Alpha Particle Confinement and Losses in JET's Tritium Campaign

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Experimental Discharge and Fast Ion Loss Measurements

This work investigates alpha transport and losses in a tritium plasma due to low frequency MHD activity. Understanding the alpha response to MHD modes is paramount for model validation and analysis of T, DT, and ITER scenarios. This paper utilizes two fast ion loss detectors on JET, an array of Faraday cups which provide spatial information on losses [1] and a scintillator-photomultiplier tube (PMT) probe array which is more sensitive to particle pitch and energy [2], for alpha confinement analysis. The reference discharge for analysis is JET pulse 99151 from the recent tritium campaign ($I_p = 2.3$ MA, $B_0 = 3.4$ T, n_e =7x10^{19} m^{-3}, $T_e = 8.5$ keV, 95% tritium with trace deuterium and hydrogen). The neutral beams are fueled with tritium resulting in TT beam-thermal and thermonuclear fusion reactions which produce MeV-scale alpha particles (see Figure 2). The pulse has an average of 20-25MW of NBI+RF injected power shown in Figure 1 (a.) and contains a variety of low frequency MHD activity evident in subplot (b.). In particular, a long-lived $n = 2$ mode at ~ 30 kHz and ELM bursts (not visible in Figure 1) give rise to measureable fast ion losses.

Figure 3 shows example signals from one of the lost Faraday cup foils and one of the scintillator probe PMTs. Both show strong losses associated with the long-lived $n = 2$ mode which has been labeled a neoclassical tearing mode (NTM) based on soft x-ray phase analysis and frequency mathcing to the charge-exchange rotation measurements. The Faraday foil and PMT channels correspond to losses of high energy ions (in excess of 1 MeV). TRANSP [3] produced fast ion distributions show that these energies are dominated by alpha particles (see Figure 2)

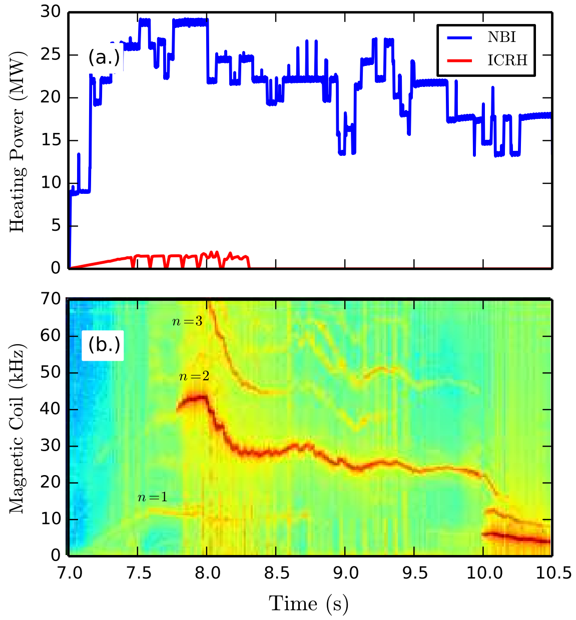

Figure 1: External heating power for JET pulse 99151, (a.), and a spectrogram from an edge-magnetic coil, (b.).

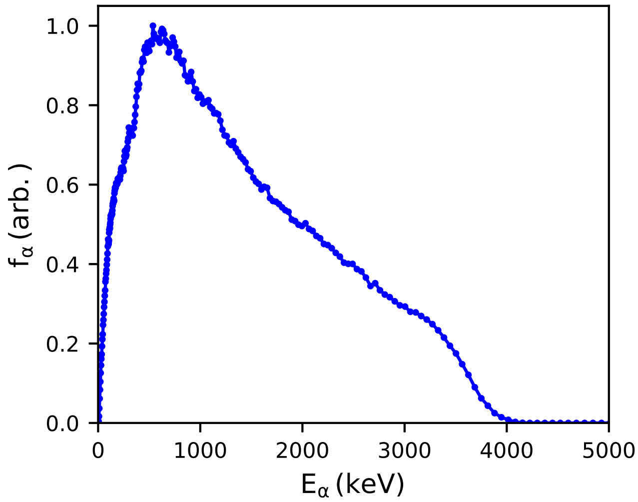

Figure 2: Normalized alpha particle distribution as a function of energy calculated from TRANSP.

originating from reactions of RF-heated tritons (distribution not shown).

