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

The proposed experiments will investigate the plasma conditions near the last-closed flux surface (pressure gradients, collisionality, plasma flows, ...) that are associated with ohmic L-H transitions. In particular, we wish to explore an edge-plasma phase-space boundary that has been identified by Rodgers [1] and Guzdar [2] as a threshold condition for the formation of H-modes. We also wish to use our new set of edge flow diagnostics to explore plasma flow and flow shear as the L-H threshold is approached.

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

Results from recent C-Mod experiments have lead to a deeper understanding of edge plasma transport phenomena, making some clear connections with first-principles theoretical models. For example, analysis of SOL profiles in L-mode has uncovered evidence that pressure gradients near the separatrix are set by electromagnetic fluid drift (EMFD) turbulence [3]. The local pressure gradient, normalized by the poloidal magnetic field strength squared (i.e., \( \alpha_{\text{MHD}} \)) appears to be invariant in plasmas with the same normalized collisionality despite having vastly different currents and magnetic fields. Figure 1 shows normalized edge pressure gradients (\( \alpha_{\text{MHD}} \)) plotted versus an inverse collisionality parameter (\( \alpha_{\text{cl}} \), as defined in [1, 4]) for a wide range of plasma conditions. These data suggest that local gradients are pinned to a ‘critical gradient’ condition that is sensitive to local collisionality – a behavior that connects with first-principles EMFD turbulence simulations [1, 4]. Most recently, this result for L-mode discharges has been verified for a wider range of currents with both upper and lower-null magnetic topologies [5] and for forward/reversed magnetic field directions [6]. It is interesting that peak pressure gradients in the H-mode pedestal are also found to follow a nearly identical
scaling, maintaining an invariant $\alpha_{MHD}$ value at fixed plasma collisionality [7]. Thus the near SOL forms a weak ‘pedestal’ in L-mode and also becomes the base of the stronger H-mode pedestal. These observations suggest that the near SOL plays an important role in the formation and development of the H-mode pedestal.

Previous data from ohmic L-H transitions have suggested another tantalizing piece of physics: discharges just prior to the L-H transition are found to lie on a boundary very similar to that predicted by Guzdar [2]. Is this just coincidence? Or, does the ohmic L-H threshold condition indeed arise from crossing a boundary in the ‘phase-space’ of EMFD turbulence, as first suggested by Rodgers et al. [1] and later parameterized in detail by Guzdar?

Figure 2 shows the machine parameters that were run to obtain the data in Fig. 1. All but one of the ohmic H-mode modes were created with plasma current of $\sim 0.75$ MA. Yet, an important test of the ‘Rodgers/Guzdar boundary” would be to run ohmic H-mode discharges with different plasma currents. If the Rodgers/Guzdar dimensionless parameterization is indeed correct, then ohmic H-modes should form at the same boundary, regardless of plasma current value.

Low-power ohmic discharges are an ideal vehicle to study this L-H transition physics; multiple scanning probes can be used to record edge profiles of density, electron

Fig. 1. Normalized electron pressure gradients ($\alpha_{MHD}$) versus inverse collisionality ($\alpha_{d}$) evaluated near the separatrix. Blue triangles are L-mode data from a variety of plasma currents (0.5, 0.75, 1.05 MA), toroidal fields (4.0, 5.3, 6.0 tesla) and densities (0.1 < n/nG < 0.5). It is striking that EDA and ELM-free ohmic H-modes appear to form near the ‘Guzdar L-H boundary’—a principal focus of this miniproposal.
temperature, plasma potential and flow information with sub-millimeter resolution. In the absence of RF waves, the interpretation of a Langmuir probe’s I-V characteristic is straightforward and reliable.

