Observation of Multi-Harmonic Electrostatic Ion-Cyclotron Waves in the Presence of Inhomogeneous Parallel Ion Flow

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Abstract

Generation of broadband multi-harmonic spectra of electrostatic ion-cyclotron waves is demonstrated in magnetized laboratory plasma in which shear in the magnetic-field-aligned (parallel) ion flow and a relative parallel electron drift are present. Shear correlates with increased number of harmonics and decreased electron drift speed. Wave and particle measurements indicate that cyclotron damping is reduced and even becomes negative. The fluctuations in the time domain are spiky, similar to electric-field fluctuations observed both in the Earth's auroral zone and in numerical simulations.

The ion-cyclotron resonance can support one of the most important oscillating modes in magnetized plasma and can be exploited to efficiently transfer energy from electric or magnetic field fluctuations to the ions. The discovery long ago of unstable ion-cyclotron waves represents a major advance in plasma physics. Recently, multiscale coherent structures and broadband waves observed by the Fast Auroral Snapshot (FAST) satellite have been interpreted with a new mechanism for exciting electrostatic ion-cyclotron waves [1, 2]. This mechanism requires inhomogeneity in the magnetic-field-aligned (parallel) drift velocity of the ions. The mechanism involves inverse ion-cyclotron damping, parallel-velocity shear and inverse electron Landau damping.

We demonstrate in a Q machine the generation of broadband multi-harmonic spectra (up to eleven harmonics) of electrostatic ion-cyclotron waves in magnetized laboratory plasma in which positive shear in the ion parallel drift velocity is present. We use a nonperturbative technique for determining directly the ion parallel-velocity and temperature by means of laser induced fluorescence. We show that shear reduces significantly ion-cyclotron damping and, in some cases, induces inverse ion-cyclotron damping. As predicted by the model, we measure that the ion-cyclotron damping reduces and the number of harmonics increases with increasing shear and with decreasing perpendicular wavelength. Inverse electron Landau damping also contributes to wave growth, as evidenced by the wave parallel phase velocity being measured to be in the same direction as and smaller than the electron drift velocity. A number of measured characteristics are very different from the current-driven electrostatic ion-cyclotron waves in homogeneous plasma [3]. For example, the mode frequency can be up to 9% below the ion cyclotron frequency, the square of the product of the perpendicular wavevector component times the ion gyroradius is very close to unity, the azimuthal mode number is three, and the excitation threshold is significantly lower. In the presence of negative shear, the waves cannot be excited. These observations are consistent with the effect of the shear on the waves as predicted by the model. The ratio of ion perpendicular and parallel temperatures, in the presence of the waves, is found to be between 1 and 2. At frequencies much lower than the ion-cyclotron frequency, a related ion parallel-velocity shear mechanism is responsible for exciting shear-modified ion-acoustic waves by reducing the ion Landau damping (the $n = 0$ manifestation of the ion-cyclotron damping). The fluctuations in the time domain of the multi-harmonic ion-cyclotron waves are spiky, similar to electric field fluctuations observed in the Earth's auroral zone and in numerical simulations. These results may be relevant to observations of strong inhomogeneities in parallel current in the Earth's auroral region.

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References:

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