Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Thermal Electron Bernstein Wave Conversion to O-Mode at 8-36 GHz in H-Mode Plasmas**

OP-XP-720	Revision:	Effective Date: Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Thermal Electron Bernstein Wave Conversion to O-Mode**
at 8-36 GHz in H-Mode Plasmas No. **OP-XP-720**
AUTHOR: **S.J. Diem** DATE: **04/03/07**

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1. Overview of planned experiment

The goal of this experimental proposal is to investigate 8-36 GHz thermal electron Bernstein wave (EBW) emission coupling via the slow extraordinary mode to the ordinary electromagnetic mode (B-X-O emission) in H-mode plasmas. Experiments for the 2007 run campaign will focus on investigating possible causes of the low H-mode EBW emission results from previous experiments.

The experiment has three objectives: 1) investigate collisional effects on B-X-O mode coupling, 2) investigate the effects of plasma parameters on B-X-O mode coupling, and 3) investigate the effects of plasma parameters on B-X-O coupling. Experiments will be conducted using two-antenna systems, each with an oblique view at bay G mid-plane, a local gas puff injector, and a wide acceptance angle spiral, cavity-backed antenna. One antenna will measure fundamental (8-18 GHz) thermal EBW emission and the second antenna will measure second harmonic (18-36 GHz) thermal EBW emission. Each antenna is coupled to a dual-channel EBW radiometer at bay G mid-plane. The local gas puff injector will be used to study collisional effects of the B-X-O mode conversion process and the spiral antenna, located on the midplane between Bay I and J, will measure any EBW emission outside of the two-antenna systems' field of view.

2. Theoretical/ empirical justification

The mode conversion and tunneling process between EBWs and the electromagnetic O-mode requires the coincidence of the X-mode and O-mode cutoffs [1-5]. This process has been studied extensively on Wendelstein 7-AS both for heating [6] and as a $T_e(R)$ emission diagnostic [7]. The B-X-O emission leaves the plasma through an angular window at an oblique angle with a transmission function given by [3,5]:

$$T(N_\perp, N_{//}) = \exp\left\{-\pi k_o L_n \sqrt{(Y/2)}\left[2(1+Y)(N_{//,opt} - N_{//})^2 + N_\perp^{\;2}\right]\right\}$$

where: k_ω is the wavenumber, $N_{//,opt}^{\;2} = [Y/(Y+1)]$, $Y= (\omega_{ce}/\omega)$, ω_{ce} is evaluated at the cutoff and ω is the wave frequency. For NSTX this B-X-O emission window is located at about 55° from the direction of the magnetic field. The emission window has a width that increases with decreasing L_n at the O-mode cutoff. For high power EBWCD systems, modeling predicts that the resiliency of the coupling efficiency to variations in L_n can be improved by polarization adjustments to the launched microwave power allowing efficient EBW coupling over a broad range of L_n [8].

In the 2006 NSTX run campaign thermal EBW emission (EBE) measurements were obtained at the 12-18 GHz and 24-32 GHz frequency ranges (fundamental, second and third harmonics) with two remotely steerable antennas coupled to dual channel radiometers. Two distinct types of EBE were observed during the last run campaign: bursting emission and decaying emission.

A. Bursting Emission

During XP-625, a detailed scan in toroidal and poloidal space of the B-X-O mode conversion efficiency was attempted for 15.5 GHz and 24 GHz frequencies in a 1 MA discharge with central electron temperature of ~0.9 keV and electron density of $6x10^{13}$ m^{-3}. However, for this discharge, there was a burst of EBE shortly before the current flattop which then fell to <10's eV (see figure 1).

Therefore, the B-X-O mode conversion efficiency was less than 10% during the current flattop for all toroidal vs. poloidal positions where measurements were taken. The expected EBE polarization is ~1.7, which was determined from EBE simulations. However, the EBE polarization measured shortly after the EBE burst was <1, indicating the diagnostic was measuring scattered radiation (figure 2).

