Letter to the Editor: Interpretations of new features of time domain electric-field structures in the auroral acceleration region

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Interpretations of new features of time domain electric-field structures in the auroral acceleration region

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Abstract. Possible theoretical interpretations of the various nonlinear electric-field structures in the auroral acceleration region are provided.

Introduction

In a very interesting letter, Mozer *et al.* (1997) presented experimental evidence of new localized electric structures, associated with the plasma acceleration that produces discrete auroras. Specifically, the observations revealed the simultaneous presence of energetic particles and very large amplitude solitary waves, spiky electric field structures, wave envelopes of parallel (to the geomagnetic field $B_0\hat{\mathbf{z}}$) electric fields, and intense nonlinear coherent ion-cyclotron waves in the auroral acceleration region. It seems likely that the nonlinear entities act as a particle accelerators. The frequencies or repetition rates of the spiky electric field structures are of the order of 10 Hz which is close to the hydrogen ion-cyclotron frequency. Furthermore, it was found that the parallel and perpendicular electric field strengths are larger than hundreds of mV/m, and that the structures can move along the geomagnetic field lines with velocities of the order of 100 km/s. Accelerated particles have been observed in conjunction with the electric field spikes, and there are also indications of magnetic field disturbances as well as amplitude modulations of the electrostatic ion-cyclotron (EIC) wave packets. Our objective here is provide theoretical insights for understanding the physics of the self-consistent generation of such non linear structures and the acceleration that they produce.

Discussion

It is well known that auroral plasmas contain essential free energy sources in the form of ion conics and magnetic field aligned currents. The latter, which are probably the dominant energy source, couple to the EIC waves which then grow from thermal noise. Finite amplitude EIC waves either interact with themselves or with the background plasma and then self-organize to form solitary structures. In the past, several authors (e.g., Chaturvedi, 1976; Mozer *et al.*, 1980; Yu *et al.*, 1980; Shukla and Tagare, 1984) have made substantial contributions to the theory of large amplitude, nonlinear EIC waves in the auroral zone and solar flares. However, we feel that the salient features of the recently observed (Mozer *et al.*, 1997) coherent nonlinear EIC waves should be understood from the nonlinear fluid model presented by Yu *et al.* (1980). The nonlinear dynamics of their EIC waves, whose parallel phase velocity is much smaller than the electron thermal velocity, requires Boltzmann-distributed electrons as well as strongly magnetized ions governed by the continuity and momentum equations. Thus, the ion advection and the nonlinear ion Lorentz force play a significant role in the formation of the EIC solitary wave structures. It turns out that the existence of finite amplitude localized EIC wave packets can be established from an energy equation which is derived from such nonlinear hydrodynamic equations involving EIC waves. The fully nonlinear EIC wave model thus predicts bare solitons consisting of density compressions that move at near sonic speeds. The widths of the localized structures is of the order of the ion gyroradius. All the characteristics of the finite amplitude EIC solitary waves are in good agreement with the recent observations.

Finite amplitude EIC waves can also be modulated when they nonlinearly interact with the ambient auroral plasma. This interaction is governed by a nonlinear Schrödinger equation for the EIC wave envelopes associated with nonlinear density and magnetic field perturbations. The finite amplitude theory of the modulation of EIC waves by Shukla and Tagare (1984) can then account for the observations in Mozer *et al.* (1997).

Let us now focus on the particle acceleration that is produced by the ponderomotive force of the nonlinear EIC waves. Previously we have considered ion acceleration by the ponderomotive force of electromagnetic ion-cyclotron waves (Shukla *et al.*, 1996). Similarly, ion acceleration

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$m_i d_t \mathbf{v}_i$ is also produced by the ponderomotive force $\mathbf{F}=\mathbf{F}_\perp+\hat{\mathbf{z}}F_\parallel$ of the present localized EIC were structures. For our purposes, we have for the perpendicular (to $\hat{\mathbf{z}}$) and parallel components of the EIC ponderomotive force

$$\mathbf{F}_\perp = -\frac{e^2}{m_i(\omega^2-\omega_{ci}^2)}\left(\nabla_\perp + \frac{\omega_{ci}}{\omega}\hat{\mathbf{z}}\times\nabla\right) \cdot\left(\frac{\omega^2}{\omega^2-\omega_{ci}^2}|\mathbf{E}_\perp|^2+(1+\sigma)|\mathbf{E}_\parallel|^2\right), \quad (1a)$$

and

$$F_\parallel = -\frac{e^2(1+\sigma)}{m_i\omega^2}\nabla_\parallel\left(\frac{\omega^2}{\omega^2-\omega_{ci}^2}|\mathbf{E}_\perp|^2+(1+\sigma)|\mathbf{E}_\parallel|^2\right), \quad (1b)$$

where e is the magnitude of the electron charge, m_i the ion mass, ω the frequency of the EIC wave, ω_{ci} the ion gyrofrequency, $\sigma=T_i/T_e$ the ratio between the ion and electron temperatures, and $\mathbf{E}_\perp$ and $\mathbf{E}_\parallel$ the perpendicular and parallel components of the electric field vector of the EIC wave, respectively. Here, the $\perp$ and $\parallel$ indices refer to directions perpendicular and parallel to the geomagnetic field lines. We note that Eq. (1) has been derived by averaging the ion advection nonlinearity over the EIC wave period with the perpendicular and parallel ion fluid velocities due to the EIC wave fields. It follows that the ponderomotive force accelerates both the ions and the electrons parallel and perpendicular to the geomagnetic field lines, as an ambipolar electric field is built up due to the charge separation effect. For electric fields of the order of one tenth V/m and EIC wavelengths comparable to the ion gyroradius, the ion energies can be of the order of several hundreds eV over characteristic acceleration lengths of a few kilometers. Thus, we have offered a physical mechanism for the generation of the nonlinear EIC wave structures and the associated charged particle acceleration in the auroral region.

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