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ON THE POSSIBILITY OF PURELY ACOUSTICALLY HEATED CORONAE

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ABSTRACT The limiting shock strength property of acoustic waves and the minimum coronal energy flux requirement allow to derive acoustically heated corona models. We find that the existence of purely acoustically heated coronae is not very likely and that they would have very low base pressures and energy fluxes.

INTRODUCTION

Recent observations indicate that very slowly rotating stars may have acoustically heated chromospheres: Schrijver (1987) has shown that the correlation of chromospheric emission with the magnetically dominated coronal X-ray emission improves, if one subtracts a so called basal chromospheric emission flux. This colour dependent basal flux is identical to the minimum of the observed emission flux of very slowly rotating stars. Similarly, Middelkoop (1982) and Judge (1989) find that very late type giant stars or those with peculiar chemical abundances do not show a chromospheric activity variability which is characteristic of magnetically dominated chromospheric heating. The chromospheric emission variability in F-stars is strongly reduced as observed by Walter and Schrijver (1987). This evidence may all be explained by acoustic heating, which is independent of rotation and strongly increases towards earlier spectral type.

In the present work we ask the question: If there are stars which have purely acoustically heated chromospheres, could such stars also have *purely acoustically heated coronae*?

ACOUSTIC WAVE ENERGY FLUX

We try to answer this question by combining the knowledge about the energy flux behaviour of acoustic waves and the minimum energy requirements of coronae. Acoustic waves, due to the rapid density decay in the outer stellar layers, quickly form shocks. A general property of monochromatic acoustic shock waves in isothermal atmospheres is, that they reach a *limiting strength* in which the amplitude *increase* due to the diminishing density and the amplitude*decrease* due to shock dissipation balance each other. The flux $F_M = \rho v^2 c_S/3$, (ρ = density, v = velocity, c_S = sound speed) of limiting strength acoustic shock waves is proportional to the gas pressure p and to the square of the wave period P. The acoustic wave spectrum generated in the convection zone is roughly in the range $P_A/10 \leq P \leq P_A$, where $P_A = 4\pi c_S/(\gamma g)$ is the acoustic cut-off period. Here g is the stellar gravity and $\gamma = 5/3$ the ratio of specific heats. After Bohn (1984) the acoustic spectrum for solar-type stars peaks near $P_A/10$, and for later spectral type towards larger wave period, say $P = 0.5\ P_A$. Fig. 1 shows the range of acoustic flux for late-type stars as a function of pressure.

MINIMUM FLUX CORONAE

Hearn (1975) has shown that for a given base pressure the overall coronal energy loss must exceed a minimum value, $F_{COR} > F_{MFC}$, which occurs at a certain coronal temperature. For larger coronal temperatures, the wind energy losses and the radiation losses from the transition layer increase rapidly, while for smaller coronal temperatures the coronal radiative losses become large. At the time, Hearn assumed, that the coronae realized in nature must be of the *minimum flux* type. Endler et al. (1979), however, demonstrated that the minimum flux assumption is incorrect and that it is the damping length of the heating mechanism which determines the type of corona. Nevertheless, the minimum flux corona theory determines by its very definition the *minimum possible* energy loss of a stellar corona – which, in our case, must be balanced by acoustic wave heating. For the present application we have recalculated, similar to Endler et al., the minimum coronal energy losses for spherically symmetric atmospheres consisting of an unheated transition layer and an isothermal corona. These calculations had to be extended to much smaller base pressure, and are shown in Fig. 1.

ACOUSTIC CORONAE

In Fig. 1, the drawn curve labeled MFC specifies the minimum possible energy loss of a stellar corona. The actual coronal energy losses must lie *above* this curve. The dashed curves give the energy flux that is carried by an acoustic wave of a given period. Not all of this energy can be fed into a corona; part of it is reflected back from the steep temperature gradient in the transition layer. Therefore, the acoustic energy that is available for coronal heating must lie *below* the corresponding dashed curve (e.g. $0.5\ P_A$). Consequently, the intersection of the two types of curves determines upper limits for the base pressure and for the total energy losses of a corona that is heated exclusively by acoustic waves. The intersection point depends sensitively on the wave period. Short period waves could produce only coronae with base pressures and total energy fluxes many orders of magnitude smaller than those of solar coronal holes (cf. the area termed CH in Fig. 1, after Withbroe 1988). For coronal holes one would need wave periods of at least $2P_A$, which are unlikely to exist in nonpulsating stars.

DISCUSSION AND CONCLUSIONS

We cannot exclude the existence of purely acoustically heated coronae which after our calculations must have very low coronal base pressures. However, if slowly rotating stars have observable coronae, it is extremely unlikely that these coronae are produced purely acoustically. They must be energized predominantly by magnetic heating mechanisms or by waves of period $P > P_A$ derived from radial or nonradial pulsations.

It is conceivable that even very slowly rotating stars continue to produce magnetic fields at a low rate. Or, magnetic flux may be left from the end of the active dynamo phase. In both cases, the field is energized by convective motions, with sufficient energy to sustain a corona. The magnetic field need not be large. Let us assume, for instance, a 100 times smaller field than for the Sun ($B = 1500\ G$, filling factor $f = .01$). If such a field is completely spread over the surface, its field strength $B = 0.15\ G$ corresponds to a magnetic pressure $p_M = B^2/8\pi = 10^{-3}\ dyn/cm^2$. Therefore, even with such a small magnetic field the atmosphere becomes magnetically dominated long before acoustic waves alone are able to produce a corona.

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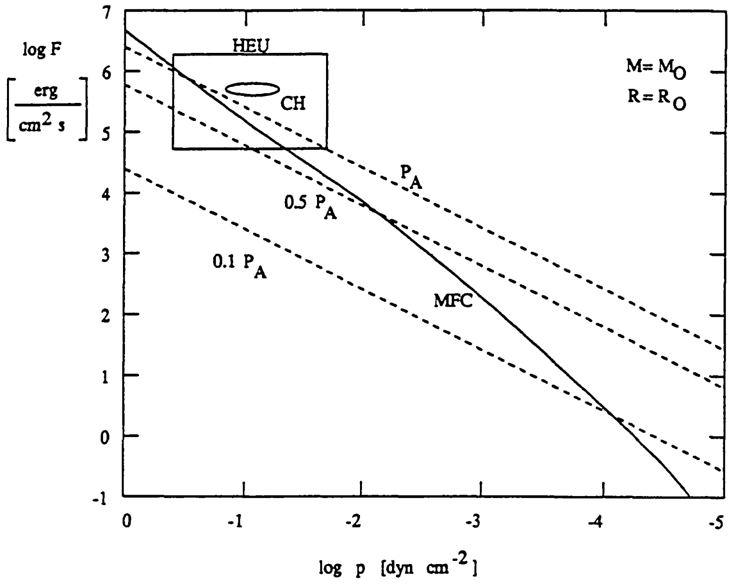

Fig. 1 Valid purely acoustic corona models are found when the coronal energy loss flux (MFC, drawn) can be balanced by the acoustic flux (dashed, curves between $0.1P_A$ *and* $0.5P_A$*). The coronae considered by Hammer et al. (1983) are marked by a box. CH labels observed solar coronal hole energy losses after Withbroe (1988).*