PPPL-2424

UC20-G

DR 0257-7

PPPL-2424

EIGENMODE ANALYSIS OF COMPRESSIONAL WAVES IN THE MAGNETOSPHERE

By

C.Z. Cheng and C.S. Lin

APRIL 1987

PLASMA
PHYSICS
LABORATORY

PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY,
UNDER CONTRACT DE-AC02-76-CHO-3073.

EIGENMODE ANALYSIS OF COMPRESSIONAL WAVES IN THE MAGNETOSPHERE

PPPL--2424

DE87 010633

C.Z. Cheng
Plasma Physics Laboratory, Princeton University
P.O. Box 451, Princeton, New Jersey 08544

and

C.S. Lin
Department of Space Sciences, Southwest Research Institute
San Antonio, Texas 78284

Abstract

A field-aligned eigenmode analysis of compressional Alfvén instabilities has been performed for a two component anisotropic plasma in a dipole magnetic field. The eigenmode equations are derived from the gyrokinetic equations in the long wavelength ($k\rho < 1$) and low frequency ($\omega < \omega_b$) limits, where ρ is the hot particle gyroradius and ω_b is the hot particle bounce frequency. Two types of compressional instabilities are identified. One is the drift mirror mode which has an odd parity compressional magnetic component with respect to the magnetic equator. The other is the drift compressional mode with an even parity compressional magnetic component. For typical storm time plasma parameters near geosynchronous orbit, the drift mirror mode is most unstable and the drift compressional mode is stable. The storm time compressional Pc 5 waves, observed by multiple satellites during November 14-15, 1979 [Takahashi et al., 1987], can be explained by the drift mirror instability.

Introduction

Compressional Pc 5 waves with periods in the range of 150-600 sec have been the subject of many observational studies [Brown et al., 1968; Hasegawa, 1969; Lanzerotti et al., 1969; Allan et al., 1982; Walker et al., 1982; Takahashi et al., 1985; Lin and Barfield, 1985; Takahashi et al., 1987; etc.]. Of particular interest are the multiple satellite (SCATHA, GOES 2, GOES 3, and GEOS 2) observations of an event during November 14-15, 1979, near geosynchronous orbit. The event, which followed a large magnetic storm on November 13, occurred on the dayside and was characterized by long-duration (≈ 50 hours), highly compressional magnetic perturbations with saturated amplitudes, and modulation in energetic particle fluxes. Magnetic field data from the four satellites were used to construct the eigenmode structures along the ambient magnetic field lines [Takahashi et al., 1987]. The wave had a dominant compressional component and smaller transverse components with a full latitudinal range of about 20°. The compressional component was found to have an odd parity with respect to the magnetic equator, whereas the transverse components had an even parity. The compressional component oscillated 90° out of phase with the azimuthal component, but oscillated in phase or 180° out of phase with the radial component. The wave propagated westward with respect to the ground with typical propagation velocities of 5-50 km/sec and large azimuthal wave number $m \approx 40-120$ [Takahashi et al., 1985]. The radial extent of the waves was observed to be as large as 1.7 R_E, which is much larger than the azimuthal wavelength. The observed wave frequencies are about one order of magnitude smaller than the Alfvén frequency obtained from the measured plasma density and wave structures along the ambient magnetic field at geosynchronous orbit.

For the first time, these satellite observations can provide an important test to the theories of the storm time Pc 5 waves. Previous theories of the storm time Pc 5 waves have been presented in terms of drift mirror instabilities [Hasegawa, 1969; Walker et al., 1982; Lin and Cheng, 1984], drift compressional instabilities [Hasegawa, 1971; Ng et al., 1984], bounce magnetic drift resonance excitation of ULF waves [Southwood, 1976], and box-model of externally driven Alfvén waves [Southwood and Kivelson, 1986]; however, the field-aligned mode structures have not been studied. In this paper, we will present an eigenmode analysis of long wavelength ($k\rho < 1$), low frequency ($\omega < \omega_b$) compressional waves in a dipole magnetic field, where ρ is the hot particle gyroradius and ω_b is the hot particle bounce frequency. Our results show that there are only two types of instabilities -- drift mirror and drift compressional modes. The drift mirror instability has an odd parity compressional magnetic component with respect to the magnetic equator, and the drift compressional instability has an even parity. From the instability conditions, we show that for typical storm time plasma parameters, the odd parity drift mirror instability can be driven more favorable than the even parity drift compressional instability. Our theory requires that the satellite observations were taken on the outer edge of the ring current plasma, in order to explain the relative phase relationships of different magnetic components of the westward propagating waves.

Eigenmode Equations

Let us consider a magnetospheric plasma consisting of a cold background component and a hot component with $n_h \ll n_c$ and $\beta_h \gg \beta_c$. The cold plasma has a local Maxwellian distribution and the hot plasma has a bi-Maxwellian distribution given by $F_h(E,\mu,\Psi) = \tilde{N}(\Psi)\ [2\pi T_\parallel(\Psi)/M]^{-3/2} \exp\ [-ME/T_\parallel + M\mu B_0/T_{\perp 0}(\Psi)]$, where $E = v^2/2$, $\mu = v_\perp^2/2B$. The plasma density $n_h(\Psi,B) = \tilde{N}T_\perp(\Psi,B)/T_\parallel = \tilde{N}(1-$

