Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: **Determination of Weak RWM Stability Rotation Profiles**

OP-XP-1020	Revision: **2.0**	Effective Date: **4/9/10** *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: J.W. Berkery	Date
ATI – ET Group Leader: S.A. Sabbagh	Date
RLM - Run Coordinator: E. Fredrickson	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Determination of Weak RWM Stability Rotation Profiles** No. **OP-XP-1020**

AUTHORS: **J.W. Berkery, S.A. Sabbagh, H. Reimerdes** DATE: **4/9/10**

1. Overview of planned experiment

Kinetic theory indicates that plasmas with ω_φ in between ω_D and ω_b resonances have weakened stability to the resistive wall mode (RWM)[1]. It is key to understand passive stability in regimes of high importance to the future of the ST (low l_i). The main goal of this experiment is to work towards verification of a unified, quantitative physics model for RWM stability based on variations of key variables in the plasma near marginal stability. To do this we will measure the RWM marginally stable points, and the stable RWM growth rate and mode rotation frequency (γ and ω_r), using active MHD spectroscopy, as a function of ω_φ and other key parameters in low l_i plasmas and compare to kinetic theory prediction calculated by the MISK code. A secondary goal is to provide input to the eventual goal of realtime stability limit detection via resonant field amplification (RFA) measurement.

2. Theoretical/ empirical justification

Recent work comparing kinetic stabilization theory calculations to NSTX experimental results have shown that NSTX discharges with plasma rotation profiles intermediate to the stabilizing precession drift and bounce resonances can have weakened stability to the RWM, leading to unstable RWM growth[1]. Figure 1 shows contours of MISK calculated normalized RWM growth rate, $\gamma\tau_w$, on a plot of scaled collisionality vs. scaled rotation for an NSTX discharge. The theoretically predicted range of weakened stability corresponds to the experimental rotation profile at the time of instability. In the present experiment, we hope to make direct measurement of the RWM damping rate (stable growth rate) via MHD spectroscopy.

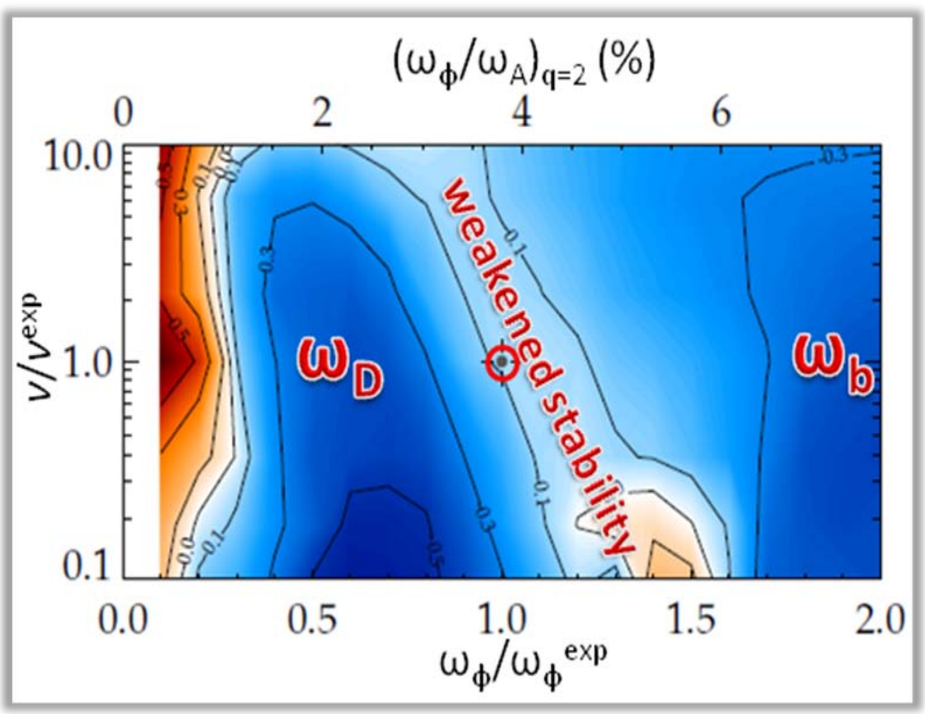

Figure 1: Contours of $\gamma\tau_w$ for NSTX 121083 @ 0.475 s. Blue is stable and red is unstable.

