Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**
Title: Suppression of Frequency Chirping by HHFW Heating of Beam Ions

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PROPOSAL APPROVALS	
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ATI – MHD Group Leader: Steve Sabbagh	Date
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Responsible Division: Experimental Research Operations	
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MINOR MODIFICATIONS (Approved by Experimental Research Operations)	

Suppression of Frequency Chirping by HHFW Heating of Beam Ions

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1. Overview of planned experiment:

Beam-driven instabilities with rapid frequency chirping are produced. The addition of HHFW heating increases the effective collision rate of the resonant fast ions, which will suppress the frequency sweeping (if the Berk-Breizman theory of phase-space holes and clumps is applicable). The dependence of chirping on beam energy and angle is also studied.

2. Justification:

Although much is known about the linear stability of fast-ion driven instabilities, nonlinear saturation is less understood. Some instabilities (such as the classic PDX fishbone) have frequencies that change by a factor of two on a millisecond timescale, while the frequencies of other instabilities are virtually constant on this timescale. Some empirical observations are perplexing. For example, despite many similarities between devices, frequency chirping in the sub-TAE frequency range is common in NSTX [1] but rare in DIII-D [2]. A fundamental understanding of these differences can guide predictions of the saturated amplitude of alpha-driven instabilities in ITER and other burning plasmas.

A simplified model developed by Berk and Breizman explains some of the nonlinear phenomenology of fast-particle driven instabilities. In their model [3], frequency chirping is associated with the formation of holes and clumps in the phase space that describes the fast-particle distribution function. When collisions are weak, these phase-space structures persist and frequency chirping is possible. When the effective collision rate is large, the structures are rapidly destroyed and no frequency chirping occurs.

Maslovsky and Mauel [4] used energetic electrons in a dipole to test the Berk-Breizman model. When additional RF energy was absorbed by the resonant electrons, chirping was suppressed.
Modeling indicated that the increase in the effective collision rate could account for the suppression.

The basic idea of this experiment is to replicate the Maslovsky-Mauel hot-electron experiment with beam ions in NSTX. Neutral beam heating creates the energetic-particle population that drives chirping instabilities [1]. The HHFW system accelerates the beam ions in the perpendicular direction [5], effectively scattering them in phase space. For this to work, the chirping instability and the fast-wave heating must act on the same class of particles in phase space. Although it is difficult to insure manipulation of the same portion of phase space, it is straightforward to select particles with similar energies: choose conditions where both the chirping instabilities and the HHFW alter the neutron rate. (The neutron rate is determined principally by full-energy beam ions.) Fortunately, plasma conditions where the chirping modes cause drops in the neutron rate [1] and where HHFW causes an increase in the rate [5] are rather common.

A secondary goal is to explore the dependence of chirping instabilities on the fast-ion distribution function through systematic variations in beam voltage and injection angle.

[1] E. Fredrickson *et al.,* Nucl. Fusion **43** (2003) 1258.
[2] W.W. Heidbrink, Plasma Phys. Cont. Fusion **37** (1995) 937.
[3] H.L. Berk *et al.,* Phys. Plasmas **6** (1999) 3102.
[4] D. Maslovsky *et al.,* Phys. Plasmas **10** (2003) 1549.
[5] A. Rosenberg, Ph.D. Thesis (2003).

3. **Plan:**

The goal is to achieve sets of comparison discharges with and without HHFW for various fast-ion distributions. The basic approach is to establish a condition with strong chirping for a particular beam source (or sources), then add HHFW. If full-power HHFW suppresses the chirping, the power is reduced to find the threshold. Then the beam parameters are changed and the process is repeated. Ideally, the background plasma conditions will change little as the beam parameters are varied.

Successful coupling of the HHFW power to the plasma is a key issue. We plan to begin with a DND configuration that has shown good control of the outer gap with rtEFIT. L-mode discharges with moderately low current often exhibit strong chirping. Our initial target plasma is a 0.7 MA, L-mode, one-beam-source, plasma with good outer gap control. The strongest chirping instabilities may occur near the end of the current ramp, so HHFW injection may commence relatively early (as in Rosenberg's shot 108273). Midplane gas puffing may prove useful in delaying the onset of H-mode. A more radical approach is to push the plasma onto the inner wall but simultaneous control of the outer gap requires discharge development.