$B_0T_\parallel/BT_{\perp 0})^{-1}$, the parallel pressure $P_\parallel(\Psi,B) = n_hT_\parallel$, and the perpendicular pressure $P_\perp(\Psi,B) = n_hT_\perp$. This bi-Maxwellian distribution satisfies the force balance along a field line. For a dipole magnetic field in the spherical coordinate (r,ϕ,θ), the magnetic field is given by $\vec{B} = \nabla\Psi \times \nabla\phi = B_0 (\cos\theta\ \hat{\theta} + 2\sin\theta\ \hat{r})/\cos^6\theta$, where Ψ = constant defines the magnetic flux surface, $B_0 = B(r=r_0,\ \theta=0)$ is the magnetic field at the magnetic equator at a distance r_0 from the earth. We will consider the plasma near geosynchronous orbit where $r_0 \approx 6.6R_E$, $B_0 \approx 10^{-3}$G. If the hot proton temperature is taken as $T_h \approx 10$ keV, pressure gradient scale length $L_h \approx R_E$, then the ion cyclotron frequency is $\omega_{ci} \approx 10\ \sec^{-1}$, the hot proton gyroradius is $\rho \approx 100$ km, the hot proton bounce frequency $\omega_b \approx 4 \times 10^{-2}\ \sec^{-1}$, the bounce-averaged magnetic drift frequency $\langle\omega_d\rangle \approx 10^{-4}m\ \sec^{-1}$, the hot proton diamagnetic drift frequency $\omega_* = 4 \times 10^{-4}m\ \sec^{-1}$, and $k_\phi\rho \approx 2.5 \times 10^{-3}m$. For the November 14-15, 1979 event, the compressional Pc 5 waves have $\omega \approx (0.5\text{-}2) \times 10^{-2}\ \sec^{-1}$ and $m \approx 40\text{-}120$. Therefore, we shall adopt the orderings: $k_\parallel < k_\perp$, $\omega < \omega_b$ and $k\rho < 1$ for the hot component, and $\omega \gg k_\parallel v_\parallel$ for the cold component. Since $n_h \ll n_c$, we can take the parallel electric field to be zero $E_\parallel = i(k_\parallel\Phi - \omega A_\parallel/c) \approx 0$, where Φ is the electrostatic potential and $A_\parallel$ the parallel vector potential.

We will describe waves by the eikonal representation; i.e., a perturbed quantity $\Phi(\Psi,\phi,\Theta) = \phi(\Theta)\exp[iS(\Psi,\Phi)]$ with $\vec{k}_\perp = \nabla\Psi(\partial S/\partial\Psi) + \nabla\phi(\partial S/\partial\phi) \equiv k_\Psi\hat{e}_\psi + k_\phi\ \hat{e}_\phi$. Following the derivations of Berk et al., [1983] which employ the gyrokinetic equations, we obtain a set of eigenmode equations for low frequency, long wavelength electromagnetic waves:

$$\{\hat{B}\cdot\nabla \frac{\sigma}{k_\perp^2B^2}\hat{B}\cdot\nabla + (\frac{\omega}{k_\perp v_A})^2\ [1 - \frac{n_h\omega_{*\perp}}{n_c\omega} + \frac{n_h}{n_cb}\frac{(\omega_{*\perp}\omega_B + \omega_{*\parallel}\omega_k)}{\omega^2}]\}\ \tilde{\Phi}$$

$$+ \frac{n_h\omega_{*\perp}\omega}{n_cb(k_\perp v_A)^2}\tilde{B}_\parallel - \frac{4\pi\omega(\omega_B\delta\tilde{p}_\perp + \omega_k\delta\tilde{p}_\parallel)}{(\omega_{ci}b)^2\ B^2} = O(\frac{\omega}{\omega_b}) \quad , \tag{1a}$$

and

$$\{\vec{B}\cdot\nabla \frac{\sigma}{k_\perp^2 B^2} \vec{B}\cdot\nabla - [1-(\frac{\omega}{k_\perp v_A})^2 + \beta_\perp(1-\frac{T_\perp}{T_\parallel})]\} \tilde{B}_\parallel$$

$$+ (\frac{\beta_\parallel \omega_{*\perp}}{2\omega}) \tilde{\Phi} + \frac{4\pi\delta\tilde{p}_\perp}{B^2} = 0(\frac{\omega}{\omega_b}) \quad , \tag{1b}$$

where $\tilde{B}_\parallel = \delta B_\parallel/B_0$, $\tilde{\Phi} = e\Phi/T_\parallel$, $\sigma = 1 + (\beta_\perp-\beta_\parallel)/2$, $b = (k_\perp\rho)^2/2$, $\omega_B = (cT_\perp/eB)$ $\vec{k}_\perp\cdot\hat{e}_b\times\nabla\ln B$, $\omega_k = (cT_\parallel/eB)\ \vec{k}_\perp\cdot\hat{e}_b\times\vec{\kappa}$, $\omega_{*\perp,\parallel} = \omega_*(dP_{\perp,\parallel}/d\Psi)/(T_\parallel\partial n_h/\partial\Psi)$, $\omega_* = (cT_\parallel/eB)\ \vec{k}_\perp\cdot\hat{e}_b\times\nabla\ln n_h$, $\vec{\kappa} = \hat{e}_b \cdot \nabla\hat{e}_b$, and $\vec{B}\cdot\nabla = J^{-1}\,\partial/\partial\theta$ with the Jacobian $J = r_o \cos^7\theta/B_o$ for a dipole field. The perpendicular and parallel perturbed trapped particle pressures are given by

