ELECTROSTATIC TURBULENCE INSIDE COHERENT ALFVÉNIC STRUCTURES IN THE AURORAL IONOSPHERE

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Abstract. Coherent Alfvénic structures observed by the FAST satellite in the topside auroral ionosphere (at 1000 km altitudes) as large-amplitude nonlinear signatures in the electric field and magnetic-field-aligned current on the transverse scales of ~10^2-10^3 m are evaluated by the theories of electrostatic wave generation in inhomogeneous equilibrium configurations. A quantitative analysis shows that in addition to inhomogeneous energy-density-driven (IEDD) waves of EIC type, such structures are capable of destabilizing oblique ion acoustic (IA) waves modified by a shear in the parallel drift of ions. It is demonstrated that the dominating branch of the electrostatic turbulence is determined by the interplay of various driving sources inside a particular coherent structure. The sources do not generally act in unison, so that their common effect may be inhibiting for excitation of electrostatic waves of a certain type. In the presence of large magnetic-field-aligned current, which is not correlated to the inhomogeneous electric field inside the structure, the ion-acoustic branch becomes dominating. In other cases, the transverse-velocity-shear modified EIC branch is more central.

1. Introduction

High-resolution satellite and rocket measurements in the topside auroral ionosphere often indicate nonlinear coherent structures in the electric field and magnetic-field-aligned current, sometimes accompanied by variations in a plasma density. Their scale sizes transverse to the ambient magnetic field $\boldsymbol{B}_0$ cover the range from electron inertial length ($\lambda_e \sim 10^2$ m) to a few km. The structures are usually interpreted in terms of non-linear evolution of dispersive Alfvén waves. It is well known that Alfvénic coherent structures are filled with the electrostatic turbulence, increasingly dominating the measurements with frequency growth. Two points, regarding the theory of this turbulence, remain unclear. One is the source (or sources) of free energy which drives the turbulent emissions, the other is the branch of the turbulence (its identification from spacecraft data is controversial). In the present study we perform a quantitative analysis of electrostatic turbulence generation inside coherent structures in order to examine a relative importance of various sources of free energy, as well as to clarify if different branches can dominate the turbulence under different conditions.

2. Evaluation of space-observed coherent structures by the theories of electrostatic wave generation in an inhomogeneous plasma

Coherent structure 1 encountered by the FAST satellite in the afternoon auroral zone is shown in Figure 1.

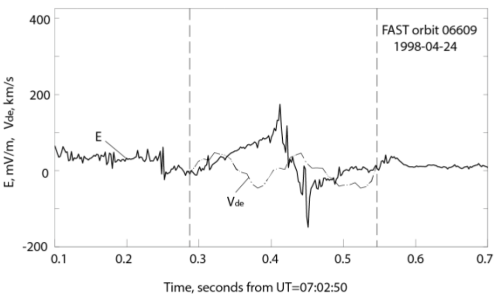

Fig.1. Coherent structure 1 observed by the FAST satellite. The transverse electric field is plotted as a solid line and the parallel drift velocity of electrons V_{de} by the dashed-dotted line. The dashed lines mark the borders of the structure.

Strongly inhomogeneous electric field E inside the structure implies shears in the velocity $V_E = E \times B_0$, which can be effective in exciting inhomogeneous energy-density-driven (IEDD) waves, according to the mechanism proposed by Ganguli et al.[1,2,3] The unstable ($\gamma>0$) solutions of the nonlocal dispersion relation for the IEDD waves of EIC type, with coherent structure 1 (Fig.1) considered as the equilibrium configuration, are shown in Fig.2.

The solutions were obtained for $\mu=m_i/m_e=29392$ (O^+ plasma), $\tau=T_i/T_e=1$, $u \equiv k_\parallel/k_\perp = 0.1$, and $\omega_r = 0.93, 0.94, 0.95$. In Fig.2 $b \equiv (k_y^2\,\rho_i^2)/2$.

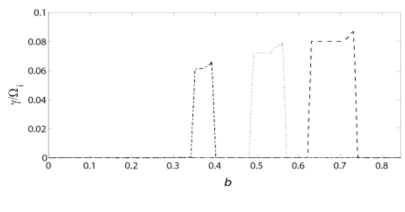

Fig.2. IEDD solutions for structure 1.

To clarify the effect of the field-aligned current inside structure 1 on the unstable solutions for IEDD waves, we repeated the calculations with preserving only inhomogeneous electric field inside the structure (the parallel drift of electrons V_{de} was set to zero) and did not find any appreciable difference from the case illustrated in Fig.2. This implies that structure 1 is effective in driving the IEDD waves entirely due to the inhomogeneous electric field. We also found that structure 1 appears ineffective in excitation of the ion-acoustic waves because the parallel drift of electrons is too low.

We come to the conclusion that solely IEDD waves can be excited inside structure 1, the inhomogeneous transverse electric field being the major source of free energy.

Unlike previous structure, coherent structure 2 observed by FAST in the dayside cusp (a closeup is presented in Fig. 3) is embedded in a density depletion shown by the long-dashed line in Fig. 3. The plasma density n_0 decreases by factor of ~5 toward the center of the structure from n_0 = 2.2·10^9 m^{-3} at its edges. This results in an increased drift of electrons V_{de} inside structure 2.

