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Ion species mix, magnetic field, and distribution function dependence of instabilities in the ion cyclotron range of frequencies

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A Frontier Science experiment in the DIII-D tokamak explored the compressional Alfvén eigenmodes (CAEs) and coherent ion cyclotron emission (ICE) dependence on the plasma ion species mix, magnetic field strength, and energetic ion species and their phase space distribution. The results from this experiment advance understanding of energetic ion-driven instabilities in the radiation belts—electromagnetic ion cyclotron (EMIC) and "equatorial noise"—that resemble the CAEs and ICE seen in tokamaks. The flexible neutral injection beam capability of DIII-D was used to explore ten different combinations of energetic ion species and their phase space distributions. Energetic ion species included hydrogen (H+) and deuterium (D+), and the highly anisotropic distributions were varied in terms of the direction (co- vs. counter current), pitch (v||/v), energy (81/55 kV) and radial location (on- vs. off-axis) of the energetic ions at birth. The background plasma was D+ with H+ and helium (3He++) in different mixtures throughout the experiment. The instabilities of interest were measured using toroidal magnetic loops with a digitization range of 1–100 MHz. Spectroscopy, neutron rate, and toroidicity-induced Alfvén eigenmode (TAE) frequency were all used to determine the species mix of the plasma, as well as to cross-check calculation outputs.
The addition of H+ and 3He++ to the plasma introduces emission bands below their respective cyclotron frequencies reminiscent of those seen in H+, He+, and oxygen (O+) plasmas in space. Emission below the deuterium cyclotron frequency (fcD) has a higher dB amplitude for on-axis co-current D+ injection, magnetic fields at or below 1.25 T, and high concentrations of H+ in the thermal plasma. Low-energy, off-axis, and/or counter-current D+ injection and high magnetic field strengths are detrimental to this lower-frequency emission. Above fcD, 81 keV counter-current D+ injection produces the strongest emission, followed closely by high-energy on-axis injection. In this frequency range, increasing H+ in the plasma inhibits emission and magnetic field has no effect. The distribution functions that drive these instabilities are calculated by NUBEAM [A. Pankin, Comp. Phys. Comm. 2004]; compared with fast-ion D-⍰ (FIDA), imaging neutral particle analyzer (INPA), and neutron data; and analyzed for bump-on-tail features. The effects of species mix on the distribution function are considered.

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