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WHAT DO THE MG II LINES TELL US ABOUT WAVES AND MAGNETIC FIELDS?

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ABSTRACT. For different flux tube distributions over a solar surface element and for various energies of MHD-waves propagating along the tubes, the Mg II k and Ca II K lines integrated over the area are simulated. We discuss the influence of various physical parameters on the line shape.

1. Introduction

It is very difficult to observe magnetohydrodynamic waves propagating along solar magnetic flux tubes because the tube diameters as a rule are much below the resolution limit of about one arc sec. Spectral line observations therefore average over a whole ensemble of different surface features which in addition to non-magnetic regions usually include many flux tubes. Due to the spreading of the flux tubes with height this averaging process is even more complicated. However, not all of the information on the waves and the filling factor or geometry of the magnetic field is lost. In the present work we show some first results of our investigation of how the spatially integrated Mg II k and Ca II K line shapes change, if the physical parameters of a solar surface element and of the waves propagating along the tubes are varied.

2. Method and Results

We assume a solar surface element to be uniformly covered with vertically directed magnetic flux tubes. Fig. 1 shows a vertical slice through the flux tube field. The tube diameter at the bottom is $d_{bot} = 100\ km$. The tubes are assumed to spread with height reaching eventually a maximum diameter d_{max} where the field fills out the entire available space. The distance of neighbouring tubes is d_a. For the non-magnetic atmosphere outside the tube we have computed a nongrey NLTE H^- and Mg II line radiative equilibrium atmosphere. Using a considerably modified code after Herbold et al. (1985) we have calculated a series of longitudinal MHD waves along the tubes. Various wave energies and a wave period of 30 s were chosen. It should be noted that different choices for the flux tube geometry (e.g. d_a and d_{max}) will strongly influence the physics of the wave propagation, the radiation damping and the shock formation in the tube as has been discussed by Ulmschneider et al. (1987). The radiation damping in the tube is due to nongrey NLTE H^- and Mg II line emission. The tube is assumed optically thin in H^- with the mean intensity given by the outside atmosphere. For the outside atmosphere H^- has been computed by solving the transfer

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equation. For the Mg II line it is assumed that the transfer is mainly in vertical direction (Fig. 1). Here and for the Ca II K line complete redistribution has been assumed. After completion of the wave computation the solar surface element is sampled every 40 *km* at equidistantly spaced points (Fig. 2, boxes) and the transfer along the different rays, which for a given aspect angle α contribute to the integrated line profile, is evaluated (Fig. 1, dashed). For preliminary computations we have used linear sampling where only rays from the bottom row of boxes in Fig. 2 was used. This overestimates the flux tube contribution compared to the non-magnetic contribution.

Fig. 3 shows the temperature profile of three different phases of the waves for an *active region* flux tube distribution ($d_{max} = d_a = 220\ km$). Here a longitudinal MHD tube wave with an energy flux of $1.0 \cdot 10^8 erg/cm^2 s$ and a period $P = 30s$ was assumed. Phase A is at time $t = 6155\ s$, B at $t = 6200\ s$ and C at $t = 6270\ s$. The radiative equilibrium temperature distribution of the atmosphere outside the flux tube is shown dotted. Phase A and C show the moments where shocks are transmitted at the top boundary. It is seen that at great heights the temperature rises steeply due to unbalanced shock heating when the main emitter gets destroyed due to the ionization of Mg II to Mg III. This behaviour is different if Lyman α emission were included but a similar effect would eventually happen at greater heights when hydrogen ionizes, as has been discussed by Ulmschneider et al. (1987). Fig. 5 gives the corresponding theoretical, not instrumentally degraded, integrated, linearly sampled Mg II k line shape of the three different phases of Fig. 3. Note that due to our two level treatment the line is a singlet. It is seen that the transition-layer-like rapid temperature rise at great heights does not influence the line core and that the core is formed near 1000 km height.