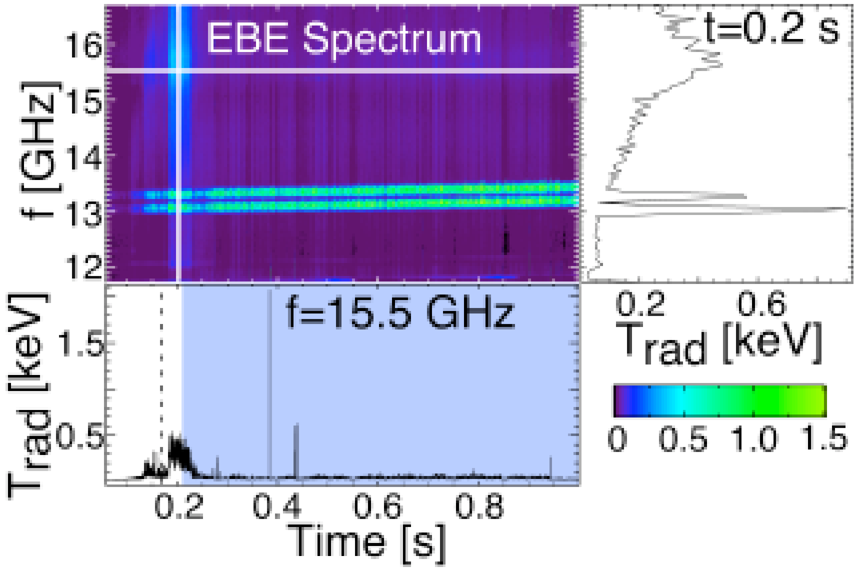

***Figure 1**. Shown is the EBE spectrum for fundamental frequencies of 12-16.5 GHz for shot 120910. There is a burst of emission present around 0.2 s (shortly after the L-H transition). The burst of emission then reduces to ~10's of eV during the current flattop.*

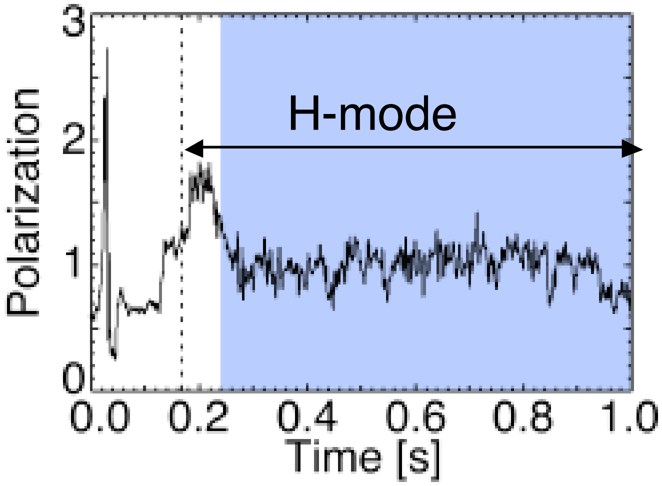

***Figure 2.** Shown is the polarization vs. time for discharge 120910. The polarization for B-X-O emission is 1.7, however, after the burst of emission ends the polarization measured is ~1 indicating the diagnostic is measuring scattered emission.*

A possible cause of the sudden reduction of emission that will be investigated during the 2007 run campaign is the Doppler broadening of the EBW. In figure 3 below is plotted the radiation temperature (for 15.5 GHz emission) versus time as well as the vertical position of the plasma magnetic axis. Just after the EBE burst ends, the vertical position of the plasma shifts down ~2 cm. This observation may be an indication that the emission is coming from a Doppler broadened location further out in the plasma after t~0.2s.

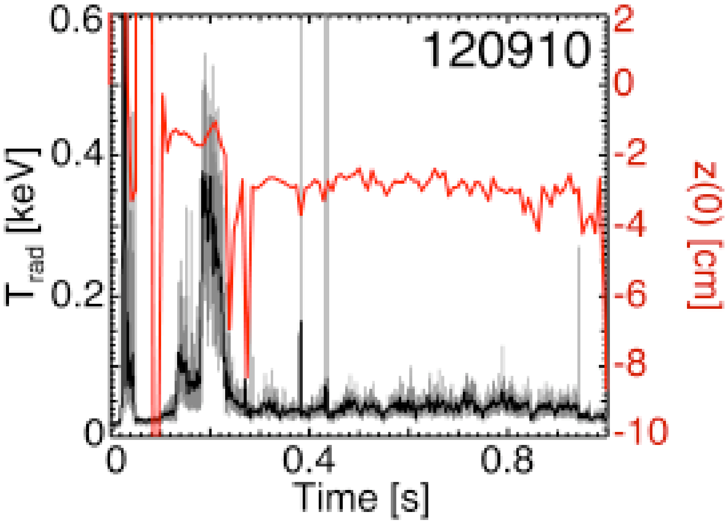

Figure 3. *The radiation temperature (f=15.5 GHz) vs. time is plotted in black while the vertical position of the plasma magnetic axis is plotted in red. As the radiation temperature falls to ~10's of eV the vertical position of the plasma falls to -3 to -2 cm.*

B. Slowly Decaying Emission

Several shots during the 2007 and 2006 run campaign exhibited EBW emission that would peak shortly after the L-H transition and then slowly decay during the current flattop (see figure 4 below).

