Date Approved: _____ By: _____

General Atomics

NSTX Mini–Proposal

Subject: Marginal Island Width of NTMs in NSTX **NSTXMP No.**

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1. Purposes of Experiment

Small island stabilizing effects (transport, polarization current, etc.) set the marginal beta above which neoclassical tearing modes (NTMs) can be excited. The marginal full island width w_{marg} is the value of w at which growth, $\mathrm{d}w/\mathrm{dt}$, is largest. This island size plays an important role in determining the electron cyclotron current drive (ECCD) requirements for stabilization in ITER. In "high" aspect ratio devices with $\mathrm{R/a} \approx 3$ (ASDEX-Upgrade, DIII-D and JET), the marginal island width is found to be about twice the ion banana width, $2\varepsilon^{1/2}\rho_{\theta i}$. The purpose of this experiment, in NSTX, is to investigate if this scaling occurs at different aspect ratio.

2. Background and Motivation

An NTM can be excited when there is a region of parameter space with $\mathrm{d}w/\mathrm{dt} > 0$ between $w = w_{\mathrm{crit}}$ $(\mathrm{d}w/\mathrm{dt} \equiv 0)$ and $w = w_{\mathrm{sat}}$ $(\mathrm{d}w/\mathrm{dt} \equiv 0)$. In general $\mathrm{d}w/\mathrm{dt}$ is a maximum at w_{marg}. When sufficiently seeded, $w_{\mathrm{seed}} \geq w_{\mathrm{crit}}$, the island grows to the saturated size w_{sat}. If beta is then slowly reduced, the island shrinks as the destabilizing bootstrap current $j_{\mathrm{bs}} \propto \beta_\theta$ is reduced. When $w \lesssim w_{\mathrm{marg}}$, $\mathrm{d}w/\mathrm{dt} \lesssim 0$ for all w and stabilization occurs. An example from DIII-D is shown in Fig. 1. Data from ASDEX Upgrade, DIII-D and JET is plotted in Fig. 2; this is the normalized electron beta poloidal, the dominant destabilizing perturbed bootstrap term, versus the normalized poloidal ion gyroradius at $q = 3/2$ for the <u>spontaneous stabilization</u> of the $m/n = 3/2$ NTM. This is equivalent to a scaling of $w_{\mathrm{marg}} \approx 2\varepsilon^{1/2}\rho\theta_i$. However, $\varepsilon^{1/2}$ is essentially the same in all cases. While $w_{\mathrm{marg}} \approx 2\varepsilon^{1/2}\rho\theta_i$ is most consistent with the polarization threshold, this is <u>not</u> a proof.

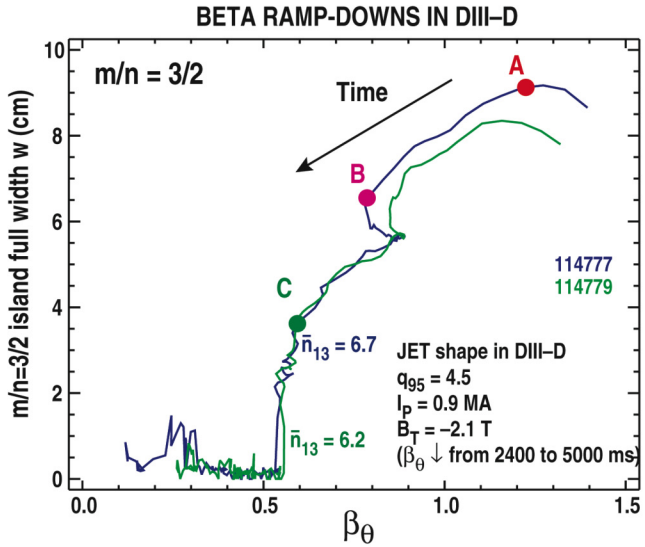
The empirical scaling predicts ITER will be very susceptible to destabilization, as also shown in Fig. 2.

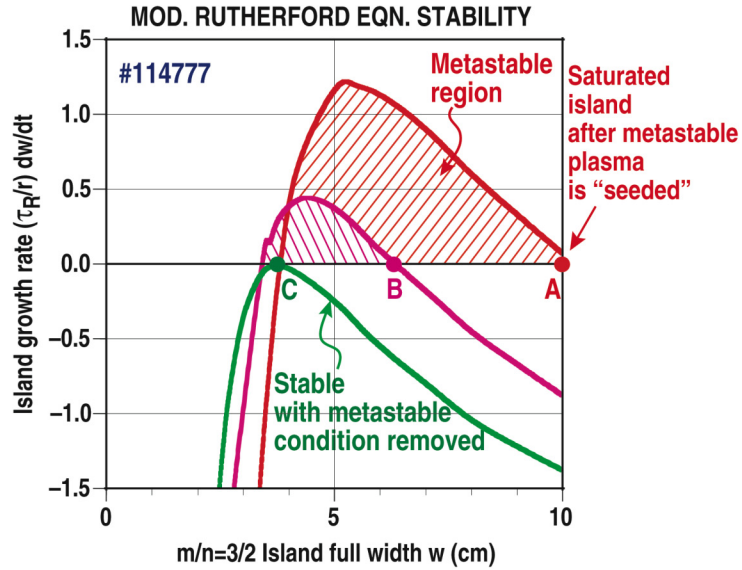
NSTX, with a much larger a/R has a larger $\varepsilon^{1/2}$ and can extend tests of small island threshold physics. With $R/a \approx 5/4$, $q(0) \approx 1$, and $q_{95} \approx 4.5$, one expects $\varepsilon^{1/2}$ to be $\left[3/(5/4)\right]^{1/2} \approx 1.6$ times larger in NSTX.

