SPACE-RELEVANT LABORATORY STUDIES OF ELECTROSTATIC ION-ACOUSTIC WAVES DRIVEN BY INHOMOGENEITY IN THE FIELD-ALIGNED CURRENT

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ABSTRACT

Oblique ion-acoustic waves, excited by the combination of magnetic-field-aligned (parallel) electron drift and sheared parallel ion flow, are investigated in magnetized laboratory plasma that is characterized by ion-temperature anisotropy. Direct measurements of the parallel and perpendicular ion temperatures, ion drift velocities, electron temperature and drift velocity, wavevector components, and mode frequency and growth rate are used to elucidate the shear-modified ion-acoustic instability mechanism and document an observed correlation between ion-temperature anisotropy and wave-propagation angle. Experimental measurements show that anisotropy significantly influences the growth rate and propagation angle of oblique ion-acoustic waves.

INTRODUCTION

Broadband, ion-acoustic waves propagating 0° to 60° to the magnetic field are seen [1] in the ionosphere where the ion-electron temperature ratio is unity. Explaining these waves with homogeneous-plasma theory requires this ratio to be lowered to an unrealistic value of 0.33, otherwise ion Landau damping dominates electron Landau growth. A parallel-velocity shear mechanism that shifts the ion-acoustic phase velocity out of the strongly ion Landau-damped regime has been described [2] using a kinetic model for a current-carrying inhomogeneous plasma. The frequency and consequently the phase velocity shift by a factor involving shear, wavevector obliqueness, and ion gyrofrequency.

RESULTS

Our experiment is performed in a double-ended Q machine. The ion distribution parallel to the magnetic field is measured directly, non-perturbatively, and precisely by laser-induced fluorescence. Electron parallel-velocity shear is zero and consequently the ion shear in the electron frame $(dv_{di}/dx)_e$, the electron shear in the ion frame $(dv_{de}/dx)_i$, and the ion shear in the lab frame dv_{di}/dx have identical values. In the presence of negative parallel-velocity shear, ion-acoustic waves arise spontaneously with $k_z v_{de} > 0$ and $0<|\omega_R/k_z v_{de}|<1$, as expected for a wave driven by electron Landau growth, and with positive k_z/k_y and negative $k_y(dv_{di}/dx)/(k_z\omega_{ci})$, as required for these shear-modified ion-acoustic (SMIA) waves. We document the validity of the instability mechanism with the following measurements [3]: the ion distribution function [for obtaining knowledge of the inhomogeneous profile of ion drift velocity $v_{di}(x)$], the ion parallel-velocity shear dv_{di}/dx relative to the electrons [for quantifying the phase-velocity shift], the Doppler shift $k_z v_{di}$ [for recognizing the mode frequency and wave phase velocity in the ion frame], small and large values of propagation angle [for demonstrating the role of the phase-velocity shift], and the growth rate [for connecting the observed wave with a linear description of an instability mechanism].

DISCUSSION

The growth rate is shown to increase with increasing shear, as predicted, and wave propagation is shown to be possible 20°-60° to the magnetic field, consistent with space observations. A correlation observed between large values of k_z/k_y (=2.2) and large values of T_{iy}/T_{iz} (=2.4) can be understood simply by requiring the wave phase velocities in the two directions to exceed by the same percentage the ion thermal speeds associated with the two directions, leading to k_z/k_y being related to T_{iy}/T_{iz} [4]. The significance of this experimental verification is the potential of this instability mechanism to explain several unresolved aspects of the broadband waves that are responsible for the most common and most intense ion heating in the ionosphere. At higher frequencies ($\omega \approx n\omega_{ci}$), a related shear mechanism is responsible for exciting ion-cyclotron waves by reducing ion-cyclotron damping (the n>0 manifestation of Landau damping) [5].

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