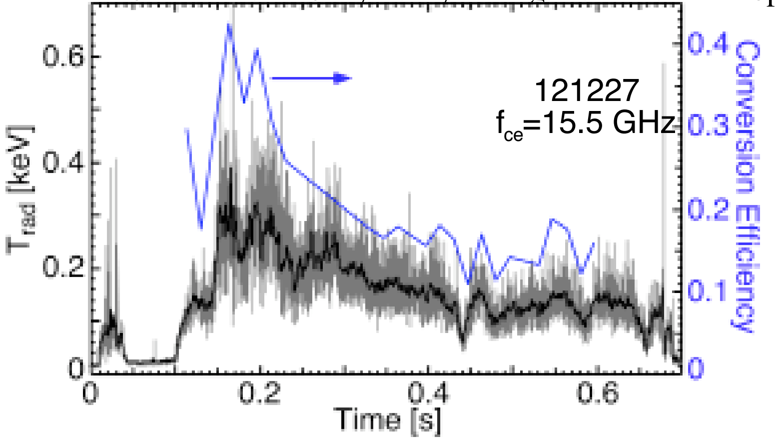

Figure 4. *Shown is an example of a plasma with slowly decaying EBE (120227). The EBE reaches a peak value of 300 eV and decays to 150 eV. Also shown in this figure is B-X-O conversion efficiency vs. time.*

For the plasma shown in figure 4 above, the B-X-O coupling efficiency peaks at 40% and decays to 15% during the plasma current flattop. These results are similar to bootstrap current effects observed on MAST [9]. During H-mode discharges, there is a higher bootstrap current fraction near the edge of the plasma where the mode conversion layer is. This bootstrap current may be large enough to change the edge field pitch gradient, hence moving the B-X-O emission window outside of the field of view of the EBW antennas on NSTX.

References:

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[8] IGAMI, H., *et al*, Plasma Phys. And Cont. Fusion **46**, 261 (2004).
[9] SHEVCHENKO, V.F., *et al*, "Prospects of EBW Emission Diagnostics and EBW Heating in Spherical Tokamaks."

3. Experimental run plan

The goal of this experimental proposal is to investigate 8-40 GHz thermal electron Bernstein wave (EBW) emission coupling via the slow extraordinary mode to the ordinary electromagnetic mode (B-X-O emission) in H-mode discharges. The experiment has three main objectives:

1. **To investigate collisional effects on B-X-O mode coupling.**
   A local gas puff injector was installed on Bay G near the EBW antennas. Gas puffs of varying amounts, durations, and type will be injected to change the collisionality of the plasma edge. If Li pellet injector is available we will try to use it to modify edge temperatures and change the edge collisionality at the B-X-O mode conversion layer.
2. **To investigate the effects of plasma parameters on B-X-O coupling.**
   rtEFIT will be used to modify various plasma parameters such as, Ip, plasma elongation, B_t, vertical position, magnetic field pitch, etc.
3. **To investigate the effect of bootstrap current from the pressure gradient at the H-mode pedestal on B-X-O emission.**
   This field pitch change may be large enough to move the B-X-O emission window outside of the antenna acceptance angle, blocking emission from the core. A wide acceptance angle spiral antenna has been installed at Bay-G to detect EBE outside the antennas' acceptance angle.

Data will be taken in piggy-back mode to determine a suitable target shot free of any major stability issues (i.e. large MHD events or disruptions). A quiescent H-mode discharge such as 120215 or 120217 is desirable as an initial target discharge for this XP. Shot development time would be needed to increase the plasma current to 1 MA and extend the H-mode duration during the current flattop. The following is the shot list:

Shot #:	**Description:**
1-5	Shot development of bursting emission H-mode (target discharge 123088) - Starting antenna pointing directions: - 8-18 GHz (T=-5.8, P=3.4) - 18-40 GHz (T=0.6, -9.6)
6-7	Optimize antenna alignment
8	Reflectometer and fast reciprocating probe data shot for low bootstrap current discharge established during shot development
	Vertical position scan using rtEFIT
9-10	- (2 shots) Starting with established target discharge, move the vertical position of the plasma +2 to +3 cm 200 ms into the current flattop
11	- (1 shot) Repeat previous shot for reflectometer and fast reciprocating probe data shot
12-13	- (2 shots) Use rtEFIT to move vertical position from +0 to +6 cm during I_p flattop
14-15	- (2 shots) Using target discharge, move the vertical position of the plasma -3 to -2 cm 200 ms into the current flattop
16	- (1 shot) Repeat previous shot for reflectometer and fast reciprocating probe data shot
17-18	- (2 shots0 Use rtEFIT to move vertical position from +0 to -6 cm during I_p flattop
	Outer gap scan
19-20	- (2 shots) Increase outer gap by 5 cm
21-22	- (2 shots) Increase outer gap by 10 cm
23-24	- (2 shots) Decrease outer gap by 5 cm

