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ON THE ACOUSTIC AND MAGNETOACOUSTIC HEATING OF THE OUTER ATMOSPHERE OF STARS*

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Abstract. Observational and theoretical evidence indicates that chromospheres are very likely heated by acoustic and by slow mode magnetohydrodynamic waves. The acoustic heating of coronae which has recently been disclaimed still appears to be an important possibility.

Recent empirical and theoretical work allows considerable progress in the knowledge of the outer stellar atmosphere. The new semiempirical solar models from Vernazza *et al.* (1981), e.g., permit much better insight in the chromospheric heating mechanism. When comparing for instance a model for an intense magnetic field region (model F) with a model where the magnetic field is weak or absent (model A) the surprising result is, that the temperature distribution in both models looks quite similar. In models F and A the temperature minima are nearly at the same height, the net radiative cooling rate just above the temperature minimum rises steeply by about three orders of magnitude to a high value of 0.1 $\mathrm{erg\,cm^{-3}\,s^{-1}}$. An enhanced temperature distribution leads to a net chromospheric radiation flux in model F, which exceeds that of model A by a factor of six. Additional empirical facts can be deduced from observed stellar Mg II and Ca II observations. Mg II emission fluxes $F_{\mathrm{Mg\,II}}$ from late type stars exhibit a rather strong dependence on T_{eff} but a very weak if any dependence on gravity g. There are stars with the same T_{eff} and g but different $F_{\mathrm{Mg\,II}}$.

Is there a mechanism which can explain all these facts? Ulmschneider and Stein (1981) argue that the high values of the required mechanical flux points to acoustic- or magnetohydrodynamic wave heating. However from the four types of wave dissipation processes, radiative-, Joule-, thermally-conductive and viscous heating none appears able to provide for the large value of the net radiative cooling rate and its rapid onset, unless one allows for the formation of hydrodynamic shocks. One thus concludes that acoustic waves heat the non-magnetic regions (model A) while slow mode waves heat the magnetic areas (model F).

New in this picture is the heating of strong magnetic field areas by slow-mode waves. This appears to agree well with the observational facts. As shown by Stein (1981), slow-mode waves are much more efficiently produced than acoustic or

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fast-mode waves. He showed that due to the monopole-type generation mechanism slow-mode waves (as well as Alfvén waves) have a high dependence on T_{eff}, but a low if any g dependence. Because both acoustic and slow mode waves are produced by convective motions and as they propagate and form shocks in a very similar way it is not surprising that empirical solar chromosphere-models look similar (Ulmschneider and Stein, 1981).

Although detailed theoretical calculations for the high chromosphere are presently missing, there seem to be indications that the acoustic and slow-mode wave picture supplies barely enough energy to great heights. Here, very efficiently produced Alfvén waves (Stein, 1981) appear as an attractive alternative if a method of dissipation for these waves (mode coupling, surface waves) could be found.

Now to the acoustic heating of coronae. Here Linsky (1980) as well as Vaiana *et al.* (1981) have concluded on the basis of XUV observations from the OSO-8 and Einstein satellites that acoustic heating can now be disregarded. Ulmschneider and Bohn (1981) have disputed this claim. They argued that due to the low resolution of the OSO-8 data and the lack of time-dependent analyses the observed acoustic fluxes are quite uncertain. In addition the acoustic heating of coronae of early type stars does not depend on the presence of convection zones as claimed by Linsky (1980) because, very likely, radiative amplification processes are at work. The main arguments against the acoustic heating-theory of stellar coronae, however, were derived from a comparison of stellar X-ray fluxes with theoretical acoustic fluxes using the Lighthill theory.

Here recent work by Bohn (1981) has shown that older acoustic-flux calculations are inadequate and that in the Lighthill theory large corrections have to be made. On basis of this work the insufficiency argument is no longer valid. The large X-ray variability is explained as due to magnetic enhancement of the acoustic energy-generation and due to the large variation of the efficiency of conversion into X-rays or wind as it is caused by differing magnetic geometries, i.e., in open or closed field regions. Ulmschneider and Bohn (1981) thus conclude that acoustic heating of stellar coronae can at present not be rejected. More detailed observations are needed to show how acoustic heating ties in with the other mechanisms which are thought to operate in stellar coronae.

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