1. Purpose of Experiments

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

The immediate goal of these experiments is to produce steady state internal transport barriers (ITB’s) in Alcator C-Mod at 4.5 T by a simultaneous application of off-axis (80 MHz) and central (70 MHz) ICRF minority heating. These experiments will build on recent observations of density barrier formation in C-Mod at low field (4.5 T) with strong off-axis ICRF minority heating (see for example experiments on 1000523, 1000607, 1000615, and 1000630). In this mini-proposal we plan to add a central source of auxiliary heating to determine if in addition to the density barrier, an energy barrier (i.e. temperature) could also be created, i.e., a true energy transport barrier would be formed. A second goal of this mini-proposal is to demonstrate control of the ITB by changing the local temperature and density gradients by varying the on-axis and off-axis ICRF heating powers.

An important area of future Alcator C-Mod research is the study of advanced tokamak (AT) physics. This mini-proposal could be crucial to C-Mod’s AT program if it succeeds in demonstrating that ITB’s can be produced under steady state conditions (i.e., no radiative collapse or collapse due to MHD). Ultimately this class of discharges could also provide the high-β target plasmas for lower hybrid current profile control experiments that are planned for the future AT program.

2. Background

Discuss Physics basis of the proposed research, Prior results at Alcator or elsewhere, and any related work being carried out separately
As pointed out in MP 275 [Greenwald et al., “ITB Formation and RF Flow Drive"],
edge and core barriers may be due to suppression of ion turbulence by sheared \( \mathbf{E} \times \mathbf{B} \) flows [1]. A positive feedback loop can develop between the pressure gradient, radial electric field \( E_r \), and sheared flow suppression. Since the diamagnetic contribution to \( E_r \) is negative, rotation in the counter-current direction can enhance the effect and co-current rotation can inhibit it [2]. In C-Mod, we have consistently measured co-rotation which is particularly strong in RF heated H-modes [3]. If the rotation could be reduced or reversed, barriers might form much more readily. In fact, recent theories [4] suggest that the flow could be reversed by moving the ICRF resonance to the high-field side (inboard) of the plasma. Recent experiments (see 1000523 and 1000607) to test this theory did show an apparent reduction/reversal of the toroidal flow [5]. However, a conclusive connection to the theories presented in Ref. [4] could not be demonstrated due to complications arising from the abrupt formation of a reproducible density barrier at 4.5 T with off-axis ICRF minority heating. While a strong density barrier was formed approximately half way out radially, the central temperatures remained modest (\( \sim 1 \) keV). At the same time strong impurity accumulation was observed, ultimately leading to a radiative collapse of the barrier. A logical extension of this experiment is to add a source of central heating to explore the formation and control of internal thermal (i.e., temperature) barriers.

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.

The heating method employed in this mini-proposal is hydrogen minority absorption. The required field in these experiments is 4.5 T. In order to heat simultaneously off-axis and on-axis will require the tunable ICRF sources to be set to 70 MHz (J-port antenna) to heat near the plasma center. The 80 MHz ICRF power (D and E port antennas) will heat off-axis (9.5 cm to the tokamak high field side).

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

**Toroidal Field:** 4.5 T

**Plasma Current:** 800 kA

**Working gas species:** Deuterium (majority), Hydrogen (minority)

**Density:** Target \( \simeq 2 \times 10^{20} \text{ m}^{-3} \), H(2-3%)

**Equilibrium configuration** (if possible, refer to database equilibria): Use configuration from Shot # 1000607008

**Pulse length, typical current & density waveforms, etc.** Refer to database or sketch desired waveforms: Use waveforms from Shot # 1000607008
4.2 Auxiliary Systems

**RF Power, pulse length, phasing:** Maximum power available at 80 MHz (≈ 3 MW) from D & E ports

Maximum power available at 70 MHz (≈ 2 MW) from J-ports

**Pellet Injection (species):** Not required

**Impurity blow-off injection:** Not required

**Diagnostic Neutral Beam:** Use if available

**Special gas puffing:** Argon puffing for HIREX

**Other:**

4.3 Diagnostics

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

HIREX for toroidal rotation and \( T_i \)-profiles.

Density profiles from visible Bremstrahlung.

Central \( T_i \) measurement from neutrons.

GPC1 and GPC2 for \( T_e \)-profiles.

YAG Thomson scattering for \( T_e \) and \( n_e \) profiles.

All standard core diagnostics.

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.

Two run days required.

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.

A. Day 1:

(1) Establish an ICRF heated H-mode at 4.5 T with central ICRF heating only (70 MHz and 1-3 MW). (9 shots)

(2) Establish density barrier at 4.5 T with off-axis ICRF heating only [80 MHz and 2-2.5 MW]. (5 shots)
(3) Apply both frequencies at 4.5 T and establish thermal energy barrier formation using 2 MW at each frequency. (8 shots)

B. Day 2:

(1) Optimize ITB by varying $B_t$ from 4.3-4.7 T, and by varying each ICRF source power (1-3 MW). (10 shots)

(2) Get $T_i$ profile measurement from HIREX. (5 shots)

(3) Get poloidal rotation measurement from HIREX. (5 shots)

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.

Positive results from this mini-proposal would lead to a publication in Physical Review Letters and would provide the material for an APS poster. Positive results from this experiment would establish excellent target plasmas for future AT research in C-Mod.

7. References

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