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**See Annex of J. Pamela et al., "Overview of Recent JET Results and Future Perspectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).*

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ABSTRACT.
An important question for extrapolating the stability of fast particle driven modes on ITER is which is the most appropriate model to evaluate the wave damping by the background plasma. The different damping mechanisms of Alfvén Eigenmodes (AEs) are studied on JET by directly measuring damping rates, γ/ω, of stable AEs in different operating scenarios. Section 1 presents measurements of γ/ω for $n = 1$ Toroidal AEs (TAEs) in plasmas with different directions of the ion ∇B-drift, showing a significant difference between the two. The link between the mode stability limit and the fast particle distributions is also investigated using direct observations of the fast particle driven AEs for the case of ICRH heated plasmas and measurements of the fast ion energy distribution function from a Neutral Particle Analyser (NPA). Measurements of this kind are reported in Section 2 for monochromatic and polychromatic ICRH scenarios.

1. MEASUREMENT OF γ/ω FOR N = 1 TAES IN PLASMAS WITH OPPOSITE ION ∇B-DRIFT DIRECTION.

Among the terms that are not present in fluid models, but which can be included in gyro-kinetic models [1], are the ∇B terms. A controlled experiment was conducted to study how such terms, and in particular the ion ∇B-drift direction, can affect the value of the background plasma damping of AEs. Limiter phases of the discharges and similar plasma conditions were chosen, with the plasma kept in L- mode, with only minor differences in density and temperature profiles due to the different breakdown scenario.

Two in-vessel saddle coils were used as antennas to drive and detect stable low-n AEs. Repetitive sweeps and real time control of the driving frequency according to the evolution of the plasma parameters and the plasma response to the driven perturbation allow us to find and track the plasma resonances corresponding to the mode under investigation [2]. This method yields accurate measurements of the mode frequency and damping rate.

Figure 1 shows the main plasma parameters and γ/ω for $n = 1$ TAEs in two similar discharges with ion ÑB-drift directed towards the divertor (named as B^+ in the figure, Pulse No: 52196) and away from the divertor (B^-, Pulse No: 59668). In relation to the H-mode threshold, the two directions are commonly referred to as favourable and unfavourable, respectively. We notice that γ/ω is significantly higher for unfavourable ∇B-drift direction for TAEs with similar frequency and radial location. This data clearly suggests that the favourable ion ∇B-drift direction would correspond to a significantly lower instability threshold for ITER. More importantly, the significant difference in the observed damping and its time evolution for different ion ∇B-drift directions indicates that fluid models are in this scenario inadequate to predict the AE damping, and motivates further theoretical developments.

2. AE SPECTRA AND $F_{FAST}(E)$ FOR POLYCHROMATIC VERSUS MONOCHROMATIC ICRF HEATING

A comparison of the fast particle distributions and their effect on the plasma mode stability in the AE frequency range is performed between the monochromatic and polychromatic ICRF H- minority heating schemes. In addition to contributing to the database of mode stability vs. fast ion distribution, in view of extrapolating the marginal stability limit for AEs to ITER, such comparison is useful to assess the suitability of the different ICRH heating schemes for different applications, including for simulating alpha particle physics.

The magnetic fluctuation spectra shown in fig.2 provide a first piece of information on the fast particle distribution [3]. During the ICRF phase, for the discharge with polychromatic heating (Pulse No: 57296, resonance layer spread over ~30cm on the low field-side), an n = 4 TAE and an n = 3 EAE are detected at f»200kHz and f»400kHz. For the discharge with monochromatic on-axis heating (Pulse No: 57298), no EAEs are detected and two TAEs with n = 4,5 are observed around f ≈ 200kHz. As indicated on the figure, poloidal mode numbers are also extracted from the edge magnetic measurements. This helps establishing the mode radial position by locating the relevant Alfvén spectral gap on the reconstructed q-profile. From such analysis and a comparison with similar discharges in which full reconstructions of the AE mode structure were performed, we conclude that TAEs are more centrally located than EAEs (r/a~0.4 and r/a~0.7, respectively). The excitation of TAEs and EAEs are therefore indicative of the existence of a fast particle pressure gradient close to the core or towards the edge, respectively. In the polychromatic case EAEs are driven unstable and TAEs are driven to much smaller amplitudes than for monochromatic heating. Both observations indicate a broader radial profile of fast particles, with a weaker drive for TAEs in the core, and a larger drive for EAEs closer to the edge.

To assess the two ICRH schemes in terms of the produced fast particle energy distribution these observations are complemented by measurements performed on hydrogen using a Neutral Particle Analyser (NPA). The JET high energy NPA measures the fast particle energy distribution in the plasma core, f_{FAST} (E), in the range 0.3 ≤ E (MeV) ≤ 1.5, with a time resolution of 20 ÷ 50ms [4]. The fast ion temperature, $T_{\perp FAST}$, can then be extracted. As shown in fig.3, the absolute value of f_{HFAST} (E) is ~25% higher in Pulse No: 57296 than in Pulse No: 57298, indicating a larger n_{HFAST}/n_{e0} for a similar volume-averaged hydrogen concentration. Figure 4 shows that $T_{\perp HFAST}$ is ~20% higher for monochromatic than polychromatic heating. This difference is significantly larger than the error bar on $T_{\perp HFAST}$, $|\Delta T/T| \approx 10\%$.

