ACOUSTIC WAVE GENERATION IN VERTICAL MAGNETIC FIELDS

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ABSTRACT. We extended Stein's hydrodynamic theory of acoustic wave generation to accommodate the effect of a vertically uniform magnetic field. It is shown that in the presence of a uniform vertical field with pure horizontal field fluctuations the acoustic waves are produced both from a non-magnetic monopole source of the Reynolds stress and by the magnetic field fluctuations. The computed acoustic flux is found to be confined to the topmost of the spot's convection zone with a small range of depth.

In Stein's approach (Stein, 1967) the hydrodynamic equations are combined to inhomogeneous wave equation for one variable, the perturbed pressure P_1, with a source function S_o $(\vec{x},t)$ for acoustic waves driven by the pure hydrodynamic turbulent stress f_o. In the presence of uniform and vertical magnetic field, the linearized momentum equation is given by

$$\rho_o \frac{\partial \vec{v}}{\partial t} + \vec{\nabla} p_1 - \rho_1 \vec{g} - \frac{1}{4\pi}(\vec{\nabla}\times\vec{B}_1)\times\vec{B} = \vec{f}_o$$

where B is assumed to be made up with B_o and its fluctuations B_1. The magnetic force $\vec{f}_B = \frac{1}{4\pi}(\vec{\nabla}\times\vec{B})\times\vec{B}$ comprises two terms, the linear f_L and non-linear f_N components,

$$\vec{f}_B = \vec{f}_L + \vec{f}_N = \frac{1}{4\pi}(\vec{\nabla}\times\vec{B}_1) \times \vec{B}_o + \frac{1}{4\pi}(\vec{\nabla}\times\vec{B}_1) \times \vec{B}_1 \ .$$

The linear force term f_L is the term which affects the wave propagation, and the non-linear term f_N is associated with the source function via $\vec{\nabla}.\vec{f}_N$ and $\vec{g}.\vec{f}_N$. In general, $\vec{\nabla}.\vec{f}_L$ and $\vec{g}.\vec{f}_L$ do not vanish. However, we can make them vanish by forcing $\vec{B}_1$ to have only the horizontal component.

Thus as long as $\vec{B}_1$ lies in the horizontal direction, the wave propagation becomes independent of the presence of uniform vertical field. Under such a condition, the non-linear force $\vec{f}_N$ simply becomes $\vec{f}_N = -\frac{\partial}{\partial z}\left(\frac{B_h^2}{8\pi}\right)\hat{z}$ which acts along the vertical direction. In this case the

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source function $S(\vec{x},t)$ can be readily evaluated, since the terms associated with the magnetic contribution $\vec{\nabla}.\vec{f}_N$ and $\vec{g}.\vec{f}_N$ are given in terms of $h=B_h/\sqrt{4\pi\rho_0}$ as $\vec{\nabla}.\vec{f}_N = -\frac{\partial^2}{\partial z^2}(\frac{1}{2}\rho_0 h^2)$ and $\vec{g}.\vec{f}_N = g\frac{\partial}{\partial z}(\frac{1}{2}\rho_0 h^2)$.

The turbulent stress in fluid motion can be expanded in monopole, dipole and quardrupole terms (Unno 1964). In the present work only the monopole term is considered in view of the strong tendency of fluid motion to be aligned along vertical field lines. In such a case the source function comprises two terms, one arising from pure turbulent motions and the other, associated with the magnetic fluctuations. Regarding the choice of the correlation functions needed for the calculation of the Fourier transform of $S(\vec{x},t)$, we adopted the Gaussian form given by Unno (1964) both for the turbulent and magnetic fluctuations.

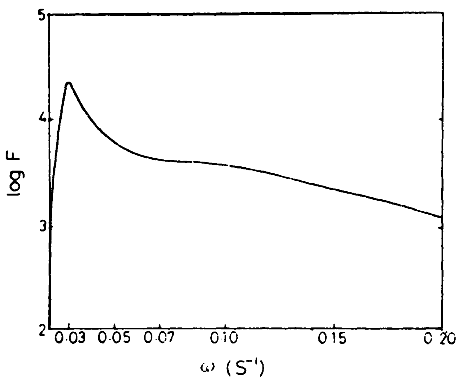

Fig.1 Computed acoustic flux spectra

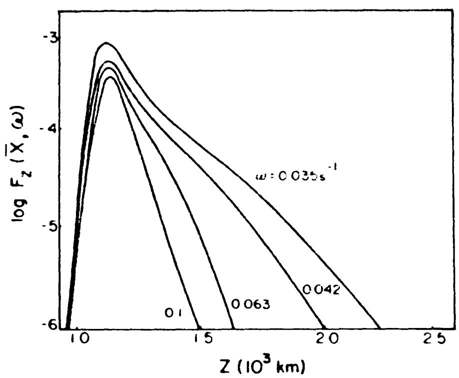

Fig.2 Computed acoustic emission rate per unit volume

We estimated the horizontal field strength from Yun's magnetostatic model No 7 (T_{eff}=4000K, B=3200 Gauss) with the use of Mullan's magnetic diffusion theory (Mullan, 1974). Figure 1 is the computed acoustic flux spectra where the flux F is in erg/(cm^2 sec H_z). Figure 2 shows the acoustic emission rate per unit volume which is confined to the topmost of the spot convection zone.

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