Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: Thermal Electron Bernstein Wave Conversion to X-Mode		
OP-XP-519	**Revision: 1**	Effective Date: February 22, 2005 *(Ref. OP-AD-97)* Expiration Date: February 22, 2007 *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

OP-XP-519: Thermal Electron Bernstein Wave Conversion to X-Mode

1. Overview of Planned Experiment

The goals of this experiment are to demonstrate the measurement of the electron temperature on NSTX using therma EBW emission converted to X-mode radiation and EBW to X-mode (B-X) conversion efficiency ≥ 80% on NSTX as a prerequisite for installing an EBW heating and current drive system. An EBW antenna with two radially adjustable carbon limiters (Fig. 1) is installed on NSTX between Bays I and J to measure extraordinary electromagnetic mode emission converted via B-X conversion and to maximize the B-X conversion efficiency with a local limiter. The EBW antenna has two quad-ridge horns that can be used for both EBW radiometery and O-mode reflectometry. The electron density scale length (L_n) at the B-X mode conversion layer is an important parameter determining the B-X conversion efficiency. The O-mode reflectometer can measure L_n at the B-X mode conversion layer in front of the EBW antenna.

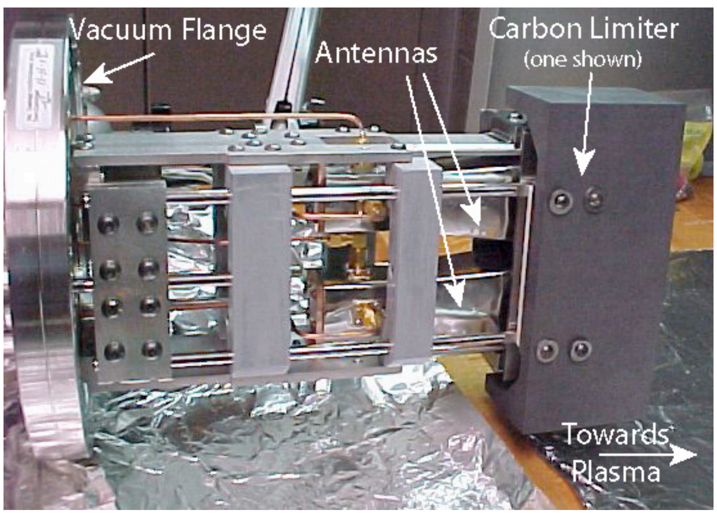

Figure 1 *Photograph showing a side view of the NSTX EBW B-X antenna assembly with radially adjustable carbon limiters. The two carbon limiters can be moved independently over a major radial distance of about 3 cm. The assembly has two quad-ridged horn antennas. In addition to EBW radiometry the horns can be used by an O-mode reflectometer to measure L_n at the B-X conversion layer. The antenna includes a port for a gas injection valve.*

2. Theoretical/Empirical Justification

Fundamental EBWs convert and tunnel to the fast X-mode at the upper hybrid resonance (UHR) that usually surrounds the NSTX plasma just outside the last closed flux surface (LCFS) [1-3]. EBWs first convert to the slow X-mode at the UHR. A cutoff-resonance-cutoff triplet formed by the left hand cutoff of the slow X-mode, the UHR, and the right hand cutoff of the fast X-mode allows the slow X-mode to tunnel through the UHR to the fast X-mode. The mode conversion efficiency (C) for $k_{//} = 0$ is given by [3]:

$$C = 4e^{-\pi\eta}\left(1 - e^{-\pi\eta}\right)\cos^2(\phi/2 + \theta) \qquad (1)$$

where $cos^2(\phi/2+\theta)$ is a phase factor relating to the phasing of the waves in the mode conversion region and the term preceding this is the maximum mode conversion efficiency. Here η is a tunneling parameter, which for magnetic scale lengths much greater than the density scale length at the UHR [3], is given by:

$$\eta \approx \left[\omega_{ce} L_n / (c\alpha)\right]\left[(1+\alpha^2)^{1/2} - 1\right]^{1/2} \tag{2}$$

where L_n, the density scalelength, and $\alpha = \omega_{pe}/\omega_{ce}$ are evaluated at the UHR layer and c is the velocity of light. From these equations it can be seen that the B-X conversion efficiency is sensitive to changes in L_n at the UHR layer where the wave frequency, $\omega = \omega_{UHR}$.

The UHR layer for fundamental EBW conversion lies in the scrape off layer outside the LCFS where L_n can be modified by a local limiter without affecting plasma performance. On NSTX the maximum mode conversion efficiency for fundamental EBWs occurs for $L_n \sim 0.3$ - 0.6 cm.

