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EFFECTS OF METALLICITY ON CHROMOSPHERIC EMISSION IN COOL GIANTS: RESULTS FROM ACOUSTIC WAVE MODELS

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ABSTRACT We present acoustically heated chromosphere models for moderately cool giants which differ in metallicity by a factor of 100 and show that the Mg II core emission remains largely unaffected by metal abundances consistent with observations. The Mg II emission also agrees well with the observed basal flux limit. Both results are a key for attributing chromospheric heating in non-magnetic non-pulsating late-type stars to acoustic energy dissipation.

INTRODUCTION

For many years it has been thought that the chromospheres of cool stars are dominated by magnetic heating. This view was ultimately modified by results of Schrijver (1987) and Rutten et al. (1991) who presented a detailed statistical analysis of flux-flux and flux-color relations derived from selected emission lines for a large sample of late-type stars. They found that the statistical correlations can best be understood when the stellar emission line fluxes are assumed to consist of two components: a "basal" flux, which is independent of stellar rotation and a "magnetic" flux, which depends on rotation and age. The basal flux could unequivocally be identified as an intrinsic property of the stars and is not an artifact of the detection limits.

An important feature of the "chromospheric basal flux limits", largely overlooked by the scientific community, is the potential impact of different metal abundances. It was found that the basal flux limits are relatively sharp, indicating that they are unaffected by different metallicities. The limits were also found to be unaffected by differences in stellar gravity (i.e., they are the same for dwarfs and giants of given effective temperature), which can be understood on the basis of acoustic wave calculations (Ulmschneider 1989).

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The metallicity problem, however, remains unexplained. Despite the fact that for some stars the metal abundances are reduced by a large factor, the Mg II and Ca II emissions remain the same. A drastic example was given by Dupree et al. (1990) who studied IUE observations for a total of 10 metal-deficient giant stars. All stars were Population II stars, with metal abundances lower by factors of ~10–100 relative to the Sun. Nevertheless, the Mg II emissions were observed to be commensurate with the values found for disk giant (Population I) stars of similar color. The authors did not give an explanation for these results, but speculated that these stars might have additional atmospheric activity to compensate the otherwise reduced Mg II emission caused by the lack of Mg atoms. Can this result be understood on the basis of acoustic heating as well? We will show that this is indeed the case.

RESULTS AND DISCUSSION

The computation of acoustic waves has been discussed in previous papers and therefore does not need to be described again. It suffices to say that the time-dependent hydrodynamic equations and the radiative transfer equations for the H^- continuum as well as the Mg II *k* and H Lyα lines (as representative chromospheric emitters) are solved simultaneously using the method of characteristics. After the acoustic wave calculations are completed, CRD and PRD line profiles are computed for selected phases of the wave using a new operator splitting method of Ulmschneider (1994). As stellar parameters we take $T_{eff} = 5012$ K and $g = 10^3$ cm s^{-2}. As initial acoustic energy flux we take $F_M = 2.0 \cdot 10^8$ ergs cm^{-2} s^{-1} and as wave period we take $P = P_A/5 = 1120$ s, representing the peak of the acoustic frequency spectrum. These data are chosen according to results from traditional convection zone calculations (Bohn 1984, Musielak et al. 1993). As element abundances we use solar, 1/10 solar, and 1/100 solar metallicity, which gives us a grid of three giant star chromosphere models.

Our wave models show the following behavior: After a time of 15 wave periods, dynamic equilibrium is achieved. Over a distance of about 5 orders of magnitude in pressure, extended quasi-isothermal atmospheres with an average temperature of about 4500 K are found. The time-averaged temperatures in these regions are close to the radiative equilibrium temperature of the initial atmosphere, being 300 K higher at most. The chromospheres are permeated by acoustic waves, in which the temperatures behind the shocks reach peaks of about 6000 K. For comparison we have evaluated similar phases of the wave in all three models. We computed the emerging PRD (and for comparison CRD) Mg II emission line fluxes for the wave phases Δt^i and $\Delta t^i - P/2$, giving us good estimates for the average values. We found a PRD Mg II emission flux of 5.48, 5.55, and 5.57 (in logarithmic CGS units) for the wave models with solar, 1/10 solar, and 1/100 solar metallicity, respectively. The corresponding emission in the CRD approximation is 6.81, 6.43, and 5.98. These values can be compared with observational constraints.

