Tritium mix in simulations of D-T plasmas

on the investigation of ion cyclotron emission spectra

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- Magnetoacoustic cyclotron instability (MCI)

2. Simulation setup
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- Simulations

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4. Summary

ICE

- Suprathermal emission visible at multiple ion harmonics
- Driven by the MCI, brought on by strong gradients in energetic minority (alpha-particles) velocity-space distribution
- Measurement is passive, non-intrusive and multi-angled

Location of resonance inferred from magnetic field strength from the ion harmonic spacing,

$$B(r) = m\Omega/q$$

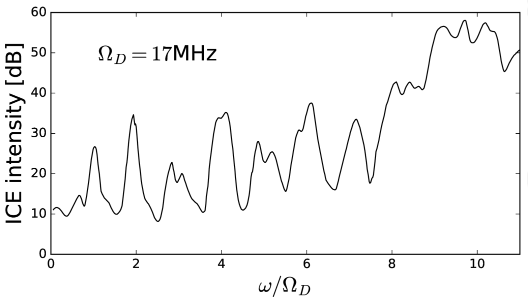


Figure: Power spectra, adapted from [1]

MCI

Magnetoacoustic **C**yclotron **I**nstability (**MCI**):

1976 - Brought on by "*a small quantity of thermonuclear reaction products in a plasma*" which are "*sufficient to excite magnetoacoustic cyclotron waves*" [2]

1992 - Inclusion of ion cyclotron emission, "*resonation excitation of perpendicular fast Alfvén waves with ion Bernstein waves*" which was "*driven by the energetic products of fusion reactions*" [3]

Today - Now, MCI is defined as a velocity-space instability, characterised by the cyclotron resonance between the FAW (in the bulk) and an energetic minority ion (alphas)

PIC code

- Particle-in-cell (PIC) code EPOCH [4]
- Self-consistently evolves the kinetics of particles and EM fields under the Maxwell-Lorentz system of equations
- Third order shape-function
- Pseudo/macro-particles

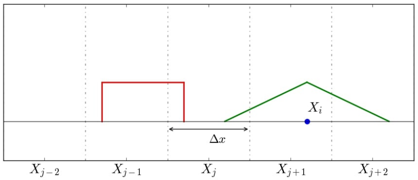


Figure: Zeroth and first order shape functions with a cell width Δx, and pseudo-particle located at X_i in cell X_{j+1}

Simulations

- JET plasma 26148 parameters

$$n_0 = 10^{19} m^{-3} \ , \ B_0 = 2.1T \ , \ T_{i,e} = 1keV \ , \ B\angle\mathbf{k} = 89^\circ$$

- Introduced ξ_T parameter (tritium concentration)
- Conserved Number Density Weighting: $\boxed{NDW = \frac{n_\sigma}{C_\sigma N_x}}$
- Pure deuteron (0%) trace tritium (1%) JET 26148 plasma (11%) and near future high concentration ITER (50%)
- Supplementary simulations of 5%, 18% and 30%

Energy densities

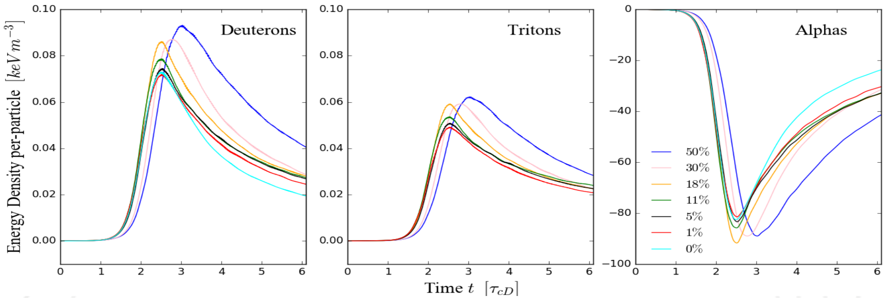
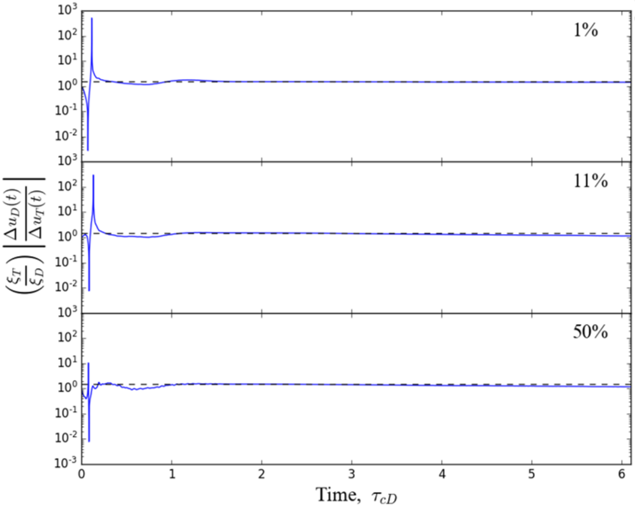


Figure: Change in kinetic energy densities (Δu) for (left-to-right) deuterons, tritons and alphas. Units given in $keVm^{-3}$ and triton concentration as in right-hand figure legend

