Neutral Beam Ion Loss Accompanying Bursting MHD in NSTX*

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Abstract: NSTX plasmas exhibit a variety of fast particle driven MHD instabilities, including bursts of Energetic Particle Modes (EPMs), Reverse Shear Alfvén Eigenmodes (RSAEs), and Beta-induced Alfvén Acoustic Eigenmodes (BAAEs). These are all driven by the 80-90 kV D beam ions. Loss of fast ions is observed during EPM bursts and during RSAEs. The EPMs rapidly develop into multiple toroidal mode numbers present concurrently, and loss of beam ions over a wide range of pitch angles is observed. This loss is interpreted as a stochastization of the particle phase space by the modes. During the RSAE upward frequency sweep, beam ion loss is also seen, but over only a limited pitch angle range, in contrast to the EPM bursts. Fast ion loss is also seen during TAE avalanches or concurrent multiple-n TAEs, but this loss also is seen over a limited range in pitch angle, again suggesting the loss mechanism differs from that in the EPM bursts

Goal: Characterize fast ion losses and loss mechanisms during bursting Alfvénic modes

Motivation: Evidence of sizable loss seen in NSTX bursting events. If similar loss processes were to occur in ITER, plasma heating would be reduced and first wall could be damaged

Modes studied: The modes studied here are all ones driven by superthermal ions. They include Toroidal Alfvén eigenmodes (TAEs) with frequencies around $f_{TAE}=v_A/4\pi qR$ with $v_A=B/\rho^{1/2}$ and ρ is the plasma mass density. These modes have frequencies ~100 kHz in NSTX, and are normal modes of the plasma in toroidal geometry.

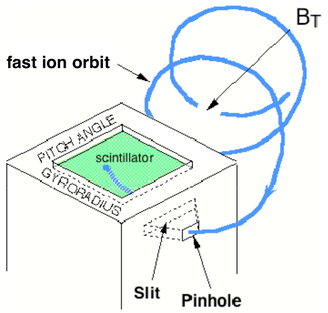
Also considered are Reverse Shear Alfvén eignmodes (RSAEs), sometimes termed Alfvén cascades, which are TAEs in a reversed shear plasma. These modes often exhibit a time-changing frequency as the q profile of the discharge evolves.

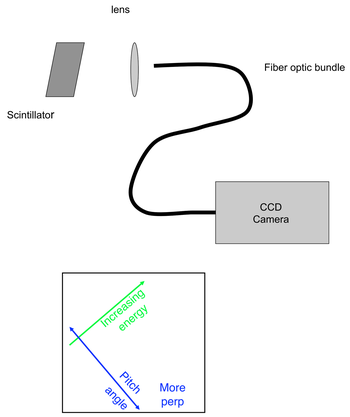
Energetic Particle Modes (EPMs) are modes which appear in the same frequency band as TAEs but which are not normal modes of the plasma itself and whose existence depends upon the presence of the energetic particle population. In practice, though, their behavior is much like TAEs
Beta-induced Alfvén Acoustic Eigenmodes (BAAEs) are modes in which the Alfvén and acoustic waves couple, and which span the range of frequencies from acoustic to Alfvénic (~20–100 kHz in NSTX.) The EPM event portrayed in this poster has characteristics consistent with being a series of BAAEs.

Avalanches are short bursts of activity in which several mode numbers and, perhaps, several types of modes are simultaneously present in the plasma, often causing substantial loss of fast ions.

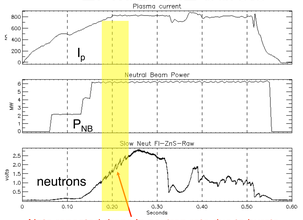
Methodology: Measure mode characteristics with Mirnov coils. Measure total fast ion loss from drop in neutron rate during mode activity (since neutron production in NSTX is all due to beam-plasma reactions). Also measure time history and pitch angle distribution of lost beam ions with the scintillator Fast Lost Ion Probe (sFLIP). The sFLIP is located at the edge of the plasma and uses an aperture pair plus the intrinsic field of the plasma to disperse lost fast ions onto a phosphor plate, where their pitch angle and gyroradius determine their strike point. The resultant pattern of luminosity gives the distribution function of the lost fast ions as a function of time and is recorded by a videocamera.

sFLIP Diagnostic

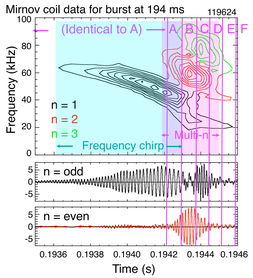




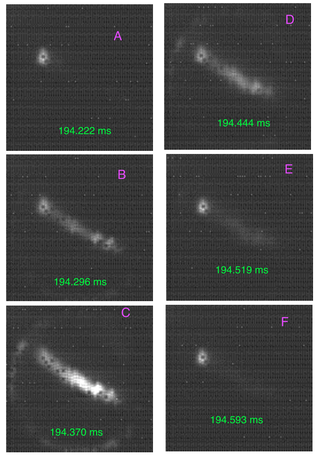
EPM/BAAE bursts



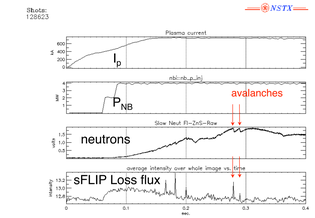
Note repeated drops in neutron rate due to bursts