$$\begin{pmatrix} \delta\tilde{p}_\perp \\ \\ \delta\tilde{p}_\parallel \end{pmatrix} = \int_T d^3v\ F_h \frac{\tilde{\omega}_0 - \omega_*^T}{\omega - \langle\omega_d\rangle} \langle Y\rangle \begin{pmatrix} M\mu B \\ \\ Mv_\parallel^2 \end{pmatrix} \quad , \tag{2}$$

where $\tilde{\omega}_0 = -(T_\parallel\omega/M)\partial\ln F_h/\partial E)$, $\omega_*^T = \omega_*(\partial\ln F_h/\partial\ln n_h)$, $\omega_d = \omega_B(M\mu B/T_\perp) + \omega_\kappa(Mv_\parallel^2/T_\parallel)$, $Y = \omega_d\tilde{\Phi}/\omega + (\mu MB_0/T_\parallel)\tilde{B}_\parallel$, and the bounce average of X is defined by $\langle X\rangle = (\oint dlX/v_\parallel)/(\oint dl/v_\parallel)$. Equation (1a) describes the shear Alfvén branch and (1b) the compressional Alfvén waves. Two branches are coupled through the hot particle density n_h, hot pressure gradient, and perturbed trapped particle pressures $\delta\tilde{p}_\perp$ and $\delta\tilde{p}_\parallel$.

Drift Mirror and Drift Compressional Instabilities

To obtain analytical solutions of the compressional waves, we consider $\tilde{B}_\parallel$ >> $\tilde{\Phi}$ so that in the lowest order the compressional waves decouple from the shear Alfvén waves. We first consider $\tilde{B}_\parallel$ to have odd parity with respect to the magnetic equator. There is no hot trapped particle contribution since $\langle \tilde{B}_\parallel \rangle = 0$ and Eq. (1b) reduces to the MHD equation for mirror modes. Looking for localized solutions, we expand Eq. (1b) around $\theta = 0$ and obtain a Weber equation, which describes wave trapping in a potential well,

$$[\frac{d^2}{d\theta^2} + C - D\,\theta^2]\,\tilde{B}_\parallel = 0 \quad , \tag{3}$$

where $C = F(\omega^2 + \gamma_0^2)$, $D = F[9\omega^2 - 27\beta_\perp A(A-1)\omega_A^2] + CG$, $\gamma_0^2 = [\beta_\perp(A-1)-1]\omega_A^2$, $F = (r_0/v_A)^2/[1+\beta_\parallel(A-1)/2]$, $G = 9\beta_\parallel[(1+A)/2-A^2]/2[1+\beta_\parallel(A-1)/2] - 2$, $\omega_A = k_\perp v_A$, $A = (T_\perp/T_\parallel)_{\theta=0}$. The solution of Eq. (3) with decaying asymptotic behavior for $\theta \to \pi/2$ is given by the odd parity parabolic cylinder function [Abramowitz and Stegun, 1964] with the dispersion relation $C = (2N+1)\,D$, $N = 1, 3, \ldots$. The lowest order ($N=1$) solution is given by

$$\tilde{B}_\parallel = \theta \exp\,[\frac{-D^{1/2}\theta^2}{2}] \quad . \tag{4}$$

The corresponding eigenvalue for $\omega < \omega_A$ is given by

$$\omega_{MHD}^2 = -\gamma_0^2 + \frac{3\omega_A v_A}{r_0}\,\{13.5\ \beta_\perp A(A-1)[1+\frac{\beta_\parallel(A-1)}{2}]\}^{1/2} \quad , \tag{5}$$

which predicts either purely growing or oscillatory modes. Equation (5) gives the correct stability threshold, but overestimates the growth rates. Also, it does not provide the real frequency for instabilities, which requires higher order terms in (ω/ω_b). Including higher order trapped particle terms in (ω/ω_b), the eigenmode equation for $\tilde{B}_\parallel$ becomes an integro-differential equation

$$\{\hat{B}\cdot\nabla\,\frac{\sigma}{k_\perp^2 B^2}\,\hat{B}\cdot\nabla - [1-(\frac{\omega}{k_\perp v_A})^2 + \beta_\perp(1-\frac{T_\perp}{T_\parallel})]\}\tilde{B}_\parallel$$

$$-4\pi \int_T d^3v \frac{F_h}{T_\parallel} \frac{\omega-\omega_*^T}{\omega-\langle\omega_d\rangle} M^2\mu^2 \{\langle\tilde{B}_\parallel\rangle + \sum_{p=1}^{\infty} \frac{2\Gamma^2}{\Gamma^2-p^2} [\cos(p\hat{\theta})\langle\cos(p\hat{\theta})\tilde{B}_\parallel\rangle$$

$$+ \sin(p\hat{\theta})\langle\sin(p\hat{\theta})\tilde{B}_\parallel\rangle] - \sum_{p=1}^{\infty} \frac{2p\Gamma(-1)^p\sin(\Gamma\hat{\theta})}{(\Gamma^2-p^2)\cos(\pi\Gamma)} \langle\sin(p\hat{\theta})\tilde{B}_\parallel\rangle\} = 0 \quad , \tag{6}$$

