Final Report

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On Wave Processes in the Solar Atmosphere

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SUMMARY OF COMPLETED WORK

This grant was awarded by NASA/MSFC to The University of Alabama in Huntsville (UAH) to investigate the physical processes responsible for heating and wind acceleration in the solar atmosphere, and to construct theoretical, self-consistent and time-dependent solar wind models based on the momentum depositon by finite amplitude and nonlinear Alfven waves.

In summary, there are three main goals of the proposed research:

(1) Calculate the wave energy spectra and wave energy fluxes carried by magnetic non-magnetic waves.

(2) Find out which mechanism dominates in supplying the wave energy to different parts of the solar atmosphere.

(3) Use the results obtained in (1) and (2) to construct theoretical, self-consistent and time-dependent models of the solar wind.

We have completed the first goal by calculating the amount of non-radiative energy generated in the solar convection zone as acoustic waves and as magnetic tube waves. To calculate the amount of wave energy carried by acoustic waves, we have used the Lighthill-Stein theory for sound generation modified by Musielak, Rosner, Stein & Ulmschneider (1994). The acoustic wave energy fluxes for stars located in different regions of the H-R diagram have also been computed (Ulmschneider, Theurer & Musielak 1996; Ulmschneider, Theurer, Musielak & Kurucz 1998). The wave energy fluxes carried by longitudinal and transverse waves along magnetic flux tubes have been calculated by using both analytical and numerical methods. Our analytical approach is based a theory developed by Musielak, Rosner & Ulmschneider (1989) and Musielak, Rosner, Gail & Ulmschneider (1995), which allows computing the wave energy fluxes for linear tube waves. A numerical approach has been developed by Huang, Musielak & Ulmschneider (1995) and Ulmschneider & Musielak (1998) to compute the energy fluxes for nonlinear tube waves. Both methods have been used to calculate the wave energy fluxes for stars located in different regions of the HR diagram (Musielak, Rosner & Ulmschneider 1998; Ulmschneider, Musielak & Fawzy 1998).

Having obtained the wave energy fluxes for acoustic and magnetic tube waves, we have investigated the behavior of these waves in the solar and stellar atmospheres. The results of our extensive studies have been published in many papers (Stark & Musielak 1993; Alicki et al. 1994; Krogulec et al. 1994; Musielak & Moore 1995; Huang (1996); Wu et al. (1996); Stark et al. 1996; Krogulec & Musielak 1998; Sutmann, Musielak & Ulmschneider 1998; Huang, Musielak & Ulmschneider 1999a, b), and presented at numerous

scientific meetings (see references below). In these studies, we have investigated different aspects of propagation and dissipation of acoustic and magnetic waves, the efficiency of energy transfer along magnetic structures in the solar atmosphere, and the behavior of Alfven waves in steady and expanding solar and stellar atmospheres. Recently, we have used some of these results to construct first purely theoretical, two-component and time-dependent models of solar and stellar chromospheres (Cuntz, Ulmschneider & Musielak 1998; Cuntz, Rammacher, Ulmschneider, Musielak & Saar 1998).

Finally, to address the **third goal**, we have constructed first fully theoretical, self-consistent and time-dependent wind models based on the momentum deposition by nonlinear Alfven waves. The full set of single–fluid MHD equations with the background flow has been solved by using a modified version of the ZEUS MHD code. The constructed wind models are radially symmetric with the magnetic field decreasing radially and the initial outflow is described by the standard Parker wind solution. In contrast to previous studies, no assumptions regarding wave linearity, wave damping, and wave-flow interaction are made; the models thus naturally account for the backreaction of the wind on the waves as well as for the nonlinear interaction between different types of MHD waves. The models have been used to explain the origin of fast speed streams in solar coronal holes (see Ong, Musielak, Rosner, Suess & Sulkanen 1997). The obtained results clearly demonstrate that the momentum deposition by Alfvén waves in the solar wind can be sufficient to explain the origin of fast stream components of the solar wind. The range of wave amplitudes required to obtain the desired result seems to be in good agreement with recent observations.

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