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Active Feedback on Locked Modes in DIII-D[1] E.D. FREDRICKSON, L.C. JOHNSON, M. OKABAYSHI, Princeton Plasma Physics Laboratory, R.J. LAHAYE, E.J. STRAIT, R.T. SNIDER, J.T. SCOVILLE, General Atomics, G.A. NAVRATIL, A.M. GAROFALO, Columbia University, E.A LAZARUS, Oak Ridge National Laboratory, M. GRYAZNEVICH, UKAEA Fusion — Experiments to control low density locked modes have been carried out on DIII–D, using switching power amplifiers (SPAs) to drive external coils in a closed loop configuration. There are six external "picture frame" coils mounted around the midplane and each coil spans 60 degrees in the toroidal direction and about 50 degrees in the poloidal direction. The SPAs are designed with less than 0.1 msec internal time delay, adequate for feedback experiments at frequencies comparable to the wall time constant. The maximum radial field which the coils can drive is about 40 G at the vacuum vessel wall. Feedback was tried with the "smart shell" algorithm and with direct feedback on the mode amplitude. In this first experiment, the locked modes were not stabilized.

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☐ Prefer Oral Session
☒ Prefer Poster Session

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Special instructions: DIII-D Poster Session 1, immediately following GA Navratil

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Active Feedback on Locked Modes in DIII-D

(and Study of Physics of Low Density Locked Modes)

Abstract

Experiments to feedback stabilize locked modes using high power amplifiers to drive external coils in a closed loop configuration are planned for DIII-D. The experiments will use a set of three recently installed switching power amplifiers (SPAs). The amplifiers are used to drive the existing "C" coils originally installed for quasi-dc error field correction. Each of the six picture frame "C" coils spans 60º in toroidal angle and are located on the midplane of DIII-D. The SPAs were designed to have less than 0.1 msec internal time delay, adequate for feedback experiments at frequencies comparable to the wall time constant. The SPAs are driven by ≈ 300 Volt DC supplies and the maximum current is set by the maximum allowable current in the C-coils which is 5 kA times 4 turns. With this voltage the dI/dt into the C-coil inductive load is about 2 kA/msec. At full current, the C-coils can provide about 40 Gauss at the vacuum vessel wall for feedback control. Various feedback techniques are being considered.

