Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Assess Effect of Alfvén Cascades on Fast Ion Transport**		
OP-XP-808	Revision:	Effective Date: Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS	
Responsible Author:	Date
ATI – ET Group Leader:	Date
RLM - Run Coordinator:	Date
Responsible Division: Experimental Research Operations	

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Assess Effect of Alfvén Cascades on Fast Ion Transport** No. **OP-XP-808**

AUTHORS: **Neal Crocker** DATE: **Mar 14, 2008**

1. Overview of planned experiment

This XP will devote approximately one half the run time towards documenting fast ion redistribution by Alfvén Cascades (AC) modes and the second half towards using the AC modes to measure the effective specific heat of the thermal electrons, thermal ions and beam ions, identify the β_{fast} threshold for AC excitation and separate β and β' role in AC frequency sweep suppression. Discharges with AC modes from 2006 (120106, 120107 and 120109) show evidence of enhanced fast ion losses during the frequency sweep period of n=3 an AC mode. We propose to duplicate this shot and use the new FIDA diagnostic, as well as an NPA scan to document to the extent possible the pitch angles and energies of the lost/redistributed fast ions. In parallel with the NPA scan, there will be a radial scan of the scattering volume for the high-k scattering diagnostic to look for coupling of the AC to Kinetic Alfvén Waves (KAW).

The minimum in the frequency sweep of the AC modes, c.f., the n=2 mode in 123096 at 300 ms, is believed to be the GAM frequency. This frequency depends on the mass density and effective gammas of the thermal and fast ion populations. By reducing the beam power, we can reduce the contribution of the fast ions to this frequency, and the scaling of the frequency should give a measurement of the effective fast ion gamma, and thus, also the effective gamma for the thermal ion population. This power scan will incidentally also give the β_{fast} threshold for AC excitation. HHFW heating of the electrons, and triggering an H-mode, with flat density profile, will help separate ω_{min} dependence on thermal and fast ion components as well as separate pressure from pressure gradient terms.

W. Lee will piggy back on these experiments to look for the mode conversion to Kinetic Alfvén waves (KAW) at the radii of the intersection of the AC modes with the continuum with the high-k scattering diagnostic (his thesis project).

If additional time remains, we would explore one or more of the following important issues. Can AC modes be excited in H-mode plasmas? Does reduction of the fast ion contribution to beta, perhaps at higher field, allow for AC mode excitation at higher density operation (e.g., with better reflectometer data). In such a plasma, can we document the spatial profile of the AC modes, perhaps demonstrating the conversion from AC to TAE? What is the structure of the AC mode during the downward frequency sweep? What additional information can we acquire regarding the 2nd Gap AC modes?

2. Theoretical/ empirical justification

Alfvén Cascade or rsAE modes have been studied on many conventional tokamaks. They are found to be an accurate indicator of the $q_{min}(t)$. Their presence in reverse-shear plasmas on DIII-D, in plasmas with neutron deficits, has also raised suspicion that they may enhance fast ion transport. Until recently, AC modes were absent from reverse shear plasmas in STs, and a theoretical explanation was developed which predicted that AC modes would only be present at very low (by ST standards) beta.

Alfvén Cascade-like modes were discovered at very low beta in ultra-low density plasmas during XP607 in the '06 campaign. The predicted suppression at high electron beta was observed. Experiments in '07 acquired MSE data and confirmed identification of modes as Alfvén Cascades. A return to this experiment would allow for more complete documentation of the beta-threshold, as well as investigation of their role in fast ion redistribution. The expanded array of reflectometer channels might also make possible the documentation of the expected change in mode structure as the frequency chirp saturates.

3. Experimental run plan

Run starts with attempt to reproduce AC spectrum and sFLIP losses as seen on shots 120106, 120107 or 120109. This most likely requires very precise replication of current profile evolution, density evolution and possibly He fraction, monitored by comparison of neutron rates. All proposed shots will include early source A for TRANSP q-profile initialization, if it doesn't adversely impact AC mode spectrum evolution.

The measurement of fast ion and thermal γ_{eff} will be done in part 1. In Part 2 the toroidal field is increased to 5.5 kG to increase the range of the Cascade frequency sweeps.

Part 3 will address measurement of the internal mode structure of AC and TAE modes by attempting to increase target density at higher field, lower fast ion beta.

Part 4 will extend AC operational regime to H-mode plasmas, or at least minimize uncertainties in interpretation of neutron data by reducing He concentration. The flat density profiles in H-mode will reduce the β', leaving only the frequency shift from temperature gradient and gradient of fast ion density. The substitution of Deuterium for Helium should increase the thermal ion beta (twice the ion density for the same electron density).

In Part 5, HHFW will be used to increase the electron temperature to determine the dependence of minimum frequency on electron β.

Part 6 will study effects of rotation/rotational shear on AC mode stability (Joule milestone).

The affect of AC modes on fast ion transport will be documented in the second half of the experiment. This phase requires remotely steered high-k scattering, available in April?. The NPA scan (part 2) will include High-k scattering radial scan of scattering volume and some scan of the spectrum for the fast FIDA system. If sFLIP losses can't be reproduced, then FIDA, NPA and High-k scans should be moved to Part 5 in the hope that we'll have good mode amplitude and mode structure data to interpret fast ion redistribution and high-k scattering data.