Edge-localized mode (ELM) induced losses measured with the scintillator probe are presented in Figure 4 and show the inverse trend. Namely, the ELMs strongly interact with lower

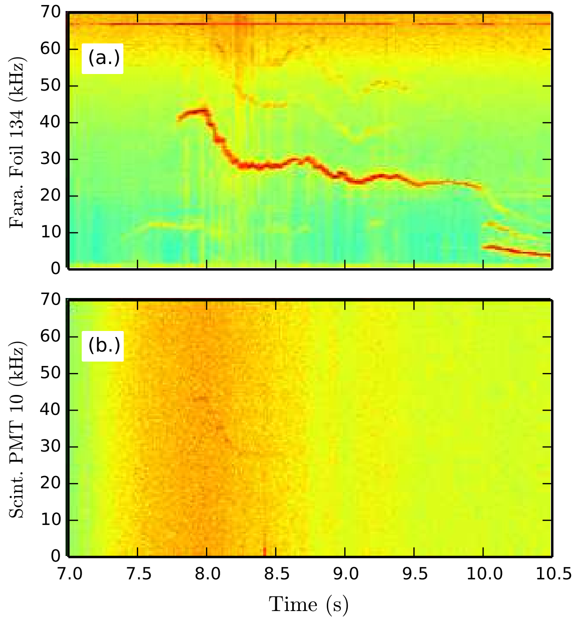

Figure 3: A spectrogram from Faraday foil 134, (a.), and a spectrogram from scintillator PMT 10, (b.) showing coherent $n = 2$ mode losses.

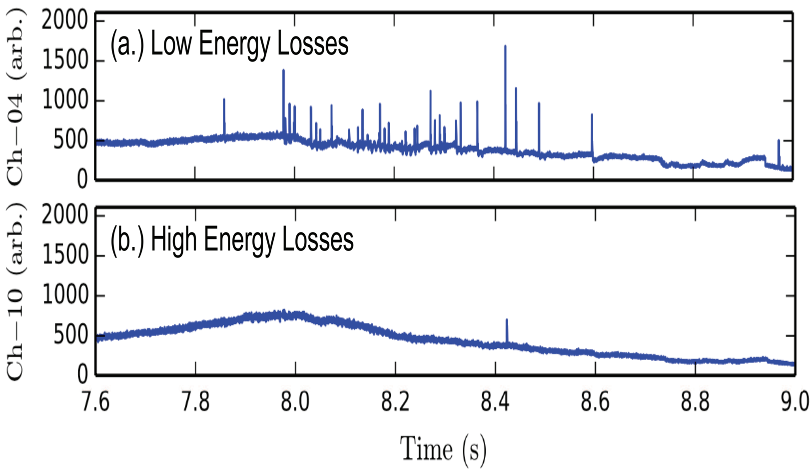

Figure 4: ELM induced losses in the scintillator probe present in the low energy PMT channel 4 and absent in the high energy PMT channel 10.

energy particles (i.e. the beam-born tritons) and largely ignore the MeV alpha particles.

The poloidal and radial fast ion loss deposition is presented in Figures 5 and 6, respectively, summed at the $n = 2$ frequency from 7.8-9 s across all foils. Figure 5 shows that the losses initially decrease as one looks down from the midplane but then increase (point at $\sim 20^\circ$ is suspected to be broken foil). Evidenced in Figure 6, the fast ion losses appear to peak closer to the LCFS. It is theorized that this may be due to the relatively large alpha particle Larmour radius (~11-13 cm) relative to cup spacing (2.5 cm). Simulations are ongoing to confirm this.

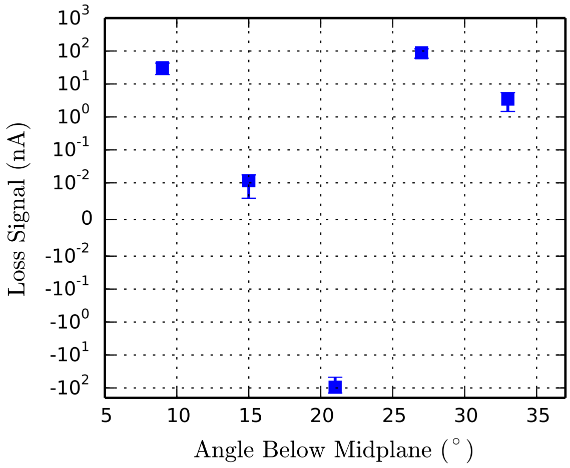

Figure 5: Integrated fast ion loss signal as a function of poloidal position as measured from the Faraday cups.