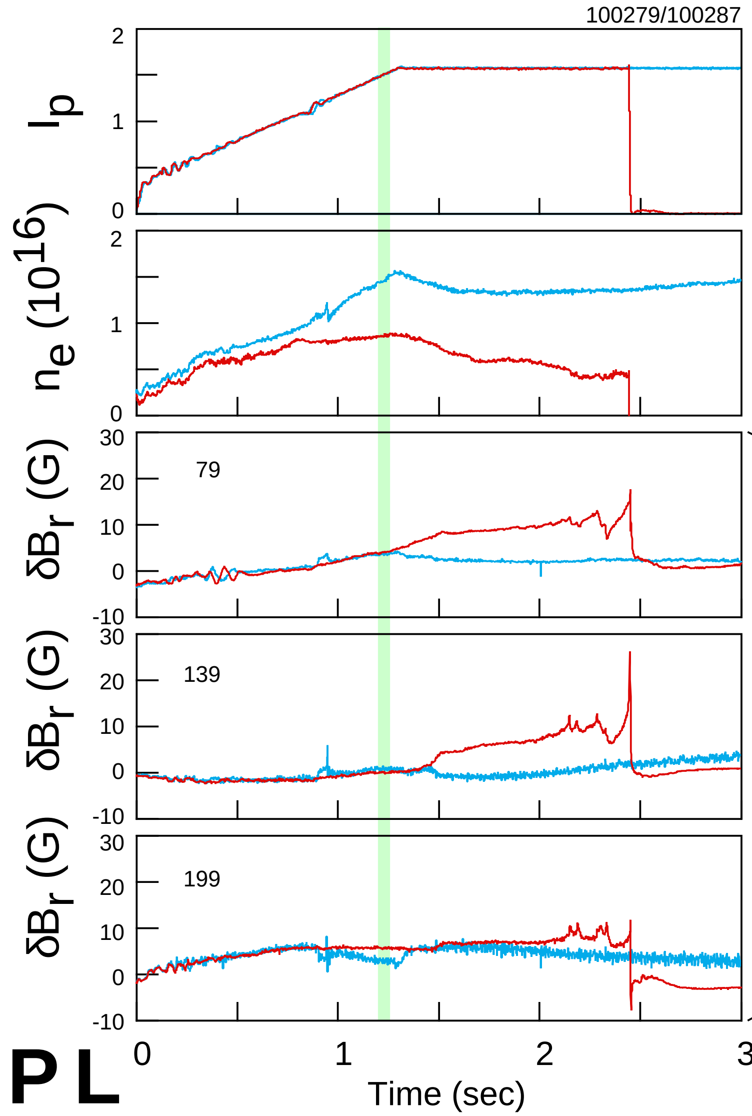
Physics of Locked Mode Disruptions

"Standard Model":

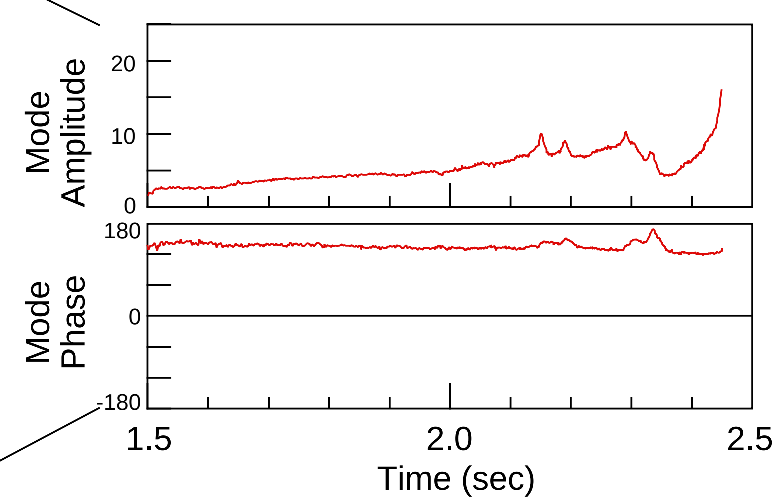
1) Low density allows error fields to penetrate plasma.
2) Error fields trigger tearing mode.
3) Tearing mode grows to point of island overlap, wall contact or global stochasticity.
4) Thermal quench leads to disruption.

5) By controlling locked mode, may avoid disruption.

Disruptions occur as plasma density drops below threshold; Disruptions may be triggered by a tearing mode.



- Stationary Magnetic Perturbations are seen as density is lowered below threshold.
- Some or all of signal may be attributable to a non-rotating tearing mode.
- There is a final, rapid growth of the mode which precedes a disruption.



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Interpretation of Saddle Loop Signals

Contributions to Non-axisymmetric Saddle Loop Signal:

1) Saddle Coil misalignments (static and dynamic)