It should be noted that the data shown in Figs. 1 & 2 came primarily from the 2000 run campaign. However, since that time, plasma flows have been found to play an important role in the boundary layer, setting a ‘flow boundary condition’ for the confined plasma [8] and perhaps influencing the x-point dependence of the L-H threshold power [9]. Moreover, significant improvements to the edge plasma diagnostic set have since occurred, including: a new multi-electrode scanning probe has been added to the high-field side SOL (WASPs [10]); A-port, F-port and WASP probes have been upgraded to a ‘Gundestrup’-type geometry to record cross-field flow information [11]; gas-puff and DNB viewing fibers have been installed, allowing measurements of toroidal flows (high and low-field side) and poloidal flows (low-field side only) in the pedestal region [12]. In addition a new bent-crystal x-ray spectrometer (HIREX Sr.) has been installed, allowing profile measurements of toroidal flows using argon and intrinsic molybdenum [13]. Finally, two new toroidally-viewing Lyman-alpha arrays have been installed, viewing the low-field SOL [14], providing ionization and particle flux information across the separatrix and SOL regions.

These new diagnostics, in conjunction with a dedicated study of ohmic L-H transitions, will provide a new opportunity to unfold the role of equilibrium plasma flow and flow shear at the L-H transition. For example, otherwise identical lower-single null and upper single-null L-modes discharges can be investigated. What are the differences in pressure profiles and plasma flow profiles that are seen between these two cases? Can these differences suggest a reason why the upper-null, run with the same machine parameters, does not transition into an H-mode? Furthermore, as the H-mode evolves from its L-mode precursor state, how do these profiles evolve?

Fig. 2. Machine parameters for the data shown in Fig. 1.
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 approach is to simply revisit ohmic H-modes in C-Mod, running them with different plasma currents and interrogating them in detail with the full array of edge profile and plasma flow diagnostics. For reference, the previous ‘recipe’ that was used to generate 0.8 MA ohmic H-modes (2000 campaign) is shown in Fig. 3. The ohmic H-mode is initiated by ramping the toroidal field down to a value of ~3.2 tesla and then back up after the L-H transition to promote an EDA H-mode. In this case, the L-mode ‘target’ NL04 was 0.7x10^{20} m^{-2}. Ohmic H-modes at 1.0 MA have been known occur without a toroidal field ramp (for example, 1001019009). In this case, the L-mode ‘target’ NL04 was 0.8x10^{20} m^{-2} with toroidal field of 5.3 tesla. However, in order to gain some control over the time when the L-H transition occurs, a toroidal field ramp-down should always be used. For plasma currents of 1.0 MA and above, perhaps a higher starting value of toroidal field is needed, such as 6 tesla.

If ohmic H-modes do indeed observe the Rodgers/Guzdar boundary, then an important machine control parameter would be q_{95}. In this case, the same ohmic H-mode behavior seen at 0.8 MA (Fig. 3) should also be seen when the toroidal field ramps below ~2.4 and ~4.8 tesla for the respective plasma currents of 0.6 MA and 1.2 MA. It is interesting that the H-mode observed at 1.05 MA in Fig. 2 (q_{95} ~ 3.5) could be viewed as consist with such a scaling; ohmic H-modes at q_{95} ~ 3.5 were also seen at 0.8 MA.

![Fig. 3. A recipe of a toroidal field ramp-down with q_{95} dropping below 3 was used to create ohmic H-modes during the 2000 campaign.](image-url)
4. Resources
4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field:** between 6 and 2.4 tesla (normal direction)
- **Plasma Current:** 0.6, 0.8, 1.2 MA (normal direction)
- **Working Gas Species:** Deuterium
- **Density:** NL04 around 0.8x10^{20} m^{-2}

Equilibrium configuration (if possible, refer to database equilibria):

Standard LSN with optimized scanning probe targets.

4.2 Auxiliary Systems

- **RF Power, pulse length, phasing:** none
- **Pellet Injection (species):** Lithium pellet allowed at end of some shots
- **Impurity blow-off injection:** none
- **Diagnostic Neutral Beam:** As needed
- **Special gas puffing:** NINJA puff as necessary for GPI, Argon as necessary for HIREX systems
- **Non-axisymmetric Coils (Connections, Current):** standard locked-mode compensation

4.3 Diagnostics

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

Key diagnostics for this study are: ASP, FSP and WASP scanning probes, edge Thomson scattering, GPI and DNB-viewing plasma flow measurements, HIREX and HIREX Sr. We will need to optimize the targeting for all scanning probes such that they record the electron pressure and plasma flow profiles across the separatrix. It is particularly important that the probes are inserted deep enough to resolve the cross-field flow shear layer. This may require several repeated shots. Matt Reinke’s new midplane-viewing Lyman-alpha array is also desired for these discharges.

