THE UMBRAL FLASH AS A MAGNETO-ACOUSTIC WAVE PHENOMENON

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Abstract. The suggestion that an 'umbra flash' may be caused by a magneto-acoustic wave phenomenon is examined. It is suggested that the flash in Ca II lines is formed during the compressional stage in a magneto-acoustic wave. The compression which is assumed to be adiabatic will produce a rise in temperature and a corresponding increase in number of Ca II atoms. The variations in line emission (absorption) coefficient of the Ca II K-line are calculated on this assumption and are found to be in general agreement with the observed variations. Other observed quantities as proper motion, magnitude of line shift etc., also agree with the wave hypothesis. Further observations which may serve as tests on the wave hypothesis are suggested.

1. Introduction

Beckers and Tallant (1969) have recently discovered emission features (called 'umbral flashes') in lines of Ca II above sunspot umbrae. Beckers and Tallant suggest that a flash may be a magneto-acoustic wave phenomenon. This assumption seems reasonable in view of the observed proper motions and wavelength shifts measured for the flashes.

2. A Possible Flash Mechanism

It has been shown (Eriksen and Maltby, 1967) that a compressional progressive wave travelling in an emitting (absorbing) medium, will affect both the strength and the wavelength of the emitted (absorbed) lines. The ordered particle motion, which may be regarded as superposed on the thermal motion, will determine the wavelength shift. At the same time, density and temperature changes will affect the line emission (absorption) coefficient. Eriksen and Maltby (1967) considered the effect of a sound wave on lines of heavy elements as Fe I and Fe II. The particle velocity and the pressure vary in phase and the maximum line shift occurs at maximum intensity.

Although the effects of sound waves may be observed as flashlike events if we have sufficient time and spatial resolution, such waves cannot explain the observed properties of the umbral flashes. The speed of a sound wave is approximately 7 km/s at the heights in the spot where the flashes occur, whereas the proper motion of the flashes may reach 70 km/s (Wittman, 1969). Further, the wavelength shift of the line caused by a progressive sound wave will be one order of magnitude less than the observed shift in the flashes.

On the other hand, the line shift and the proper motion may be explained if we consider magneto-acoustic waves. The wave velocity is

$$V = V_A \cdot 2^{-\frac{1}{2}} \{1 + r \pm [(1 + r)^2 - 4r \cos^2 \varphi]^{\frac{1}{2}}\}^{\frac{1}{2}}. \tag{1}$$

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Here $r=(V_S/V_A)^2$ and V_S and V_A are the speed of sound and the Alfvén velocity, respectively and φ is the angle between the direction of propagation and the magnetic field. Two modes (fast and slow) will generally be present, referring to the plus and minus sign, respectively. At a given height in the spot, the maximum wave velocity will occur for $\varphi=90°$ where the fast mode becomes a magneto-sonic wave with velocity $V=(V_A^2+V_S^2)^{\frac{1}{2}}$. According to Table II in Beckers and Tallant (1969) we find that for $\varphi=90°$ the velocity $V=(V_A^2+V_S^2)^{\frac{1}{2}}\approx 40$ km/s in a (thin) layer around $h=0$ km. (The zero point in height is such that a height $h=-120$ km corresponds to an optical depth $\tau_{5000}=0.01$). The average of the observed proper motion of the flashes is also approximately 40 km/s.

In order to obtain a blue shift of the K line when observed in a flash near the center of the solar disk, the angle φ must be somewhat less than 90° so that the wave velocity has a component towards the observer. Exact calculations of wave propagation and line shifts for such a case would be extremely complicated, especially so if we were to take into account changes of the magnetic field and changes in the gas density, temperature etc. In addition our knowledge about the necessary parameters is also very uncertain. The calculations will thus represent only rough approximations to the real situation. We therefore choose to calculate the line shifts as if they were formed by a magneto-sonic wave. This has been treated by Maltby (1968) and though his results are not directly applicable to the case when φ (in Equation 1) is somewhat less than 90°, they are regarded as a first approximation to the real case.

The maximum wavelength shift of a line influenced by a magnetosonic wave (Maltby 1968) is, when we neglect the Zeeman splitting,

$$\Delta\lambda_m = \frac{\lambda_0 V \cos\theta}{c} \frac{\Delta\varrho_m}{\varrho_0}. \tag{2}$$

Here V is the magneto-sonic wave velocity $V=(V_A^2+V_S^2)^{\frac{1}{2}}$ and λ_0 is the wavelength of the undisturbed linecenter, c is the speed of light, the density amplitude of the magneto-sonic wave is $\Delta\varrho_m/\varrho_0$ and θ is the angle between the line of sight and the direction of propagation of the wave. The spot geometry in outline is shown in Figure 1. Let us in the following assume that the wave propagates adiabatically. Thus, the temperature changes in phase with the density. If an increase in density and temperature caused by the magneto-sonic wave leads to an increased number of atoms capable of emitting (absorbing) the line in question, the emission (absorption) coefficient will reach a maximum at the line shift given in Equation (2). This will be the case for Ca II around $h=0$ in sunspots. In sunspots calcium is either neutral or singly ionized. A slight increase in temperature occurring during the compressional stage will increase the number of singly ionized calcium atoms and we get a corresponding increase in emission (absorption) coefficients for lines from this element. Equation (2) shows that the sign of the line shift at maximum compression depends on the sign of $\cos\theta$. Thus, we should observe a blue shifted flash if the direction of propagation is towards the observer and a red shifted flash if the wave moves away from the observer. Beckers and Tallant (1969) have found that the flashes are displaced towards the blue. Their