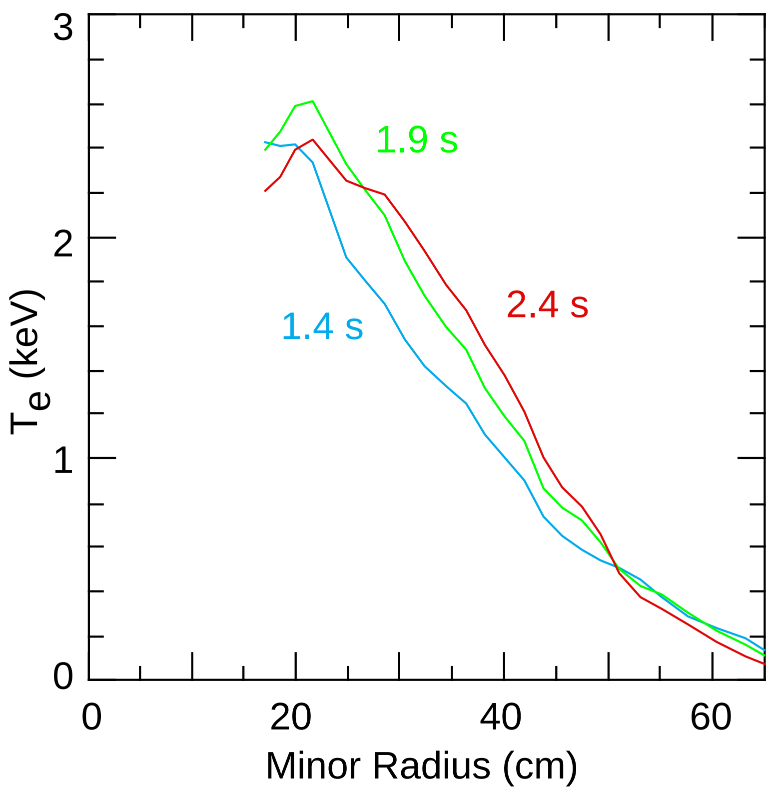
2) Eddy Currents

3) Intrinsic Error fields (static and dynamic)

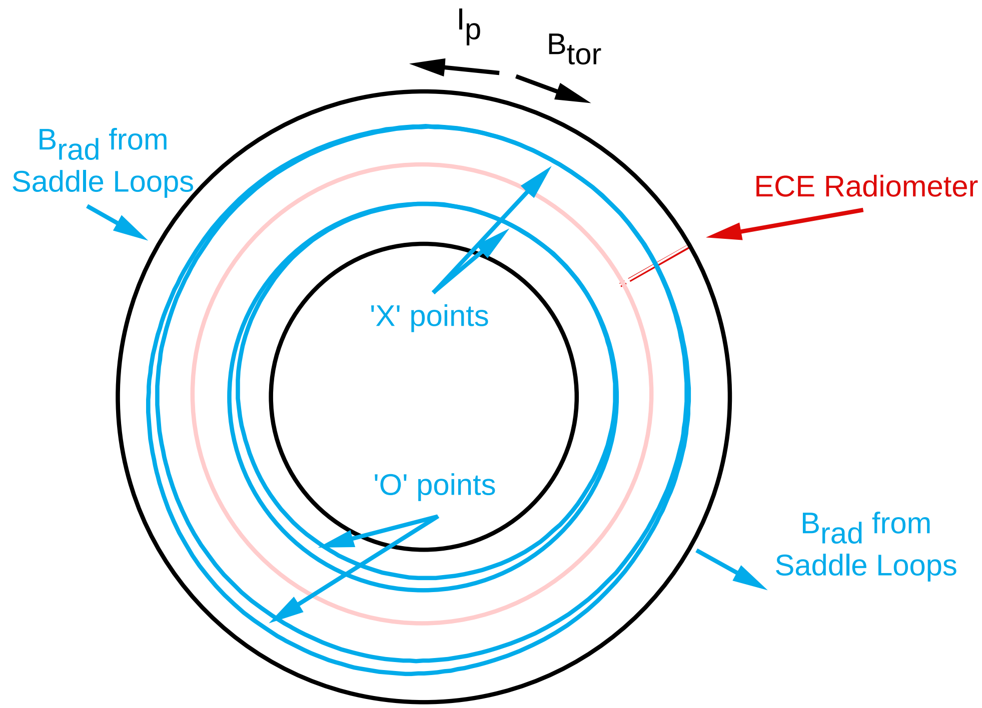
4) Other non-axisymmetric currents (Halo currents)
Sensitive to plasma conditions (density)?

ECE Radiometer sees island 'x' point

T_e profiles - no flatspots



m=2, n=1 Plan View; Cartoon



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Closed Loop Feedback on Locked Mode

