ON CONVECTION IN STELLAR ATMOSPHERES FAR FROM LOCAL THERMODYNAMIC EQUILIBRIUM

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Abstract. Non-thermal effects generated by sub-photospheric convection are considered. It is shown that convective cells are destroyed by shocks generated when convective velocities reach the speed of sound. Terminologically this process is given the name of 'sonic-boom-interrupted convection'. An estimate is made on the dependence of convective velocities on stellar parameters. It is suggested that the process being investigated could explain why some stars do not belong to any branch of the theoretical Hertzsprung-Russell diagram.

1. Introduction

An attempt is made to explain the simultaneous occurrence of emission lines, strong blue continuum and violent macroscopic movements in the atmospheres of some giant stars and other objects. Scarce evidence is available on the origin of high-speed motions. In the present approach they are thought to be connected to large-scale sub-photospheric convection, assuming that the violent sub-photospheric convection breaks into shock waves, thereby generating non-thermal processes in the atmosphere. We shall first consider the conditions under which shock waves are directly generated by convection.

Electrodynamic processes can produce non-thermal effects if a hydrodynamically driven dynamo-mechanism is supposed to generate a strong sub-photospheric magnetic field. In this case, it is assumed that (a) the appearance of non-thermal phenomena is not only indirectly connected to strong sub-photospheric convection but the sudden dissipation of field energy can be brought about directly by hydrodynamic processes, and (b) non-thermal phenomena appear as a consequence of the interaction between the magnetic field and the violent convection. Biermann (1948) suggested a special way in which shock waves and non-thermal effects of mechanical origin can be generated. In his model the mean radial fluctuation of convective velocities turns into shock waves. However, this theory, in which the velocities are supposed to be low compared to the speed of sound, is unable to account for high-energy flares since the velocity fluctuations could never transport thousand times the value of the total energy radiated from a quiet star. This model does not seem to work for stellar atmospheres which are far from being in thermodynamic equilibrium.

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2. A New Aspect of the Generation of Shock Waves

In the earlier conceptions the top of the outer convective zone is taken to be a layer in which the density and temperature are the same as those of the convective cells. Upon reaching the photosphere, the material of the convective elements mixes with that of the environment which is in radiative equilibrium. It can be shown (Grandpierre, 1977) that there are given physical conditions under which the convective transfer will cease in a manner different from the way described above. Let us now examine in detail the physical background which causes the convection to cease.

According to the Schwarzschild criteria there exists an interval, given as \( r_1 < r < r_2 \) (see Figure 1), which is in convective instability. In this interval the ascending convective cells are accelerated at an increasing rate by a growing buoyant force. The rate of acceleration starts to decrease in the interval \( r_2 < r < r_3 \), and at \( r_3 \) the buoyant force goes to zero. Inert convective elements which overshoot this point are gradually stopped by the negative buoyant force acting in the interval \( r_3 < r < r_4 \). Dissipative effects are neglected in the above consideration.

Convective cells can be accelerated to the speed of sound before reaching the interval of the negative buoyant force if the actual temperature gradient 'sufficiently' differs from the adiabatic gradient (see Figure 2). Although some investigators (e.g., Hoyle and Schwarzschild, 1955) have already pointed out that in some stars convective velocities could reach the speed of sound, no in-

![Temperature distribution when convection ceases with zero velocity; \( r \) is the distance from the centre of the star.](image-url)