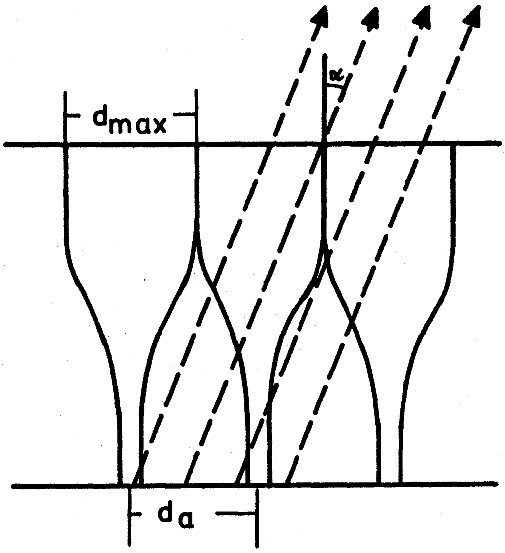

Fig. 1 Flux tube geometry, side view

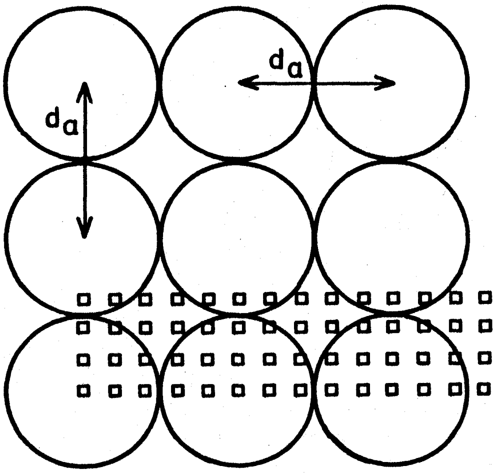

Fig. 2 Surface area sampling

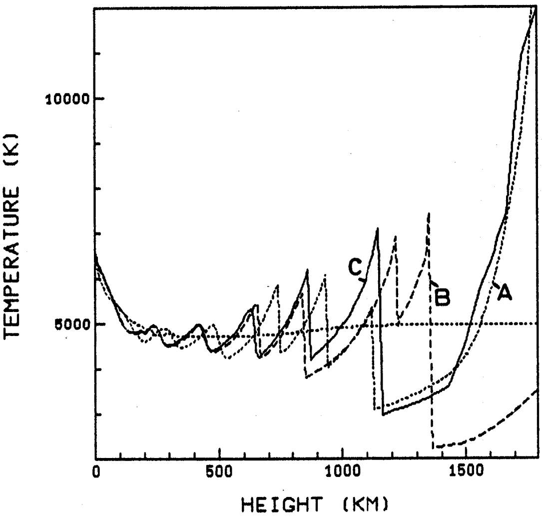

Fig. 3 Wave phases in an active region

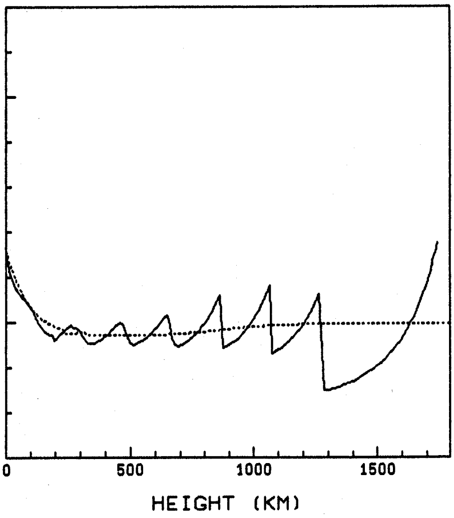

Fig. 4 Wave in a quiet region

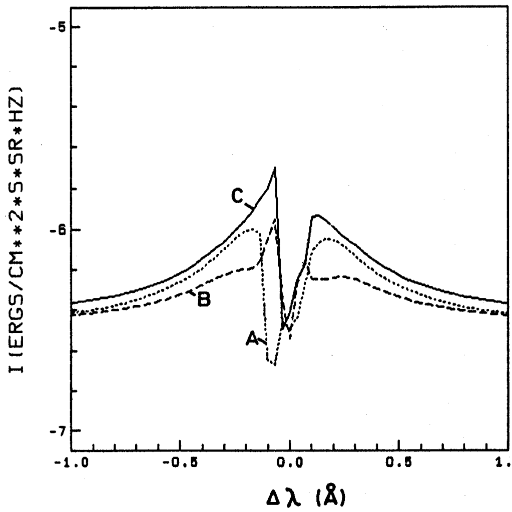

Fig. 5 Mg II profiles for different phases

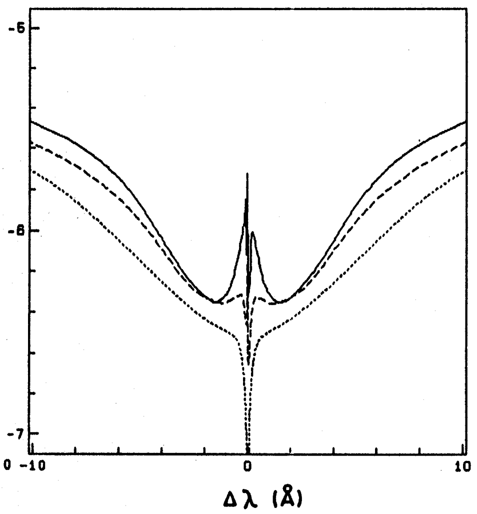

Fig. 6 Change of the filling factor

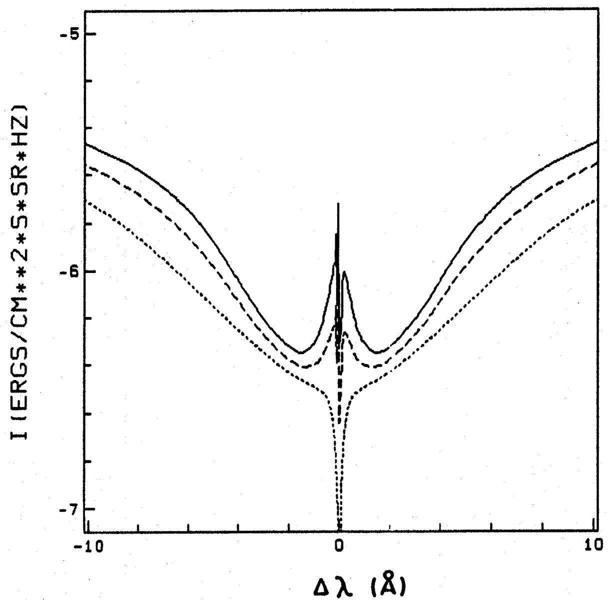

Fig. 7 Change of the geometry

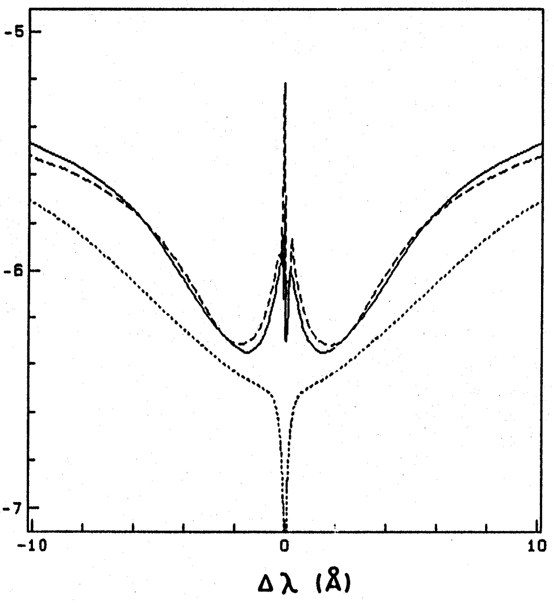

Fig. 8 Increase of the wave flux

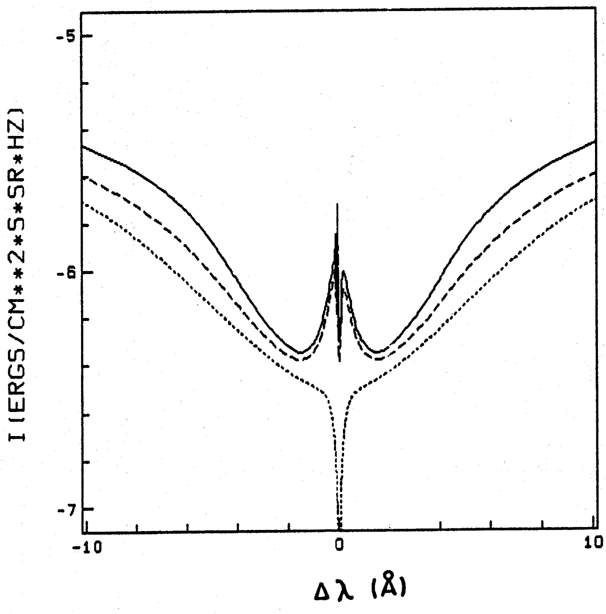

Fig. 9 Linear and 2D sampling

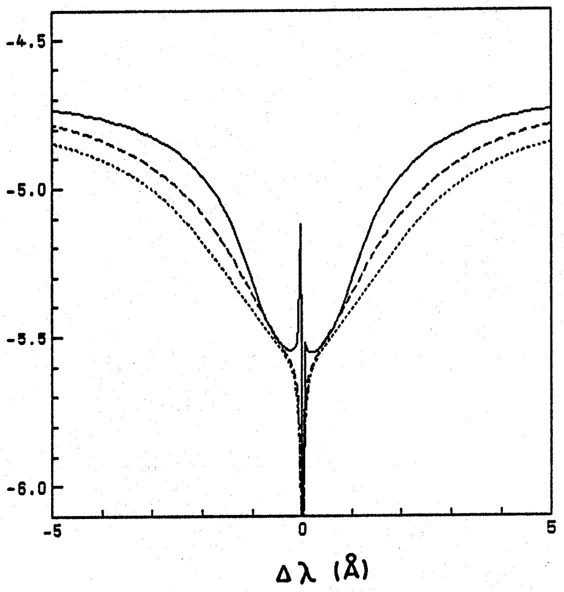

Fig. 10 Ca II line similar as Fig. 6

Fig. 4 displays the temperature profile for a wave of the same energy and period as in Fig. 3 but propagating in a flux tube relevant for a *quiet region* ($d_{max} = d_a = 600\ km$). It is seen that this wave, due to the much greater spreading of the tube, has a much smaller amplitude growth. Fig. 6 shows the comparison of the integrated line shapes for the active region (phase C, solid) and the quiet region (dashed). The radiative equilibrium line profile (Fig. 6, dotted) shows that the absence of waves leads to a pure absorption line. It is seen that for the chosen wave