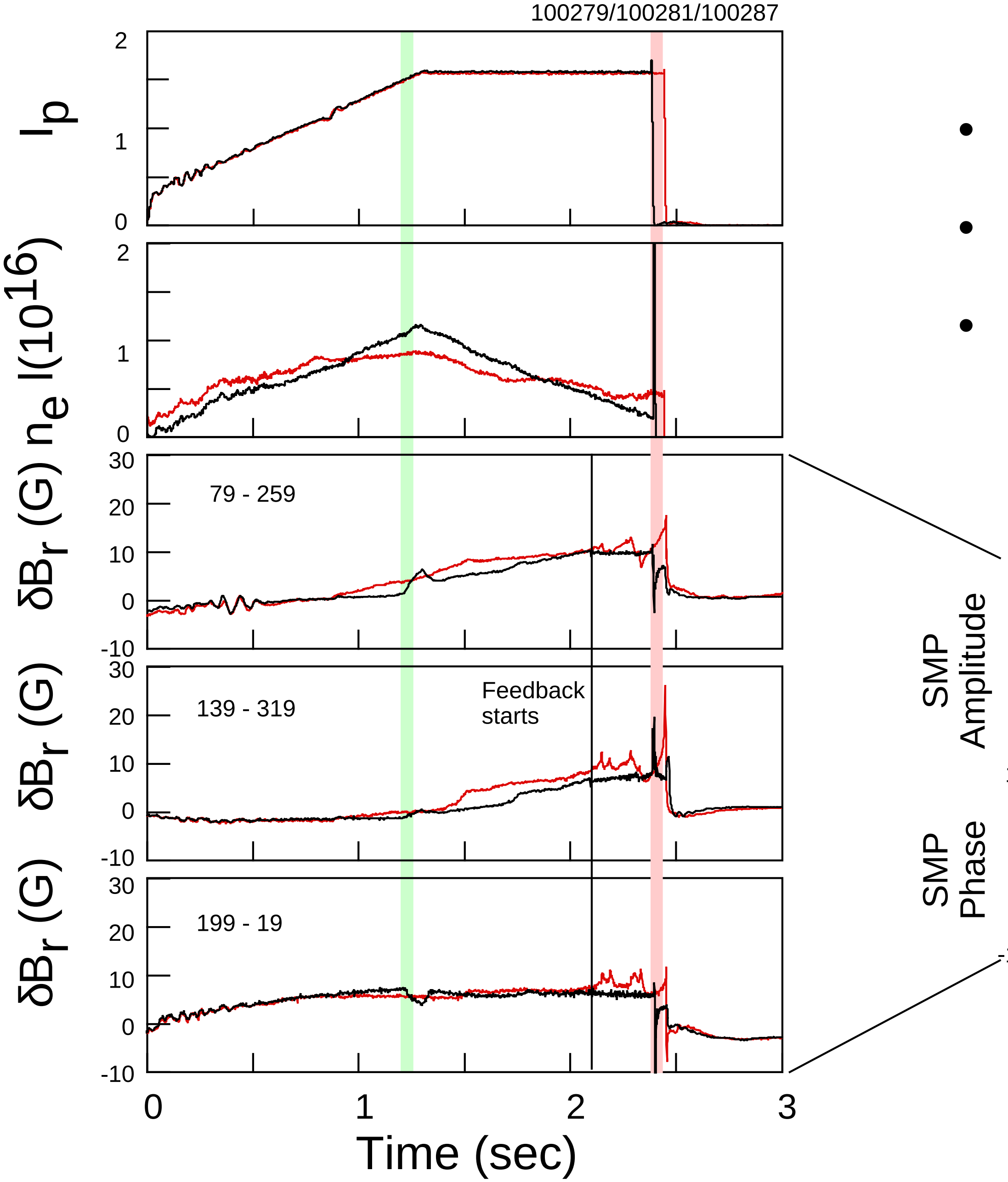
Experiment revisits the study of low density locked mode physics and attempts to feedback stabilize locked mode.

Closed loop system has three independent amplifiers driving 3 coil pairs in odd-n configuration.

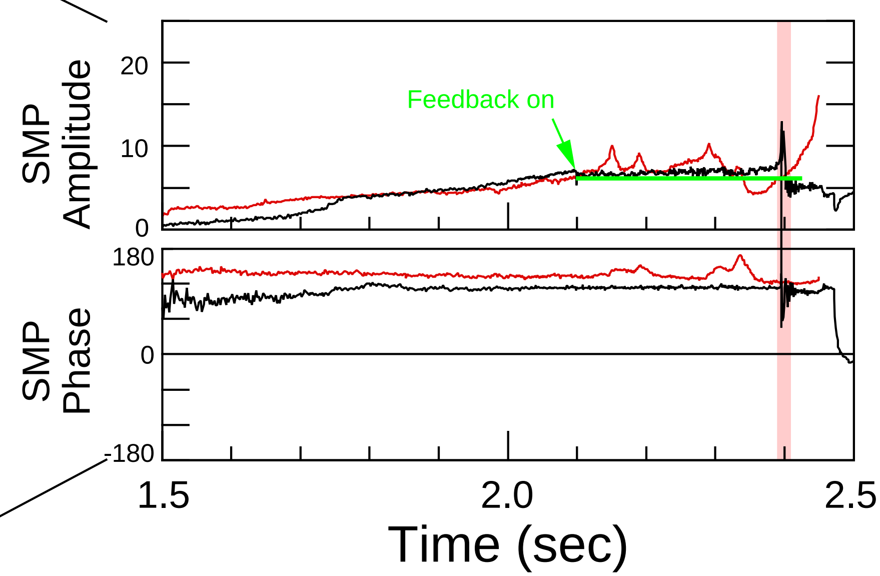
Bandwidth of amplifiers limited by available voltage (300 V) and coil inductance.

