Kinetic simulations of Ion Cyclotron Emission (ICE) in plasmas

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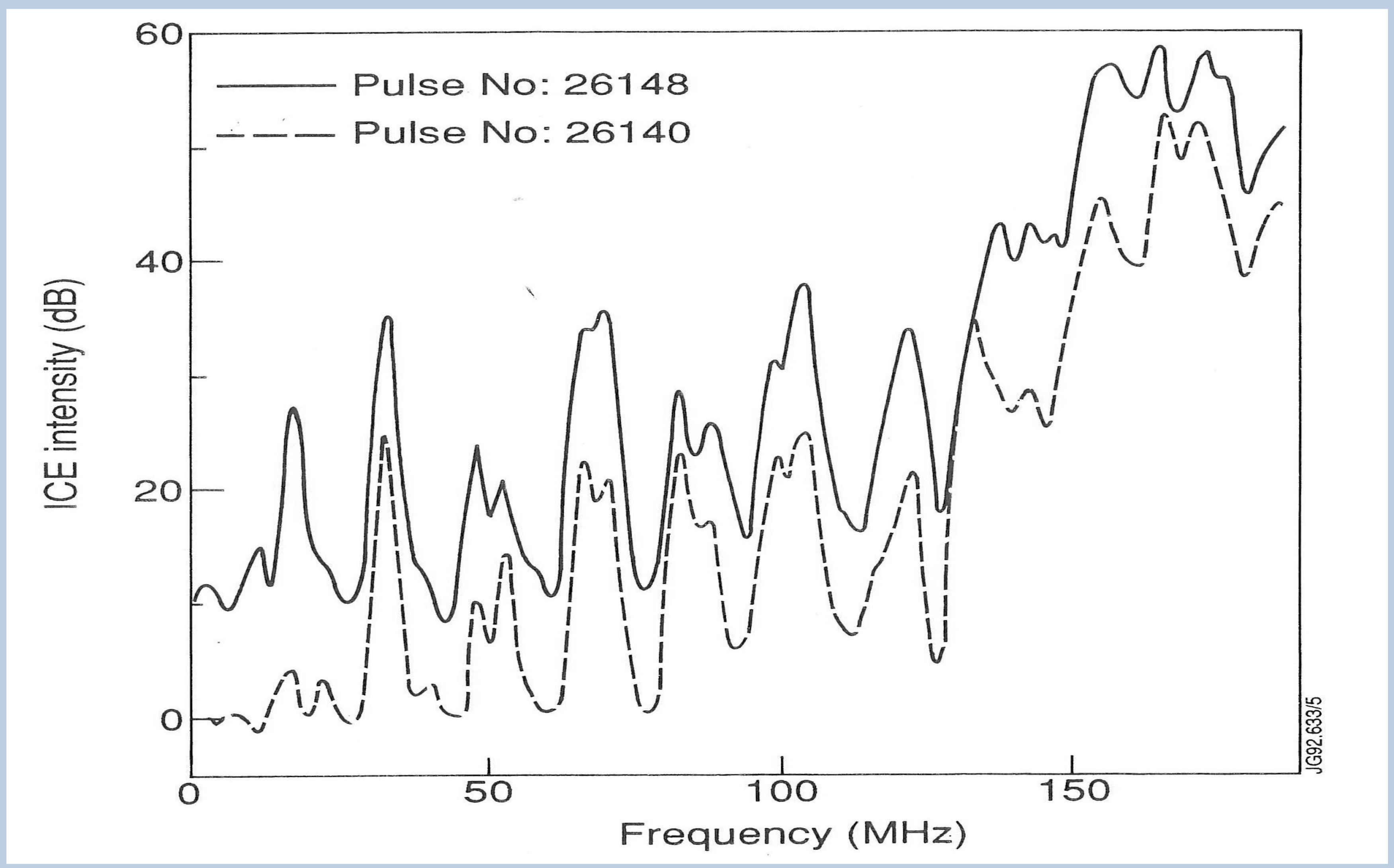
Abstract

Ion cyclotron emission (ICE) was the first collective radiative instability, driven by confined fusion-born ions, observed in all large MCF experiments, in JET, ASDEX-Upgrade, DIII-D, LHD and KSTAR, and TFTR. ICE comprises strongly suprathermal emission, which has spectral peaks at multiple ion cyclotron harmonic frequencies as evaluated at the outer mid-plane edge of tokamak plasmas. The excitation mechanism for ICE is the magnetoacoustic cyclotron instability (MCI). ICE is a potential diagnostic for confined 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. [1]

Detection of ICE



Spectral peaks are at sequential cyclotron harmonics of fusion-born alpha-particles, evaluated at the outer mid-plane edge of the tokamak.

