LA-UR-97-340

CONF-970724--1

Title: NONLINEAR WHISTLER WAVE SCATTERING IN SPACE PLASMAS

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Submitted to: XXIII ICPIG
July 17-22, 1997
Toulouse, France

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Nonlinear whistler wave scattering in space plasmas

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1. Introduction

In this paper the evolution of nonlinear scattering of whistler mode waves by kinetic Alfven waves (KAW) in time and two spatial dimensions is studied analytically. We suggest this nonlinear process as a mechanism of kinetic Alfven wave generation in space plasmas. This mechanism can explain the dependence of Alfven wave generation on whistler waves observed in magnetospheric and ionospheric plasmas. The observational data [1,2] show a dependence for the generation of long periodic pulsations Pc5 on whistler wave excitation in the auroral and subauroral zone of the magnetosphere. This dependence was first observed by Ondoh T. I. [1]. For 79 cases of VLF wave excitation registered by Ondoh at College Observatory (L=64.6 N), 52 of them were followed by Pc5 geomagnetic pulsation generation. Similar results were obtained at the Loparskaia Observatory (L=64 N) [2] for auroral and subauroral zone of the magnetosphere. Thus, in 95% of the cases when VLF wave excitation occurred the generation of long periodic geomagnetic pulsations Pc5 were observed. The observations also show that geomagnetic pulsations Pc5 are excited simultaneously or insignificantly later than VLF waves [2]. In fact these two phenomena are associated genetically: the excitation of VLF waves leads to the generation of geomagnetic pulsations Pc5 [2]. The observations [3] show intensive generation of geomagnetic pulsations during thunderstorms. Using an electromagnetic noise monitoring system covering the ULF range (0.01-10 Hz) A.S. Fraser-Smith observed intensive ULF electromagnetic wave during a large thunderstorm near the San-Francisco Bay area on September 23, 1990. According to this data the most significant amplification in ULF wave activity was observed for waves with a frequency of 0.01 Hz and it is entirely possible that stronger enhancements would have been measured at lower frequencies.

2. Theoretical results

We use two-fluid magnetohydrodynamics and kinetic plasma theory to describe three wave interactions. We consider the parametric decay of a whistler wave WW into a KAW and another whistler wave:

$$\mathrm{WW} \to \mathrm{WW} + \mathrm{KAW}$$

We assume that the process takes place in a locally uniform plasma with a uniform magnetic field because the wave length of the interacting waves is less than the scale size of the background ionospheric plasma inhomogenity by about three order of magnitude. We select the direction of magnetic field line to be parallel to the z-axis of a Cartesian system of coordinates. The conservation of energy and momentum in this process is reflected in the frequency and wave vector matching conditions:

$$\omega_0 = \omega_1 + \omega_A$$
$$\vec{k}_0 = \vec{k}_1 + \vec{k}_A \qquad (1)$$

Where ω_0 , k_0 are the frequency and wave vector of whistler pump wave; ω_1 , k_1 are the frequency and wave vector of scattered WW; ω_A , k_A are the frequency and wave vector of the KAW. For the case when the plasma parameter $\beta \ll 1$, the electric field of the KAW can be written:

$$\vec{E}_A = -\vec{\nabla}\varphi_A - \frac{1}{c}\frac{\partial}{\partial t}A_z\vec{e}_z \qquad (2)$$

By using the set of two - fluid MHD equations we obtain the dispersion equation for KAW coupling with whistler waves:

$$\eta_A\varphi_A = \mu_A E_0 E_1^* \qquad (3)$$

Where E_0 is the electric field of whistler pump wave; $\eta_A = \omega_A^2 - k_{Az}^2 V_A^2(1 + k_{Ax}^2\rho_s^2)$

From the set of two - fluid MHD equations we obtain dispersion equation for WW coupling with KAW and whistler pump wave:

$$\eta_1\varphi_1 = \mu_1 E_0\varphi_A^* \qquad (4)$$

Where $\eta_1 = \omega_1^2 - c^4 k_1^2 k_{1z}^2 \omega_{Be}^2 / \omega_{pe}^2$

and μ_A , μ_1 are the coupling coefficients.