System configured to feedback on n=1 component only.

Smart Shell" Feedback prevents flux leakage



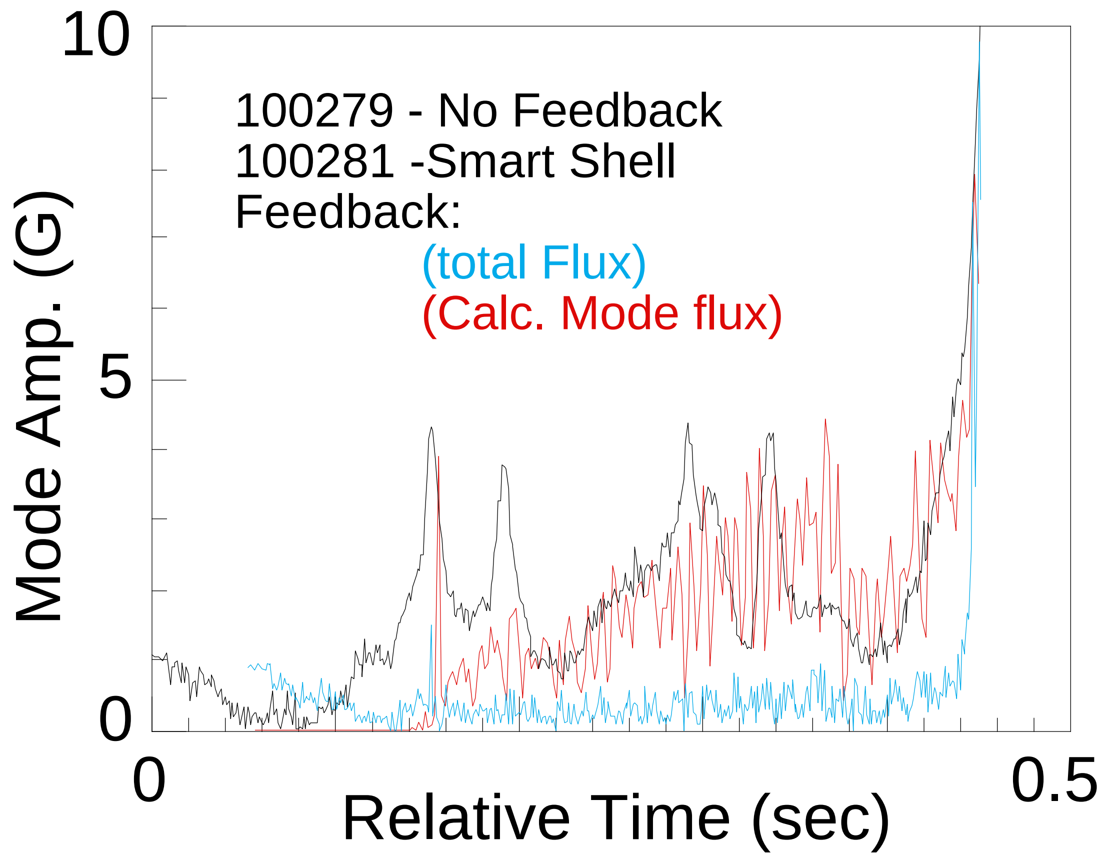
- Feedback starts at 2.1 sec
- Error field already substantial.
- The error field can provide a substantial drive for tearing mode.



Locked Mode Feedback Experiments

- "Smart Shell" algorithm worked, keeps flux leakage through wall small.

- With Smart Shell feedback, inferred mode amplitude and growth rate similar to no feedback case.



