HEATING OF SOLAR AND STELLAR CHROMOSPHERES AND CORONAE BY MHD WAVES

Z. E. MUSIELAK
University of Alabama in Huntsville
Huntsville, AL 35899, U.S.A.

1. Introduction

Ground-based and satellite observations have shown that all late-type dwarfs possess hot outer envelopes, and that the chromospheric and coronal emissions observed from these envelopes vary significantly for a given, fixed spectral type. In addition, there is growing evidence for nonhomogeneous and locally strong magnetic fields in the atmospheres of these stars. It is obvious that any heating theory must account for these two observational constraints as well as for the mean level of heating.

There are at least two general classes of models that deal with the required heating. The first class assumes that outer stellar atmospheres are heated by hydrodynamic (mainly acoustic) or magnetohydrodynamic (MHD) waves, and that these waves are generated by turbulent motions in the stellar convection zones. The second class considers dissipation of currents generated by photospheric motions as the primary source of energy. Neither observation nor theory has been able to definitively determine which one of these two general classes of models dominates in the atmospheric heating. The main aim of this paper is to briefly present recent developments in the MHD wave heating theory. The key problems that will be addressed are: where and how efficiently are MHD waves generated, and how do these waves propagate and dissipate energy ?

2. Generation of MHD Waves

It is generally believed that the highly turbulent convective zones of the Sun and late-type dwarf stars are the main sources of both acoustic and MHD waves. Three recent advances in the theory of wave generation give some hope that realistic wave energy fluxes can be calculated (Musielak 1991, and references therein). The first is a deeper understanding of the physics of the wave generation process, including identification of the fluctuating buoyancy force in convecting fluids. The second advance is the advent of fully-compressible hydrodynamic simulations, which allow us to begin extending analytical calculations beyond the very narrow confines of linear theory. The third advance is the incorporation of the highly intermittent spatial structure of stellar surface magnetic fields (flux tube structures) into wave generation theory. The results recently obtained by Musielak et al. (1989) demonstrate that the theory of heating based on magnetic tube waves may formally account for the observational constraints. Still, more work is needed to estimate the amount of wave energy which dissipates at different heights in stellar chromospheres and coronae.

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There are also some other sources of MHD waves in stellar chromospheres and coronae. Two of them seem to be particularly important, namely, the excitation of MHD waves in magnetic loops by the interaction of the loops with upward propagating acoustic waves (Chitre and Davila 1991), and the generation of MHD (in particular, Alfven) waves by microflares (Parker 1991, Moore et al. 1991). In the latter case, the authors suggested that Alfven waves generated by microflares may be important in the energy balance in the regions of open magnetic fields (coronal holes). In both cases, however, the power spectra and wave energy fluxes are presently unknown.

3. Propagation and Dissipation of MHD Waves

To determine the role played by MHD waves in chromospheric and coronal heating, the rate of dissipation of the wave energy in stellar atmospheres must be calculated and compared to the observed radiative losses. Calculations of this sort are rather difficult because stellar atmospheres show both continuous changes in physical parameters with height and also localized nonhomogeneities. The latter may support the existence of MHD surface waves which are likely to dissipate their energy by resonant absorption. The fact that this process can be important in the heating of solar corona was first recognized by Ionson (1978); recent large scale numerical calculations indicate that resonant absorption is still a viable heating mechanism in coronal loops (Goossens 1991). The continuous changes may lead to wave reflection, wave trapping, nonlinear mode coupling and shock formation which all may be important in the heating process. As shown by Moore et al. (1991), Alfven wave reflection in solar coronal holes can be the dominant process in both the local heating and the wind acceleration. Ulmschneider et al. (1991) demonstrated that nonlinear coupling between transverse and longitudinal magnetic tube waves may significantly contribute to the local heating in the chromospheric network. To understand better the complex behavior of MHD waves in stellar atmospheres and to calculate the rate of dissipation of the wave energy, it seems to be necessary to carry out large scale numerical computations.

4. Concluding Remarks

Dispite the recent progress in our understanding of the generation, propagation and dissipation of MHD waves in solar and stellar atmospheres, it is too early to form a conclusion about the importance of these waves in the chromospheric and coronal heating. MHD wave heating might supply enough energy flux for given free choice of magnetic field strength and filling factor, but it remains to be seen whether the required choices are allowed by the observations.

References

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