The AE spectrum and NPA measurements together indicate that the polychromatic heating is less effective than monochromatic heating in creating a high-energy tail, and produces a less peaked fast particle distribution. This is consistent with previous measurements in similar scenarios, which reported a less peaked $T_e(r)$ and a smaller T_{i0} than with monochromatic heating [5,6].

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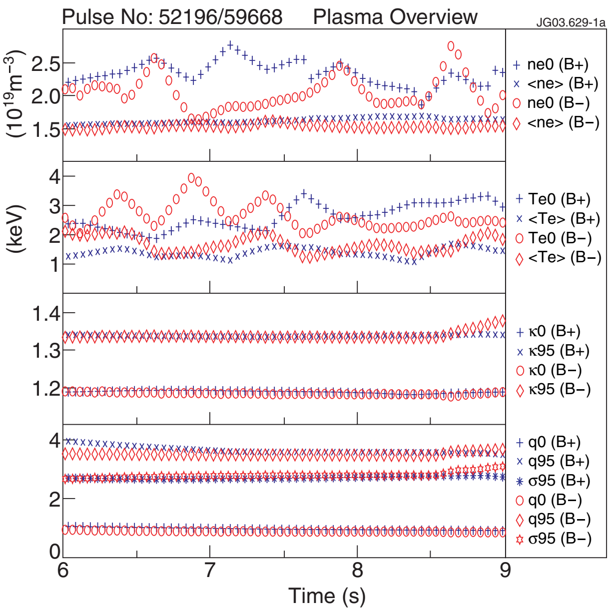

Figure 1(a): Plasma parameters for the discharges shown in Fig.1b: Pulse No: 52196 (blue) and Pulse No: 52198 (red). Here n_{e0} and $<n_e>$ are the electron density in the plasma core and volume averaged (and similarly for the electron temperature T_e), κ_0 and κ_{95} are the elongation on axis and at 95% of the normalised poloidal flux ψ_N (and similarly for the safety factor q_0 and q_{95} and the magnetic shear σ_{95}).

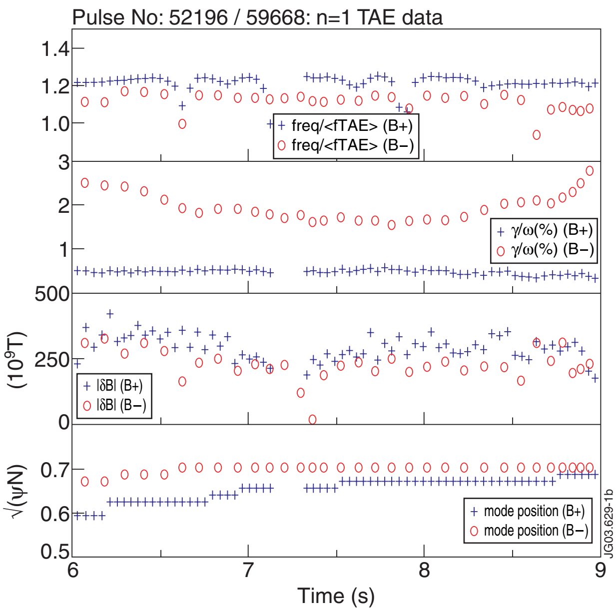

Figure 1(b): Measurement of frequency, damping rate γ/ω, mode amplitude $|\delta B|$ and radial position for n=1 TAEs as function of the direction of the ion ∇B-drift. Here $<f_{TAE}>$ is the volume averaged TAE frequency. The mode position is inferred from the radial profile of f_{TAE} and using synchronous ECE and reflectometer measurements, giving good agreement. The CSCAS code was used to verify the data for the case of B^+.

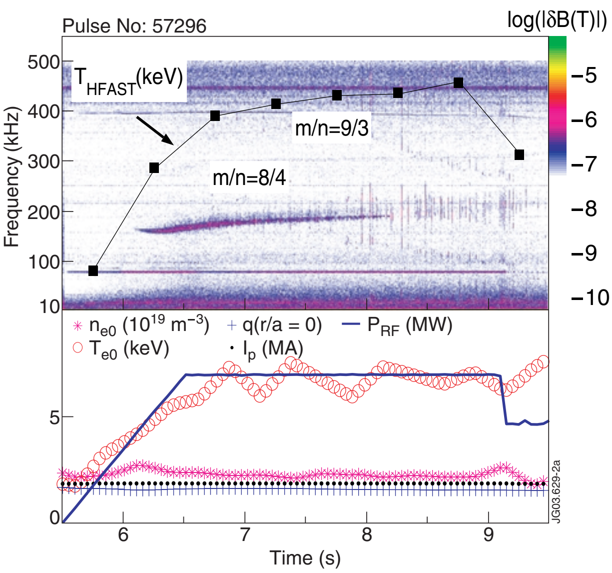

Figure 2(a). MHD spectrum for Pulse No: 57296, the case of polychromatic ICRH heating.

