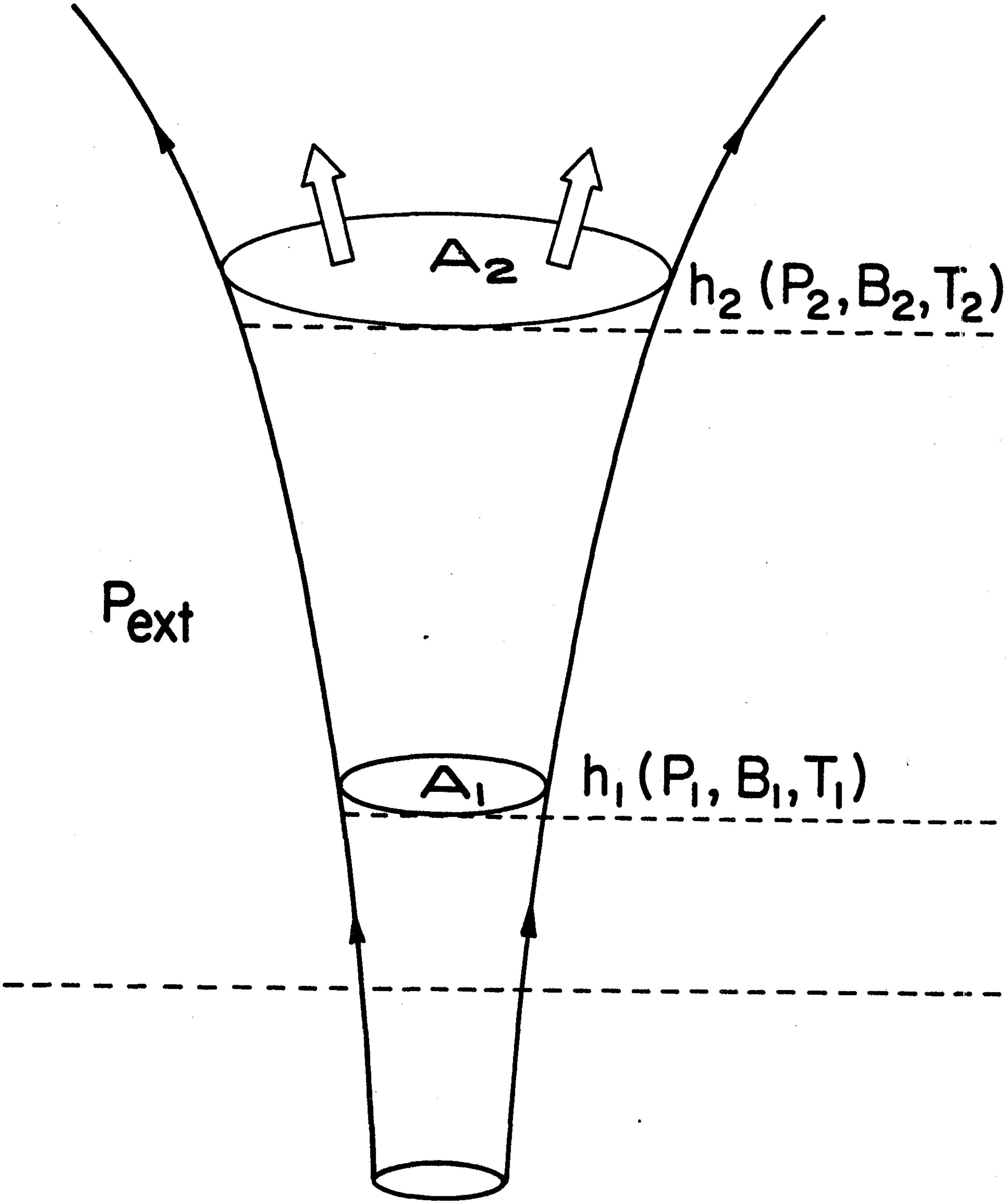

Figure 1. - Schematic model of a magnetic flux tube.