We solved this system of nonlinear dispersion relations (3,4) numerically taking into account the frequency and wave vector matching conditions (1), and attenuation factors for KAWs and WWs known from kinetic plasma theory, and assuming an amplitude for the whistler pump wave of E=1 mV/m, for the typical ionospheric plasma parameters at an altitude of 300 km. The dependence of the instability growth rate on the angle between the whistler pump wave vector and the geomagnetic field line is shown in Fig. 1.

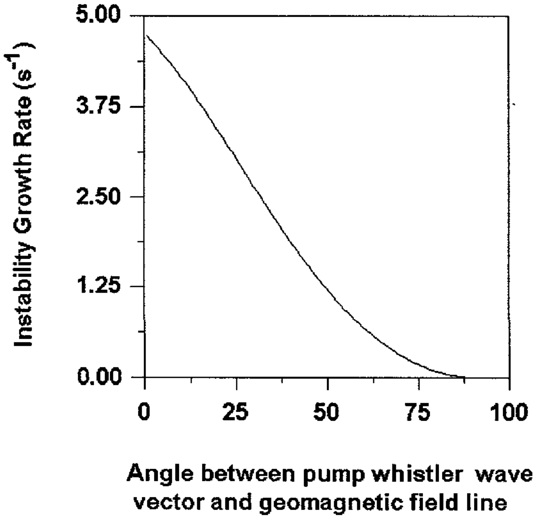

Fig. 1

Figure 2 shows the dependence of the instability growth rate on the angle between the scattered whistler wave vector and the geomagnetic field line.

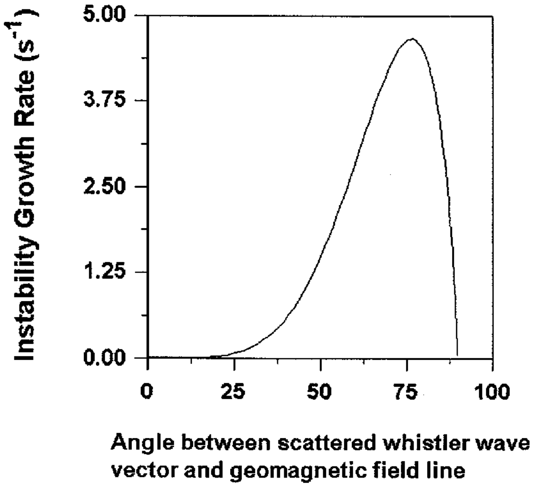

Fig. 2

3. Discussion and conclusion

Using a two-fluid MHD approach to study three wave interactions of whistler mode waves with KAWs (which can interact with other types of waves much more efficiently than MHD Alfven waves because of the presence of a longitudinal electric field component for the KAW [4,5]) we conclude that VLF whistler waves can be scattered by ULF kinetic Alfven waves, and that the latter will be enhanced in such cases. The amplification of ULF waves is indeed observed during thunderstorms, simultaneously with excitation of VLF electromagnetic radiation[3]. Some recent satellite observations also show the presence of KAWs in the magnetosphere and in the topside of the ionosphere [6,7]. In the magnetosphere the long-periodical geomagnetic pulsation generation dependence on whistler waves is observed as well. This dependence was first noted in [1]. Similar results were obtained for the subauroral zone in [2]. In the auroral zone the geomagnetic pulsation generation was observed simultaneously or later than whistler excitation. It can be concluded that whistler excitation in the magnetosphere leads to long-periodical geomagnetic pulsation generation. The mechanism discussed in this paper can be applied for the case of whistler wave propagation in the magnetosphere as well.

4. References

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