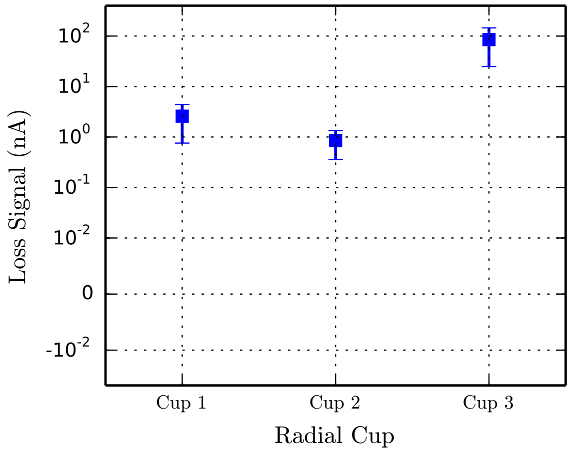

Figure 6: Integrated fast ion loss signal as a function of radial position for the Faraday cups closest to the midplane poloidally. Cup 1 is closest to the plasma while cup 3 is closest to the wall (2.5 cm between cups).

Fast Ion Modeling Results

The ORBIT-kick model [5] has been used to examine the triton and alpha particle transport associated with the $n = 2$ NTM. An analytic form [6] was taken for the NTM mode structure while a reasonable estimate of $\delta b/B \sim 10^{-5}$ was used for the mode amplitude. The effect of the mode was calculated for 200,000 tritons and alphas. The resulting RMS-energy spread for each species at varied energy is shown in Figure 7. The high energy alphas exhibit a strong interaction with the mode while the beam-born tritons interact weakly. It was found that 6.7% of the modeled alphas were lost while the tritons were highly confined with only 0.02% losses. The strongest interactions are with the trapped particle region which agrees with the detectors.

Summary and Ongoing Work

A JET tritium discharge has exhibited fast ion losses associated with a long-lived NTM mode and ELM bursts. The energy and spatial dependence has been revealed with JET's fast ion loss detectors. Low energy ions, i.e. beam-born tritons, are impacted by ELM bursts while

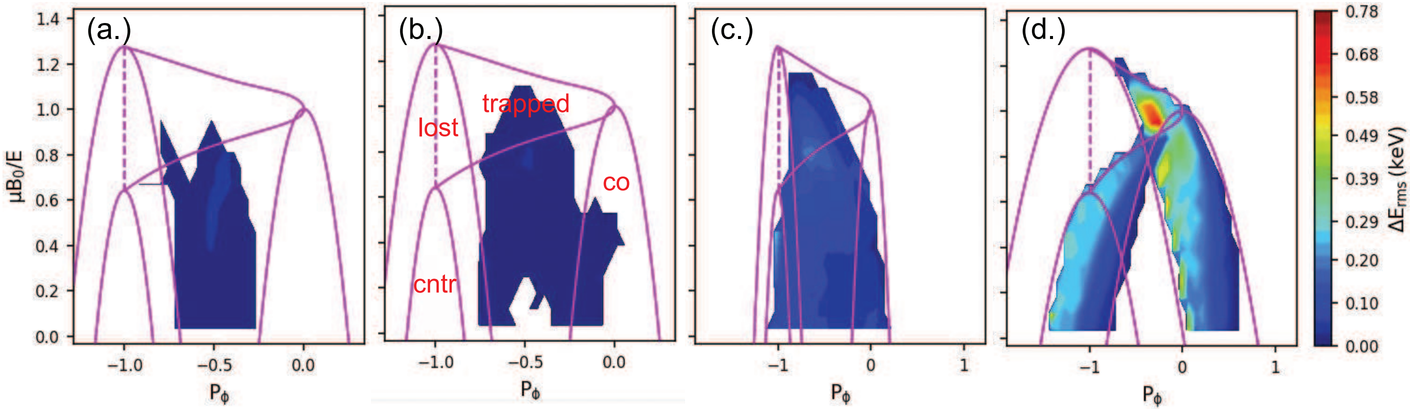

Figure 7: ORBIT calculated RMS-energy interaction with the $n = 2$ mode for 110 keV tritons, (a.), 340 keV tritons, (b.), 200 keV alphas, (c.) and 1900 keV alphas, (d.). Magenta lines denote topological orbit boundaries. The red labels denote the orbit types within the respective boundaries.

high energy ions, i.e. TT-born alpha particles, are strongly transported by the NTM mode. The experimental observations have been confirmed with initial ORBIT-kick modeling which reveal that trapped alpha particles exhibit the strongest interaction with the mode.

Comparisons among the measured and simulated spatial losses is ongoing. Additionally, the measurements are being further constrained against realistic, synthetic, losses produced within ORBIT [7]. Supporting measurements with line-integrated neutron signals are being sought as well. Lastly, the investigation and comparison to low frequency MHD induced alpha particle losses in the recent JET DT-campaign is also underway. The present analysis contributes to the validation of EP models that will be used to assess the role of MHD on alpha particle losses in DT. This analysis can then be extrapolated to ITER scenarios to predict alpha transport and losses in reactor relevant plasmas.

Acknowledgements

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