Alcator C-Mod

Mini-Proposal

MP No. 538

Subject: E_r Profile Studies

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Group: Transport/ Rotation-Momentum

Date: February 22, 2008

Approved by: **Date Approved:**

1. Purpose of Experiments

The purpose of this experiment is to study the radial and temporal behavior of the edge radial electric field before and during L-H transitions in order to characterize the role the field plays in the transition and the effect the structure of the field has on H-mode confinement. Additionally, the potential connection between the radial electric field and the QC mode will be explored.

2. Background

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

The edge radial electric field, E_r, and its shear are believed to play a causal role in the suppression of edge turbulence, which enables tokamak plasmas to transition from L-mode to H-mode [1]. As future fusion devices, like ITER, will require H-mode confinement to meet their operational goals, a detailed understanding of the H-mode triggering mechanism is highly desirable, thus motivating detailed studies of E_r behavior both before and after L-H transitions. Specifically, what is the temporal and radial structure of the field around the L-H transition? Can measurements of E_r confirm the existence of a critical ExB shear rate necessary to suppress edge turbulence as predicted by the BDT model [2]? Is there a correlation between the depth or width of the well and plasma confinement, or type of H-mode achieved? Is there any importance to the relative magnitudes of the various terms in the force balance equation, used to calculate E_r? And is there a connection between the structure of the radial electric field and the location and frequency of the QC mode?

Experimental observations on many different tokamaks have demonstrated the existence of a specific temporal and radial structure to the edge electric field during the transition from L-mode to H-mode. On Alcator, L-mode electric fields are positive and small, a few kV/m, becoming only slightly negative with modest shear just inside the LCFS.

However, in H-mode the field becomes sharply negative, with strong E_r shear one cm inside the LCFS [3]. The E_r well is not fixed in space, but rather, moves with the position of the LCFS, indicating it marks the boundary of improved confinement.

These observations are not unique to C-Mod, they have been observed on most fusion experiments capable of H-mode operation including ASDEX Upgrade [4, 5], DIIID [6, 7, 8, 9, 11], JET[13] and JFT-2M [10]. On Alcator, the E_r well is approximately 0.5cm in width and of order -100 to -200 kV/m deep [3]. This magnitude is considerably larger than has been observed on other machines. For example the E_r well on DIII-D is typically of order -15 to -25 kV/m [7], although wells as deep as -100kV/m [9] have been observed in their Q H-modes indicating the depth of the well may be related to the quality of the plasma confinement or some other parameter that also scales with improved confinement such as pedestal height, H-factor, or stored energy. ASDEX upgrade has also observed that the E_r well depth is deeper in their “improved H-modes”[5] (-50kV/m from -30 to -40kV/m) and that its depth increased when the toroidal magnetic field was increased for a fixed value of q_a and neutral beam input power [4]. Since the plasma current was necessarily increased when the toroidal field was increased in order to maintain the same edge safety factor and the input power was held constant, this result again suggests a scaling of the E_r well depth with plasma stored energy. This MP will map out the scaling of the E_r well depth and width with plasmas stored energy (if there is one).

On both JFT-2M and DIII-D the initial change in the radial electric field at the L-H transition toward a more negative value is measured through an increase in impurity ion poloidal velocity in the electron diamagnetic direction. At this time the impurity ion poloidal velocity term is the dominant term in determining the radial electric field. The diamagnetic term does not become significant until tens of milliseconds later at which time, it, and not the poloidal velocity, becomes the dominant contribution in calculating E_r [6, 7, 10]. The radial electric field on JET is completely dominated by the pressure gradient term; no edge poloidal velocity shear has been observed [13]. On Alcator C-Mod, to date, no evolution of E_r has been seen before an L-H transition and in all H-modes, the impurity ion poloidal velocity and diamagnetic contribution to E_r are of the same order. The evolution of the relative dominance of the various terms in the radial force balance equation around the L-H transition has not yet been determined.

On both ASDEX Upgrade and DIII-D changes in radial electric field structure have been observed as a function of plasma triangularity, elongation and magnetic topology [5, 7]. On ASDEX upgrade, radial electric field wells similar to those seen on Alcator, DIII-D and JFT-2M were observed for LSN and DN discharges, however, in USN H-modes the usual E_r well did not form, the value of the electric field remained positive throughout the pedestal region even in H-mode operation. The ASDEX teams attributes this feature to the poorer plasma confinement in USN plasmas and the impact the upper divertor configuration has on the parallel fluxes in the plasmas [5]. The effect of topology on E_r well structure has not yet been explored on C-mod.