where $\Gamma = (\omega-\langle\omega_d\rangle)/\omega_b$, $\hat{\theta} = \omega_b \int_{-\theta_T}^{\theta} d\theta' \, JB/|v_\parallel| - \pi$, and θ_T is the trapped particle turning angle. Numerical solutions of Eq. (6) have been performed by using the cubic B-spline finite element method [Cheng and Chance, 1987]. Figure 1 shows the numerical eigenfrequencies versus temperature anisotropy A for the fixed parameters: $k_\perp\rho = 0.15$, $n_h/n_c = 0.1$, $\beta_\parallel = 0.5$, $L_h/\rho = -50$, $k_\perp r_o = 64$, $L_h/L_B = -0.1$. The N=0 even mode is stable for this set of parameters. The eigenfrequencies for the N=1 (odd) and N=2 (even) modes are shown along with the MHD growth rates γ_{MHD} for the N=1 mode for comparison. Note that $\omega_r \approx (0.2 - 0.3)\omega_* < \omega_b$, $\gamma \ll \gamma_{MHD}$, and the critical A is unchanged. Since $\omega_r < 0$ and $m > 0$, the wave is a westward propagating wave with respect to the ground. This solution is the low-frequency version of the drift mirror instability studied by Hasegawa [1969].

For even parity $\tilde{B}_\parallel$ modes, we assume $\langle\tilde{B}_\parallel\rangle \approx \tilde{B}_\parallel$ for the N=0 mode and Eq. (1b) reduces to

$$\{\vec{B}\cdot\nabla \frac{\sigma}{k_\perp^2 B^2} \vec{B}\cdot\nabla - [1-(\frac{\omega}{k_\perp v_A})^2 + \beta_\perp (1-\frac{T_\perp}{T_\parallel})]$$

$$+ 4\pi \int_T d^3v \frac{M^2\mu^2 F_h}{T_\parallel} \frac{(\omega-\omega_*^T)}{\omega-\langle\omega_d\rangle}\} \tilde{B}_\parallel = 0 \quad . \tag{7}$$

For simplicity we assume $\omega \gg \langle\omega_d\rangle$ and expand Eq. (7) around $\theta = 0$ to obtain a Weber equation in the form of Eq. (3). For $k_\perp r_0 \gg 1$, the dispersion relation is given by

$$(\frac{\omega}{\omega_A})^3 - (1+\beta_\perp)(\frac{\omega}{\omega_A}) + \frac{\beta_\perp A\omega_*}{\omega_A} = 0 \quad , \tag{8}$$

and the instability condition is given by

$$(\frac{\beta_\perp A\omega_*}{2\omega_A})^2 > \frac{(1+\beta_\perp)^3}{27} \quad . \tag{9}$$

This is the low-frequency version of the drift compressional instability first studied by Hasegawa [1971].

For typical plasma parameters near geosynchronous orbit, our theory indicates that the odd parity (N=1) $\tilde{B}_\parallel$ drift mirror mode is unstable, and the even parity (N=0) drift compressional mode is stable. This leads us to conclude that the multi-satellite observations of compressional Pc 5 waves by Takahashi et al. [1987] may be related to the drift mirror instabilities. To compare more closely with the observations, we calculate the mode structures of different $\delta\vec{B}$ components. Since $\omega^2 << (k_\parallel V_A)^2$, Eq. (1a) gives

$$\frac{1}{J}\frac{d}{d\theta}\frac{\sigma}{B^2 J}\frac{d}{d\theta}\tilde{\Phi} = -(\frac{n_h}{n_c})^2 (\frac{\omega\omega_*}{bV_A{}^2})\tilde{B}_\parallel \quad . \tag{11}$$

For the N=1 odd parity mode with $\tilde{B}_\parallel$ given by Eq. (4), the radial component of $\delta\vec{B}$ is obtained by assuming $k_\Psi << k_\phi$:

$$\tilde{B}_r \equiv \frac{\delta\vec{B}\cdot\nabla\Psi}{B_o|\nabla\Psi|} = \frac{T_\parallel k_\phi}{M\omega\omega_{ci}\cos^3\theta BJ}\frac{d\tilde{\Phi}}{d\theta}$$

$$\approx \frac{n_h\omega_{ci}\omega_* r_o}{n_c k_\phi V_A{}^2\sigma D^{1/2}}\left[1 - (\frac{9A}{2} + G)\theta^2\right]\exp[-\frac{D^{1/2}\theta^2}{2}] \quad . \tag{12}$$

The azimuthal component of $\delta\vec{B}$ is given by

$$\tilde{B}_\phi \equiv \frac{\delta\vec{B}\cdot\nabla\phi}{B_o|\nabla\phi|} = \frac{i}{\cos^4\theta k_\phi r_o}\frac{d}{d\theta}\left(\frac{B_o\tilde{B}_\parallel}{B}\right)$$

$$\approx \frac{i\cos^2\theta(1-D^{1/2}\theta^2)}{k_\phi r_o(1+3\sin^2\theta)^{1/2}}\exp\left[-\frac{D^{1/2}\theta^2}{2}\right] \quad . \tag{13}$$

Figure 2 shows the eigenmode structures of the three magnetic field components for the N=1 drift mirror mode versus θ for the parameters: $\beta_\parallel = 0.5$, $A = 2.2$, $L_h/\rho = -50$, $k_\phi r_o = 64$, $n_h/n_c = 0.1$, $r_o/\rho = 425$, $T_\parallel/T_c = 10^3$, and $L_h/L_B = -0.1$. The wave is localized within $|\theta| < 10°$. Note that $\tilde{B}_\parallel$ and $\tilde{B}_r$ oscillate 180° out of phase for $\theta < 5°$ and in phase for $\theta > 5°$, $\tilde{B}_\parallel$ and $\tilde{B}_\phi$ are out of phase by + or - 90°. These mode structures are in close agreement with the satellite observations only if the energetic ion pressure gradient is negative ($\omega_* < 0$), which indicates that the satellite observations occurred on the outer edge of the ring current plasma for the westward propagating waves.