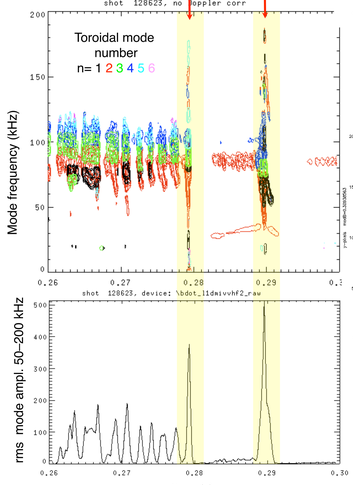
Individual camera frames show broad range of pitch angles lost, with no evidence of sweeping in time, at least not at a rate comparable to camera's (13,500 frames/s). Loss is all at the injection energy (90 kV). The simultaneous loss of a broad range of pitch angles (15°–64°) suggests the loss is not a resonant process, but is perhaps a stochastization of the phase space of the beam ions due to the temporal overlap of modes with differing helicities (i.e. Differing n numbers)



Avalanches

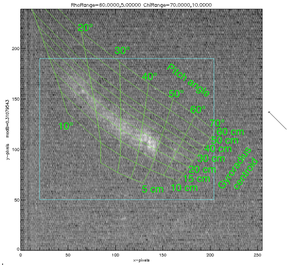


MHD spectrogram

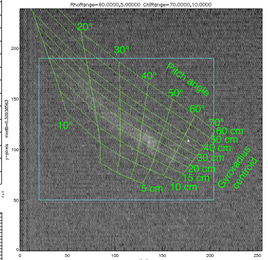


Numerous bursts occur between 260 and 290 ms, but only those at 279 & 290 ms result in a significant drop in the neutron rate and an increase in the loss rate. The rms amplitude of these two events is 2–3 times larger than the others and they cover a greater extent in frequency and, possibly, a greater range of mode numbers.

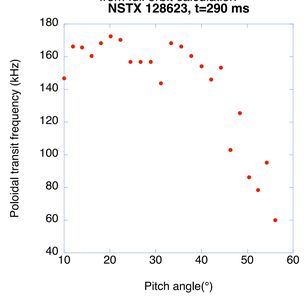
sFLIP image at 279 ms, showing broad range of pitch angles lost at full energy during avalanche



sFLIP image at 290 ms, with very similar features. Frames at other times show no no loss discernable above noise

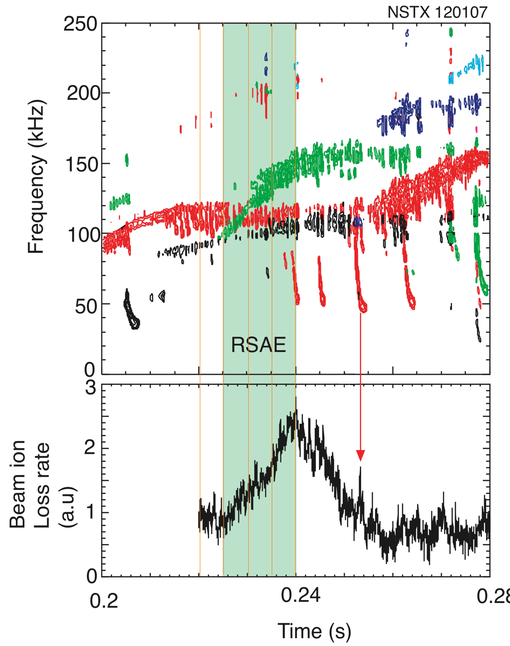


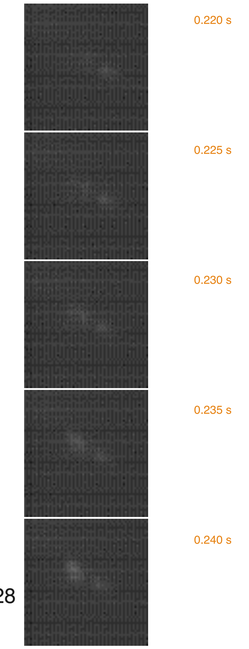
Poloidal transit frequency vs pitch angle, from full orbit calculation
NSTX 128623, t=290 ms



The range of poloidal transit frequencies for lost particles coincides approximately with range of frequencies seen in avalanches, so particle loss could conceivably be through resonant interaction between the modes and particles. However, the relatively low amplitude of the modes with f > 120 kHz in these two avalanches suggests resonant loss would appear predominantly at pitch angles above ~50°. In contrast, the measured losses extend to below 20° in both bursts. That, plus the simultaneous presence of multiple n number modes means the wide range of pitch angles lost might be better explained by a stochastization of the particle phase space due to the multiple modes.

RSAEs





RSAE, while sweeping up in frequency, enhances beam ion loss rate, but only over a narrow range in pitch angle, even though multiple n are present—why?

Summary & Conclusions: Several fast ion driven MHD modes have been observed to produce fast ion loss from NSTX plasmas. One issue of significant importance for ITER is that bursts such as EPMs (BAAEs) and TAE avalanches cause the loss of a wide range of pitch angles, with substantial loss fractions. Loss from EPMs, and possibly avalanches, appear not to be a resonant phenomenon but a stochastization of the particle phase space, possibly sweeping across a range of minor radius. If similar events can occur in the ITER range of parameters, then significant performance degradation and first wall damage could occur.