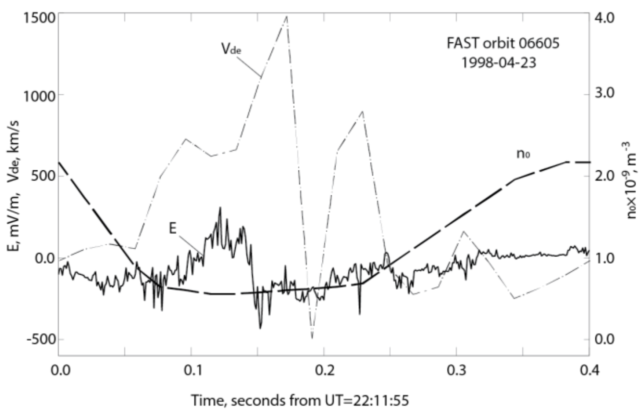

Fig.3. Structure 2 observed by the FAST satellite in the dayside cusp inside a density depletion. The density variation is indicated by the long-dashed line.

A key feature of structure 2 is that it contains intense inhomogeneous field-aligned current (with parallel drift of electrons V_{de} reaching more than 400 km/s), which is not in phase with the *E*-field (Fig. 3).

In such a case, a common effect of electric field and parallel drift of electrons is inhibiting for IEDD wave excitation, as can be seen from a comparison of Fig. 4a, where in evaluating structure 2 only *E*-field was taken into account, and Fig. 4b, where both *E* and V_{de} were included. While excitation of transverse-velocity-shear-assisted EIC-like waves is inhibited inside structure 2 (see Fig.4), this coherent structure is effective in destabilizing oblique IA waves modified by shear in the parallel drift of ions[4], if one assumes that a fraction of field-aligned currents associated with the structure is carried by thermal ions.

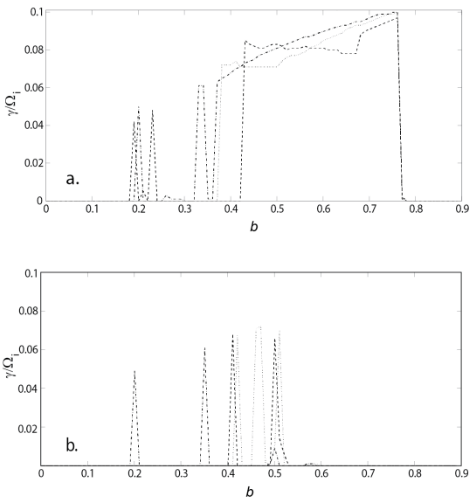

Fig.4. Degeneration of unstable solutions for IEDD waves inside coherent structure 2 shown in Fig.3: solutions (a) with only inhomogeneous *E* included, and (b) with both *E* and V_{de} included. The dashed line refers to the real frequency ω_r = 0.93, dotted line to ω_r = 0.94, dashed-dotted line to ω_r = 0.95. The values of the free parameters are the same as previously adopted.

Fig. 5 shows the observed values of $\left|V'_{di}\right|$ normalized by Ω_i (the O^+ gyrofrequency is ~ 30 Hz in the FAST environment) under the assumption that the fraction of the field-aligned current carried by ions is 10^{-3}. It is shown in Ref.[4] that for such values of $\left|V'_{di}/\Omega_i\right|$ the critical electron drift for the oblique ion-acoustic waves is low (by more than an order of magnitude lower than that inside structure 2) and nearly insensitive to the variation of τ in the range 10^{-1}-10^{1}. Another remarkable feature of the ion-acoustic waves in the presence of $\left|V'_{di}/\Omega_i\right| \neq 0$ is their broadband character[4], which is consistent with observations in the auroral zone.[5]

We conclude that the ion-acoustic branch is likely to dominate the electrostatic turbulence inside coherent structure 2.

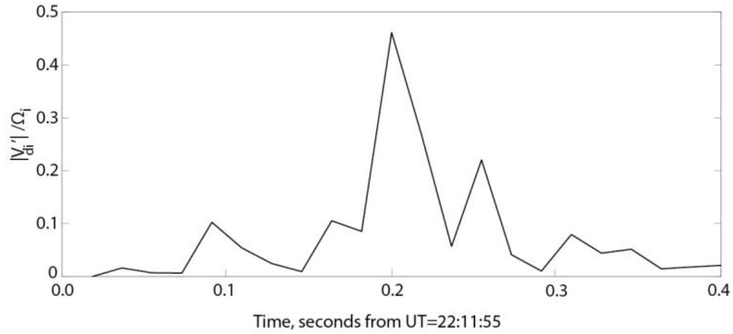

Fig.5. The values of $\left|V_{di}^{'} / \Omega_i\right|$ inside structure 2 shown in Fig. 3 under the assumption that the thermal ions carry 10^{-3} of the field-aligned current associated with the structure.

3. Summary

We have provided a quantitative analysis of Alfvénic coherent structures, i.e., large-amplitude nonlinear signatures with ~ 0.1-1 s duration in the spacecraft frame at about 1000 km altitude in the auroral zone, for the ability to destabilize electrostatic turbulence due to various sources of free energy that such structures contain. It is shown that the presence inside Alfvénic coherent structures of electrostatic emissions (which are broadband and persistent to elevated T_i/T_e ratios, contrary to the predictions of the classical theory[6]), can be understood on the basis of the existing theories of electrostatic wave generation in inhomogeneous equilibrium configurations. On the whole, the coherent structures are effective in destabilizing the transverse velocity-shear-assisted EIC-like (or IEDD) waves, as well as ion-acoustic waves modified by shear in the parallel drift of ions. The observational fact that different branches may dominate the electrostatic turbulence in different conditions can be explained by the interplay of various destabilizing factors inside a particular structure. Thus a large magnetic-field-aligned current, especially in combination with a background density depletion, suggests that the ion-acoustic branch is dominating. In case of small or moderate parallel currents, the IEDD instability is more central. To complete this exposition, we refer to our recent studies[7,8,9] where the physics of coherent Alfvénic structures and of associated electrostatic turbulence is considered more in detail.

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