HEATING OF INTENSE MAGNETIC FLUX TUBES BY MAGNETOHYDRODYNAMIC WAVES

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ABSTRACT

Theoretical models of intense magnetic flux tubes embedded in the photospheres of late-type stars have been calculated. Magnetohydrodynamic waves generated in the convective zone are radiatively damped in the lower part of the flux tube and then dissipated. We discuss how the presence of flux tubes in stellar photospheres influences the temperature minimum and the chromospheric activity. We suggest a possible interpretation of the Wilson-Bappu effect in stars with strong chromospheric activity.

1. INTRODUCTION

It is generally accepted that most of the features of solar activity are connected with the existence of magnetic fields. In solar active regions the magnetic field is concentrated in discrete elements which appear as bright small elements with field strengths above 1000 G. These elements may be described by a set of magnetostatic flux tube models (Zwaan, 1977). The intense magnetic flux tubes have been considered recently by Webb and Roberts (1980a, b) and Spruit (1981a, b). In all these studies the propagation of a longitudinal and a transverse wave mode along the flux tube was discussed.

The aim of the present paper is to use theoretical models of intense magnetic flux tubes to show how the temperature minimum region and the lower part of the chromosphere are formed. Besides, we try to explain the existence of strong chromospheric activity in some late-type stars.

2. ENERGY BALANCE IN MAGNETIC FLUX TUBES

The magnetostatic models of flux tubes describe the magnetic elements as structures in equilibrium with non-magnetic surroundings. We will assume that the temperature inside the tube is equal to the exter-

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nal temperature at each depth. Further, we choose at the bottom of the flux tube a value of the magnetic field which makes the gas pressure in the tube equal to 30% of the total pressure.

Radiative damping of magnetohydrodynamic waves in the flux tube is treated in the way proposed by Webb and Roberts (1980a, b). However, to calculate the Alfvén and slow mode dissipation we have used a modified version of the mechanism of Pikelner and Lifshitz (1964) (cf. Musielak and Sikorski, 1980). The energy dissipated at each layer is balanced by radiative losses (Musielak, 1982).

3. RESULTS AND DISCUSSION

Our calculations show that magnetohydrodynamic waves can propagate within the magnetic flux tubes. These waves carry a large amount of energy, which causes the temperature minimum to be higher than in the surroundings and the temperature gradient to be steeper in the chromosphere. The later the spectral type, the steeper the temperature gradient (Fig. 1). This leads to increased chromospheric activity above the flux tubes in these stars. There are observational and theoretical suggestions that a large number of flux tubes can be produced in late-type stars (Linsky, 1980; Zwaan, 1980), which increases the activity area factor. The mechanisms mentioned above can explain the existence of late-type stars with particularly strong chromospheric activity.

The effect of appearance of a great number of magnetic flux tubes in active stars cause the "average" T_{min} and "average" magnetic field to be higher for active than for non-active stars (Bielicz and Musielak, 1982).

Our calculations of models of flux tubes embedded in the photospheres of late-type stars (EQ Vir) with strong chromospheric activity, suggest an increase of $\pi F_M{}^o$ (mechanical energy flux generated in the convection zone) compared to the corresponding quantity given by Bohn (1981). It is generally accepted that an additional mechanical flux can be produced when a magnetic field is present (e.g. Ulmschneider and Stein, 1982). However, we conclude that the generation of magnetohydrodynamic waves in the convective zone in the presence of strong magnetic fields may be less effective than has been assumed (Musielak and Bielicz, 1982).

Knowing the theoretical values of T_{min} for flux tubes embedded in photospheres of main sequence stars and giants, we can explain the Wilson-Bappu effect corrected by Glebocki and Stawikowski (1978) for stars with strong chromospheric activity. The intensity of the K reversal (I_K) depends mainly on the activity level of the chromosphere model, i.e., on the relative area of the active region in comparison with the whole surface of the star. Accordingly, I_K is proportional to the number

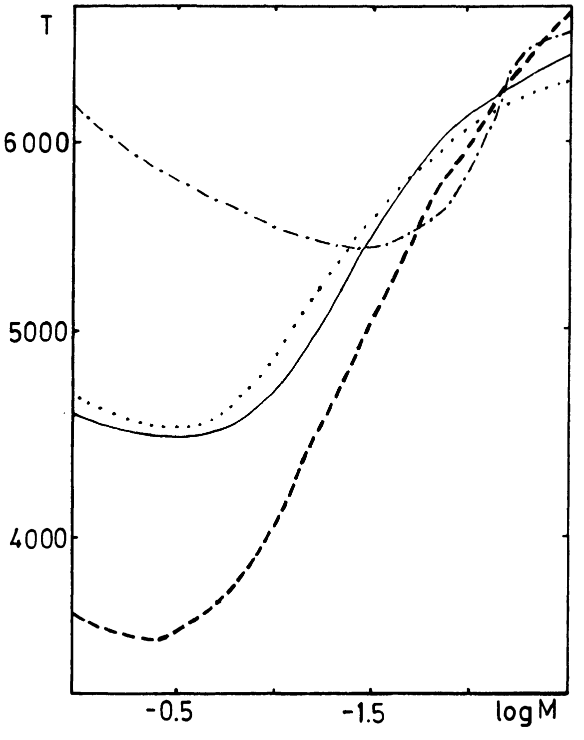

Fig. 1. Temperature as a function of the logarithm of the mass column density for flux tubes embedded in the photospheres of γVirN (dashed-dotted line), Sun (dotted line), and EQ Vir (dashed line). The models were obtained for a value of $\pi F_M^o = 1.0 \times 10^8$ erg $cm^{-2}s^{-1}$ and for the magnetic fields 600 G, 2000 G, and 2300 G for γVirN, Sun, and EQ Vir, respectively. The solid line gives the solar empirical model for very bright network elements.

of flux tubes. Further, according to the method proposed by Ulmschneider et al. (1979) to tentatively explain the Wilson-Bappu effect, we can give a quantitative interpretation of the width W_o as an "average" property of the discrete magnetic flux tubes.

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