Investigation of Collective Fast Ion Instability-induced Redistribution or Loss in NSTX

S. S. Medley, E. Fredrickson, D. Darrow and the NSTX Team email: medley@pppl.gov
Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ 08543

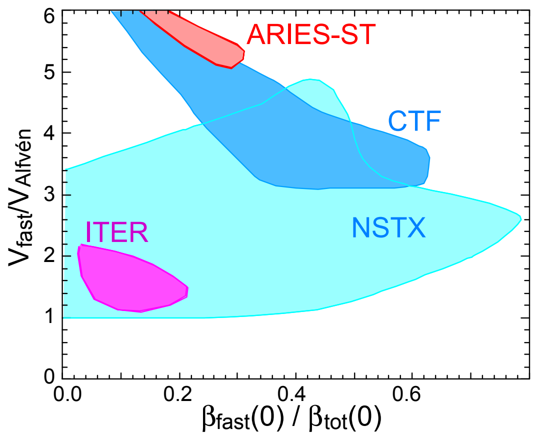

***Figure 1**: Diagram showing the operating boundaries of NSTX, ITER, CTF and ARIES-ST in the dimensionless fast particle parameters $v_{fast}/v_{Alfvén}$ and $\beta_{fast}(0)/\beta_{tot}(0)$*

The physics of plasmas that contain large populations of super-Alfvénic energetic particles is an important outstanding issue for burning plasma experiments, such as ITER. In particular, the performance of burning plasmas may, in part, be determined by the non-linear interaction of the α-particles generated by D-T fusion reactions with a variety of energetic particle modes and Alfvén waves that are resonant with the fast particles. The National Spherical Torus Experiment (NSTX) is particularly well suited to investigate fast-ion driven instabilities and their influence on fast particle confinement, since the Neutral Beam Injection (NBI) heated plasmas can match or exceed the ITER dimensionless parameter regime for $v_{fast}/v_{Alfvén}$ and $\beta_{fast}(0)/\beta_{tot}(0)$ as demonstrated in Figure 1 (albeit at much higher fast-ion ρ*) while maintaining a complete complement of profile and fluctuation diagnostics.

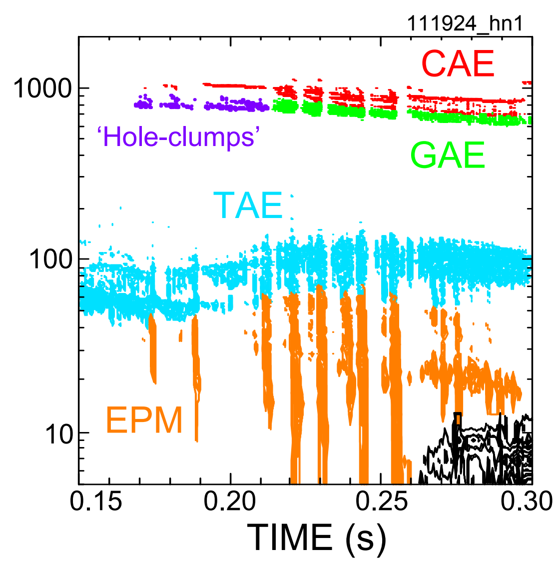

***Figure 2**: Spectrogram of a neutral beam heated shot on NSTX showing the wide variety of fast particle modes.*

As illustrated by the spectrogram shown in Figure 2, a wide variety of fast ion driven instabilities, some recently discovered, are excited during NBI in NSTX. The modes can be divided into three categories; chirping Energetic Particle Modes (EPM) in the frequency range 0 – 120 kHz, the Toroidal Alfvén Eigenmodes (TAE) with a frequency range of 50 – 200 kHz and the Global and Compressional Alfvén Eigenmodes (GAE and CAE, respectively) between 300 kHz and the ion cyclotron frequency. Some of the higher frequency modes exhibit frequency splitting characteristic of what would be expected from "hole-clump" theory[1]. Substantial fast ion losses due to fast ion driven modes are observed. The amplitude, structure, and three-wave coupling of these modes has been measured by a suite of diagnostics, including reflectometry, soft X-ray, and Mirnov magnetic diagnostics. These characteristics have been compared to those predicted by theory which incorporate measured profiles of the plasma safety factor.