0. Start with 128469. Using deuterium only, adjust geometry to kappa, triangularity, rmidout and rmidin for shot 120106, except aim for upper single null to avoid H-mode. Reproduce density, current, beams, neutron rate evolution shot 120106. If H-mode after total of 3 shots, then use helium puff to avoid H-mode.

1. DO I=1,7

    Reproduce density, current, beams, neutron rate evolution for shot 120106.

    IF(replication of AC spectrum, sFLIP measurement of losses) THEN GOTO 2.

c…Scan of β_{fast} to determine scaling of AC minimum frequency (γ).

  ENDDO

  GOTO 3.

2. Introduce source A to 150 ms to provide early measurement of q-profile

  IF (AC spectrum, fast ion losses NOT reproduced) THEN revert to no early source A shot.

  DO I=1,7

    Vertical NPA scan and High-k scattering radial scan. FIDA scan.

  ENDDO

  GOTO 3

c…Document fast ion redistribution, FIDA spectral scan, look for KAW

c…Introduce HHFW later in shot to prepare for Part 7.'

c…total 7 – 15 shots

3. Reduce beam voltage to 70 kV

c…Scan of β_{fast} to determine scaling of AC minimum frequency (γ).

  IF (AC modes unstable) THEN

    Reduce beam voltage to 65 kV

    IF (AC modes unstable) THEN

      max-stable-voltage not found

    ELSE

      max-stable-voltage is 65 kV

    END

  ELSE

    Increase beam voltage to 80 kV

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        IF (AC modes unstable) THEN
            Decrease beam voltage to 75 kV
            IF (AC modes unstable) THEN
                max-stable-voltage is 70 kV
            ELSE
                max-stable-voltage is 75 kV
             ENDIF
        ELSE
            Increase beam voltage to 85 kV
            IF (AC modes unstable) THEN
                max-stable-voltage is 80 kV
            ELSE
                max-stable-voltage is 85 kV
            ENDIF
        ENDIF
    END
    IF (max-stable-voltage found) THEN
        Change beam voltage to max-stable-voltage
        DO I=1,3
            Mini-NPA/FIDA documentation of quiescent plasma?
        END
        Increase beam voltage by 5 kV
    END
4.  Increase toroidal field to 5.5 kG
    IF (AC modes stable) THEN
        Reduce beam voltage by 5 kV, look for AC return
    ENDIF
c…Higher field, lower beam power may increase density threshold for suppression
c…≈5 shots for 3&4
5.  DO I=1,3 (at 5.5 kG)
        Density scan at lowest beam voltage shot with good AC modes up to "β-suppressed"
        density.
c…Get better reflectometer data on AC mode structure
c…Determine β scaling of minimum frequency
    ENDDO
    DO I=1,2
        Move source A 'on' time back to t1, t2 < 300ms (to be determined) to document q
    evolution.
    ENDDO
```

c…couple of points to document q-profile evolution

6. DO I=1,3

    Replace He prefill and puffing with D prefill and puffing, maintain low density

  ENDDO

c…Attempt AC modes in H-mode plasma, measure fast ion redistribution with FIDA

c…Reduce β' to determine role in minimum frequency

  IF(L-mode) THEN

    Add/extend source A

  ENDIF

  DO I=1,2

    Move source A 'on' time back to t1, t2 < 300ms to be determined to document q evolution.

  ENDDO

c…≈10 shots for 5&6

7. Add as much HHFW to heat electrons from 150ms to 300ms.

  DO I=1,2

    Move source A 'on' time back to t1, t2 < 300ms to be determined to document q evolution.

  ENDDO

c…Increase electron β relative to other terms, sort out electron gamma

8. Set n=3 non-resonant braking to 800A

  DO I=1,3

    Choose moderate density AC shot, increase n=3 braking in 150A increments

  ENDDO

c…Stop rotation to minimize rotational shear effects

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

FIDA/NPA/sFLIP/ssNPA required. MSE is a must. N=3 braking capability is desired. 5-channel reflectometers and two "correlation reflectometers" set to intermediate frequencies. Fast Mirnov, sources A and C required. Remotely steered high-k scattering req'd.

5. Planned analysis

Apart from the initial and simple analysis of the frequency chirping, sufficient data should have been acquired for careful NOVA modeling of the Cascade mode chirps, comparison of Nova radial eigenfunctions to multipoint reflectometer data, and possibly Orbit estimates of the effect of the Cascades on fast ion confinemnt.

6. Planned publication of results

I would envision one or more papers on AC impact on fast ion transport, experimental measurement of fast ion gamma and contributions to a thesis on coupling to KAW.

PHYSICS OPERATIONS REQUEST

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Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **34-65** Flattop start/stop (s): **0.0/1.0**

I_P (MA): **0.8** Flattop start/stop (s): **0.2/0.9**

Configuration: **128469**

Outer gap (m): Inner gap (m):

Elongation κ: Upper/lower triangularity δ:

Z position (m):

Gas Species: **He,D** Injector(s): Midplane/Inner wall

NBI Species: **D** Sources: **ABC** Voltage (kV): **90/60-90/60-90** Duration (s): **0.9s**

ICRF Power (MW): **2-3 MW** Phasing: **180º** Duration (s): **0.02**

CHI: **Off** Bank capacitance (mF):

LITER: Off

Shot numbers for setup: **128469**

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 – ExB 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		✓