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Change of level population density with time in the solar quiet chromospheric atmosphere

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Abstract. Employing a law of weak acoustic wave, the ratio of population density N_2/N_1 with time for the Ca II H and K lines appropriate for the solar quiet chromosphere have been calculated. This has been done by solving the equations of radiative transfer and statistical equilibrium for two level plus continuum atom simultaneously. From the calculation it has been shown that even a small deposit of weak acoustic wave energy can enhance the emission peak of resonance lines.

Key words : solar quiet chromosphere - weak shock wave - level population density - time.

1. Introduction

One of the big problems in the solar physics is to understand the mechanism of heating of the chromosphere and corona. It is believed that the acoustic wave energy is deposited in the atmosphere which in turn heats the atmosphere. The acoustic waves may be weak or strong. For some weak acoustic wave, the energy deposit can create emission profiles of resonance lines.

As a physical model we consider here that an weak acoustic wave is propagating in an isothermal slab with a fixed electron density. It is noted that lines of different species are formed at different chromospheric layers. One way of studying the quiet chromospheric atmosphere is to study Ca II lines for a long period oscillations (see Liu 1974, Cram and Dame 1983, Kariyappa et al 1994). Employing the weak acoustic wave we have calculated ratios of level population density for the Ca II H & K lines for the period 30 seconds. For the atomic model we consider two level plus continuum atom which reflect the rough reality.

2. Theoretical model

2.1 Pressure and velocity in quiet chromosphere

For a weak acoustic wave, the pressure and velocity at any time is given by (Narain & Ulmschneider 1989)

$$p = p_o + p_m - p_m t/P \quad \text{and} \quad v = v_m - 2v_m t/P \qquad (1)$$

where P is the wave period and p_o (the unperturbed pressure), p_m and v_m (maximum amplitude) are given by

$$p_o = 12F_M/(\gamma C_s \eta_s^2), \quad p_m = \gamma P_o \eta/2 \quad \text{and} \quad v_m = C_s n_s/2, \; F_M \qquad (2)$$

where F_M is the wave energy flux, γ the ratio of specific heats, C_s the sound speed and η_s the shock strength given by

$$\eta_s = (\rho_2 - \rho_1)/\rho_1 \qquad (3)$$

where ρ_1 and ρ_2 are the densities in front and behind the shock, and $\tau = 0.015p$ and $n = 10^{11}$.

2.2. Radiative transfer and statistical equilibrium equations

The equation of radiative transfer equation is given by (Mihalas 1978)

$$\mu\delta(x, \mu, r)/\delta r = k_1 \, [\beta + \phi\,(x, \mu, r)]. \, [S(x, \mu, r) - I(x, \mu, r)], \qquad (4)$$

where $S(x, \mu, r)$ and $I(x, \mu, r)$ are the source function and specific intensity. The equation (4) has been solved by the Chandrasekhar's discrete ordinate method (Chandrasekhar 1960).

From the statistical equilibrium equation for two level plus continuum (Mihalas 1978), the ratio between the upper level and lower level population densities can be written as (assuming complete frequency redistributions) :

$$N_2/N_1 = A_4[P_{12} + A_1] + A_2 P_{12}/A_2[P_{21} + A_3] + A_4 P_{21} \qquad (5)$$

where

$$P_{12} = B_{12} \int \phi_x J_x dx + C_{12}, \qquad P_{21} = A_{21} + B_{21} \int \phi_x J_x dx + C_{21},$$

$$A_1 = R_{1k} + C_{1k}, \qquad A_2 = R_{1k} + C_{1k}, \qquad A_3 = R_{2k} + C_{2k},$$

$$A_4 = (R_{k2} + C_{2k})\,(N_2/N_1)^*, \; (N_2/N_1)^* = (g_2/g_1) exp(-h\nu_{12}/kT) \qquad (6)$$

Employing the weak acoustic wave solution from equations 1-3, we have solved the radiative transfer equation 4 and the statistical equation 5 simultaneously. Thus ratio of the level population density N_2/N_1 from equation 5 has been calculated for Ca II H & K lines for the wave period 30 seconds and presented in Fig. 1.