Bootstrap current scan to maximize edge bootstrap current

25-26 - (2 shots) Introduce gas fueling later in target discharge to increase edge collisionality

27-28 - (2 shots) Starting with target discharge, increase κ to 2.5

29-30 - (2 shots) Starting with target discharge, ramp toroidal field from 4.5-5.0 kG at 200 ms into the current flattop

31-33 - (3 shots) Starting with target discharge, include later gas fueling, κ increase to 2.5 and TF ramp from 4.5-5.0 kG at 200 ms into the current flattop and maintain current flattop for ~100-200 ms

34 - (1 shot) Repeat last shot for reflectometer and fast reciprocating probe shot

35-36 - (2 shots) Introduce H-L transition 300 ms into current flattop -> inject He to introduce H-L or decrease inner gap

Total~36 shots (~1 day)

The Bay G gas puffer will also be used during this XP to inject high-Z gas (neon or argon) into the plasma edge to change the edge collisionality. These gas puffs will be from 50-165 Torr-l/s and will be injected into the plasma well into the current flattop (after 600 ms).

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

I_p~0.8-1 MA, B_t~3-5.5 T, rtEFIT control, and I_p flattop ~ 300 ms. EBW radiometers, Thomson scattering with additional point(s), UCLA reflectometer, magnetics, UCSD fast reciprocating probe.

5. Planned analysis

Compare measured B-X-O mode coupling efficiency (T_{rad}/T_e) and emission polarization with the calculated coupling efficiency and wave polarization using the density scale length at the electron plasma frequency cutoff, EFIT equilibria, and electron kinetic profiles from laser Thomson scattering.

6. Planned publication of results

PPPL report, a journal publication in Physics of Plasmas, and conference proceedings paper from the 17th Topical Conference on Radio Frequency in Plasmas in Clearwater, FL. This research will support an invited talk at the 17th Topical Conference on Radio Frequency in Plasmas in Clearwater, FL. on May 7-9th, 2007.

PHYSICS OPERATIONS REQUEST

Title: EBW Coupling at 8-36 GHz in H-mode Plasmas OP-XP-720

Machine conditions (specify ranges as appropriate)

I_{TF} (kG): 4.5-5.0 kG Flattop start/stop (s):

I_P (MA): 0.8-1.0 MA Flattop start/stop (s):

Configuration:

Outer gap (m): **5-20 cm** Inner gap (m):

Elongation κ: **2-2.7** Triangularity δ:

Z position (m): **-3 to +3 cm**

Gas Species: Injector(s):

NBI - Species: **D** Sources: Voltage (kV): Duration (s):

ICRF – Power (MW): Phasing: Duration (s):

CHI:

Either: List previous shot numbers for setup: 123088

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 **OP-XP-720**

Diagnostic	Need	Desire	Instructions
Bolometer – tangential array		X	
Bolometer – divertor			
CHERS – toroidal			
CHERS – poloidal			
Divertor fast camera			
Dust detector			
EBW radiometers	X		
Edge deposition monitors			
Edge pressure gauges			
Edge rotation diagnostic			
Fast ion D_alpha - FIDA			
Fast lost ion probes - IFLIP			
Fast lost ion probes - SFLIP			
Filterscopes		X	
FIReTIP		X	
Gas puff imaging			
Hα camera - 1D			
High-k scattering			
Infrared cameras			
Interferometer - 1 mm		X	
Langmuir probes - divertor			
Langmuir probes – RF antenna			
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			
Mirnov coils – poloidal array			
Mirnov coils – toroidal array			
MSE		X	
NPA – ExB scanning			
NPA – solid state			
Neutron measurements			
Plasma TV			
Reciprocating probe		X	
Reflectometer – 65GHz		X	
Reflectometer – correlation			
Reflectometer – FM/CW	X		
Reflectometer – fixed f		X	
Reflectometer – SOL	X		**Need density scrape off data**
RF edge probes			
Spectrometer – SPRED		X	
Spectrometer – VIPS			
SWIFT – 2D flow			
Thomson scattering	X		
Ultrasoft X-ray arrays		X	
Ultrasoft X-ray arrays – bicolor		X	
Ultrasoft X-rays – TG spectr.			
Visible bremsstrahlung det.		X	
X-ray crystal spectrometer - H			

Diagnostic	Need	Desire	Instructions
X-ray crystal spectrometer - V			
X-ray fast pinhole camera			