# Alcator C-Mod

# Mini-Proposal

**MP No. 495**

**Subject:** Alfvén Cascades studies with ICRH and LHCD

**From:** E. Edlund, M. Porkolab, M. Austin, P. Bonoli, A. Hubbard, L. Lin, R. Parker, P. Phillips, A. Schmidt, J. Snipes, G. Wallace, R. Wilson, S. Wukitch

**Group:** MHD

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**Approved by:** **Date Approved:**

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## 1. Purpose of Experiments

Include immediate goal of the experiments, scientific importance and/or programmatic relevance. Refer to any relevant program milestones.

The purpose of these experiments is to investigate the excitation of Alfven Cascades (also known as reversed shear Alfven eigenmodes) in the ramp-up and in near steady-state plasmas with the application of ICRH and LHCD. Ideal steady state profiles with an off-axis peak in the current density, generating a reversed shear (RS) q-profile may be most efficiently achieved by arresting and maintaining the desired reversed shear q-profile through off-axis LHCD while applying ICRH. The lower hybrid system operating at moderate or high $n_{||}$ (90 or 120 degree phasing) would be used to drive current at r/a >0.5 and thus maintain an RS profile. The slow evolution of current arising from joint operation of ICRH and LHCD could produce long-lived Alfven cascades which would be beneficial for mode number identification as well as mode structure measurements. Additionally, the frequency evolution of these modes may be used as a monitor for the evolution of $q_{min}$. Developing a more complete data set for benchmarking NOVA [1] will be useful in future uses of Alfven cascades for indirect measurement of the q-profile.

## 2. Background

Discuss Physics Basis of the proposed research. Prior results at Alcator or elsewhere, and any related work being carried out separately.

Previous C-Mod experiments investigating Alfvén cascades during the current ramp found that intense ($\geq$3MW) ICRH delayed the onset of sawteeth by at most out to 0.30 s, ostensibly due to the reduction of core resistivity [2]. The ICRH generated fast-ion tail can provide a free-energy source for Alfvén cascade modes in the presence of a reverse shear q profile. Once driven unstable, these modes, residing in the vicinity of the minimum in the q profile, can evolve quickly as they are very sensitive to small changes in the minimum of the q profile . The frequency spectrum is given approximately by

$$\omega_{AC}^2 = \frac{2T_e}{m_i R_0^2}\left(1+\frac{7}{4}\frac{T_i}{T_e}\right)+\frac{V_A^2}{R_0^2}\left(\frac{m}{q_{\min}}-n\right)^2 . \qquad \text{(Eq. 1)}$$

Prior experiments on Alcator have shown that the general form of Eq. 1 describes the evolution of the cascades well, though the absolute value of the initial frequency offset does not always agree with results from NOVA. Studies on C-Mod and elsewhere [3,4,5,6,7,8] have shown the utility of Alfvén cascades as a means of 'MHD spectroscopy", a method of determining the q-profile from the frequency characteristics of MHD modes. Further study of these modes will provide a better means of benchmarking the NOVA code.

## 3. Approach

Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.

Use of ICRF in conjunction with LHCD will be investigated for its joint effectiveness to maintain a near steady state reversed shear q-profile with $q_{\min}$ above unity for times up to a second (skin time). The LH system will be initially configured for moderate $n_{||}$ operation at 90 degree phasing. The ICRF system will use on-axis heating at 5.4 T with 78/80 MHz, E and J antennas. We will first establish the functionality of the ICRH system before simultaneous operation with LHCD.

Once good ICRH operation is established, (nominal 2.5 -3.0 MW of ICRH) the LHCD system will be applied and its power will be increased to the 0.5 MW level simultaneously with ICRH. The relative timing of ICRH and LHCD will also be varied to optimize the delay of sawteeth. Subsequently the powers will be increased as much as possible without arcing. Later operation will investigate further off-axis LHCD at 120 degree phasing.

Monitoring of the development of the RS q-profile will be done via the excitation of Alfvén cascades by fast ions from ICRH. In addition, the temperature dependence of the initial minimum frequency (geo-acoustic deformation, see Eq. 1) needs further data which could also be provided by the present experiments [9]. Finally, triggering of mini-ITBs in the presence of RS profiles at rational q values on a longer time scale is an intriguing possibility (see JET [10], also in DIII-D-Max Austin [11]) and will be monitored by the FRCECE system.

