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Letter to the Editor

Magnetohydrodynamic parametric instabilities driven by a standing Alfvén wave in the planetary magnetosphere

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Abstract. The parametric instabilities driven by a standing Alfvén wave of circular polarization are studied. Above a certain threshold amplitude, a standing Alfvén wave can generate convective or purely growing MHD parametric processes. It is shown that the threshold conditions can be satisfied by the ULF waves in the planetary magnetospheres. Large density fluctuations and cavities may result from the ponderomotive interaction of Alfvén and acoustic waves. Application of this theory to the observation of Alfvén-acoustic turbulence in the Earth's auroral plasma is discussed.

Key words: Magnetohydrodynamics(MHD)–plasmas–instabilities–Earth–Planets and satellites: general

1. Introduction

Ultralow-frequency planetary magnetohydrodynamic (MHD) waves, oscillating below the local ion-cyclotron frequency, are one of the dominant features of the dynamics of solar wind-magnetosphere-ionosphere coupling system. These waves have been detected in several planetary magnetospheres: Earth (Southwood & Hughes 1983; Fukunishi 1987), Mercury (Russell 1989), Jupiter (Walker & Kivelson 1981; Glassmeier et al. 1989), Saturn (Khurana et al. 1990), Uranus (Khurana et al. 1990) and Neptune (Gurnett et al. 1989). Standing structures of MHD waves in the planetary magnetosphere are easily excited. For exemple, standing Alfvén waves may be generated as Alfvén waves are guided along the field lines in the magnetosphere-ionosphere system and reflected by the lower ionosphere at the end of the field line due to the high conductivity of ionosphere (Southwood & Hughes 1983; Fukunishi 1987). This standing Alfvén wave pattern may act as an electromagnetic coupling mechanism between the auroral acceleration region of magnetosphere and the ionosphere. In addition, standing MHD waves, resulting from fast MHD waves being reflected between the bow shock and a turning point within the planetary magnetosphere, may also be driven by the solar wind (Harold & Samson 1992).

Extensive observational data of standing Alfvén waves in the Earth's magnetosphere are now available (Southwood & Hughes 1983; Fukunishi 1987). Recently, Fukunishi & Lanzerotti (1989) detected ground signature of standing Alfvén waves excited by the flux transfer events, indicating that these waves may provide key information on solar wind-magnetosphere coupling at the Earth's dayside magnetopause. Bloch & Fälthammar (1990) reported the measurement by the Viking satellite of standing Alfvén waves in the 0.1-1 Hz frequency range trapped within a density cavity of high Alfvén velocity between about half and a few Earth radii; the observed wave spectra are usually quite broad, albeit almost monochromatic waves around 0.4-0.6 Hz are often seen in the late morning sector. Knudsen et al. (1990) used rocket and HILAT satellite data to analyze the electric and magnetic fields of standing Alfvén waves in the Earth's auroral ionosphere. A standing Alfvén wave current system can be set up in the Jovian magnetosphere by a large electric field induced by the corrotating plasma (Gurnett & Goertz 1981). Proof of such current system has been given by Pioneer 10 (Walker & Kivelson 1981) and Voyager 1 (Acuña et al. 1981; Glassmeier et al. 1989). In the Mercury's magnetosphere Russell (1989) identified, from the Mariner 10 data, narrowband harmonic of the fundamental standing Alfvén wave.

Standing Alfvén waves in the planetary magnetospheres may sometimes be of finite amplitude (the meaning of "finite amplitude" will be clarified in Section 2). A finite amplitude Alfvén wave may be unstable to parametric instabilities, leading to the development of a turbulent cascade (Sagdeev & Galeev 1969; Goldstein 1978). Previous theories of Alfvén parametric instabilities are mostly restricted to a traveling pump wave. The case of a standing pump wave was studied by Hung (1974) and Lashmore-

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Send offprint requests to: A.C.-L. Chian[2] force acts on the acoustic wave (the LHS of (2), (5) and (10)) to amplify the density perturbations. In the subsonic limit ($\partial_t^2 \ll c_S^2 \partial_z^2$), (2) yields the relation $\rho \propto -|\mathbf{b}|^2$, which shows that a density cavity appears in the region of high Alfvén wave amplitude. For an Alfvén wave amplitude of 150 nT and background density of $3 \times 10^4 cm^{-3}$ measured in the auroral plasma, the ponderomotive potential is 0.9 eV, which is much larger than the background temperature. Thus, the ponderomotive effects of the observed intense Alfvén waves may be the cause of large density variations. The observed density cavity is localized, indicating that the MHD parametric instability is operating in the purely growing regime. According to our theory, for the purely growing Alfvén oscilating two-stream instability, density perturbations grow at a rate $\Gamma_{max} \propto b_0^2$ in the subsonic regime and $\Gamma_{max} \propto b_0^{2/3}$ in the supersonic regime. Hence, the larger the pump amplitude, the larger the growth rate and consequently the larger the density fluctuations. This is in good agreement with the auroral rocket data (Boehm et al. 1990), which show that for near-sinusoidal small-amplitude Alfvén waves $\rho/\rho_0 \ll 1$, whereas for step-like intense Alfvén waves $\rho/\rho_0 \to 1$.

The MHD parametric instabilities discussed in Section 2 may lead to turbulent dissipation process whereby the energy of Alfvén waves is converted to the kinetic energy of plasma particles. The conversion of wave energy to particle energy may be due, for example, to the acoustic waves induced by an MHD parametric instability being damped via Landau damping (Melrose 1986). This dissipation mechanism resulting from wave-particle interactions may produce plasma heating as well as particle acceleration. In fact, during the Alfvén-acoustic turbulence event reported by Boehm et al. (1990), significant temperature increase and energetic electron precipitation were both observed in the auroral plasma.

In addition to the Earth's magnetosphere, finite amplitude standing Alfvén waves were detected by Voyager 1 in the Io plasma torus (Acuña et al. 1981; Glassmeier et al. 1989), as predicted by the nonlinear Alfvén wave current model of Gurnett & Goertz (1981). Presumably, the theory developed in Section 2 should have relevant applications in the magnetosphere of Jupiter and other planets.

4. Conclusion

We have shown that, above a certain threshold field value, a finite amplitude standing Alfvén wave of either right or left-hand circular polarization can excite two classes of MHD parametric instabilities in the planetary magnetosphere: convective instabilities and purely growing oscillating two-stream instabilities. These MHD parametric instabilities may play an important role in the dynamics of Alfvén-acoustic turbulence and its associated large density fluctuations and cavities observed in the planetary auroral plasmas, and contribute toward energization of planetary magnetospheres.

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