Discussion

Following their interpretation of the multi-satellite observations of compressional Pc 5 waves during November 14-15, 1979, Takahashi et al. [1987] pointed out a serious challenge against the drift mirror mode. For the interval of 1900-2300 UT of November 14, the SCATHA ion data (17 eV-300 keV) indicated that $\beta_\parallel \approx 0.16 - 0.21$ and $\beta_\perp \approx 0.23 - 0.3$, which does not satisfy the drift mirror instability condition, Eq. (5). This might be explained by the fact that the SCATHA ion data were taken during the recovery phase of the magnetic storm and the magnetic fluctuation is in a nonlinearly saturated state. The drift mirror modes must have been excited during the large magnetic storm on November 13. The nonlinear effect of the odd parity $\tilde{B}_\parallel$ mode, although conserving the total energy will result in the exchange of perpendicular and parallel energies leading to the modulation of the pitch angle distribution as the dominant cause of the flux pulsation [Takahashi and Higbie, 1986]. Another feature of the nonlinear state is the often observed frequency doubling (called second harmonic) near the magnetic equator with $|\theta| < 5°$ [Higuchi et al., 1986; Takahashi et al., 1986; Kokubun, 1985; Coleman, 1970].

Our eigenmode equations are derived under the assumptions that $k_\perp \rho < 1$ and $|(\omega_d - \langle\omega_d\rangle)/\omega_b| < 1$. One can easily show from Eq. (6) that resonance instabilities of the type $(\omega - \langle\omega_d\rangle)^2 = (p\omega_b)^2$, $p = 0, 1, 2, \ldots$, are impossible for odd parity $\tilde{B}_\parallel$ modes because the resonant contributions cancel out. But if $k_\perp \rho \gtrsim 1$ and $(\omega_d - \langle\omega_d\rangle) \gtrsim \omega_b$, Chen and Hasegawa [1986] have shown that the $(\omega - \langle\omega_d\rangle)^2 = (p\omega_b)^2$ type resonance instability may be possible. This instability requires a higher ion temperature of $T_h > 100$ keV for wave number $m \gtrsim 100$. Finally, compressional instability is also possible if the hot particle distribution is such that $\partial F_h/\partial E|_{\mu,\Psi} > 0$ at resonance [Rosenbluth et al., 1983]. These possibilities definitely merit further investigation.

Acknowledgments

We would like to thank Dr. A. Hasegawa and Dr. L. Chen for valuable discussions. This work was supported by U.S. DoE Contract No. DE-AC02-76-CHO-3073 and by NSF grant ATM-8405536.

References

Abramowitz, M., and I.A. Stegun, Handbook of Mathematical Functions, U.S. Department of Commerce, National Bureau of Standards, AMS 55, 1964.

Allan, W., E.M. Poulter, and E. Nielson, SATRE observation of a Pc 5 pulsation with large azimuthal wave number, J. Geophys. Res., 87, 6163, 1982.

Berk, H.L., C.Z. Cheng, M.N. Rosenbluth, and J.W. Van Dam, Finite larmor radius stability theory of EBT plasmas, Phys. Fluids, 26, 2624, 1983.

Brown, W.L., L.J. Cahill, Jr., L.R. Davis, C.E. McIlwain, and C.S. Roberts, Acceleration of trapped particles during a magnetic storm on April 18, 1965, J. Geophys. Res., 73, 153, 1968.

Chen, L., and A. Hasegawa, Excitation of hydromagnetic Alfvén waves by energetic ring current protons, EOS, 67, 1182, 1986.

Cheng, C.Z., and M.S. Chance, NOVA: a nonvariational code for solving MHD stability, J. Comput. Phys., in press, 1987.

Coleman, P.J., Jr., Geomagnetic storms at ATS 1, in Intercorrelated Satellite Observations Related to Solar Events, edited by V. Manno and D.E. Page, pp. 251-279, D. Reidel, Dordrecht-Holland, 1970.

Hasegawa, A., Drift mirror instabilities in the magnetosphere, Phys. Fluids, 12, 2642, 1969.

Hawegawa, A., Drift wave instabilities of a compressional mode in a high β plasma, Phys. Rev. Lett., 27, 11, 1971.

Higuchi, T., S. Kokubun, and S. Ohtani, Harmonic structure of compressional Pc 5 pulsations at synchronous orbit, Geophys. Res. Lett., 13, 1101, 1986.

Kokubun, S., Statistical characteristics of Pc 5 waves at geostationary orbit, J. Geomag. Geoelectr., 37, 759, 1985.

Lanzerotti, L.J., A. Hawegawa, and C.G. Maclennan, Drift mirror instability in the magnetosphere: particle and field oscillations and electron heating, J. Geophys. Res., 74, 5565, 1969.

Lin, C.S., and C.Z. Cheng, Tail field effects on drift mirror instability, J. Geophys. Res., 89, 10771, 1984.

