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Space-Plasma Campaign on stationary inertial Alfvén waves

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For cold, collisionless, the stationary inertial Alfvén wave can accelerate electrons parallel to a background magnetic field and cause large, time-independent plasma-density variations having spatial periodicity in the direction of the convective flow over a broad range of spatial scales and energies plasma [1]. These fundamental properties of the stationary inertial Alfvén wave may play a role in the formation of discrete auroral multiple arcs. Experimentally, an off-axis, fixed channel of electron current (and depleted density) is created in the Large Plasma Device Upgrade at UCLA while the surrounding larger plasma column rotates about its cylindrical axis. A variety of diagnostic methods are employed to study plasma equilibrium and stability. We use a small, heated, oxide-coated electrode at one plasma-column end and we show that the larger plasma column rotates about its cylindrical axis from a radial electric field imposed by a special termination electrode on the same end. We show that both launched and spontaneously arising inertial Alfvén waves concentrate in this off-axis electron current channel, consistent with predictions. We observe the expected stationary wave pattern.

The stationary inertial Alfvén (StIA) wave [1] is a nonfluctuating, nontraveling electromagnetic pattern in perturbed electric field, perturbed magnetic field, perturbed plasma density, perturbed ion flow and perturbed electron flow. This pattern has zero time dependence except for that associated with any inherent slowly evolving plasma conditions. The free energy of StIA waves is magnetic-field-aligned (s-direction) electron drift energy that overcomes collisional dissipation and collisionless phase mixing. The wave pattern is purely spatial and represents an equilibrium solution analogous to a spatially driven spatial oscillator. The StIA wave vector is approximately perpendicular to the magnetic field, a case for which electron-inertia effects become significant.

To understand the StIA wave, one must transform to the laboratory frame of reference from the plasma-convection frame, rather than transform into a frame that moves at the phase speed which does not exist for a stationary pattern. The historical root of the StIA wave is the papers by Maltsev et al. [2] and Mallinckrodt and Carlson [3], whereas the historical root of the dispersive inertial Alfvén wave [4] is the paper by Goertz and Boswell [5]. Whereas the dc parallel electric field of the StIA wave may accelerate electrons having speeds on the order of the Alfvén speed to higher speeds on the order of 50 times the Alfvén speed, the velocity-space resonance associated with dispersive Alfvén waves inherently limits the maximum attainable electron velocity to speeds on the order of twice the Alfvén speed [1].

Magnetized plasma can support non fluctuating, non traveling electromagnetic perturbations in an Earth- fixed frame if there is dc magnetic-field-aligned electron current and uniform background plasma convection. Such a stationary pattern should not be confused with standing waves that oscillate in time within a stationary envelope. A stationary wave has no time variation in the Earth-fixed frame. In the plasma-convection frame, there is an apparent propagation speed. The laboratory experiment is designed to subject an off-axis, fixed channel of electron current (and depleted density), created using a small mesh anode or heated, oxide-coated electrode at one plasma-column end, to plasma convection from the plasma column rotating about its cylindrical axis. This rotation is a result of the E×B drift due to a radial electric field imposed by differentially biased, concentric, annular end segments at the same plasma-column end as the mesh anode.

As with the inertial Alfvén wave, the StIA wave carries a cross-field ion polarization current closed by an electron-dominated field-aligned current. Knudsen's model has been generalized to include the effects of electron and ion collisional resistivity, as well as non-zero thermal pressure [6, 7]. The generalized model describes the stationary Alfvén (StA) wave in both the inertial and kinetic regimes, and is capable of making predictions of StA wave signatures in laboratory plasma. The set of coupled nonlinear differential equations describing the StA wave [7] are solved numerically for plasma parameters typical of the plasma afterglow (remnant plasma after the main discharge current is terminated) in the LAPD, *c.f.* Table 1 in Finnegan et al. [7].

We have assumed, for nearly perpendicularly propagating StA waves, that the balancing of the parallel component of electric field is governed primarily by the parallel electron dynamics. With this assumption, the parallel component of the electric field is calculated from the parallel component of the electron momentum equation. The parallel component of electric field is balanced by electron inertia, parallel resistivity, and parallel electron thermal pressure.

The LArge Plasma Device upgrade [8] produces a high density, magnetized plasma via a pulsed anode-cathode discharge. The experiment is described in terms of a Cartesian coordinate system (x,y,z) whose origin is located at the center of the plasma-producing anode, with the z-axis being aligned with the magnetic-field-aligned cylindrical plasma column. Note that the disk electrode is concentric with the LAPD cylindrical axis and that the mesh-anode electrodes axis of symmetry is paraxial (7.5 cm shifted) to this cylindrical axis. In this way, E × B convection, caused by the disk electrode, will be azimuthal and the electron drift, caused by the mesh-anode electrode, will be longitudinal. The segmented disk electrode, with inner radius of the innermost disk is 5.2cm and outer radius of the outermost disk is 14.5cm, is centered on the cylindrical axis of the plasma column. The perpendicular ion drift maximizes in the region of the multiple-segment disk electrode.

Time-stationary structure is evident in the two-dimensional map of longitudinal ion drift. This structure is confined to the current channel and appears reproducibly at a specific time in the plasmas afterglow decay, presumably upon the transition from the kinetic Alfvén-wave regime to the inertial Alfvén-wave regime, without launching of waves. Spatially periodic structuring of the ion current (plasma density) is apparent within the boundaries of the current channel. The wavelength of this structure is approximately 1.2 cm which corresponds to the prediction. Prior to the initialization of the parallel current, the ion current collected at these two locations is the same. When the parallel current is turned on, the ion current is restructured spatially, decreasing the value of ion current measured at the trough relative to the ion current measured at the crest. The measured ion current at these two spatial locations resumes being the same when both the parallel current and plasma rotation are turned off. These experimental results are recently published by Koepke [9].

Conclusion

Sub-Alfvénic E×B flow is produced by a multi-segment disk electrode in the Large Plasma Device Upgrade (LAPD-U) at UCLA. Launched Alfvén waves concentrate within a cylindrical channel of partial plasma-density depletion. When electron current, density depletion, and cross-field convection are combined, time- stationary, self-excited, structure is apparent in the perturbed-plasma quantities.

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