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Parametric Instabilities of Alfvén Waves in the Laboratory: Connecting Theory and Experiment on LAPD

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Akira Hasegawa's pioneering work laid the theoretical foundation for understanding the nonlinear dynamics of Alfvén waves, including the development of parametric instability theory for finite-amplitude waves. In this talk, I will present a series of laboratory experiments that directly test theories for parametric instability. The Basic Plasma Science Facility (BaPSF) at UCLA is a US national collaborative research facility for studies of fundamental processes in magnetized plasmas. The centerpiece of the facility is the Large Plasma Device (LAPD), a 20m long, magnetized linear plasma device[1]. LAPD has been utilized to study a number of fundamental processes, including: collisionless shocks, dispersion and damping of kinetic and inertial Alfvén waves, compressional Alfvén waves for ion-cyclotron range of frequencies heating, flux ropes and magnetic reconnection, three-wave interactions and parametric instabilities of Alfvén waves, turbulence and transport and interactions of energetic ions and electrons with plasma waves. An overview of research using the facility will be given, followed by a more detailed discussion of experiments studying nonlinear processes relevant to parametric instabilities of shear Alfvén waves. First, the first laboratory observation of the Alfvén-acoustic mode coupling at the heart of the Parametric Decay Instability[2] will be discussed. This study is conducted by launching counter-propagating Alfvén waves from antennas placed at either end of the LAPD. A resonance in the beat wave response produced by the two launched Alfvén waves is observed and is identified as a damped ion acoustic mode based on the measured dispersion relation. Other properties of the interaction including the spatial profile of the beat mode and response amplitude are also consistent with theoretical predictions for a three-wave interaction driven by a nonlinear ponderomotive force. Second, experiments will be discussed that have resulted in the first laboratory observation of the parametric instability of shear Alfvén waves[3]. Shear waves with sufficiently high $\omega/\Omega_{c,i}$ (> 0.6) and above a threshold wave amplitude are observed to decay into co-propagating daughter waves; one is a shear Alfvén wave and the other a low-frequency quasimode. The observed process is parametric in nature, with the frequency of the daughter modes varying as a function of pump wave amplitude. The daughter modes are spatially localized on a gradient of the pump wave magnetic field amplitude in the plane perpendicular to the background field, suggesting that perpendicular nonlinear forces (and therefore $k_\perp$ of the pump wave) play an important role in the instability process. Despite this, modulational instability theory with $k_\perp = 0$ has several features in common with the observed non-resonant mode and Alfvén wave sidebands.

References

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