Lin, C.S., and J.N. Barfield, Azimuthal propagation of storm time Pc 5 waves observed simultaneously by geostationary satellites GOES 2 and GOES 3, J. Geophys. Res., 90, 11075, 1985.

Ng, P.H., V.L. Patel, and S. Chen, Drift compressional instability in the magnetosphere, J. Geophys. Res., 90, 10763, 1984.

Rosenbluth, M.N., P.J. Catto, and X.S. Lee, Effects of ion bounce resonances on ballooning-interchange modes, Phys. Fluids, 26, 216, 1983.

Southwood, D.J., A general approach to low-frequency instability in the ring current plasma, J. Geophys. Res., 81, 3340, 1976.

Southwood, D.J., and M.G. Kivelson, The effect of parallel inhomogeneity on magnetospheric hydromagnetic wave coupling, J. Geophys. Res., 91, 6871, 1986.

Takahashi, K., P.R. Higbie, and D.N. Baker, Azimuthal propagation and frequency characteristics of compressional Pc 5 waves observed at geostationary orbit, J. Geophys. Res., 90, 1473, 1985.

Takahashi, K., and P.R. Higbie, Antisymmetric standing wave structure associated with the compressional Pc 5 pulsation of November 14, 1979, J. Geophys. Res., 91, 11163, 1986.

Takahashi, K., J.F. Fennell, E. Amata, and F.R. Higbie, Field-aligned structure of the storm time Pc 5 wave of November 14-15, 1979, J. Geophys. Res., in press, 1987.

Walker, A.D.M., R.A. Greenwald, A. Korth, and G. Kremser, SATRE and GEOS2 observations of a storm time Pc 5 ULF pulsation, J. Geophys. Res., 87, 9135, 1982.

Figure Captions

Figure 1. The eigenfrequencies of the N=1 odd and N=2 even drift mirror instabilities versus temperature anisotropy A from solving Eq. (6), where the MHD growth rate γ_{MHD}, obtained from Eq. (5), for the N=1 mode is shown to be much larger than the kinetic results. The fixed parameters are $k_\perp \rho = 0.15$, $n_h/n_c = 0.1$, $\beta_\parallel = 0.5$, $L_h/\rho = -50$, $k_\perp r_o = 64$, $l_h/L_B = -0.1$.

Figure 2. The eigenmode structures of different $\delta\vec{B}$ components for the N=1 odd parity drift mirror mode versus magnetic latitude θ. The parameters are $r_o/\rho = 425$, $n_h/n_c = 0.1$, $\beta_\parallel = 0.5$, $L_h/\rho = -50$, $k_\perp r_o = 64$, $L_h/L_B = -0.1$, $T_\parallel/T_c = 10^3$, $A = 2.2$.

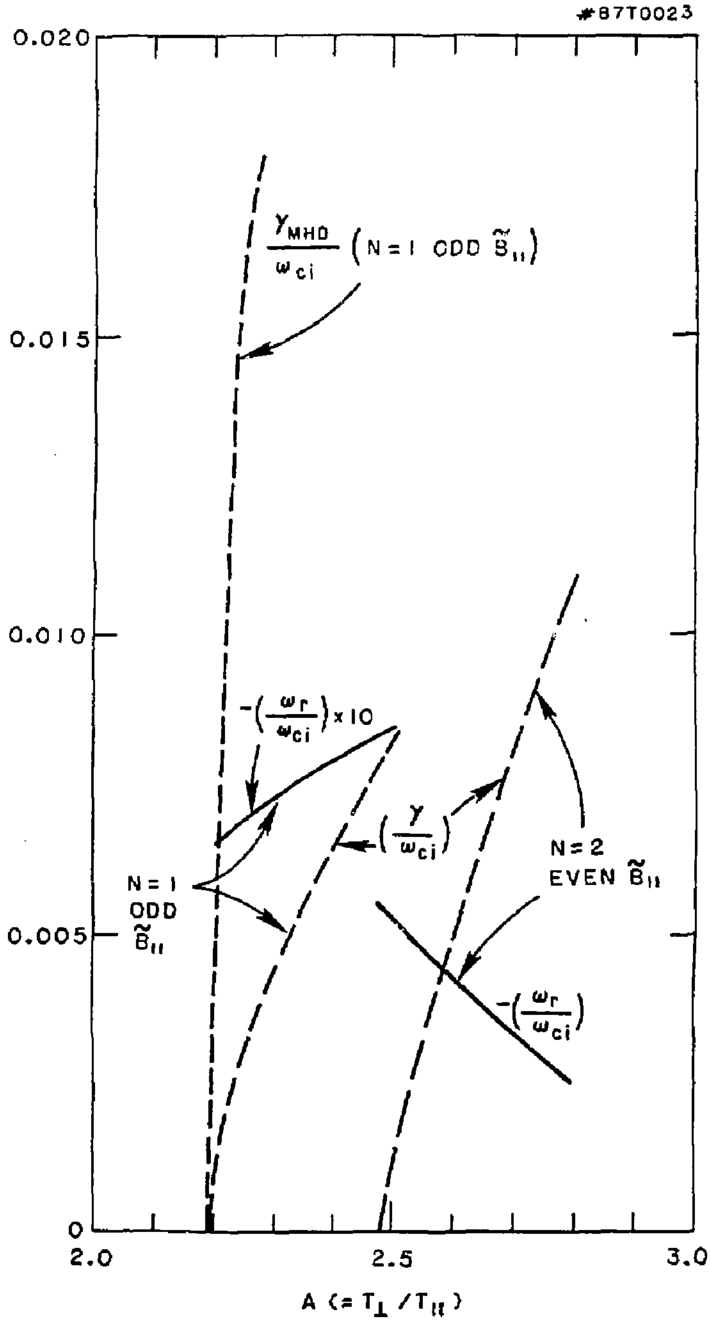
#87T0023
0.020
0.015
0.010
0.005
0
2.0
2.5
3.0
A (= T⊥ / T∥)
$\frac{\gamma_{MHD}}{\omega_{ci}}$ (N = 1 ODD $\tilde{B}_{\parallel}$)
$-\left(\frac{\omega_r}{\omega_{ci}}\right) \times 10$
$\left(\frac{\gamma}{\omega_{ci}}\right)$
N = 1 ODD $\tilde{B}_{\parallel}$
N = 2 EVEN $\tilde{B}_{\parallel}$
$-\left(\frac{\omega_r}{\omega_{ci}}\right)$

