GENERATION OF TRANSVERSE MAGNETIC TUBE WAVES AND X-RAY EMISSIONS FROM LATE-TYPE DWARFS

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ABSTRACT : We show that transverse magnetic tube waves generated in stellar convective zones may formally account for X-ray emissions observed from late-type dwarfs.

WAVE HEATING MODELS FOR STELLAR CORONAE

It is now well established that X-ray emissions observed from late-type stars vary significantly for a given, fixed spectral type (Rosner, Golub and Vaiana 1985). In addition, there is a growing evidence for inhomogeneous and locally strong magnetic fields in stellar atmospheres (e.g., Robinson, Worden, and Harvey 1980; Saar 1987, 1989). According to these observational data, any plausible heating theory of stellar coronae must account for: (1) Sufficient mechanical energy flux to sustain the X-ray emission from stellar coronae; (2) The wide range of the observed X-ray emissions for each spectral type; and (3) Inhomogeneous and locally strong magnetic fields in stellar atmospheres. It has already been shown that both *acoustic* and *MHD wave heating theories* (the latter considered with uniform magnetic fields) **fail** to account for all these crucial tests (Rosner and Musielak 1987; Musielak and Rosner 1988), in particular for the test (2) and (3). To account for the test (3), it seems to be reasonable to assume that stellar magnetic inhomogeneities may be similar to the 'flux tube' structures observed in the solar atmosphere outside sunspots. If so, then magnetic flux tubes may become 'tunnels' through which the wave energy generated in stellar convective zones is carried by various types of waves to the overlying corona. The main problem is how efficiently these waves are generated in magnetic flux tubes embedded in the convective layers of a star (Musielak, Rosner and Ulmschneider

1989, henceforth called MRU) and to determine whether any tube wave heating theory may formally account for the coronal X-ray emissions. MRU have already shown that the heating by longitudinal magnetic tube waves is unlikely to be important in the coronal heating as it cannot, for example, explain transferring the energy to the corona. Therefore, in this paper, we consider the heating by transverse magnetic tube waves and suggest that this is a viable wave heating theory that formally accounts for the observational constraints. In our preliminary calculations, we find that wave energy fluxes generated in the form of transverse magnetic tube waves in stellar convective zones show wide variations for a given spectral type, variations which can be attributed to changes in two free parameters: the tube magnetic field strength and the stellar flux tube filling factor. We compare the range of these parameters chosen in our calculations with the observational data (Saar 1989).

ENERGY FLUXES FOR TRANSVERSE TUBE WAVES

We consider an isolated magnetic flux tube embedded in a magnetic field-free, turbulent, compressible and isothermal medium. The tube is assumed to be thin, untwisted, and oriented vertically, with circular cross-section, and in temperature equilibrium with its surroundings. Our approach is steady-state and linear. We calculate the total wave luminosity (see MRU) by taking into account the fraction of the stellar surface covered by the tubes and obtain the total wave luminosity $[ergs\ s^{-1}]$ due to transverse tube waves in the form:

$$L_t = (4\pi)^3 N_t A_t \int_o^H dz \frac{\rho_e^2 u_t^2}{\rho_e + \rho_i} M_t^3 \omega_t \int_o^\infty d\bar{\omega} \frac{(1 + 16k^2 H_p^2)}{k^2 H_p^2} \times$$

$$\times (1 + k^2 H_p^2)\bar{k} \left(\frac{\bar{\Omega}_t}{\bar{\omega}}\right)^2 \left(\frac{\bar{\omega}^4 + \bar{\omega}_g^4}{\bar{\omega}^2}\right) \bar{J}_c(\bar{k}, \bar{\omega}) \sin(kz) \cos(kz),$$