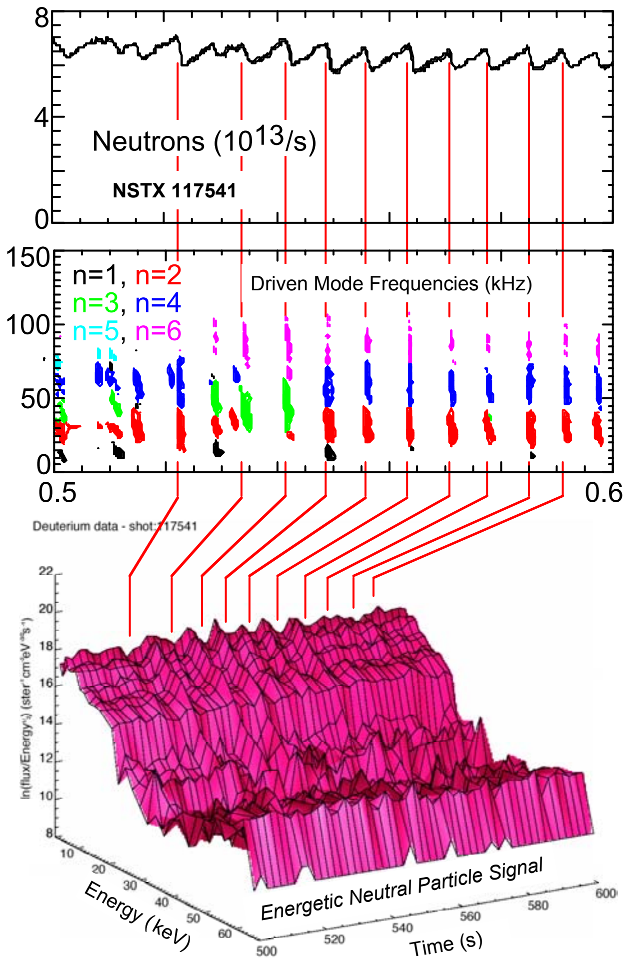

Figure 3: Modulations in neutron rate, MHD mode number and frequency, and neutral particle flux induced by multi-EPM bursts.

Energetic ion redistribution and/or loss is associated with both low frequency kink-type MHD activity [2], and modes in the higher frequency Alfvénic regime. An example is shown in Figure 3 where cyclic neutron rate drops of order 5 – 10% associated with the destabilization of EPMs occur. The neutral particle analyzer data shows the strongest particle density modulation below the injection half-energy and the density modulation of the highest energy ions is roughly 10%. Multiple large TAE bursts, similar to the "sea-of-TAEs" predicted for ITER, show comparable losses.

Both the volume-integrated neutron and the line-integrated NPA diagnostics show signal depletion due to fast-ion driven instabilities, but cannot distinguish between fast-ion redistribution or loss. Two recently implemented diagnostics on NSTX, the Motional Stark Effect (MSE) and scintillator Fast Lost Ion Probe (sFLIP), facilitate separation of loss and redistribution effects. Outward redistribution of the core-peaked energetic beam ions modifies the beam-driven current profile and hence the core q-profile. MSE-constrained q-profiles are being used to assess this effect. sFLIP measures the pitch and energy of fast ions that are ejected from the plasma and intercept the wall-mounted probe thus identifying fast-ion loss. A range of fast ion instability-induced redistribution/loss phenomena observed in NSTX will be presented.

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[1] H. L. Berk, *et al.*, Phys. Plasmas, **6** (1999) 3102
[2] S. S. Medley, *et al.*, Nucl. Fusion, **44** (2004) 1158