We note that our models are able to explain two distinct observational results. It was found that, although Population I and II stars differ in metallicity by up to a factor of 100, the Mg II emission in these stars is observed to

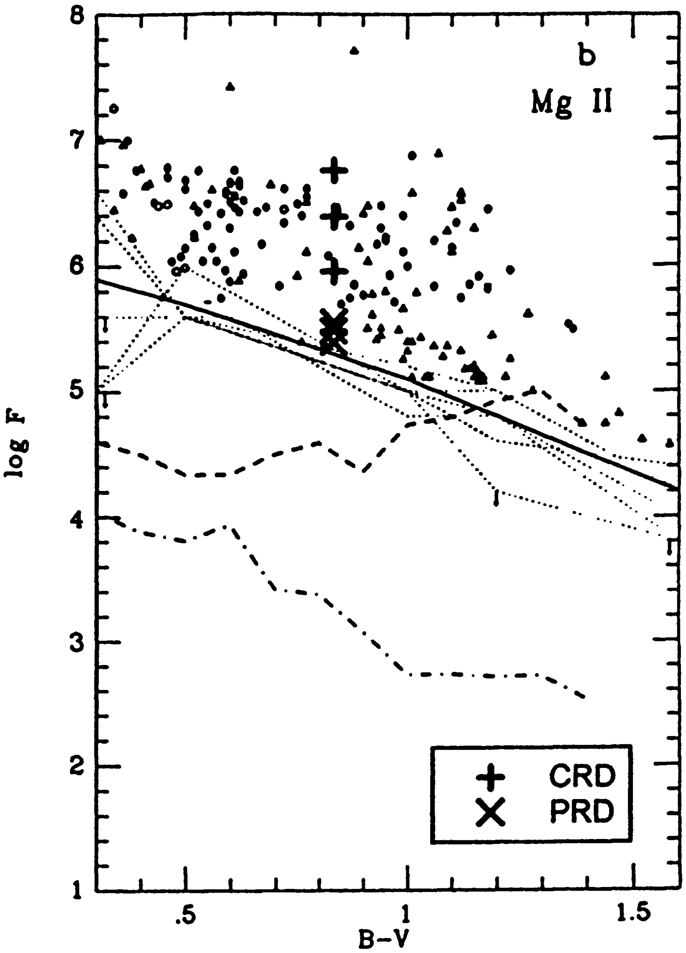

FIGURE I Theoretical emission fluxes of Mg II *h* and *k* lines based on our acoustic wave models with different metallicity compared with empirical fluxes of Rutten et al. (1991). Fluxes of lines computed assuming CRD are labeled C and assuming PRD are labeled P.

be almost identical (Dupree et al. 1990). This result can be well reproduced by our wave models. The reason is three-fold: First, the mean chromospheric temperature is slightly higher in models with lower metallicity, which helps to increase the Mg II emission flux. Second, and most important, in models with lower metallicity the optical depth of the Mg II *k* line (which was treated as a representative chromospheric emitter) is reduced, forcing the line to be formed deeper in the atmosphere, where larger particle densities are found. As a consequence, the reduced metal abundance is compensated. A third reason is the following: Because of the limiting shock strength behavior of the waves (see e.g. Cuntz and Ulmschneider 1988), the wave shape (i.e. temperature and velocity amplitude) is the same in large portions of all three model atmospheres, allowing the Mg II *k* line to be formed under similar thermodynamic conditions. The fact that chromospheric emission is independent of the metal abundances is also consistent with the scaling laws of Ayres (1979), which are found to be valid for various semiempirical chromosphere models based on IUE data.

A further observational fact can be reproduced by our models. Our PRD emission fluxes lie close to the common basal flux limit for giant and dwarf stars for the Mg II emission. In Figure I we have plotted our averaged total PRD and CRD Mg II emission fluxes into Fig. 1b of Rutten et al. (1991). It is seen that the PRD fluxes satisfy reasonably well the observed common basal flux limit, which is relatively sharp and remains furthermore unaffected by element abundances. This result is further strong evidence that the chromospheres of basal flux stars are indeed heated acoustically and has to be seen together with the strong support for this interpretation by Ulmschneider (1989) and Buchholz and Ulmschneider (1994, this volume). Note that our Mg II CRD fluxes do not agree with the basal flux limits and moreover show a strong nonobserved metallicity dependence. This is a clear indication that the CRD assumption is not valid. As our results depend on a long chain of uncertainties and technical restrictions in the codes, the agreement with observation to within a factor of 2 is satisfactory. Nevertheless, all these results must be reviewed using a more sophisticated radiation hydrodynamics code which is in preparation.

Despite our encouraging results, at least two issues related to the heating of chromospheric basal flux stars are still unresolved. First, it is observed that cool star chromospheres are highly inhomogeneous, in part probably due to CO/SiO radiative instabilities, reducing the filling factor of the hot chromospheric component significantly. Second, the magnitude of chromospheric turbulence is unexplained. Recent HST-GHRS data for α Tau (K5 III), which is also a well-known chromospheric basal flux star, revealed a high level of turbulence in the chromosphere (i.e., $\simeq 24$ km s^{-1}), which is inconsistent with "traditional" acoustic heating models (Judge and Cuntz 1993). Nevertheless, we argue that our results are a key for attributing chromospheric basal flux limits to acoustic heating. Acoustic heating is probably dominant in all non-magnetic non-pulsating late-type stars.

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