where N_t and A_t are the number of flux tubes on the stellar surface and the typical flux tube cross-sectional area, respectively. In addition, H is the thickness of the turbulent region, H_p is the pressure scale height, ρ_e and ρ_i describe density outside and inside the tube, k is the wave vector, $\omega_g = \sqrt{gk}$ and $M_t = u_t/V_t$, with u_t and V_t the turbulent and transverse wave velocity, respectively. Note also that the wave (ω) and cutoff (Ω_t) frequencies are dimensionless, and have been written in terms of a characteristic turbulent frequency $\omega_t = 2\pi u_t/l_t$ with l_t the characteristic turbulent length. $\bar{J}_c$ is a dimensionless convolution integral, defined by $\bar{J}_c = u_t^3 l_t^2 J_c$, where J_c is given in detail by MRU.

RESULTS AND CONCLUSIONS

We have calculated the wave energy fluxes generated as transverse magnetic tube waves and compared them to the range of X-ray emissions observed from late-type dwarfs (see Fig. 1). We have assumed two values for the magnetic field inside the tube ($B = 0.75 B_{equip}$ and $B = 0.5 B_{equip}$) and for the filling factor (1% and 50%). As shown in Figure 1, using these values of the free parameters, the observed range of X-ray emissions has been reproduced for F, G and K

stars. Note that the values of the free parameters used in our calculations are in a good agreement with observational data presented by Saar (1989). We may therefore conclude that our very preliminary results show that the generation of transverse magnetic tube waves is efficient enough to formally account for the observed X-ray emissions from F, G and K dwarfs. We also want to emphasize that this is the only *wave heating model* to date which formally accounts for all crucial tests required by the stellar observational data.
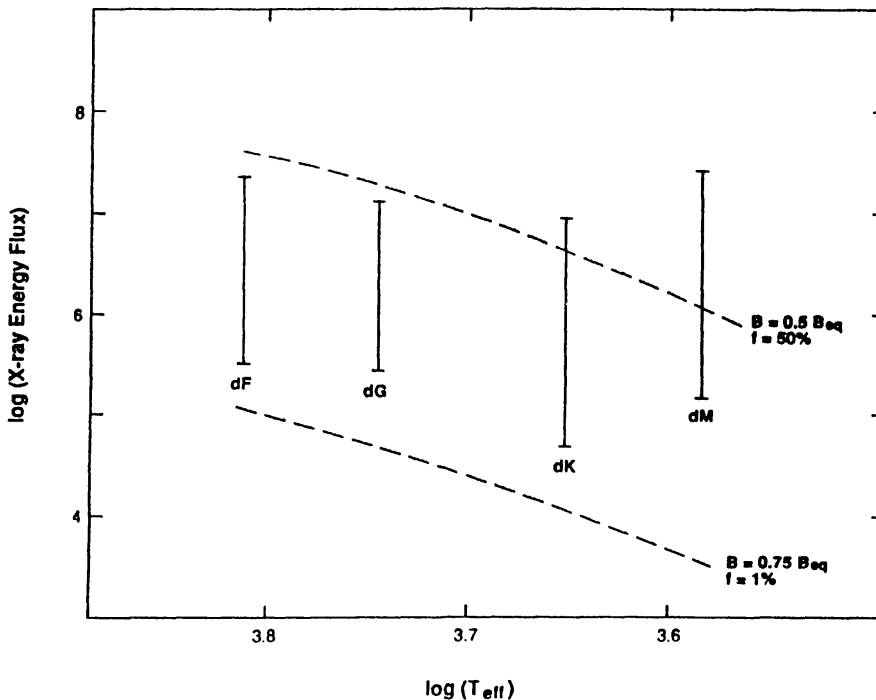

Fig. 1 The ranges of mean surface X-ray fluxes deduced from *Einstein Observatory* results (Rosner, Golub and Vaiana 1985) are plotted versus the effective temperature; vertical bars indicate the mean surface flux range within which 60% of the stars observed by the *Einstein Observatory* lie. The results of our calculations are plotted as dashed lines for two different values of the magnetic field and the filling factor.

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