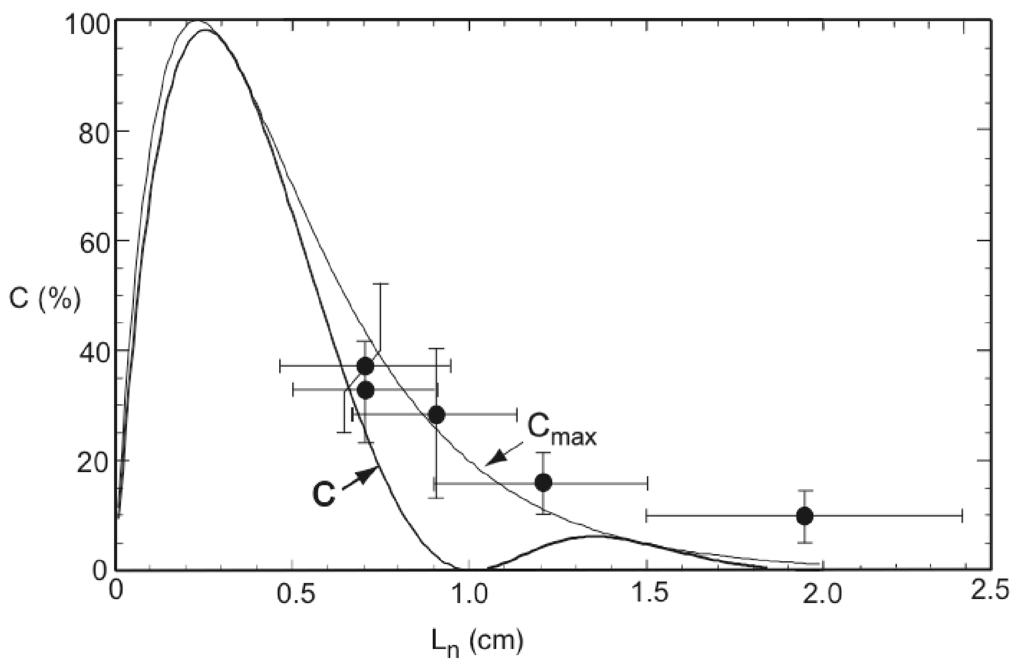

Figure 2 *Plot of theoretically expected B-X mode conversion efficiency for fundamental EBW from the NSTX core at 11.6 GHz versus density scale length (L_n) at the B-X conversion layer (lines) and the measured efficiency (T_{ebw}/T_e) and attained L_n measured by X-mode microwave reflectometry in XP-213.*

In XP-213, the B-X conversion at 11.6 GHz was increased by a factor of four when L_n at the mode-conversion layer was shortened from ~ 2 cm to about 0.7 cm (Fig. 2) [4]. In XP-213 the plasma was programmed to run with essentially no gap between the outer edge of the plasma and the Boron nitride limiters in the HHFW antenna. The maximum conversion efficiency approached 50% when the outer gap was zero and L_n was reduced to 0.7 cm, in agreement with theoretical predictions that used the local L_n at the B-X conversion layer measured by X-mode reflectometry. To reach ≥ 80% B-X conversion L_n needs to be reduced to about 0.3 cm. In XP-213 the minimum attainable L_n was limited by the connection length along the magnetic field lines between the Boron nitride tiles. Base on B-X conversion experiments on CDX-U that demonstrated ~ 100% B-X conversion efficiency by shortening L_n with a local limiter [5], an EBW antenna was designed for NSTX to have a connection length that can be made short enough to produce L_n ~ 0.3 at the UHR layer. In 2003 this antenna was installed at Bay I/J on NSTX.

In XP-404 last year we were unable to enhance the B-X mode conversion efficiency with the local antenna limiter at Bay I/J, even with the limiter fully extended in front of the B-X antenna. Measured B-X conversion efficiency in the 12-18 GHz band was only a few percent. O-mode reflectometry at Bay I/J revealed that plasma in front of B-X antenna was underdense ($\omega_{pe}<\omega_{ce}$) for 12-18 GHz EBW and consequently the local limiter was ineffective at enhancing B-X tunneling. In XP-515 we propose to puff small amounts of gas in the vicinity of the B-X antenna to provide overdense ($\omega_{pe}>\omega_{ce}$) plasma conditions at the local limiter tips.

References:

[1] NAKAJIMA, S. and H. ABE, Phys. Rev. A **38**, 4373 (1988).
[2] SUGAI, H., Phys. Rev. Lett. **47**, 1899 (1981).
[3] RAM, A.K., and SCHULTZ, S. D., Phys. Plasmas **7**, 4084 (2000).
[4] TAYLOR, G., *et al*., Phys. Plasmas **10**, 1395 (2003).
[5] JONES, B. *et al*., Phys. Rev. Lett. **90**, 165001 (2003).

