6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Experimental comparison of ion cyclotron emission in stellarator, tokamak, and space plasmas

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Ion cyclotron emission (ICE) is ubiquitously observed at integer harmonics of the cyclotron frequency of fast ions present in magnetic fusion devices such as tokamaks and stellarators. Due to the ease of detection, ICE has the potential to serve as a passive fast ion diagnostic suitable for harsh burning plasma environments, so long as this collective instability is sufficiently well understood. Similar fluctuations, known as "equatorial noise," have been measured at multiples of the proton cyclotron frequency in Earth's magnetosphere. Consequently, fusion experiments provide an excellent laboratory for studying this naturally occurring space plasma phenomenon in a controlled environment.

To this end, dedicated experiments have been performed on the LHD stellarator and DIII-D tokamak to determine the sensitivity of ICE to magnetic configuration, fast ion distribution and species (H and D), and fundamental plasma parameters including magnetic field strength, electron density, and the thermal ion species mix (H, D, and ^{3}He). Whereas ICE in DIII-D is observed uniformly on all toroidally-separated probes with dominantly compressional polarization, ICE in LHD exhibits a strong toroidal localization, indicating a major difference in eigenmode structure and propagation. In both tokamak and stellarator configurations, ICE is most commonly emitted near the plasma edge, though core emission is also possible in spherical tokamaks such as NSTX(-U) and L-mode DIII-D plasmas.

The saturated ICE amplitude dependence on plasma parameters is nuanced due to an array of intermittent behavior. Despite this challenge, the largest saturated ICE amplitudes are found to occur near $v_b/v_A \approx 0.6$, contrasting with theory which predicts the strongest instability when $v_b \approx v_A$. The presented similarities and differences between ICE in LHD and DIII-D further clarify the legitimacy of extrapolating from ICE observations in a lab setting to those naturally occurring in space.

*This work was supported by US DOE contracts DE-FC02-04ER54698 and DE-SC0022131.

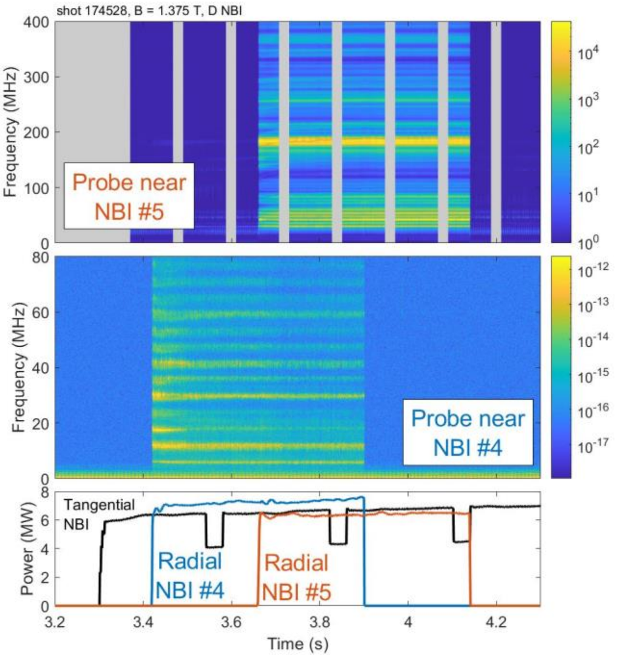

Figure 1. Power spectral density of ICE in LHD shot 174526, with D NBI and B = 1.375 T. Bottom: traces of injected neutral beam power. Middle: spectrogram from measurements with the fast magnetic probe (f < 100 MHz) located near NBI #4. Top: spectrogram from measurements with the RF antenna (f < 600 MHz) located near NBI #5.

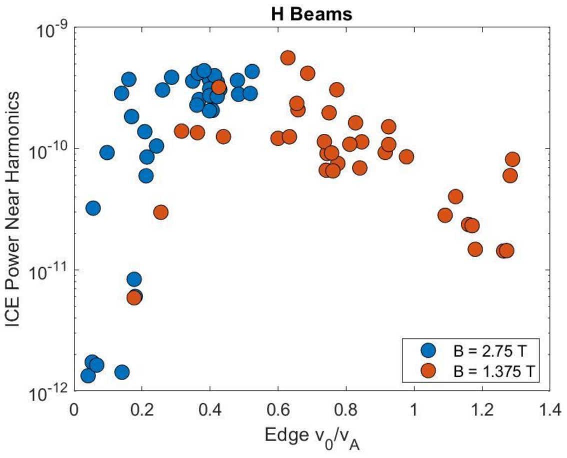

Figure 2. Dependence of ICE power on v_b/v_A evaluated near the edge. Each point averages over the portion of a shot when NB4 is fully on. The ICE power is evaluated as the sum of the power spectral density near the ion cyclotron harmonic peaks. The Alfvén speed is evaluated using the density and magnetic field on the outboard midplane at the effective radius that contains 99.9% of the plasma stored energy.