In the QH-modes on DIII-D there exists an edge harmonic oscillation (EHO), similar to the QC mode that appears on Alcator during EDA operation. The EHO, like the QC mode, is an edge density fluctuation that increases the edge particle losses, and in so doing enables constant or quiescent density operation. The location of the EHO mode coincides with the steepest part of the radial electric field and impurity ion toroidal velocity gradient implying it is from these parameters the EHO derives its free energy. This begs the question if a similar relationship between the QC mode and the edge radial electric field exists on C-Mod. Additionally, the frequency of the QC mode is observed to sweep from higher to lower frequency during the transition from L to H-mode. The frequency of the mode is observed to be inversely proportional to the core impurity toroidal rotation [12]. It is possible this frequency sweeping is correlated with the build up of the radial electric field well.

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.

This proposal calls for two full run days. The approach for the first run day is to run forward field discharges in both LSN and USN inducing L to H transitions in each through ICRF power. The edge CXRS diagnostic will be used to measure the parameters necessary to calculate the radial electric field. The current will be varied from 0.8MA to 1.2MA to change the stored energy of the plasma. Additionally, RF power will be used to change the stored energy at a given plasma current. At each target current the plasma triangularity will be changed shot-to-shot to switch the type of H-mode obtained from EDA to ELM-free. The spatial structure of the E_r well can be studied in the EDA H-modes through the natural movement of the plasmas. However, in the ELM-free H-modes, due to the rapid evolution of the edge profiles, it may be necessary to repeat shots to provide a fuller picture of the E_r spatial and temporal structure.

The second run day for this proposal has several objectives. The first portion of the day will be dedicated to finishing up any shots from day1 that were not obtained and to running EDA H-mode discharges with ramping ICRF power in an attempt to change the radial electric field depth within a single H-mode by increasing the stored energy and pedestal heights.

The second half of the day will focus on the structure of E_r and the relative magnitudes of the various components used to calculate it when the toroidal magnetic field is changed. To do this, discharges with matching q95's will be run at both Bt=4.4T and Bt=6.0T. This will enable the same ICRF heating scheme to be employed on both run days to induce the H-modes. At each field and current ICRF heating power will be used to try and obtain H-modes of similar stored energies.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

Toroidal Field:	4.4T, 5.4T, 6.0T
Plasma Current:	Ip = 0.8-1.1MA
Working Gas Species:	D2
Density:	nl04 = 0.9 $*10^{20}$ m^{-2}

Equilibrium configuration (if possible, refer to database equilibria):
LSN: 1070621003, USN : 1070830010

4.2 Auxiliary Systems

RF Power, pulse length, phasing: 1.5-3+ MW (or max available)
Pellet Injection (species): No (maybe last shot of the day)
Impurity blow-off injection: No
Diagnostic Neutral Beam: Yes, 6A beam operation
Special gas puffing: Ninja, Argon
Non-axisymmetric Coils (Connections, Current); No
Other:

4.3 Diagnostics

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

All CXRS (DNB/GPI), Edge and Core TS, ECE, PCI, Reflectometry, bolometry, Hirex family, Fast Magnetics

If available: NeSox, probes

5. Experimental Plan

Both sections must be filled in.

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.

This experiment requires two full forward field run days. The second run day will be split into two half run days. A newly boronized machine and good DNB operation are required for all three segments. DNB current must be 6A (minimum) with fast modulation 15ms low and 30-40ms high.

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.

Day 1:
All shots will be run at B=5.4T, shot 1070621003 can be used as an equilibrium starting point. The outer gap must be held as constant as possible for all shots.