3. Experimental Run Plan

Dedicated run time for this experiment will only be requested if "piggyback" operation with local gas puffing can provide overdense conditions for 12-18 GHz EBWs at the B-X antenna limiters. If overdense conditions are obtained with gas puffing dedicated run time will be requested. The following run plan requires about 16-18 similar plasma shots.

I. L_n Scan for Optimum B-X Conversion (run EBW radiometer dwelling at one frequency ~ 17 GHz (i.e. EBW emission from near the plasma axis):

a) Establish an ohmically-heated, helium plasma using the setup from shot 113544, an I_p = 800 kA with B_o = 4 kG. The experiment needs about 150 ms of I_p flattop without electron density glitches and a well-controlled shape. The experiment will begin with both the B-X antenna limiters A and B fully extended towards plasma (see Fig. 3(a)). Here we define the displacement of A and B limiters as Δ_A and Δ_B, respectively. Where a displacement of 0 cm is fully retracted and 3 cm is fully extended towards the plasma. Repeat same shot until the plasma conditions become reasonably reproducible and without significant MHD. Acquire MPTS T_e(R) and n_e(R) profile data during I_p flattop. Measure L_n at the B-X conversion layer and EBW T_{rad}/T_e, where T_e is measured by MPTS. Acquire data on two similar shots, one with the UCLA O-mode microwave reflectometer in swept mode, to obtain scrape off density profile in front of the EBW antenna, and the other with the reflectometer turned off to avoid interference with EBW radiometer measurements. **(2-4 shots)**

b) Move limiter B away from the plasma so that Δ_B = 2, 1 and 0 cm, two shots at each position, one with the O-mode reflectometer on in swept mode and one with it turned off. Measure L_n at B-X conversion layer and EBW T_{rad}/T_e. **(6 shots)**

c) Set Δ_B = 3, move limiter A back from plasma so that Δ_A = 2, 1 and 0 cm, two shots at each position, one with the O-mode reflectometer on in swept mode and one with it turned off. Measure L_n at B-X conversion layer and EBW T_{rad}/T_e. **(6 shots)**

(a)

(b)

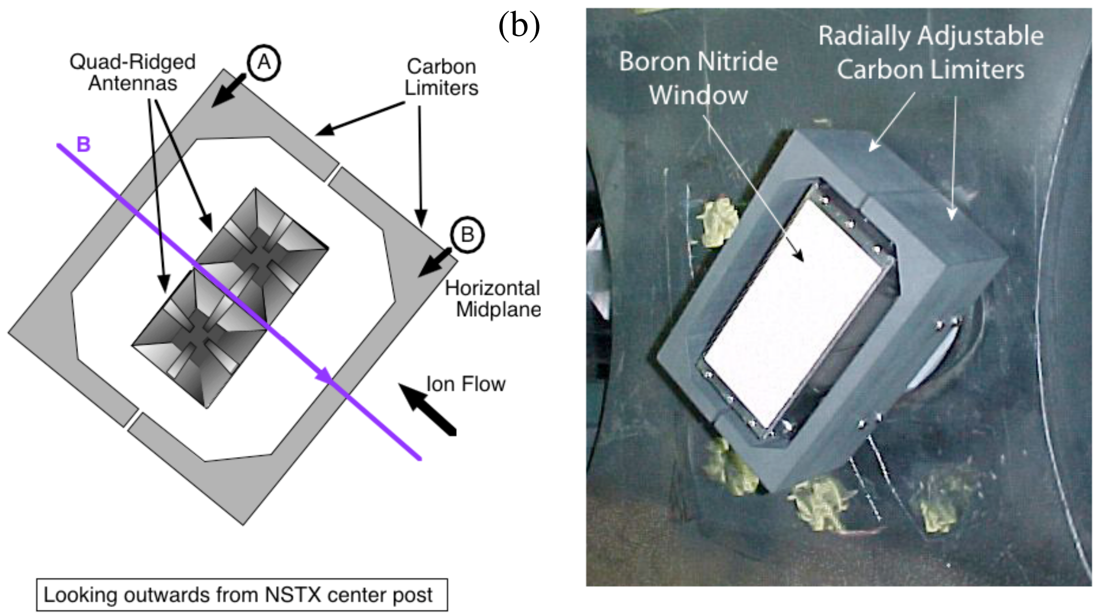

Figure 3(a) *Schematic showing the EBW B-X antenna with radially adjustable carbon limiters. The two limiters are labeled A and B. Limiter A is on the electron flow side and limiter B is on the ion flow side of the antenna.* ***(b)*** *Photograph showing the new EBW antenna installed inside NSTX. The antenna has a white Boron nitride window covering the two quad-ridged horns. The antenna is rotated to orient the ridges to be parallel and normal to the edge magnetic field.*