We want to use two different beam voltages: ~90 kV and ~65 kV. At the higher voltage, a single source should produce strong chirping. At the lower voltage, pairs of sources such as A-B and B-C will likely be needed to establish the condition.

One concern is that lost beam ions could damage the RF antenna in plasmas with large accelerating voltages, modest plasma currents, and small outer gaps. The baseline condition may need to be at somewhat higher plasma current or lower beam voltage. Alternatively, we may shorten the beam pulse to 100 ms.

1. Establish the baseline condition with strong frequency chirping and HHFW injection. Reference discharge: 112345. Source A at ~90 kV. (10 shots)
2. No HHFW comparison for baseline condition. (2 shots)
3. Source C at ~90 kV with and without HHFW. (4 shots)
4. (If time permits) Source B at ~90 kV with and without HHFW. (4 shots)
5. Sources A-B at 65 kV with and without HHFW. (4 shots)
6. Sources B-C at 65 kV with and without HHFW. (4 shots)

4. Required machine, beam, ICRF and diagnostic capabilities:

All three neutral beam sources are essential as is HHFW power of at least 2 MW.

Diagnostics: For the fast ions, the neutrons are essential and the other fast-ion diagnostics are highly desirable. For instability analysis, toroidal array measurements to 250 kHz are essential; any possible radial eigenfunction measurements are highly desirable. For calculations of fast-ion distribution function, Thomson data are essential.

5. Planned analysis:

Basic experimental analysis (EFIT, magnetic spectrographs, toroidal mode number, expected versus measured neutrons) will be performed for all discharges. Theoretical analysis with White's ORBIT code of the class of ions that resonate with the mode is needed for the best case. An estimate of the effective collision rate caused by high-harmonic absorption of the fast waves is also needed.

6. **Planned publication of results:**

A major article on the results is anticipated within one year of completion of the completion of the experiment. The results will also contribute to Fredrickson's IAEA paper.

PHYSICS OPERATIONS REQUEST

Suppression of Frequency Chirping

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **53** Flattop start/stop (s):

I_P (MA): Flattop start/stop (s):

Configuration:

Outer gap (m): **~0.05**, Inner gap (m): **0-diverted**

Elongation κ: **see ref. shot**, Triangularity δ: see ref shot

Z position (m):

Gas Species: **D**, Injector: **Inner Wall, Midplane**

NBI - Species: , Sources: , Voltage (kV): **60-90**, Duration (s): **0.5**

ICRF – Power (MW): **>2**, Phasing: **Heating**, Duration (s): **0.2**

CHI: **Off**

Either: List previous shot numbers for setup: **112345**

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	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	
Fast X-ray pinhole camera			
Filtered 1D cameras			

Filterscopes			
FIReTIP		x	
Gas puff imaging			
Infrared cameras		x	
Interferometer - 1 mm			
Langmuir probe array			
Magnetics - Diamagnetism	x		
Magnetics - Flux loops	x		
Magnetics - Locked modes			
Magnetics - Pickup coils	x		
Magnetics - Rogowski coils	x		
Magnetics - RWM sensors			
Mirnov coils – high frequency	x		
Mirnov coils – poloidal array	x		
Mirnov coils – toroidal array	x		
MSE		x	
Neutral particle analyzer	x		
Neutron measurements	x		
Optical X-ray			
Plasma TV	x		
Reciprocating probe			
Reflectometer – core	x		
Reflectometer - SOL			
RF antenna camera	x		
RF antenna probe		x	
SPRED			
Thomson scattering	x		
Ultrasoft X-ray arrays		x	High bandwidth acquisition, soft x-ray foils
Visible bremsstrahlung det.		x	
Visible spectrometer (VIPS)		x	
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray PIXCS (GEM) camera			

DIAGNOSTIC CHECKLIST

Suppression of Frequency Chirping