Ion cyclotron emission from fusion-born ions in large tokamak plasmas: from JET and TFTR to ITER

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Understanding the physics of populations of energetic ions, born in fusion reactions between thermal ions, is central to the exploitation of magnetically confined plasmas. Ion cyclotron emission (ICE) was the first collective radiative instability, driven by confined fusion products, observed from deuterium-tritium plasmas in JET and TFTR (R O Dendy *et al., Nucl. Fusion* **35** 1733 (1995)). Suprathermal emission, with peaks at multiple ion cyclotron harmonic frequencies at the outer mid-plane edge, was detected using heating antennas as receivers on JET and with probes in TFTR. The measured intensity of ICE spectral peaks scaled linearly with measured fusion reactivity. In other large tokamak plasmas, ICE has been used in DIII-D as a diagnostic for lost fast ions (W W Heidbrink *et al*., *Plasma Phys. Control. Fusion* **53** 085028 (2011)) and has been studied in detail in ASDEX-U (R D'Inca *et al*., *Proc. 38th EPS Conf. Plasma Phys.* 2012 P1.053) and JT-60U (M Ichimura *et al*., *Nucl. Fusion* **48** 035012 (2008)). The excitation mechanism for ICE is the magnetoacoustic cyclotron instability (MCI), driven by a set of centrally born fusion products, lying just inside the trapped-passing boundary in velocity space, whose drift orbits make large radial excursions to the outer mid-plane edge (R O Dendy *et al*., *Phys. Plasmas* **1** 1918 (1994); S Cauffman *et al., Nucl. Fusion* **35** 1597 (1995)). Deep understanding of the MCI is therefore of great practical interest for fusion, and advances in computational plasma physics have led to substantial recent progress. Large particle-in-cell simulations of the MCI, with fully kinetic ions and electrons, were performed by J W S Cook *et al*., *Plasma Phys. Control. Fusion* **55** 065003 (2013), using plasma parameters for JET ICE observations. The hybrid approximation for plasma simulations, where ions are treated as particles and electrons as a neutralising massless fluid, was then applied by L Carbajal *et al*., *Phys. Plasmas* **21** 012106 (2014). These simulations corroborate predictions by linear analytical theory, and extend previous studies deep into the nonlinear regime of the MCI, strengthening further the link to ICE measurements. ICE is a potential diagnostic for alpha-particles in ITER, where measurements of ICE could yield information on energetic ion behaviour supplementing that obtainable from other diagnostics. In addition, it may be possible to use ICE to study fast ion redistribution and loss due to MHD activity in ITER. For example, clear evidence has been found of links between ICE and: sawteeth and ELMs in JET; fishbones in DIII-D; and TAEs in LHD.

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