Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: Island-induced neoclassical toroidal viscosity and dependence on ν_i		
OP-XP-743	**Revision: V1.0**	Effective Date: 5/7/07 *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS	
Author: S.A. Sabbagh, K.C. Shaing, et al.	Date:
ATI – ET Group Leader: S.A. Sabbagh / N. Gorelenkov	Date
RLM - Run Coordinator: D.A. Gates	Date
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Title: <u>Island-induced neoclassical toroidal viscosity and dependence on ν_i</u> OP-XP-743

1. Overview of planned experiment

Briefly describe the scientific goals of the experiment.

The overall goal of the experiment is to test the theory of neoclassical toroidal viscosity (NTV) in the presence of islands. This theory has been quantitatively successful in matching the theoretical torque to the measured change in angular momentum in NSTX for plasmas without strong magnetic islands (W. Zhu, S.A. Sabbagh, R.E. Bell, et al., PRL **96** (2006) 225002.). In the presence of islands, the NTV scaling with plasma parameters is different, and this will be tested in the XP. Also, comparison to competing theories of induced torques on rational surfaces (e.g. electromagnetic – R. Fitzpatrick, Nucl. Fusion **33** (1993) 1049.) will be made. To summarize, the goals are:

1. Test theory of island-induced neoclassical toroidal viscosity (INTV).
2. Compare to theory of drag due to electromagnetic torque.
3. Investigate damping over range of ion collisionality and island width to determine affect on rotation damping and to distinguish theories.
4. Examine $1/\nu_i$ dependence of NTV without internal rotating modes and compare to scaling expected by INTV theory
5. Determine percentage of torque from non-resonant NTV vs. INTV vs. electromagnetic.

This experiment will also provide important results from a general physics standpoint and for ITER. It is especially important to understand the physics, and therefore, scaling of torques induced on the plasma to best understand and compute the plasma rotation expected for ITER. This rotation has direct impact on the stabilization of MHD modes in ITER. The XP addresses the rotation aspect of the NSTX R(07-2) milestone, ITPA experiments MDC-4 and MDC-12, as well as ITER issue card AUX-1

2. Theoretical/ empirical justification

Brief justification of activity including supporting calculations as appropriate

A magnetic island in a tokamak breaks the toroidal symmetry, and therefore is a source of neoclassical toroidal viscosity, which is generated by an interaction of the non-axisymmetric field with the plasma. The magnitude of this broken toroidal symmetry-induced toroidal plasma viscosity is proportional to $w^2 \sim \delta B$ in the vicinity of the island, where w is the width of the island, and δB is the perturbed magnetic field. This scaling is different from the non-resonant perturbed magnetic field-induced plasma viscosity, which scales like δB^2 as observed in NSTX (W. Zhu, S.A. Sabbagh, R.E. Bell, et al., PRL **96** (2006) 225002.). Thus in the vicinity of an island, neoclassical toroidal plasma viscosity (NTV) is enhanced.

In addition to the importance of the physics in question, the experiment is especially attractive since several leading fundamental theories of plasma viscosity can be compared in full detail and distinguished. This approach is superior to analyzing the experimental results by making simple fits to one or two parameters as is typical. First, the standard non-resonant NTV theory, that scales as $\delta B^2 (p_i/\nu_i)(1/A)^{1.5}$, yields distinct rotation profile evolution and a distinct scaling compared to other theories that include islands. For example, the present leading theory of island-induced electromagnetic torque (JxB) at rational surface (R. Fitzpatrick, Nucl. Fusion **33** (1993) 1049.) can be computed to scale as δB^2 if certain assumptions are made about the static error field, but does not depend on ν_i. Island-induced NTV (K.C. Shaing, PRL **87** (2001) 245003.) scales as δB due to toroidicity, and depends in a more complex way on ν_i. The NTV theories can be evaluated quantitatively (as was done for NTV on NSTX), and NTV can be differentiated from INTV and JxB by the distinct localization of the latter two to the rational surface associated with the island.

3. Experimental run plan

Describe experiment in detail, including decision points and processes

The primary approach of the experiment is to generate a significant island in the plasma (as was performed and diagnosed in XPs 739 and 740) and then vary two key parameters in the aforementioned theories – δB and ν_i. From experience with the recent NTM experiments XP739 and XP740, the most significant, reproducible, and easy to diagnose island is the 2/1 measured with NSTX EFIT reconstructions using MSE to be just inside the q = 2 surface. The ν_i would be varied at constant q by gas puffing and changing I_p/B_t, as was done successfully in XP619. We could also consider transitioning out of H-mode, as the n = 1 mode persists in L-mode plasmas. The δB would be varied by applying and varying a primarily n = 1 field using the non-axisymmetric field coils on NSTX. The analysis would compare the measured change in the plasma angular momentum before and after the tearing mode onset. The tearing mode onset time can be changed, if needed, by reducing plasma elongation in the range 2.1 – 1.9.