II. Run EBW radiometer in swept frequency mode (12-18 GHz) at maximum B-X conversion:

Set Δ_A and Δ_B for maximum B-X conversion and obtain and EBW T_{rad}/T_e vs radius where T_e is measured by MPTS. Two shot, one with the O-mode reflectometer on in swept mode and one with it turned off. **(2 shot)**

4. Required Machine, NBI, RF, CHI and Diagnostic Capabilities

NBI at ~ 2 MW is required. See attached list of required diagnostics and machine parameter requirements. The X-mode EBW radiometer at Bay I/J, MPTS, UCLA O-mode reflectometer at Bay I/J and EFIT equilibrium are essential for this experiment. The ORNL X-mode reflectometer at the HHFW antenna is desired to monitor the outer gap.

5. Planned Analysis

Compare measured B-X mode transmission efficiency (T_{ebw}/T_e) and the calculated transmission efficiency using L_n at the B-X conversion layer derived from the UCLA O-mode microwave reflectometer.

6. Planned Publication of Results

PPPL report and a journal publication in *Physics of Plasmas* if the results warrant it.

PHYSICS OPERATIONS REQUEST

Title: Thermal Electron Bernstein Wave Conversion to X-Mode **OP-XP-519**

Machine conditions (indicate range where appropriate):

TF: Flattop (kG) 4.0 Flattop start/stop (s) 0.0 / 0.5

I_p: Flattop (kA) 800 Flattop start/stop (s) 0.2 / 0.35

Position: Outer Gap (m) 0.02-0.05 Z (m) 0 ~~Inner wall~~ / Single null / ~~Double null~~

Gas: He (inside gas feed) Puff yes, plus LDGFIS ? n_e.I programmed to avoid flat-top tearing mode

NBI: Power (MW) 2 Start / stop (s) 2/0.35 Voltage (kV) ______

RF: Power (MW) Start / stop (s) 0.3 – 0.35Frequency (MHz) 30

CHI: Off ~~/ Start-up / Ramp-up / Sustainment~~

If this is a continuation of a previous run or if shots from a previous run are similar to those needed, provide shot numbers for setup

Setup shot 113544 an I_p = 800 kA with B_o = 4.0 kG

If shots are new and unique, sketch desired time profiles and shapes. Accurately label the sketch so there is no confusion about times or values. Attach additional sheets as required.

DIAGNOSTIC CHECKLIST

Thermal Electron Bernstein Wave Conversion to X-Mode **OP-XP-519**

Diagnostic	Need	Desire	Instructions
Bolometer – tangential array		✓	
Bolometer array - divertor			
CHERS			
Divertor fast camera			
Dust detector			
EBW radiometers (Bay I/J & Bay G)	✓		Needed at bay I/J antenna, desired at Bay G
Edge deposition monitor			
Edge pressure gauges			
Edge rotation spectroscopy			
Fast lost ion probes - IFLIP			
Fast lost ion probes - SFLIP			
Filtered 1D cameras			
Filterscopes		✓	
FIReTIP		✓	
Gas puff imaging			
High-k Scattering			
Infrared cameras			
Interferometer - 1 mm		✓	
Langmuir probes – PFC tiles			
Langmuir probes – RF antenna			
Magnetics - Diamagnetism		✓	
Magnetics - Flux loops	✓		
Magnetics - Locked modes			
Magnetics - Pickup coils	✓		
Magnetics - Rogowski coils	✓		
Magnetics - RWM sensors			
Mirnov coils – high frequency			
Mirnov coils – poloidal array			
Mirnov coils – toroidal array			
MSE			
Neutral particle analyzer			
Neutron measurements			
Plasma TV		✓	
Reciprocating probe		✓	
Reflectometer – FM/CW	✓		Essential at EBW radiometer bay I/J
Reflectometer – fixed frequency homodyne		✓	
Reflectometer –homodyne correlation			
Reflectometer – HHFW/SOL		✓	To get additional scrape-off data
RF antenna camera			
RF antenna probe			
Solid State NPA			
SPRED		✓	
Thomson scattering - 20 channel	✓		Essential to get Ln for EBW conversion efficiency
Thomson scattering - 30 channel		✓	Desired to get Ln for EBW conversion efficiency
Ultrasoft X-ray arrays		✓	
Ultrasoft X-ray arrays – 2 color		✓	
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		✓	