LSN, Ip=0.8MA(q95~4.7)
1) nl04=$0.8*10^{20}$ m^{-2} ,Delta_ave=0.44, ICRF = just over H-mode threshold (EDA)
2) nl04=$0.8*10^{20}$ m$^{-2,}$,Delta_ave=0.44, ICRF = max available (EDA)
3) nl04=$0.8*10^{20}$ m$^{-2,}$,Delta_ave=0.3, ICRF = just over H-mode threshold (ELM-free)
4) nl04=$0.8*10^{20}$ m$^{-2,}$, Delta_ave=0.3, ICRF = max available (ELM-free)

LSN, Ip=1.1MA (q95~3.4) switch to Ip=1.0MA shots if EDA can not be achieved here
5) nl04=$0.8*10^{20}$ m$^{-2,}$, Delta_ave=0.44, ICRF = just over H-mode threshold (EDA)

6) nl04=0.8*10^{20} $m^{-2,}$, Delta_ave=0.44, ICRF = max available(EDA)
7) nl04=0.8*10^{20} $m^{-2,}$, Delta_ave=0.3, ICRF = just over H-mode threshold (ELM-free)
8) nl04=0.8*10^{20} $m^{-2,}$, Delta_ave=0.3, ICRF = max available (ELM-free)

USN
Shots 9-16, same set of shots in USN time permitting!

Day 2: Part I.
Try transitioning from EDA to ELM-free in single H-Mode.

LSN, Ip=0.8MA
1)nl04=0.8*10^{20} m^{-2} Delta_ave=0.44, ICRF = starting under threshold and ramping to max available

LSN, Ip=1.0MA
2)nl04=0.8 10^{20} $m^{-2,}$ Delta_ave=0.44, ICRF = starting under threshold and ramping to max available

Repeat Any Data Points from Day1 that are desired or were not obtained.

Part II.
Request ½ Day
Change B-field, but keep q95 the same as in Bt=5.4T shots by adjusting currents.
Attempt to attain similar stored energies as the Bt=5.4T shots using ICRF power.

Goal: 8 shots
ICRF: 80MHz D-H heating
Bt=4.4T Consider 4.8T (if not able to attain H-mode or sufficient stored energies)
B=4.4T Ip=655KA (q95=4.7) nl04=0.8 10^{20} m^{-2} Delta_ave=0.44, 0.35
B=4.4T Ip=900KA (q95=3.4) nl04=0.8 10^{20} m^{-2} Delta_ave=0.44, 0.35

If B=4.8T then Ip=700 KA (q95=4.7) nl04=0.8 10^{20} m^{-2} Delta_ave=0.44, 0.35
If B=4.8T then Ip=1MA (q95=3.4) nl04=0.8 10^{20} m^{-2} Delta_ave=0.44, 0.35

Bt=6.0T Consider dropping to 5.8T if unable to attain H-mode or sufficient stored energies
If B=6.0T then Ip=890MA (q95=4.7) nl04=0.8 10^{20} m^{-2} Delta_ave=0.44, 0.35
If B=5.8T then Ip=860MA (q95=4.7) nl04=0.8 10^{20} m^{-2} Delta_ave=0.44, 0.35

If B=6.0T then Ip=1.23MA (q95=3.4) nl04=0.8 10^{20} m^{-2} Delta_ave=0.44
If B=5.8T then Ip=1.19MA (q95=3.4) nl04=0.8 10^{20} m^{-2} Delta_ave=0.44

Piggy Back Days:
½ Run Day
ICRF frequency 50MHz or 70MHz
Sufficient ICRF to induce H-modes
A lower toroidal field (<4.5T) is desired, but exact value is negotiable!

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.

