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Shear Alfvén waves in nonuniform plasmas at the U.S. Basic Plasma Science Facility

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The assumption of an ‘infinite, uniform plasma’ is ideal for understanding the basic properties of plasma waves; however, (even in space) such waves eventually encounter a boundary or other nonuniformity. Properly scaled laboratory experiments can therefore provide valuable insight for such cases. The shear Alfvén wave, for example is a fundamental, plasma mode that communicates low-frequency changes in magnetic field topology; it can also energize both ions and electrons since it possesses electric field components both perpendicular and parallel to the ambient magnetic field. In the Large Plasma Device (LAPD) [1] at UCLA’s Basic Plasma Science Facility, shear Alfvén waves are routinely studied under highly reproducible and specifically tailored plasmas. The device features a cylindrical vacuum chamber (L=20m, r=0.5m). Plasmas are generated using thermionically emitting, cathode-anode discharges. Two cathodes are installed on opposite ends of the device. One is an oxide-coated nickel sheet (r=37cm) and the other is a LaB_6 (20x20cm) design. The two sources may be used separately or together. The pulsed (1-20ms) plasmas are created using hydrogen or noble gasses at densities ranging from $10^{11} < n < 10^{13}$ cm^{-3}. The confining magnetic field can be tailored using 11 independent power supplies for a variety of field configurations with magnitudes of $100 < B_0 < 2500$ G. Electron and ion temperatures have respective ranges of $0.1 < T_e < 12$ eV and $\sim 1 < T_i < 5$ eV. Plasma discharges are repeated every second for as long as four months. Such operation allows for the collection of large, ensemble datasets (using a variety of probes) with either a large parameter variation or very detailed 3D spatial resolution using computer-controlled probe drives.

In magnetized plasmas, spatial nonuniformities may be grouped as occurring in the direction either parallel or perpendicular to the background magnetic field. Two experiments are presented here to illustrate the properties of shear wave propagation in each case.

In the first experiment, the perpendicular propagation of a launched shear wave is followed from the relatively hot, dense core plasma to the cold radial boundary. In this case, the wave travels from a regime where the local ratio of Alfvén speed to the electron thermal speed is greater than unity to where it is less than unity. Several important changes of the wave physics are measured that are relevant to naturally occurring waves propagating from the earth’s equatorial magnetosphere to the ionosphere. The first is the generation of short perpendicular wavelengths via the radial gradient in the Alfvén speed (see Fig. 1), which is predicted to lead to increased parallel electric fields; the second is a pileup of wave energy near the parallel Landau resonance layer due to an overlapping zero crossing in the perpendicular group velocity [2]. The implications of this work to the acceleration of electrons of the so-called Alfvénic aurora are discussed.

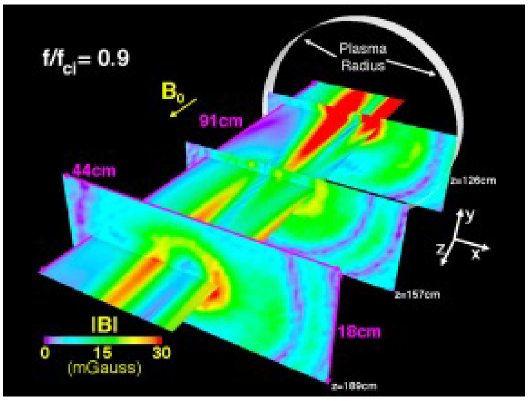

Figure 1. Instantaneous magnetic field amplitude of a shear Alfvén wave, revealing the three-dimensional wave structure.

The second experiment involves the parallel nonuniformity. In a two-ion-species plasma, the shear Alfvén wave propagates in two distinct bands: one below the gyrofrequency of the heavier ion, and one below the lighter ion gyrofrequency, but above the well-known ion-ion hybrid frequency: ω_{ii}. This latter frequency depends on the background magnetic field and the concentration ratio of the two ion species. Inspired by satellite observations, Rauch and Roux [3] used raytracing analysis to postulate that multiple reflections of Alfvén waves could occur in the earth’s dipole where $\omega=\omega_{ii}$. The concept of an ion-ion hybrid resonator was demonstrated in the LAPD using a “magnetic well” configuration, as shown in Fig. 2. The parallel propagation of these waves undergos a cutoff at $\omega=\omega_{ii}$, and discrete modes in frequency were measured. The concentration ratio of the two species was varied and the number and location of the modes were in general agreement with the theoretical values obtained using an analytic model of the system [4].

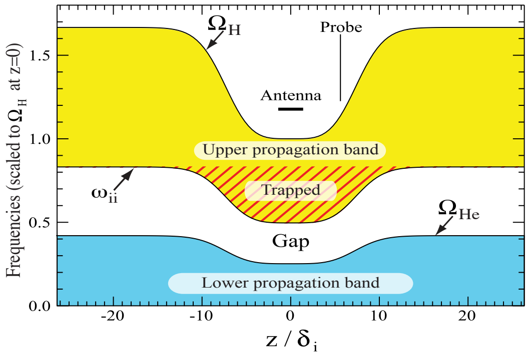

Figure 2. Axial “magnetic well” for trapping shear Alfvén waves in a H^+/He^+ plasma, as described in the text. Distance is scaled to the ion inertial length.

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