Subject: Hysteresis in L-I-Mode transitions

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Group: Transport

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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.

Explore the nature of the L-I-L and I-H-I transitions by assessing the magnitude of hysteresis in global and local parameters including total and net power, local edge parameters and their gradients.

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

The L-H transition is generally assumed to be a true bifurcation in that two distinct plasma states (L- and H-mode) can exist for the same input power. This is evidenced in the response to total input power, which, after an L-H transition can be reduced to values significantly below what would be required for the transition to H-mode [Wagner1989, Mertens1997]. The amount of hysteresis, defined in this way can be as high as factor of 2-3 in power [Thomas1998]. (In these experiments the hysteresis was observed to be independent of density while other machines reported that the phenomena disappeared at high density [1996, Ryter1998]. – one more H-mode mystery) The results were perhaps best summarized by work on C-Mod which showed a multi-valued relation between heat flux and temperature gradient – and mapped

Figure 1  Bifurcated flux-gradient curve for L-H-L transition – Hubbard 2002
out the bifurcation “S” curve [Hubbard 2002] See Figure 1. (Somewhat in contradiction, in a series of earlier studies, there was evidence for lack of hysteresis when the transition was characterized as a critical edge temperature or temperature gradient [Wagner 1989, Hubbard1998, Ryter1998].

The question we want to address here is the topology of the L-I and I-H mode transitions. Since these involve suppression of different transport channels – energy and particles respectively [Whyte 2010] – the nature of the transitions may help us understand the stabilization mechanisms, for example through the degree of positive feedback in each.

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.

These experiments will involve slow power scans up through the L-I transition and then down through the I-L transitions. In addition to global parameters, local pedestal profiles and fluctuation characteristics will be measured including edge ion temperature and Er profiles if possible. Conditions that lead to more sudden appearance of I-mode (low q) will be compared to those associated with more gradual transitions.

Once this data is obtained for each condition, the power level in the scans will be increased to access I-H-I cycles. (These shots may be obtained along the way, if we overshoot the power required for the I-H transition.)

4. Resources

4.1 Machine and Plasma Parameters
Give values or range for:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toroidal Field</td>
<td>5.3 T</td>
</tr>
<tr>
<td>Plasma Current</td>
<td>0.8-1.2 MA</td>
</tr>
<tr>
<td>Working Gas Species</td>
<td>D₂</td>
</tr>
<tr>
<td>Density</td>
<td>Target ne = 1 x 10^20</td>
</tr>
<tr>
<td></td>
<td>Target nel = 0.6 x 10^20</td>
</tr>
<tr>
<td>Boronization Requested</td>
<td>A fresh boronization may not be required, but the machine condition should be good enough to sustain H-modes long enough for a slow power ramp-down to characterize the H-I transition</td>
</tr>
<tr>
<td>Equilibrium configuration</td>
<td>for normal field 1091016033, for reversed field await successful initial experiments</td>
</tr>
</tbody>
</table>

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4.2 Auxiliary Systems

ICRF Power, pulse length, phasing: 4-5 MW
LHCD Power, pulse length, phasing: no
Pellet Injection (species): no
Impurity blow-off injection: no
Diagnostic Neutral Beam: yes (highly desired, but perhaps not essential?)
Special gas puffing:
Cryopump: if normal field
Non-axisymmetric Coils (Connections, Current):
Other:

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

Standard core diagnostics, including bolos for radiated power
All pedestal diagnostics, Edge TS, ECE and CXRS
Fluctuation diagnostics, for assessment of WCM
Lyα arrays for assessment of particle source

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.

1 Day run – under conditions favorable to I-mode access and reasonably steady H-modes. (That is some minimum quality of boronization.)

We’re looking for 4 distinct discharge trajectories, obtained by adjusting power scan limits. It is possible (with luck) that the run could be completed more quickly than estimated below.

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.

Use equilibrium from shot?

1. L-I-L cycle at 1.2 MA  8 shots
   Target ne = 1 x 10^{20}
   Target nel = 0.6 x 10^{20}
   Power scan from 3 to ~5 MW (adjust to obtain desired transition cycle)
   Power trace for scans 1 and 3 should be roughly trapezoidal as shown in figure 2a
   Power trace for scans 2 and 4 should be roughly triangular as shown in figure 2b

2. L-I-L cycle at 0.8 MA  8 shots
   Target ne = 1 x 10^{20}

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Target nel = $0.6 \times 10^{20}$

Power scan from 1.5 to ~3 MW (adjust to obtain desired transition cycle)

3. I-H-I cycle at 0.8 MA  4 shots
   Target ne = $1 \times 10^{20}$
   Target nel = $0.6 \times 10^{20}$
   Power scan from ~2 to ~3MW (adjust to obtain desired transition cycle)

4. I-H-I cycle at 1.2 MA  4 shots
   Target ne = $1 \times 10^{20}$
   Target nel = $0.6 \times 10^{20}$
   Power scan from ~4 to ~5 MW (adjust to obtain desired transition cycle)

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, an ITER request, or an external database.

1. Better understanding of the separate processes that lead to energy and particle transport barrier formation
2. If the results are clear, should be sufficient for publication
3. The stuff dreams are made of.

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

[Hubbard et al., PPCF 2002]
[Kallenberg, et al., PPCF 38, 2097, 1996]
[Mertens et al., Nucl. Fusion 37, 1607, 1997].
[Ryter et al., PPCF 40, 725, 1998]
[Whyte et al., Nucl Fus. 50, 105005, 2010]