Recently an experiment was performed in DIII-D in which plasma toroidal rotation was changed while a

[1] J.W. Berkery, *et al.*, Phys. Rev. Lett. **104**, 035003 (2010).

20 Hz n=1 field was applied. The plasma response to the applied field, measured by external magnetic sensors, can be used to calculate the growth rate and mode rotation frequency, using a suitable model[2]. Alternatively, calculated theoretical γ and ω_r can give a modeled plasma response amplitude and phase. Figure 2b shows a MISK calculation for a DIII-D equilibrium, indicating that the rotation of weakened RWM stability occurs at $\omega_\varphi\tau_A$ = 1% at the q=2 surface. The plasma response measurements in Fig. 2a show that key features of the kinetic modeling are duplicated in the experiment. The large plasma response to the external field indicates a weakly damped RWM.

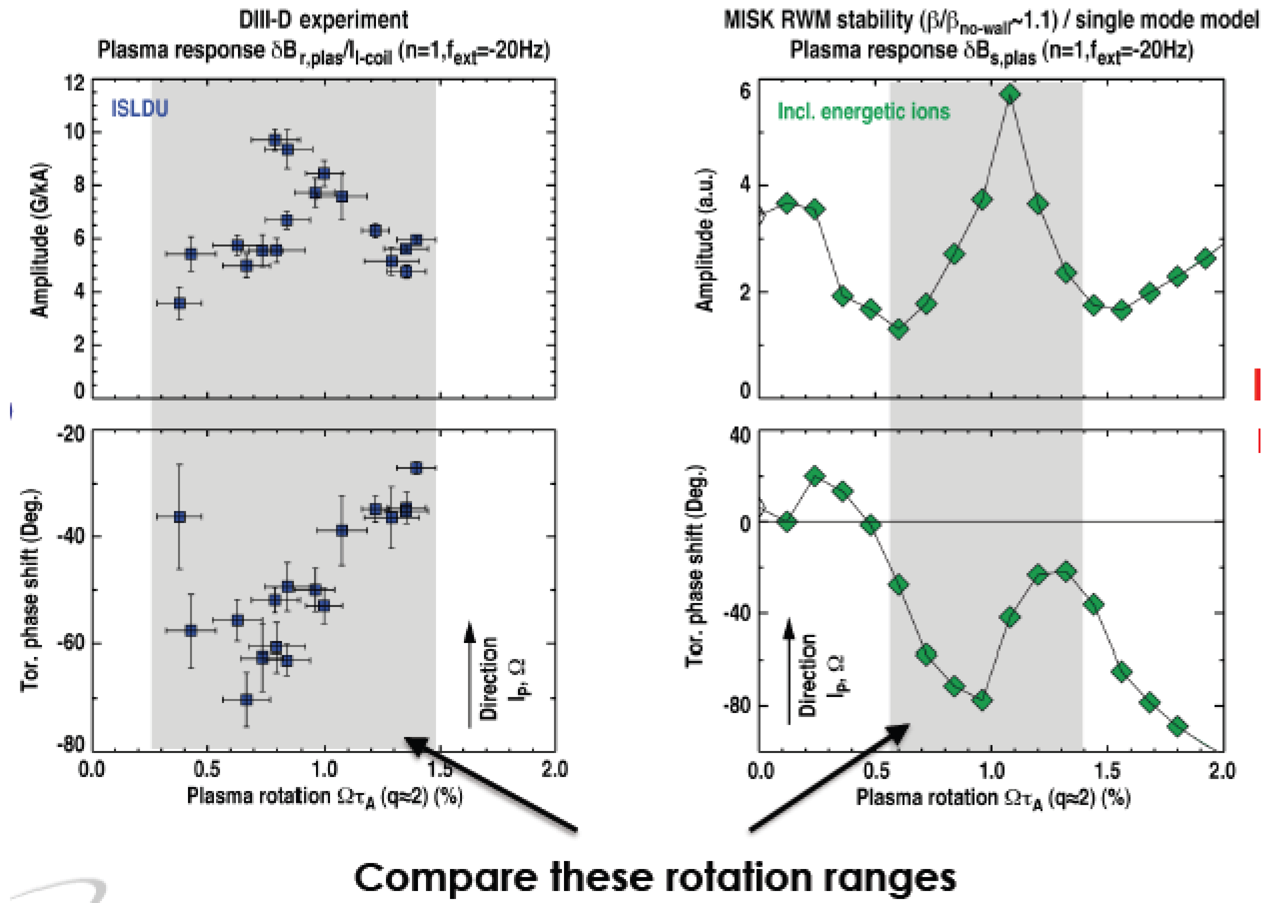

Figure 2: b) Rotation dependence of the plasma response to externally applied n=1 fields in recent DIII-D wall-stabilized discharge., b) Kinetic calculations of the RWM growth rate for a comparable DIII-D discharge using the MISK code.

There are four different effects in the kinetic theory of RWM stabilization which will be examined in this experiment. First are the rotational resonances and collisionality effects associated with the thermal particles. Second is the stabilizing effect of energetic particles due to a real restorative force that arises from conservation of magnetic flux enclosed by precessional drift orbits when the precession drift frequency is large. In other words, energetic particles make the magnetic flux more rigid and resistant to change by the RWM. Finally, another previously unexplored theoretical effect is the electrostatic effect. A destabilizing term proportional to the perturbed electric potential had been previously formulated, but not previously included in calculations or explored in experiments. Additionally, a previously unexplored aspect of the energetic particles' effect on RWM stability is that a new term, proportional to $(\tilde{B}_{\parallel}/B)(\partial f/\partial\mu)$, arises in kinetic theory when the distribution function is anisotropic. We do not yet have a full theoretical understanding of this effect or how to test it in experiment.

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[2] H. Reimerdes, *et al.*, Nuclear Fusion **45**, 368 (2007).

