Excitation of discrete and broadband whistler waves in a laboratory plasma

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Whistler mode chorus emissions with a characteristic frequency chirp largely control the dynamic variability of the Earth's outer radiation belt. They are responsible for the acceleration of outer radiation belt electrons to relativistic energies and also for the scattering loss of these electrons into the atmosphere. Here, we report on the first laboratory experiment where whistler waves exhibiting fast frequency chirping have been artificially produced using a gyrating beam of energetic electrons injected into a cold plasma. It is shown that there is an optimal beam density for frequency chirps, which indicates the existence of optimum wave amplitude for the generation of chirps. Also, frequency chirps only occur for a very narrow range of ratio of f_{pe}/f_{ce}, similar to that observed in space. Strong magnetic field gradient, which prohibits the formation of phase space electron hole, disrupts frequency chirps as expected. Broadband whistler waves similar to magnetospheric hiss are also observed at relatively high plasma density. Their mode structures are identified by the phase-correlation technique. It is demonstrated that broadband whistlers are excited through Landau resonance, cyclotron resonance and anomalous cyclotron resonance. The dominant wave mode excited through cyclotron resonance is nearly parallel-propagating, whereas wave modes excited through Landau resonance and anomalous cyclotron resonance can propagate at oblique angles that are close to the resonance cone. An analysis of the linear wave growth rates captures the major observations in the experiment. Preliminary particle-in-cell simulation captures the linear theory prediction of broadband whistlers and also gives important information on the evolution of electron distribution function.