3. Results and discussions

In our model the line formation region includes the shock front. The wave energy deposit in a quiet chromosphere is small, but it has an impact in the enhancement of the emission peak of the resonance lines. Lines of different species are formed at different chromospheric layers, but Ca II H and K lines are very sensitive in each layer.

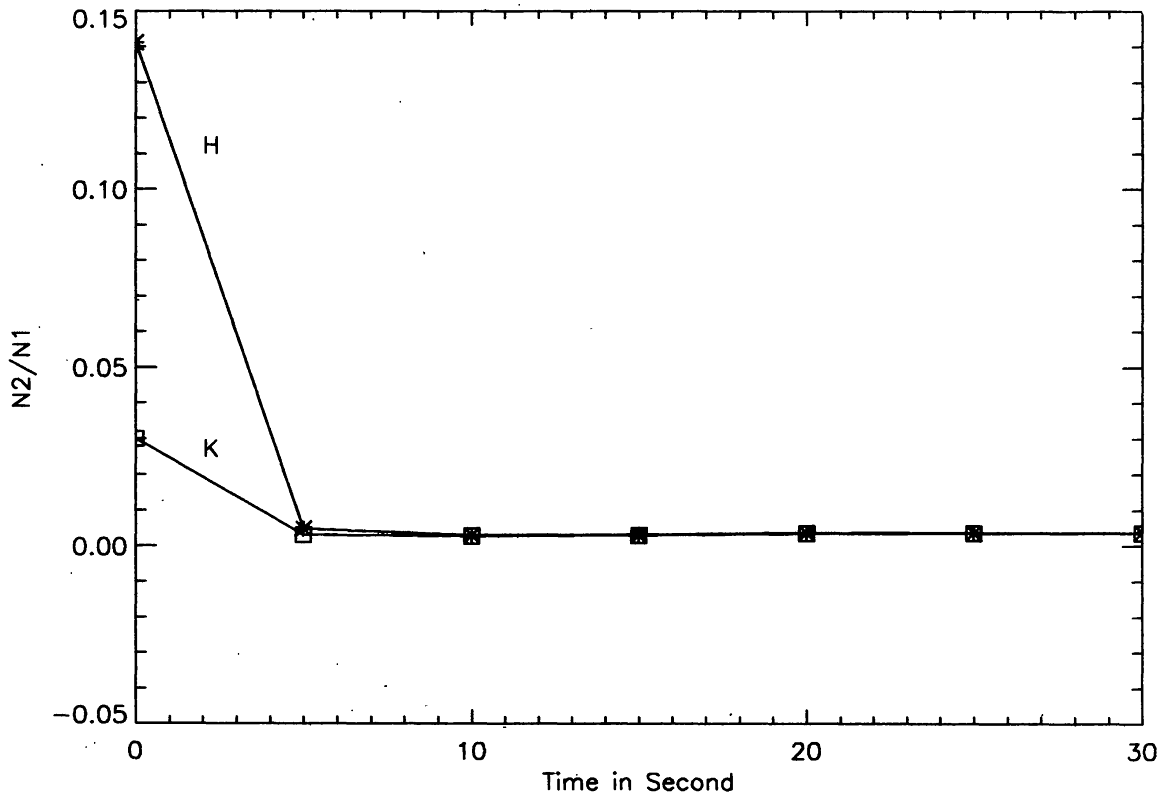

Figure 1. The ratio N_2/N_1 vs time for the Ca II H & K lines. P = 30s, $F_M = 4 \times 10^6$ erg cm^{-2} s^{-1}, $T = 7000^{\circ}$C.

From Fig. 1 we see that the ratio N_2/N_1 drops within a span of (1/5)th of the wave period and remaining constant for the rest of the period. Clearly within the span N_2 looses Ca ions resulting in the enhancement of the emission lines. N_2 looses ions due to decrease of pressure locally. For other long periods like 90s or 180s, the ratio N_2/N_1 shows the same nature. Though the deposit of weak acoustic wave energy in a quiet solar chromosphere is small, it can enhance the emission peak of resonance lines.

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