THE EFFECT OF MAGNETO-SONIC WAVES ON A
ZEEMAN TRIPLET WITH APPLICATION TO SUNSPOTS

(Research Note)

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The effect of longitudinal compression waves on stellar spectral lines has been discussed recently by ERIKSEN and MALTBY (1967). When integrated over a wavelength of the compression wave, the line-absorption coefficient will be asymmetrical. MALTBY and ERIKSEN (1967) have suggested that the Evershed effect in sunspots may be interpreted as an acoustical wave phenomenon. They showed that asymmetrical line profiles similar to those observed in sunspot penumbrae may be produced by either progressive sound waves propagating along the magnetic lines of force or by longitudinal compression waves propagating perpendicular to the magnetic field.

The wave hypothesis may be tested observationally if sufficient time and spatial resolution is obtained. An oscillation of the position of the line may possibly be detected. At the Oslo Solar Observatory we have recently installed an instrument (constructed by G. Eriksen) to look for oscillations in the line position. The observations hitherto are too preliminary to be reported here.

We shall discuss another observational test. Let us consider a longitudinal compression wave propagating perpendicular to the magnetic lines of force. We consider a progressive, isothermal wave propagating along the z-direction in an orthogonal coordinate system, where the primary magnetic field $H_0$ is parallel to the $y$-axis. Then,

$$\frac{v_z}{V} = \frac{h_y}{H_0} = \frac{\Delta \rho}{\rho_0} = \frac{\Delta \rho_m}{\rho_0} \sin \omega (t - z/V)$$

as the particle velocity $v_z$, the perturbation $h_y$ in the magnetic field and the change in density $\Delta \rho$ vary in phase - $\Delta \rho_m$ is the amplitude of $\Delta \rho$ and $\rho_0$ is the unperturbed density. The circular wave frequency is $\omega$ and $t$ is the time, while the phase velocity (which is equal to the group velocity),

$$V = (V_s^2 + V_A^2)^{1/2}.$$  

Here $V_s$ is the velocity of sound and $V_A$ is the Alfvén velocity.

The velocity, $v_z$, of the atoms associated with the wave will give a line of sight component $v_z \cos \theta$. If we consider a magnetic inactive line or the $\pi$-component in a Zeeman triplet, the absorption will be centered at the wavelength

$$\lambda'_\pi = \lambda_0 (1 + v_z \cos \theta/c)$$

where $\lambda_0$ is the rest wavelength and $c$ is the velocity of light. Using Equation (1) we may write Equation (3) as

$$\lambda'_\pi - \lambda_0 = \frac{\lambda_0 V \cos \theta \Delta \rho}{\rho_0} = \frac{\lambda_0 V \cos \theta \Delta \rho_m}{\rho_0} \sin \omega (t - z/V).$$

(4)

If we consider a fixed position in the wave the wavelength shift $\lambda'_\pi - \lambda_0$ and the perturbation in density will vary in phase.

It is likely that we lack either sufficient time or spatial resolution to observe any oscillation in the line position. We are accordingly interested in the line-absorption coefficient integrated over the wave period. If we neglect the effect of damping and assume pure absorption we may write the line-absorption coefficient (for details see ERIKSEN and MALTBY, 1967),

$$l = 2 \int_{\lambda_0 - \Delta \lambda_m}^{\lambda_0 + \Delta \lambda_m} n \alpha \left[ 1 - \left( \frac{\lambda'_\pi - \lambda_0}{\Delta \lambda_m} \right)^2 \right]^{-1/2} \exp \left[ -\left( \frac{\lambda - \lambda_0}{\Delta \lambda_D} \right)^2 \right] d\lambda'_\pi.$$

(5)

Here

$$\Delta \lambda_m = \frac{\lambda_0 V \cos \theta \Delta \rho_m}{c \rho_0},$$

(6)

$n$ is the number of atoms producing the line, $\alpha$ the absorption coefficient per atom at the Doppler shifted centre wavelength $\lambda'_\pi$ and $\Delta \rho_m$ the Doppler width caused by thermal motions. The great contribution to $l$ for $|\lambda'_\pi - \lambda_0|$ close to $\Delta \lambda_m$ is caused by the fact that the atoms spend a considerable part of their time at the larger velocities. The number of particles producing the line, $n$, will be determined by the density (and partly by the electron pressure). It appears from Equation (4) that $\lambda'_\pi - \lambda_0$ and $\Delta \rho$ vary in phase. Thus, the maximum in line-absorption coefficient may occur well shifted from the rest wavelength $\lambda_0$.

In order to determine the line profile an integration over all layers contributing to the line is necessary. It is likely that the wave strength varies with horizontal and/or vertical position in the atmosphere. Such an integration has been done by MALTBY and ERIKSEN (1967), assuming that a part of the atmosphere was not influenced by the waves. It appears that one side of the line profile is only slightly affected, while the other side of the line will be shifted away from the rest wavelength. The amount of extension of the line towards one side increases as the maximum line shift, $\Delta \lambda_m$, increases – we note that (see Equation (6)) $\Delta \lambda_m$ may be altered by either changing $\cos \theta$ or $\Delta \rho_m/\rho_0$.

Let us next consider the $\sigma$-components in a Zeeman triplet. We note that the perturbation $h_y$ is parallel to the primary magnetic field $H_0$ and find for the centre wavelengths of the $\sigma$-components, respectively:

$$\lambda'_\sigma = [\lambda_0 \pm C (H_0 + h_y)] (1 + v_z \cos \theta/c),$$

(7)

where $C$ determines the wavelength shift per gauss. Using Equations (1) and (7) we