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First direct observation of runaway electron-driven whistler waves in tokamaks[1]

DONALD A. SPONG, Oak Ridge National Laboratory

Whistlers are electromagnetic waves that can be driven unstable by energetic electrons and are observed in natural plasmas, such as the ionosphere and Van Allen belts. Recent DIII-D experiments at low density demonstrate the first direct observation of whistlers in tokamaks, with 100-200 MHz waves excited by runaway electrons (REs) in the multi-MeV range. Whistler activity is correlated with RE intensity and the frequencies scale with magnetic field strength and electron density consistent with a whistler dispersion relation. Fluctuations occur in discrete frequency bands, and not a continuum as would be expected from plane wave analysis, suggesting the important role of toroidicity. An MHD model including the bounded/periodic nature of the plasma identifies multiple eigenmode branches. For a toroidal mode number $n = 10$, the predicted frequencies and spacing are similar to observations. The instabilities are stabilized with increasing magnetic field, as expected from the anomalous Doppler resonance. The whistler amplitudes show intermittent time variations. Predator-prey cycles with electron cyclotron emission (ECE) signals are observed, which can be interpreted as wave-induced pitch angle scattering of moderate energy REs. Such nonlinear dynamics are supported by quasi-linear simulations indicating that REs are scattered both by whistlers and high frequency magnetized plasma waves. The whistler wave predominantly scatters the high energy REs, while the magnetized plasma wave scatters the low energy REs, abruptly enhancing the ECE signal. Amplitude variations are also associated with sawtooth activity, indicating that the REs sample the $q = 1$ surface. These features of the RE-driven whistler have connections to ionospheric plasmas and open up new directions for the modeling and active control of tokamak REs.

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