The secondary goal of this experiment is to provide data to the eventual NSTX goal of realtime stability limit detection via RFA. Since RFA increases near and above the no-wall β_N limit, it may be possible to detect proximity to this limit by monitoring RFA in real time. The question will be: how well does RFA predict the proximity to ideal stability limits which depend on plasma shaping, q profile, pressure peaking and internal inductance? This XP is not designed to address these issues, but will provide a starting point for a future XP that will.

3. Experimental run plan

Task	Number of Shots

1) Establish target with slow rotation ramp down and AC fields
   A) Developed or improved in XP1023. Start n=3 error field correction at 0.250 s, ramping to full amplitude at 0.300 s. Backup position: long pulse, low to moderate l_i target. 1
   B) During the period devoid of n=1 rotating mode activity, vary the n=3 DC field from correcting phase to braking phase, and vary the SPA current ramp rate and timing to optimally change plasma rotation, to find the marginal point. Attempt to navigate through the marginal point to low rotation without an unstable RWM, as slowly as possible. 2
   C) Add n=1, 40 Hz, 1kA peak to peak AC field. (Use setup from shot 133671) If 40 Hz doesn't give a strong RFA response, drop to 30 Hz. 1
   D) Come back to B, using RWM growth as a guide. Optimize rotation ramp to get as close as possible, and push to unstable RWM. 3
   E) Reduce NBI power from 6 MW to 4 MW to determine effect of RFA amplitude vs. plasma rotation at lower β_N. 1

2) Vary key parameters in the model that can alter RWM stability, to determine the effect on the plasma for comparison to theory.

   A) Energetic particle content and collisionality

   These two parameters are intertwined. By changing current and field between conditions 1 and 2, we will change both. By changing sources from conditions 3 to 4 we will change the EP distribution. Within each of the conditions below we will also attempt to change collisionality by using supersonic gas injection (which will be developed in these targets in XP1023). If we can use SGI to compensate for the collisionality change between 1 and 2, then they can be used as a scan of EP distribution (based on EP confinement time).

Condition	I_p (MA)	B_t (T)	Sources	Shots
1	1.1	0.55	A,B,C (6 MW)	5
2	0.8	0.4	A,B,C (6 MW)	5
3	0.8	0.4	A,B (4 MW)	3
4	0.8	0.4	A,C (4 MW)	3

   B) Electrostatic effect

   Use the highest and lowest collisionality conditions from above to get high/low n_i/T_i. Within those variations, probe across $\omega_E = 0$ (where the effect is strongest), at the time of peak beta. 6

Total: 30

4. Required machine, NBI, RF, CHI and diagnostic capabilities

See attached Physics Operations Request and Diagnostic Checklist.