Fig. 1

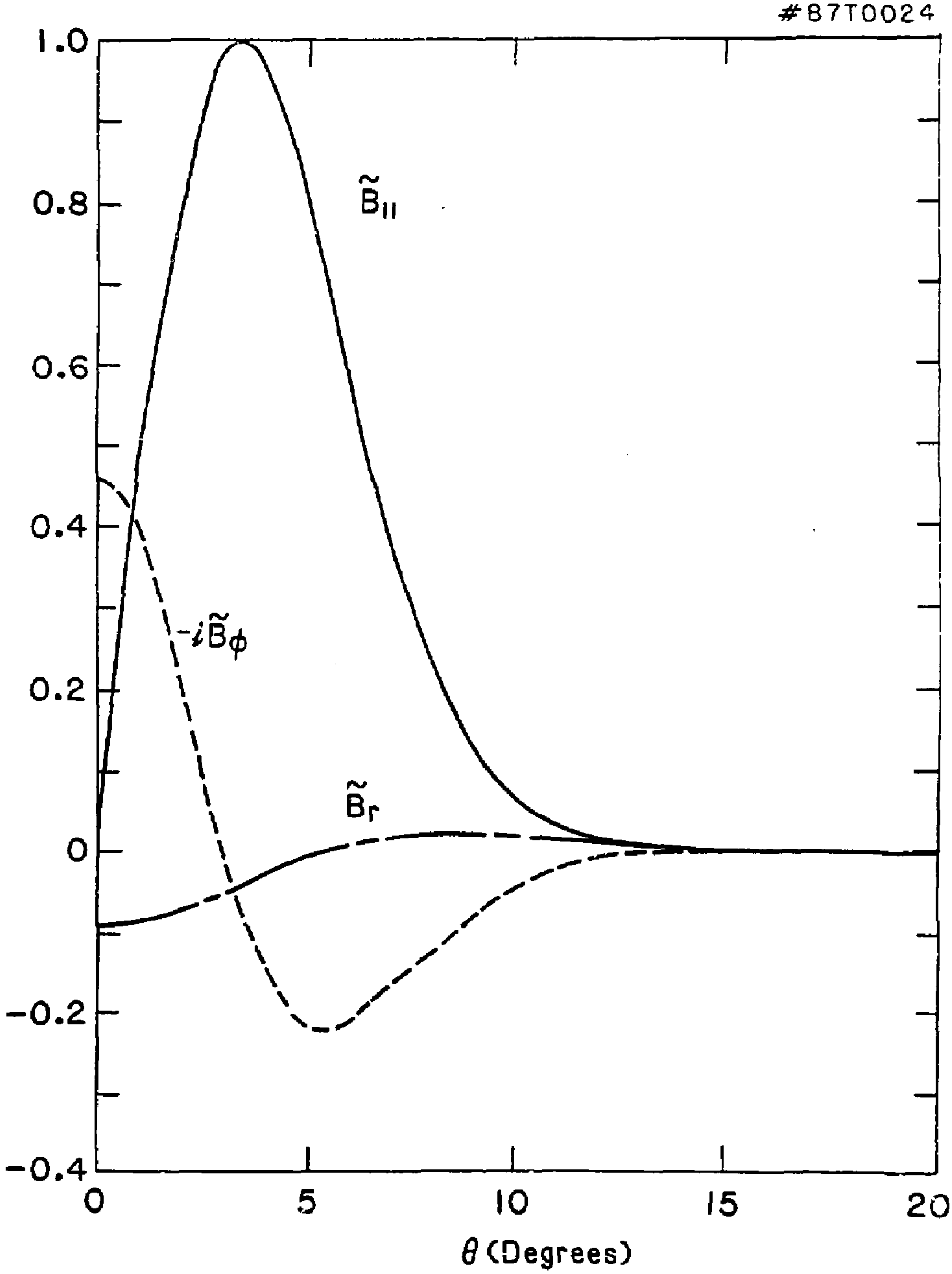
#87T0024
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
5
10
15
20
θ (Degrees)
$\tilde{B}_{\parallel}$
$-i\tilde{B}_{\phi}$
$\tilde{B}_r$

