Observations and Theory of Mode-Converted Ion Bernstein Waves in the Alcator C-Mod Tokamak

by

Eric Alan Nelson-Melby

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Abstract

This thesis discusses experimental observations and the theory of mode-converted ion Bernstein waves (IBW) in the Alcator C-Mod tokamak. IBWs are short-wavelength, hot plasma oscillations that can be excited in the core of the plasma through mode conversion of an externally launched fast magnetosonic wave (FW). The balance between ion cyclotron damping of the FW and mode conversion to an IBW as a function of minority ion species concentration is explored. In the mode conversion regime, with appropriate plasma parameters, significant amounts of power can be transferred to the IBW, which can then damp on electrons, producing localized electron heating, current profile control, and current drive. Observations of electron heating in deuterium–helium-3 plasmas at 7.8 Tesla are discussed and compared to theory and full-wave code modeling. An analytic theory based on the internal resonator model [A.K. Ram, et al., Phys. Plasmas, 3, 1976 (1996)] for mode conversion compares favorably with the experimentally measured mode-conversion efficiency, as do the results of the full-wave code TORIC [M. Brambilla, Plasma Phys. Controlled Fusion, 41, 1 (1999)]. This thesis also presents direct observations of IBW oscillations, before damping takes place. Measurements are presented of the density fluctuations driven by the wave electric field near mode conversion in three ion species (hydrogen, helium-3, and deuterium) plasmas. This has been achieved with a newly upgraded Phase Contrast Imaging (PCI) diagnostic, which is now able to detect radio-frequency waves through the use of optical heterodyning. The PCI system in C-Mod measures line-integrated density fluctuations using a CO$_2$ laser which passes vertically through the plasma. The density fluctuation pattern is an inherently 3-dimensional structure, so the full-wave code TORIC has been used to interpret the one-dimensional measurements, which have some unexpected features, such as multiple peaks and troughs in amplitude. Strong IBW signal was often observed to the low-field side of the mode conversion layer. The importance of the parallel electric field for these IBW density fluctuation measurements is identified. IBW wavenumbers from 5 to 12 cm$^{-1}$ have been detected, which is within the range of the code results.
Thesis Supervisor: Miklos Porkolab
Title: Professor of Physics
Director, Plasma Science and Fusion Center