Figure 1

NTMS Can Be Removed (or Avoided) by Removing the Metastable Condition I

- **Reducing beta without ECCD removes the island ... when the "marginal island" is reached**



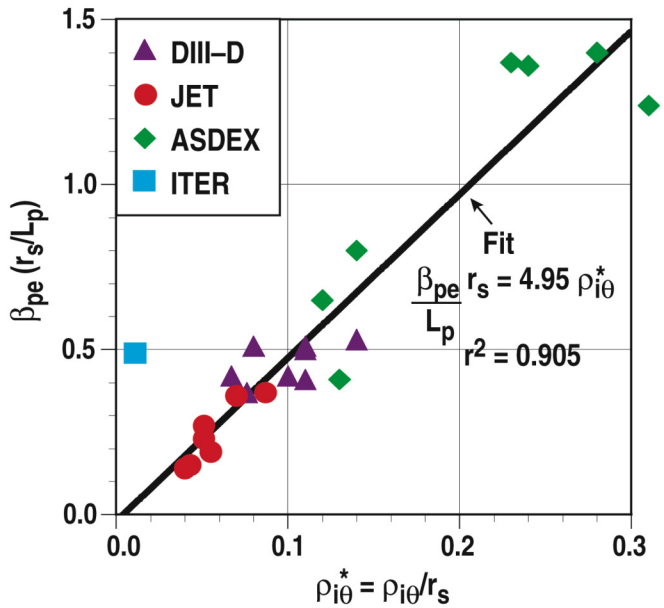


La Haye, APS 2003; Buttery, IAEA 2004

Figure 2

NTMs Can Be Removed (or Avoided) by Removing the Metastable Condition II

- **Reducing beta without ECCD removes the island**
  - ITER scenario 2 operation point is metastable



- **Metastable threshold is equivalent to a "marginal" island width**
  - ★ $w_{marg} \approx 2\, \varepsilon^{1/2}\, \rho_{\theta i}$ **(twice ion banana width)**
    - the "knee" in the dw/dt versus w stability curve
  - ★ **NSTX could further test this scaling**
    - as $\varepsilon^{1/2}$ is different

Buttery IAEA 2004

DIII-D NATIONAL FUSION FACILITY SAN DIEGO 338-06/RJL/jy

ASDEX Upgrade

JET

3. Experimental Method

To best add to the existing database, an $m/n = 3/2$ NTM needs to be excited and allowed to saturate. Desirable is $q_{95} \approx 4.5$ and $q(0) \approx 1$ so that the ρ value of $q = 3/2$ will be similar to large aspect ratio devices. Sawteeth may be needed to excite the $m/n = 3/2$ mode. Once excited and saturated at near constant heating power, the power should be lowered in steps to get beta to decrease "slowly". Steps could be -40% every $3\tau_E$ for about 4 steps taking β_θ down to $\approx 1/3$ of the saturated value. H-mode with ELMs should be retained. A density scan in beta rampdown is desirable, keeping I_p/B_T fixed, if time permits.

4. Analysis

EFIT is needed to locate $q = 3/2$ and determine B_θ. T_i profile measurement is then needed to get $\rho_{\theta i}$. Lacking ECE radiometer, w_{marg} will have to be computed from magnetics using calibration by SXR inversion if possible. Data for the marginal point, as shown as C in Fig. 1, for w_{marg}, $\rho_{\theta i}/r_s$, β_θ and $\beta_{pe}(r_s/L_p)$ will be added to the existing date set in Fig. 2.

5. Resources

5.1. Tokamak

Toroidal Field: $B_T = 4.5$ kG

for $q_{95} \approx 4.5$???

Plasma current: $I_p = 0.8$ MA

Shape: Moderate δ LSN shape as NSTX 109926, t=280 ms is preferred to match existing experimental data.

5.2. Neutral Beams

Enough power to raise beta high enough to excite the $m/n = 3/2$ mode. The presence of sawteeth may be desirable.

5.3. Diagnostics

Essential:	Magnetic (fast and slow) CER for core T_i and rotation Thomson CO_2
Desirable:	SXR for island width

6. Experimental Shot Plan

The reference discharge is shape of 109926 at t=280 msec, a moderate triangularity LSN so as to touch base with AUG, DIII-D and JET shapes. Sawteeth for $q(0) \approx 1$ and a $q_{95} \approx 4.5$ are desirable. Beam heating is needed to be added late, i.e. in the I_p flattop, to allow $q(0)$ to come down to get sawteeth. An ELMy H-mode with sawteeth is preferred in which sawteeth as beta rises excite the $m/n = 3/2$ mode but <u>not</u> high enough beta to excite the $m/n = 2/1$ NTM.

This is a ½ day experiment.

1. Establish the plasma with a reproducible $m/n = 3/2$ mode that saturates as beta stops rising. *(4 shots)*

2. Repeat with heating power stepped down serially at a time just after the mode saturated in 1. Stay in ELMing H-mode and look for the decrease in mode amplitude (by $n = 2$ Mirnov) until spontaneous stabilization occurs. *(4 shots)*

3. Repeat 2 with different densities in beta rampdown to vary the plasma conditions for stabilization. Up 50% and down 30% for a factor of 2. *(4 shots)*