The Magnetoacoustic cyclotron instability

The fast Alfven wave, propagating nearly perpendicular to the tokamak magnetic field, is the prime candidate for the excited mode. The fusion-born ion population can enter into cyclotron resonance with fast Alfven wave at frequencies $\omega_{\text{Alfven}} \approx kv_{\text{Alfven}} = n\Omega_{\alpha}$. This resonance can be:

- Wave-wave, between fast Alfven waves supported by the entire plasma and cyclotron harmonic waves supported by the fusion-born ions. [3]
- Wave-particle, at Doppler shifted cyclotron resonance of the fast Alfven waves with fusion-born ions. [4]

Conclusions

The physics underlying the excitation process for ICE, the magnetoacoustic cyclotron instability, is understood with exceptional analytical and computational fidelity.

Future fusion experiments involving deuterium-tritium plasmas (JET DTE2 and ITER) would benefit from a modest effort to detect ICE:

- A unique channel to understanding confined alpha-particle physics.
- A distinct perspective on plasma phenomena that interact with alpha-particles.
- Continuity with the knowledge base from past deuterium-tritium experiments.

Acknowledgements

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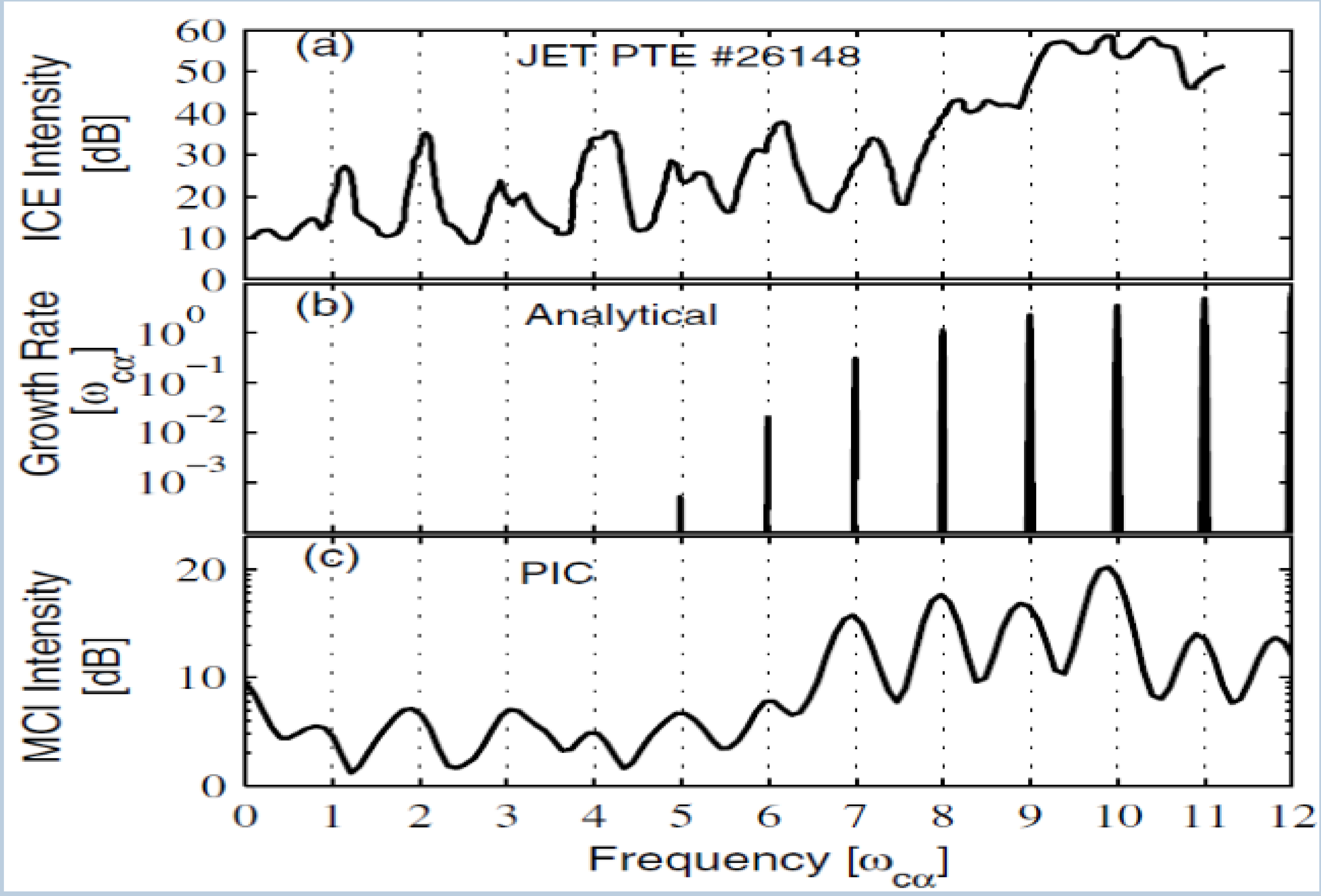
Experimental, analytical and PIC ICE spectra



Frequency is plotted in units of the alpha-particle cyclotron frequency $\omega_{c\alpha} = 17MHz$. [5]