Determination of the success of current profile control will be determined by PCI (phase contrast imaging) and magnetics measurements of Alfvén cascade activity, and the loop voltage evolution. The MSE diagnostic would be further tested in these experiments by comparing to the Alfvén cascade results.

## 4. Resources

### 4.1 Machine and Plasma Parameters

Give values or range for:

Toroidal Field: 5.4 T
Plasma Current: ramp to 0.8 MA by 0.2 sec., and flattop to 1.0 sec.
Working Gas Species: $D_2$, H minority (2%-4%)
Density: 0.5-0.7 x $10^{20}$ $m^{-2}$ (during the ramp-up, t<0.200 seconds)

Equilibrium configurations (if possible, refer to database equilibria): 1070619017

### 4.2 Auxiliary Systems

RF Power, pulse length, phasing: LH: 0.5+ MW, 0.5s, 90 and 120 degree phasing
ICRF: 3 MW, 0.5 s, H minority, 78/ 80MHz, heating phasing; may need to start with J port and E port only.
Pellet Injection (species): N
Impurity blow-off injection: N
Diagnostic Neutral Beam: Desirable, but not necessary
Special gas puffing:
Other:

### 4.3 Diagnostics

List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

PCI will be the primary diagnostic for these experiments. The high frequency magnetic pick-up coils, Thomson and ECE are required. Neutrons to monitor $T_i$. Hirex may be helpful to monitor the ion temperature profile.

## 5. Experimental Plan

5.1 Run sequence Plan
Specify total number of runs required and any special requirements, such as consecutive days, no Monday runs, extended run period – 10 hours maximum – etc.

These experiments require 1 run day.

5.2 Shot sequence plan
For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements, etc. Include contingency plans, if appropriate.

(1) Apply ICRH at 0.1sec and beyond into 0.8 MA ramp-up plasmas. Ramp ICRH stepwise up to 3.0 MW. Observe sawteeth entry time. Monitor Alfvén cascade phenomena (5 shots).

(2) Couple LHCD at 90 degree phasing into target plasma from the results of step 2 and adjust timing of LHCD from 0.10 second and beyond; Extend pulse length to 0.5 seconds. Increase power to 0.5 MW. Observe sawteeth entry time and monitor Alfvén phenomena (6 shots).

(3) Increase power from ICRH and LH as much as possible and vary relative timing of LHCD/ICRH so as to maximize sawtooth delay beyond 0.3 seconds. (6 shots)

(4) Repeat (3) but with LH at 120 degree phasing (8 shots)

Total number of shots: 25

## 6. Anticipated Results

Discuss possible experimental outcomes and implications. Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, or an external database.

We will obtain new and rich data on Alfvén cascades with controlling the q profile well beyond that obtained in previous experiments. Additional data with ECE indicating triggering of mini-ITBs would be a first in C-Mod, and could shed light on the connection between rational values of $q_{min}$ and ITB formation with $T_i \le T_e$. Results should lead to several publications, and valuable data to Eric Edlund’s thesis.

## 7. References

Include references both to external and internal literature or communications which bear on this proposal. See Section 2.

[1] C.Z. Cheng and M.S. Change, Journal of Computational Physics 71, 124 (1987).

[2] M. Porkolab, Proc. 16$^{h}$ High RF Power in Plasmas, Park City, UT.[Eds. S. J. Wukitch and P. T. Bonoli] AIP Proc, 787, 114 (2005).

[3] M. Porkolab, IEEE Transaction s of Plasma Science, **34**, 229 (2006).

[4] J. A. Snipes, et al, Phys. Plasmas, vol. 12 (2005) 056102.

[5] G.J. Kramer *et al.*, PPCF **46** (2004) L23-L29.

[6] S.E. Sharapov *et al.*, Physics of Plasmas **9**, 5 (2002).

[7] H. L. Berk *et al.*, PRL **87**, 185002 (2001).

[8] B.N. Breizman and S. E. Sharapov, PPCF **37**, 1057 (1995).

[9] B.N. Breizman, (?)Pekkar and S. Sharapov, Physics of Plasmas **12**, 112506 (2005).

[10] E Joffrin *et al*, Nucl. Fusion 43 1167 (2003).

[11] M.E. Austin *et al*, Phys. Plasmas 13, 082502 (2006).