5. Planned analysis

Equilibrium reconstructions will be performed with EFIT, with MSE and the flux iso-surface constraint, for reduced error on the q profile. These equilibria will then be analyzed with PEST to obtain the fluid δW terms and MISK to obtain the kinetic stabilization.

TRANSP will be used to obtain energetic particle pressure profiles.

Analysis of MHD spectroscopy will be performed using IDL routines.

6. Planned publication of results

Conclusions from this experiment will be incorporated into a presentation at the 2010 EPS conference in June 2010 in Dublin, Ireland, and in a publication in Physics of Plasmas in fall 2010.

PHYSICS OPERATIONS REQUEST

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(use additional sheets and attach waveform diagrams if necessary)

Describe briefly the most important plasma conditions required for the experiment:

High beta plasmas with a long MHD free phase.

We will be applying various RWM coil currents and timing.

We may wish to use beta control to keep beta just below a critical value.

Previous shot(s) which can be repeated: 135302

Previous shot(s) which can be modified: 133797 (for AC fields. No DC n=3 offset. Can extend fields past 1 s).

Machine conditions *(specify ranges as appropriate, strike out inapplicable cases)*

I_{TF} (kA): **0.3 – 0.55 T** Flattop start/stop (s):

I_P (MA): **0.6 – 1.1 MA** Flattop start/stop (s):

Configuration: ~~**Limiter**~~ **/ DN / LSN /** ~~**USN**~~

Equilibrium Control: **Outer gap / Isoflux** (rtEFIT)

Outer gap (m): Inner gap (m): Z position (m):

Elongation κ: Upper/lower triangularity δ:

Gas Species: **D** Injector(s):

NBI Species: **D** Voltage (kV) **A: 90** **B: 90** **C:** 90 Duration (s):

ICRF Power (MW): - Phase between straps (°): - Duration (s): -

CHI: **Off /** ~~**On**~~ Bank capacitance (mF): **-**

LITERs: ~~**Off**~~ **/ On** Total deposition rate (mg/min): **???**

EFC coils: ~~**Off**~~**/On** Configuration: **Odd /** ~~**Even / Other**~~ *(attach detailed sheet*

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Bolometer – tangential array		√
Bolometer – divertor		√
CHERS – toroidal	√	
CHERS – poloidal		√
Divertor fast camera		√
Dust detector		√
EBW radiometers		√
Edge deposition monitors		√
Edge neutral density diag.		√
Edge pressure gauges		√
Edge rotation diagnostic		√
Fast ion D_alpha - FIDA	√	
Fast lost ion probes - IFLIP		√
Fast lost ion probes - SFLIP		√
Filterscopes		√
FIReTIP		√
Gas puff imaging		√
Hα camera - 1D		√
High-k scattering		√
Infrared cameras		√
Interferometer - 1 mm		√
Langmuir probes – divertor		√
Langmuir probes – BEaP		
Langmuir probes – RF ant.		
Magnetics – Diamagnetism	√	
Magnetics – Flux loops	√	
Magnetics – Locked modes	√	
Magnetics – Pickup coils	√	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents		√
Magnetics – RWM sensors	√	
Mirnov coils – high f.		√
Mirnov coils – poloidal array	√	
Mirnov coils – toroidal array	√	
Mirnov coils – 3-axis proto.		

Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
MSE	√	
NPA – E||B scanning		√
NPA – solid state		√
Neutron measurements	√	
Plasma TV		√
Reciprocating probe		
Reflectometer – 65GHz		√
Reflectometer – correlation		√
Reflectometer – FM/CW		√
Reflectometer – fixed f		√
Reflectometer – SOL		√
RF edge probes		
Spectrometer – SPRED		√
Spectrometer – VIPS		√
SWIFT – 2D flow		
Thomson scattering	√	
Ultrasoft X-ray arrays	√	
Ultrasoft X-rays – bicolor		√
Ultrasoft X-rays – TG spectr.		√
Visible bremsstrahlung det.		√
X-ray crystal spectrom. - H		√
X-ray crystal spectrom. - V		√
X-ray fast pinhole camera		√
X-ray spectrometer - XEUS		√