type the main effect of increasing the filling factor of magnetic fields is an enhancement of the wings and the central core of the line. This is due to the fact that in a narrower tube, shock formation occurs at lower height, which increases the mean temperature at these heights. The smaller tube diameter at large height generates greater wave amplitudes which leads to stronger line core emission. In addition the larger filling factor implies more wave energy per surface area.

To see the purely geometrical effect of increased crowding of flux tubes we have computed the active region case C of $d_{max} = 220\ km$, making the unphysical assumption $d_a = 440\ km$, where the non-magnetic space outside the tube is increased by a factor of four. This decrease of the filling factor displaces the line profile (Fig. 7, dashed) towards the radiative equilibrium profile. In Fig. 7 and the subsequent Figs. the active region case of $d_{max} = 220\ km$ is shown solid and the radiative equilibrium profile dotted.

Fig. 8 shows the effect of increasing the wave energy. For the case of the active region tube we have increased the wave flux to $3.0 \cdot 10^8 erg/cm^2 s$. It is seen that the more energetic wave (Fig. 8, dashed) leads to increased emission both in the near wings and the line core compared to the less energetic wave. The results shown so far have been obtained by sampling the solar surface along a linear slab (c.f. Fig. 2) which goes through the tube centers. Fig. 9 shows the comparison of linear sampling (solid) with two-dimensional sampling (dashed) which covers the entire solar surface element. The 2D sampling leads to an increased contribution of the non-magnetic areas.

Fig. 10 shows a computation similar to Fig. 6 except that now the Ca II K line profile is simulated. As in Fig. 6 the active region profile is shown solid, the quiet region profile dashed and the radiative equilibrium line profile (from the non-magnetic area) dotted.

3. Conclusions

We have simulated Mg II k and Ca II K line profiles from a solar surface element which is filled by flux tubes of various size and by non-magnetic areas. Longitudinal MHD-waves are assumed to propagate along the spreading magnetic flux tubes. The variation of the magnetic field filling factor, the tube geometry and the wave energy result in characteristic changes of the integrated line profiles. This shows that, despite of a severe loss of horizontal resolution, the integrated line shapes of the chromospheric lines of stars contain significant information about the magnetic field, its geometry and filling factor and about the waves which heat the chromosphere.

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