Subject: Transient low-power (<2MW) I-mode: Changes in core and edge turbulence and transport

From: A.E. White, (add authors at EPC meeting)

Group: Pedestal / I-mode /core transport

Date: August 20, 2015

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 this experiment is to reproduce conditions from MP629 run day on 1110217 where transient “I-modes” were observed during 2MW RF pulses. Specifically, we wish to investigate changes in both core and edge turbulence and transport and shed light on the physics of I-mode transport and the I-mode transition threshold.

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

There were a variety of interesting broadband and quasi/semi coherent fluctuations in 1110217 and similar experiments run by Aaron Bader as part of his fast ion physics studies. However, the experiments were not run with all the turbulence and profile diagnostics turned on, so we were missing a lot of key data needed to really interpret these “transient I-modes”, if indeed that is what was occurring.

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 will be to reproduce the shots where “transient I-modes” were observed (see supplementary material on pages ....). We will then gather the full suite of turbulence and profile data, and will add in scans of density and Ip. It will also be of interest to attempt some shape changes (to favor I-mode) and plasma position shifts to try to use the normal O-mode reflectometer as a Doppler reflectometer (e.g. by shifting a
small plasma up and down you vary the angle at which the launched wave intersects the flux surface which changes the k-response of the reflectometer).

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toroidal Field:</td>
<td>5.0-6.0 T</td>
</tr>
<tr>
<td>Plasma Current:</td>
<td>0.6-1.0 MA</td>
</tr>
<tr>
<td>Working Gas Species:</td>
<td>Deuterium (D₂)</td>
</tr>
<tr>
<td>Density:</td>
<td>n₁₀⁴ = 0.6-1.0 x 10²⁰ m⁻²</td>
</tr>
<tr>
<td>Boronization Requested:</td>
<td>Not the night before. A few days before is o.k.</td>
</tr>
<tr>
<td>Equilibrium configuration:</td>
<td>unfavorable for H-mode. This experiment can be run in either forward or reverse field. But an example shot is 1110217018</td>
</tr>
</tbody>
</table>

4.2 Auxiliary Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRF Power, pulse length, phasing:</td>
<td>Request between 0.5 MW and 2 MW.</td>
</tr>
<tr>
<td>LHCD Power, pulse length, phasing:</td>
<td>No power. Edge reflectometer is requested.</td>
</tr>
<tr>
<td>Pellet Injection (species):</td>
<td>no</td>
</tr>
<tr>
<td>Impurity blow-off injection:</td>
<td>no</td>
</tr>
<tr>
<td>Diagnostic Neutral Beam:</td>
<td>Desired but not required.</td>
</tr>
<tr>
<td>Special gas puffing:</td>
<td>Ar for HIREX Sr</td>
</tr>
<tr>
<td>Cryopump:</td>
<td>Yes (MP629, run 1110217 had it)</td>
</tr>
<tr>
<td>Non-axisymmetric Coils:</td>
<td>no</td>
</tr>
<tr>
<td>Other:</td>
<td>None</td>
</tr>
</tbody>
</table>

4.3 Diagnostics

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

Required:
- GPC
- Thomson
- TCI
- Edge/SOL X-mode reflectometer
- HIREX SR (He and H like Ar crystal)
- Zeff/impurity spectroscopy
- PCI configured for turbulence measurements
- O-mode reflectometer
- CECE

Desired (we will run without these):
- Beam CXRS and MSE
- FRCECE
- The full suite of edge/boundary fluctuations from the edge/boundary group 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.

1 run day, about 21 good shots needed.

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.

Repeat cycle of these four shots until we are confident that we have enough good data for steady-state and perturbative transport analysis.

1. (1-2 shots) Perform locked mode calibration shot
2. (4 shots) Repeat shot 1110217018 with modulated RF power in order to confirm that transient I-modes can be obtained.
3. (4 shots) Modify density, RF power, and Bt as needed to establish shot with acceptable signal in HIREX and acceptable density profile for O-mode reflectometer coverage and a good Bt value for CECE coverage – but still with the transient I-mode using modulated RF power.
4. (4 shots) repeat 3 with modulated ICRF, but at a slightly lower power RF power each time to see at which level we no longer get the transient I-mode.
5. (4 shots) repeat some shots from 3 and 4 with changes in shape to favor I-mode (e.g. triangularity etc.) to see if transient I-mode can be triggered at lower input power with a shape change.
6. (4 shots) repeat 2 and 3 with transient I-modes and a good density for the O-mode reflectometer, but now shift plasma up / down on a shot by shot basis to vary the k-response of the reflectometer (poor-Anne’s Doppler reflectometer/backscattering)

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.

Data that will allow for better understanding of I-mode turbulence and transport. We will perform profile analysis, fluctuation analysis, TRANSP analysis, and Gyrokinetic analysis.