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.

With luck, we can complete this MP with one good run day. However, if the ohmic L-H transitions prove to be difficult to achieve and/or they do not occur at the right times relative to scanning-probe plunges, than more than one run day would be required.
Since we are looking to run a set of many reproducible H-modes, a well-conditioned, boronized, machine is 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 good starting point for this investigation is shot #1070517008 (0.8 MA, 5.6 tesla, NL04 ~ 0.95 x10^20 m^-2). This was a LSN plasma (segment#2) with near-optimum scanning probe targets and gaps. We will also need an USN plasma. Shot#1070511008 (0.8 MA, 5.4 tesla, NL04 ~ 0.6 x10^20 m^-2) is a good choice.

A. 0.8 MA, LSN – 8 shots
Reload from shot #107517008. Program a TF ramp-down, starting at 5.4 tesla at 0.3s, ramping down to 3.2 tesla by 1.0s and then back up to 3.5 tesla – this TF ramp would be the same as on shot #1000915019, but delayed by 0.2 seconds. Program NL04 ~ 0.65 x10^20 m^-2. Optimize ohmic H-mode (start time, transition from ELM-free to EDA) by adjusting TF ramp and starting density.

i. Optimize scanning probe plunge depths and scan times to record conditions just before (1 scan) and during H-mode (2 scans).

ii. Scan probes to record conditions well before the L-H transition, while q95 is ramping down.

B. 0.8 MA, USN – 2 shots
Reload from shot #107511008. Program same plasma current, TF ramp and target density as in “A”.

i. Optimize scanning probe plunge depths and scan times to record conditions as q95 is ramping down (0.5, 0.75, 1.0 s) – make sure that the probes scan deep enough to resolve shear layer.

C. 0.6 MA, LSN – 8 shots
Go back to LSN discharge. Reprogram for 0.6 MA. Start the TF ramp-down earlier at 0.1s, ramping down to 2.4 tesla by 1.0s and then back up to 2.7 tesla. Program NL04 ~ 0.6 x10^20 m^-2. Optimize ohmic H-mode (start time, transition from ELM-free to EDA) by adjusting TF ramp and starting density.

i. Optimize scanning probe plunge depths and scan times to record conditions just before (1 scan) and during H-mode (2 scans).

ii. Optimize scanning probe plunge depths and scan times to record conditions well before the L-H transition, while q95 is ramping down.
D. 0.8 MA, USN – 2 shots
Reload a shot from “B” above. Program same plasma current, TF ramp and target density as in “C”.

i. Optimize scanning probe plunge depths and scan times to record conditions as $q_{95}$ is ramping down (0.5, 0.75, 1.0 s) – make sure that the probes scan deep enough to resolve shear layer.

E. 1.2 MA, LSN – 6 shots
Back to LSN discharge, but with plasma current of 1.2 MA and toroidal field of 6 tesla. Program TF ramp-down from 6 tesla at 0.5s, to 4.8 tesla by 0.9s and then back up to 5.4 tesla. Program NL04 ~ 0.7 x10$^{20}$ m$^{-2}$. Optimize ohmic H-mode (start time, transition from ELM-free to EDA) by adjusting TF ramp and starting density.

i. Optimize scanning probe plunge depths and scan times to record conditions just before (1 scan) and during H-mode (2 scans).

F. 1.2 MA, USN – 2 shots
Reload a shot from “D” above. Program same plasma current, TF ramp and target density as in “E”.

i. Optimize scanning probe plunge depths and scan times to record conditions as $q_{95}$ is ramping down (0.5, 0.7, 0.9 s) – make sure that the probes scan deep enough to resolve shear layer.

5. 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.

The data from these experiments will allow us to examine the plasma conditions at the L-H threshold and to see if it is consistent with crossing the Rodgers/Guzdar ‘L-H boundary’ in the phase-space of electromagnetic fluid-drift turbulence. In any case, the plasma flow data from the newly installed diagnostics set should help us fill in the story with regard to edge plasma flows, flow shear and conditions that favor the L-H transition. These data will support the research goals for a number of Ph.D. theses as well as an invited talk at the November 2007 APS meeting.

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