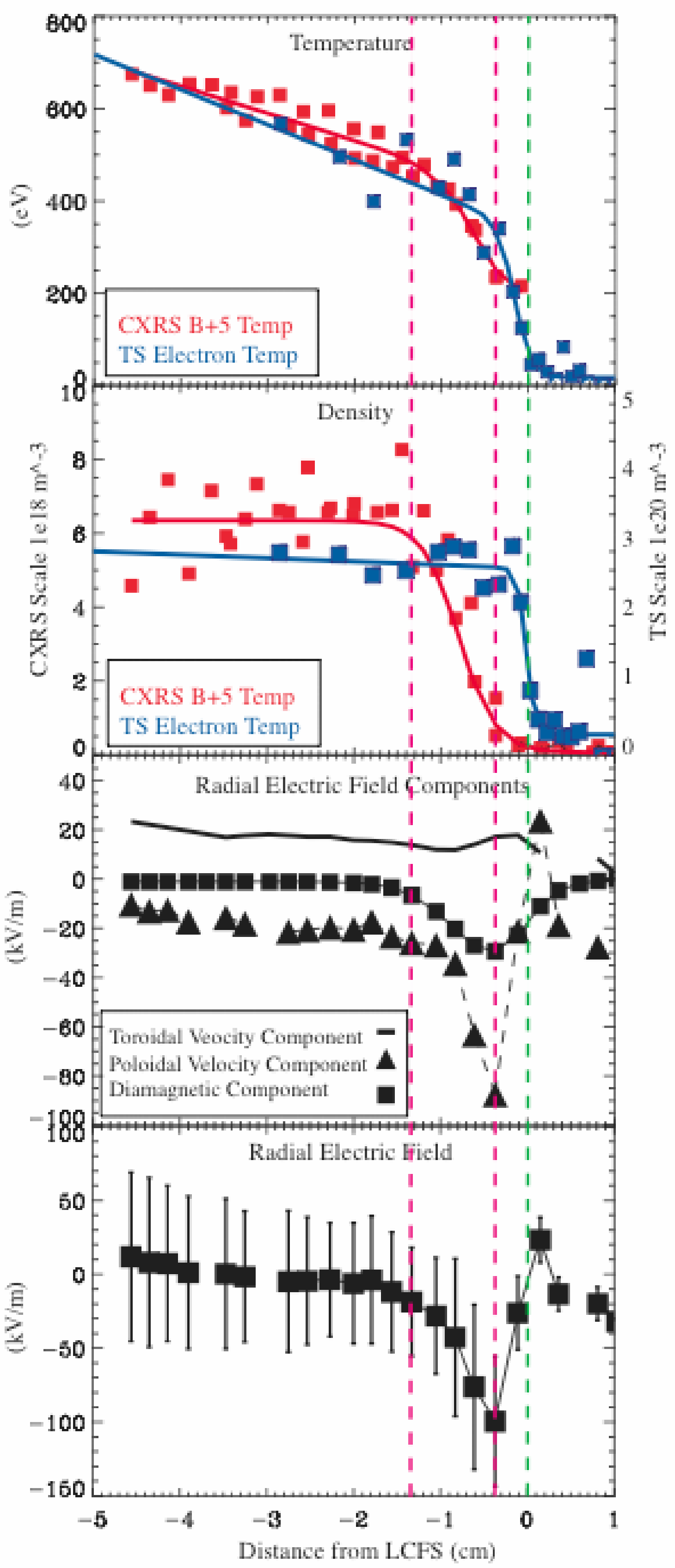
Results from this MP will support several graduate students theses including R. McDermott, K. Marr, and A. Ince-Cushman. The scaling and structure of the radial electric field with plasma parameters and topology is a topic of interest to the fusion community due to its relevance to H-mode theories. Thus, the results of this MP will potentially lend themselves to several publications. From this MP's results I expect to be able to find a scaling of the depth and width of the radial electric field well as a function of plasma stored energy or other relevant parameters. Additionally, the data from this MP will lend itself to correlating the frequency of the QC mode with electric field depth and formation.

7. References

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

[1] Burrell K H et al 1997 Phys. Plasmas 4 (5)
[2] Bigari H. et al 1990 Phys. Fluids B 2 1
[3] McDermott R M et al 2007 APS Poster
[4] Field A R et al 1992 Nuclear Fusion Vol 32 No.7
[5] Schirmer J et al 2006 Nucl. Fusion 46 S780-S791
[6] Groebner R J et al 1990 Physical Review Letters Vol. 64 No. 25
[7] Gohil P et al 1998 Nuclkear Fusion Vol 38 No 1
[8] Burrell K H et al 2001 Physics of Plasmas Vol 8 No 5
[9] Burrell K H et al 2002 Plasma Phys. Control Fusion 44 A253-A263
[10] Ida K et al 1990 Physical Review Letters Vol 65 No 11
[11] Burrell et al 1996 Plasma Phys. Control Fusion 38
[12] Rice J. 2008 Control Room Chat
[13] Hawkes N. C. et al 1996 Plasma Phys. Control Fusion 38 1261-1266

Figure 1



Temperature
800
600
400
200
0
(eV)
CXRS B+5 Temp
TS Electron Temp
Density
10
8
6
4
2
0
CXRS Scale 1e18 m^-3
5
4
3
2
1
0
TS Scale 1e20 m^-3
CXRS B+5 Temp
TS Electron Temp
Radial Electric Field Components
40
20
0
−20
−40
−60
−80
−100
(kV/m)
Toroidal Veocity Component
Poloidal Velocity Component
Diamagnetic Component
Radial Electric Field
100
50
0
−50
−100
−150
(kV/m)
−5
−4
−3
−2
−1
0
1
Distance from LCFS (cm)