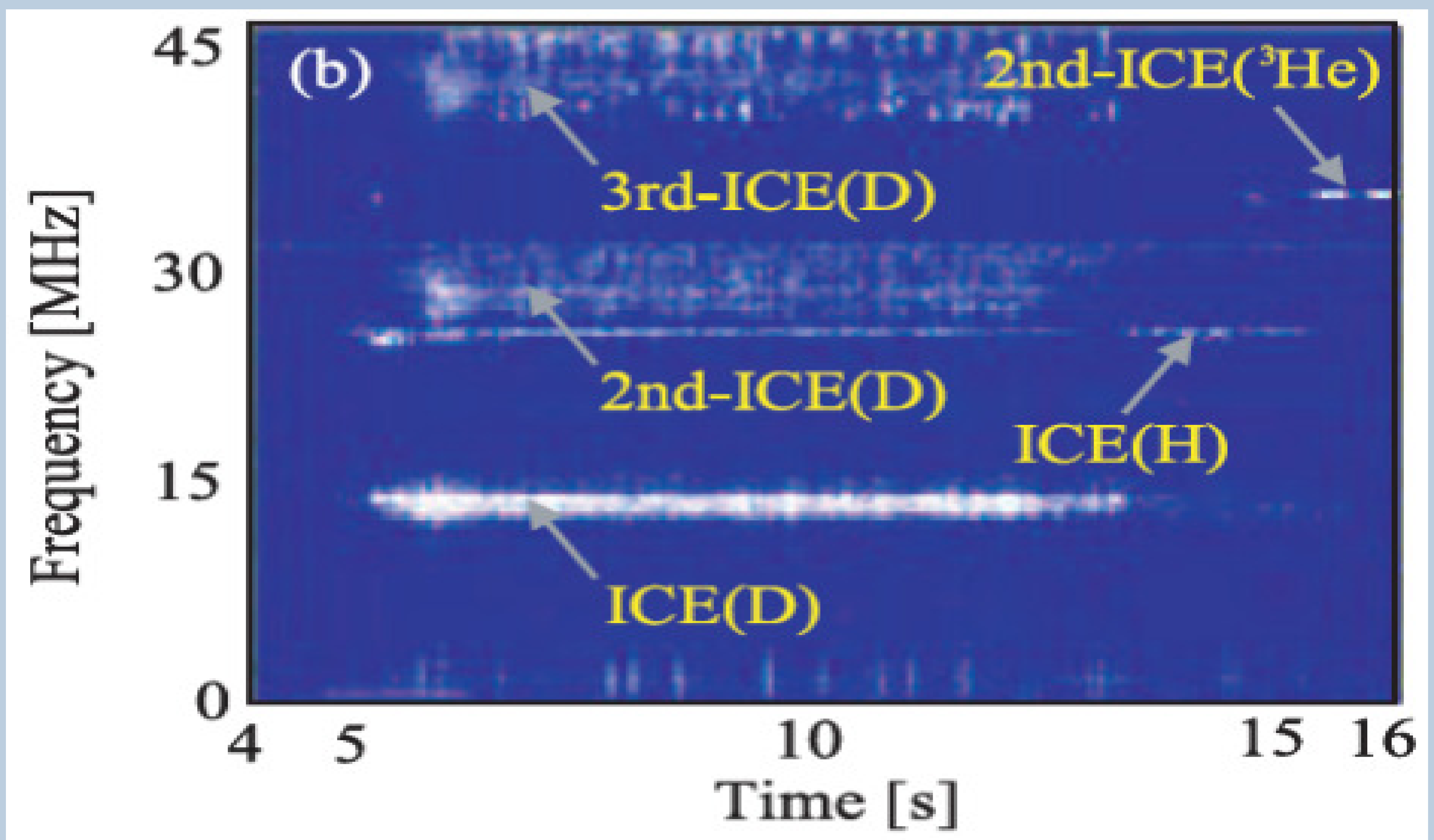
Top : Measured ICE intensity from JET PTE pulse 26148.

Centre : Linear growth rate of the MCI calculated from analytical theory.

Bottom : Intensity of waves in B_z computed in a PIC simulation of the MCI for a relaxing 3.5MeV ring distribution of minority alpha-particles with a number density ratio, $n_\alpha/n_D = 10^{-3}$.

ICE in D-D plasmas - JT-60U

ICE from D-D fusion-born H and ^3He ions, in neutral-beam-heated plasmas, detected using ICRH heating antenna.



Future work

- Use PIC simulations to understand and interpret ICE measurements, in relation to the MCI, across MCF.
- Use the PIC code EPOCH.
- Modify EPOCH to implement particle splitting, allowing for larger simulations.

References

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[5] Cook et al. *Plasmas Phys Control Fusion*, **55**, 2013.

[6] S Sato et al. *Plasma and Fusion Research*, **5, S2067**, 2010.