The shot list for the XP is:

<u>Run plan</u>:

1) Create target plasma near, but not well above the ideal no-wall beta limit (control shot)
(use recent 123866 as setup shot, reduce I_p flat-top to 0.9 MA, 2 or 3 NBI sources and NO step-down of NBI power)
A) Determine time of steady ω_ϕ and n = 1 tearing mode onset 1
B) Reduce elongation to 1.9 (increase PF1A current) if earlier n = 1 TM onset desired 1

2) Establish applied non-axisymmetric field scenarios (control shots)
A) Apply n = 1 field at TM mode onset (t ~ 0.700s) (n = 1 setup from (2B)) 2
B) Apply n = 1 field at steady ω_ϕ from (1A) (t ~ 0.490s) (n = 3 setup: 116939, 0.7 kA) 2
C) Apply n = 3 field at steady ω_ϕ from (1A) (t ~ 0.490s) (n = 1 setup: 123889, 0.8 kA) 2
3) Ion collisionality scan

A) Vary ν_i for n = 1 applied field, with tearing mode (setup from (2A) 3
B) Vary ν_i for n = 1 applied field, no rotating modes (setup from (2B)) 3
C) Vary ν_i for n = 3 applied field, no rotating modes(setup from (2C)) 3

4) Applied field scan / vary island width (pick most favorable ν_i setup from part (1A)
A) Vary n = 1 applied field (est. range 200A – 1200A) 5

Total: 22

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

Describe any prerequisite conditions, development, XPs or XMPs needed.
Attach completed Physics Operations Request and Diagnostic Checklist

As usual, standard magnetic diagnostics are essential. Diamagnetic loop and Thomson scattering are required since partial kinetic EFIT reconstructions are needed for this experiment. CHERS and MSE are required for toroidal rotation, ion temperature, and internal magnetic field line pitch angle profile evolution. The internal RWM sensor set will be required for RWM detection. The ability to pre-program nominal n = 1 and n = 3 non-axisymmetric fields using the SPAs / RWM control coil is required.

NOTE: The lithium evaporator is required for this XP if it is run with 2 NBI sources. If 3 NBI sources are available the lithium evaporator is optional, but desired as it will most likely lead to more reproducible conditions.

5. Planned analysis

What analysis of the data will be required: EFIT, TRANSP, etc.

EFIT at all run levels, including MSE and flux isosurface constraint will be important for this experiment, and will be run for each shot of interest. DCON will be used to determine no-wall and with wall β_N limits and RWM mode structure. A suite of codes will be used to compute the theoretical modes of NTV, INTV and JxB torques generated on the two-dimensional equilibria taken from the NSTX EFIT reconstructions.

6. Planned publication of results

What will be the final disposition of the results; where will results be published and when?

INTV has not been identified in experiments yet, so observing this effect would be ground and would warrant rapid publication in Physical Review Letters. A longer paper comparing the different theories of plasma viscosity with experiment should warrant an invited talk at a major meeting and subsequent publication in Physics of Plasmas, or Nuclear Fusion.

PHYSICS OPERATIONS REQUEST

Title: Island-induced neoclassical toroidal viscosity and dependence on ν_i OP-XP-743

Machine conditions (specify ranges as appropriate)

I_{TF} (T): **0.45T** Flattop start/stop (s): _____/_____

I_P (MA): **0.8 – 1.0 MA** Flattop start/stop (s): _____/_____

Configuration: **Lower Single Null**

Outer gap (m): 5**+/- 3 cm**, Inner gap (m): **5 +/-3 cm**

Elongation κ: **1.9 – 2.1**, Triangularity δ: **0.4 – 0.5**

Z position (m): **0.00**

Gas Species: D, Injector: **Midplane / Inner wall / Lower Dome**

NBI - Species: **D**, Sources: **A/B/C(optional)**,Voltage (kV): **max**; A: 90kV, Dur (s):

ICRF – Power (MW): **0**, Phasing: **Heating / CD**, Duration (s): _____

CHI: **Off**

Either: List previous shot numbers: **See shot list in XP for setup shots**

Or: Sketch the desired time profiles, including inner and outer gaps, κ, δ, heating, fuelling, etc. as appropriate. Accurately label the sketch with times and values.

DIAGNOSTIC CHECKLIST

Title: Island-induced neoclassical toroidal viscosity and dependence on ν_i OP-XP-743

Diagnostic	Need	Desire	Instructions
Bolometer – tangential array			
Bolometer array - divertor			
CHERS	X		
Divertor fast camera			
Dust detector			
EBW radiometers			
Edge deposition monitor			
Edge pressure gauges			
Edge rotation spectroscopy			
Fast lost ion probes - IFLIP		X	
Fast lost ion probes - SFLIP		X	
Filtered 1D cameras			
Filterscopes			
FIReTIP		X	
Gas puff imaging			
Infrared cameras			
Interferometer - 1 mm			
Langmuir probe array			
Magnetics - Diamagnetism	X		
Magnetics - Flux loops	X		
Magnetics - Locked modes	X		
Magnetics - Pickup coils	X		
Magnetics - Rogowski coils	X		
Magnetics - RWM sensors	X		
Mirnov coils – high frequency		X	
Mirnov coils – poloidal array		X	
Mirnov coils – toroidal array	X		
MSE	X		
Neutral particle analyzer		X	
Neutron measurements		X	
Plasma TV		X	
Reciprocating probe			
Reflectometer – core			
Reflectometer - SOL			
RF antenna camera			
RF antenna probe			
SPRED			
Thomson scattering	X		
Ultrasoft X-ray arrays	X		
Visible bremsstrahlung det.			
Visible spectrometers (VIPS)			
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray PIXCS (GEM) camera			
X-ray pinhole camera			
X-ray TG spectrometer			