Fig. 2

EXTERNAL DISTRIBUTION IN ADDITION TO UC-20

Dr. Frank J. Paoloni, Univ of Wollongong, AUSTRALIA
Prof. M.H. Brennan, Univ Sydney, AUSTRALIA
Plasma Research Lab., Australian Nat. Univ., AUSTRALIA
Prof. I.R. Jones, Flinders Univ., AUSTRALIA
Prof. F. Cap, Inst Theo Phys, AUSTRIA
Prof. M. Heindler, Institut fur Theoretische Physik, AUSTRIA
M. Goossens, Astronomisch Instituut, BELGIUM
Ecole Royale Militaire, Lab de Phys Plasmas, BELGIUM
Com. of European, Dg XII Fusion Prog, BELGIUM
Prof. R. Boucique, Laboratorium voor Natuurkunde, BELGIUM
Dr. P.H. Sakanaka, Univ Estadual, BRAZIL
Instituto De Pesquisas Espaciasi-INPE, BRAZIL
Library, Atomic Energy of Canada Limited, CANADA
Dr. M.P. Bachynski, MPB Technologies, Inc., CANADA
Dr. H.M. Skarsgard, Univ of Saskatchewan, CANADA
Dr. H. Barnard, University of British Columbia, CANADA
Prof. J. Teichmann, Univ. of Montreal, CANADA
Prof. S.R. Sreenivasan, University of Calgary, CANADA
Prof. Tudor W. Johnston, INRS-Energie, CANADA
Dr. C.R. James, Univ. of Alberta, CANADA
Dr. Peter Lukac, Komenskeho Univ, CZECHOSLOVAKIA
The Librarian, Culham Laboratory, ENGLAND
Mrs. S.A. Hutchinson, JET Library, ENGLAND
C. Mouttet, Lab. de Physique des Milieux Ionises, FRANCE
J. Radet, CEN/CADARACHE - Bat 506, FRANCE
Dr. Tom Mual, Academy Bibliographic, HONG KONG
Preprint Library, Cent Res Inst Phys, HUNGARY
Dr. B. Dasgupta, Saha Inst, INDIA
Dr. R.K. Chhajlani, Vikram Univ. INDIA
Dr. P. Kaw, Institute for Plasma Research, INDIA
Dr. Phillip Rosenau, Israel Inst Tech, ISRAEL
Prof. S. Cuperman, Tel Aviv University, ISRAEL
Librarian, Int'l Ctr Theo Phys, ITALY
Prof. G. Rostagni, Univ Di Padova, ITALY
Miss Clelia De Palo, Assoc EURATOM-ENEA, ITALY
Biblioteca, del CNR EURATOM, ITALY
Dr. H. Yamato, Toshiba Res & Dev, JAPAN
Prof. I. Kawakami, Atomic Energy Res. Institute, JAPAN
Prof. Kyoji Nishikawa, Univ of Hiroshima, JAPAN
Direc. Dept. Lg. Tokamak Res. JAERI, JAPAN
Prof. Satoshi Itoh, Kyushu University, JAPAN
Research Info Center, Nagoya University, JAPAN
Prof. S. Tanaka, Kyoto University, JAPAN
Library, Kyoto University, JAPAN
Prof. Nobuyuki Inoue, University of Tokyo, JAPAN
S. Mori, JAERI, JAPAN
M.H. Kim, Korea Advanced Energy Research Institute, KOREA
Prof. D.I. Choi, Adv. Inst Sci & Tech, KOREA
Prof. B.S. Liley, University of Waikato, NEW ZEALAND
Institute of Plasma Physics, PEOPLE'S REPUBLIC OF CHINA
Librarian, Institute of Phys., PEOPLE'S REPUBLIC OF CHINA
Library, Tsing Hua University, PEOPLE'S REPUBLIC OF CHINA
Z. Li, Southwest Inst. Physics, PEOPLE'S REPUBLIC OF CHINA
Prof. J.A.C. Cabral, Inst Superior Tecn, PORTUGAL
Dr. Octavian Petrus, AL I CUZA University, ROMANIA
Dr. Johan de Villiers, Plasma Physics, AEC, SO AFRICA
Prof. M.A. Hellberg, University of Natal, SO AFRICA
Fusion Div. Library, JEN, SPAIN
Dr. Lennart Stenflo, University of UMEA, SWEDEN
Library, Royal Inst Tech, SWEDEN
Prof. Hans Wilhelmson, Chalmers Univ Tech, SWEDEN
Centre Phys des Plasmas, Ecole Polytech Fed, SWITZERLAND
Bibliotheek, Fom-Inst Voor Plasma-Fysica, THE NETHERLANDS
Dr. D.D. Ryutov, Siberian Acad Sci, USSR
Dr. G.A. Eliseev, Kurchatov Institute, USSR
Dr. V.A. Glukhikh, Inst Electro-Physical, USSR
Dr. V.T. Tolok, Inst. Phys. Tech. USSR
Dr. L.M. Kovrizhnykh, Institute Gen. Physics, USSR
Prof. T.J.M. Boyd, Univ College N Wales, WALES
Nuclear Res. Establishment, Julich Ltd., W. GERMANY
Bibliothek, Inst. Fur Plasmaforschung, W. GERMANY
Dr. K. Schindler, Ruhr Universitat, W. GERMANY
ASDEX Reading Rm, IPP/Max-Planck-Institut fur Plasmaphysik, W. GERMANY
Librarian, Max-Planck Institut, W. GERMANY
Prof. R.K. Janev, Inst Phys, YUGOSLAVIA