7. References
Include references both to external and internal literature or communications which bear on this proposal. See Section 2.
MP629, A. Bader MIT 2011

8. Supplementary material

Examples of the past data and evidence of transient I-modes are attached on pages 4 through 39.
Evidence for transient I-modes during run 1110217

- Several shots from run 1110217 with modulated RF power show fluctuations similar to WCM fluctuations when RF is on.

- WCM type fluctuations are seen strongly in magnetics, weakly in reflectometer (but only 60 GHz channel available).

- WCM type fluctuations correlate with lower density, higher temperature phases of shots; correlate with edge temperature pedestal but no density pedestal.
1110217018: 1 MA, 5.4 T, nl04 ~ 5-8x10^{19} \text{ m}^{-2}
Reflectometer and Magnetics show WCM-type fluctuations transiently during early RF cycles (t < 1 s) not during later RF cycles (t > 1 s)
60 GHz reflectometer channel is close to LCFS in shot 1110217018
H98, $Te(0)$ higher, $ne(0)$ lower when modes are observed, No drop in edge D-alpha.
Reflectometer and Magnetics show **WCM-type fluctuations transiently** during early RF cycles ($t < 1 \text{ s}$) not during later RF cycles ($t > 1 \text{ s}$)
Edge temperature is higher and density is lower when WCM-like fluctuations are observed compared to not observed.
Edge profiles show steep $T_e$-pedestal (with no $n_e$-pedestal) when WCM-like fluctuations are observed. 0.85 < $t$ < 0.90 s, 0.90 < $t$ < 0.95 s.
Edge profiles show steep $T_e$-pedestal (with no $n_e$-pedestal) when WCM-like fluctuations are observed.

Long time averaging, average over RF duty cycle

$0.7 < t < 0.9 \text{ s}$  $1.0 < t < 1.2 \text{ s}$
Evidence for transient I-modes during run 1110217

• Several shots from run 1110217 with modulated RF power show fluctuations similar to WCM fluctuations when RF is on.

• WCM type fluctuations are seen strongly in magnetics, weakly in reflectometer (but only 60 GHz channel available).

• WCM type fluctuations correlate with lower density, higher temperature phases of shots; correlate with edge temperature pedestal but no density pedestal.

• But, the fluctuations occur at higher frequencies in the magnetics compared to the reflectometer, and some shots have the fluctuations in magnetics, but not in reflectometer, but again, only 60 GHz available from shot 17 onward.
Extra slides science meeting
Extra slides for transient I-modes in 1110217

- Following slides show some screen shots from w_fluct analysis of 1110217

- We also note that Arturo had the 75 and 88 GHz reflectometer channels still connected for shots 15 and 16, but these shots do not show the transient I-mode behavior.

- On some transient I-mode shots (e.g. 17), the WCM-type fluctuations become very narrow in frequency. Lower frequency coherent MHD modes also observed in magnetics.
On other shot, magnetics show more coherent, chirping mode $f_0 \sim 200$ - 250 kHz during RF Pulse.
Only 60 GHz reflectometer available, shows reduction in low-f fluctuations, increase in higher –f (but no clear mode)
Edge profiles show steep $T_e$-pedestal (with no $n_e$-pedestal) when coherent fluctuations are observed.

$0.85 < t < 0.90 \text{ s}$

$0.90 < t < 0.95 \text{ s}$
WCM-like fluctuations are observed in shot 23, but edge profiles seem similar for RF cycles with and without mode. Is it in I-mode throughout shot? Or are the fluctuations something else entirely?

$0.85 < t < 0.90$ s

$0.90 < t < 0.95$ s
Edge profiles show steep $T_e$-pedestal (with no $n_e$-pedestal) when WCM-like fluctuations are observed.

$0.7 < t < 0.9 \text{ s}$

$1.0 < t < 1.2 \text{ s}$
reflectometer Fluctuations for Shot 1110217017

Channel = 60 GHz
Transient I-mode and WCM type fluctuations seen in Bader’s Run 1110217 seem to be unrelated to the more “RSAE” like fluctuations seen in Bader’s Run 110309032 shot. In the 2009 shot, the RSAE like fluctuations show up on magnetics, but at much lower frequencies that a fast ion mode should show up (they are are 200 kHz or so, right in the WCM range).

But in 110309032, there is no correlation between the presence of the 200 kHz RSAE looking modes and a temperature pedestal.

Also in 110309032, H98 stays high even when neutron rate drops so presence of the 200 kHz fluctuations also does not correlate with overall confinement.
Long time averaging seems to indicate there is a $T_e$ pedestal in second half of shot when modes are present.
Short time averaging seems to indicate there is a Te pedestal when modes are not present.

Probably need much more careful check of "I-mode" characteristics of this shot.