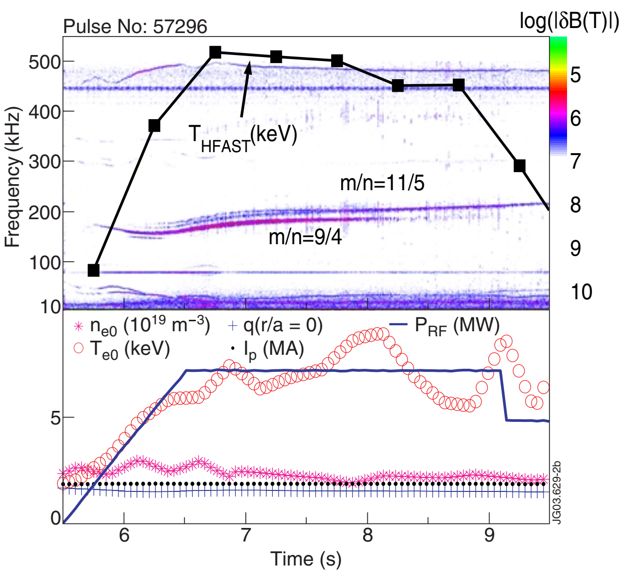

Figure 2(b): MHD spectrum for Pulse No: 57298, the case of monochromatic ICRH heating.

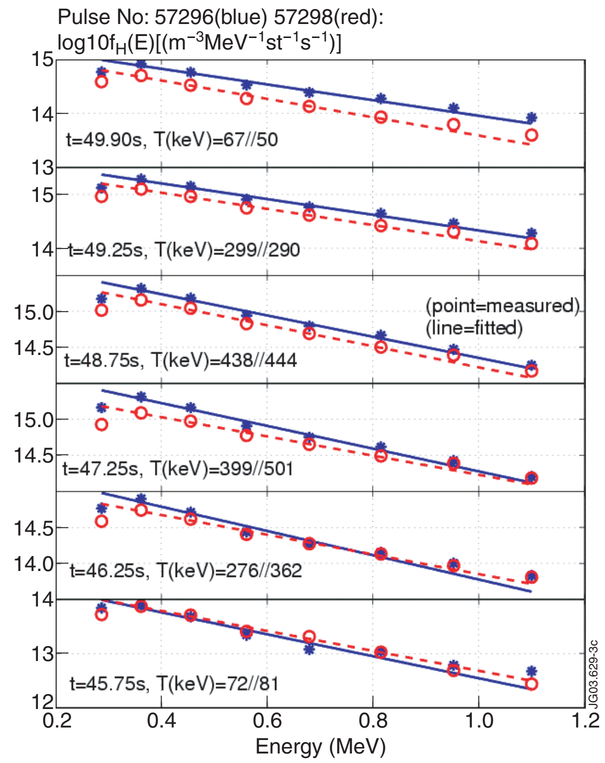

Figure 3: Measured $f_{HFAST}(E)$ for Pulse No's: 57296 (polychromatic ICRH) and 57298 (monochromatic ICRH).

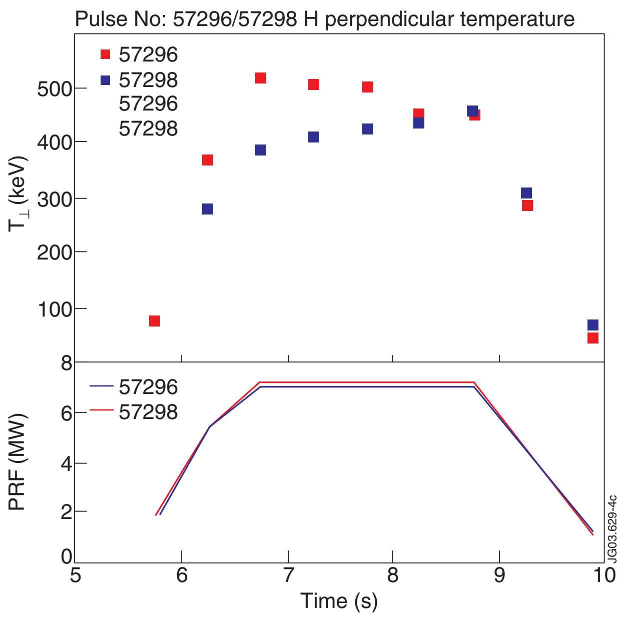

Figure 4: Measured $T_{\perp HFAST}$ for Pulse No's: 57296 (polychromatic ICRH) and 57298 (monochromatic ICRH).