- Linear MCI growth is lesser with increased ξ_T
- Energy transfer at $\xi_T = 50\%$ between D-T is almost equivalent to their mass ratios

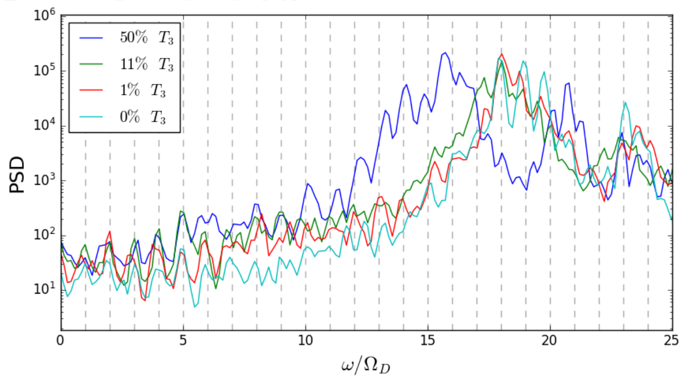
Energy densities



Gyro-resonance between deuterons (D) and tritons (T) results in a trending in the change in their energy density ratios to their inverse mass ratio

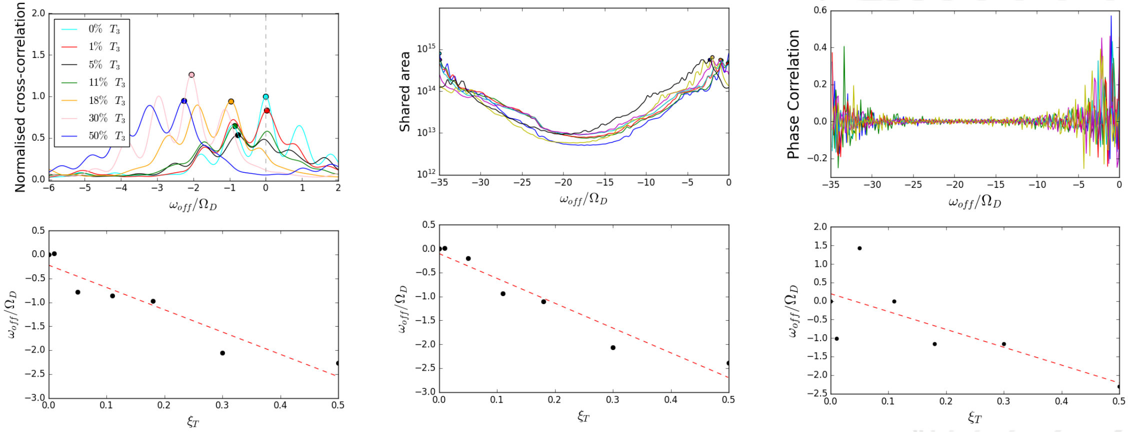
$$\left\langle \frac{\Delta u_D(t')}{\Delta u_T(t')} \right\rangle = \frac{\xi_D m_T q_D^2}{\xi_T m_D q_T^2} \ . \qquad (1)$$

Power spectral densities



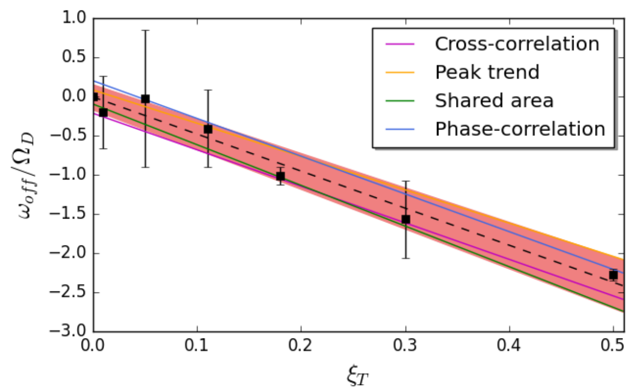
- $\xi_T > 0$ leads to shift in power spectra
- Shape is "*conserved*"
- Peaks are less intense/defined with increased ξ_T
- How to quantify this frequency shift?

Frequency offset: $\omega_{off}(\xi_T)$



Frequency offset: $\omega_{off}(\xi_T)$

$$\omega_{off}(\xi_T)/\Omega_D = (-4.74 \pm 0.34)\xi_T + (0.01 \pm 0.16) \quad (2)$$



Roughly shows that for a 20% increase of tritium, power spectral features shift down in frequency by a whole deuteron harmonic

Summary

- Rate of energisation (de-energisation) of deuterons (alphas) is slowed with increasing ξ_T
- Ratio between energisation of D-T plasma equivalent to their mass ratios due to Larmor radii matching (gyro-resonance)
- Power spectra is shifted in frequency, approximately quantified by a negative linear correlation w.r.t ξ_T, eq. (2)
- JET plasma 26148 is best represented by the 11% simulation

Despite the two ion representation working well to describe the power spectra of multi-component plasmas, simulation of three ions is a necessity for admixtures greater than a few percent, especially when considering near future ITER cases ($\geq 50\%$)

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Thank you for listening

Any questions?

References

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