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Tearing Mode Simulations

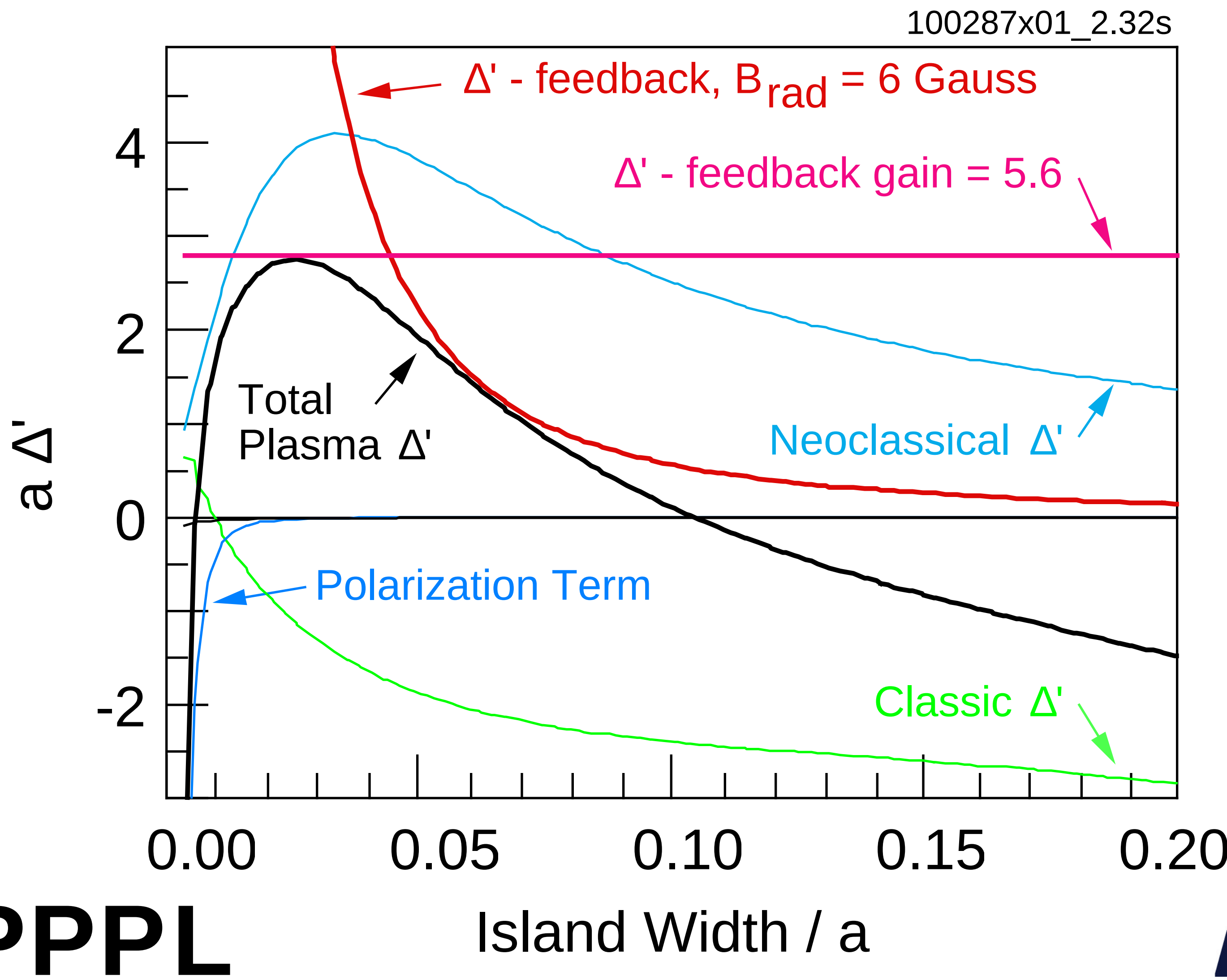
1) TRANSP run of shot to calculate bootstrap current.

2) Numerical $\Delta'(w,t)$ calculation, and terms like Δ'_{nc}, Δ'_{pol}, ...

3) Numerical integration in time of extended Rutherford equation for island width.

4) Calculation of other quantities: $B_r(w)$, feedback requirements.

Feedback gain of 6, max. field 6 Gauss needed to stabilize mode



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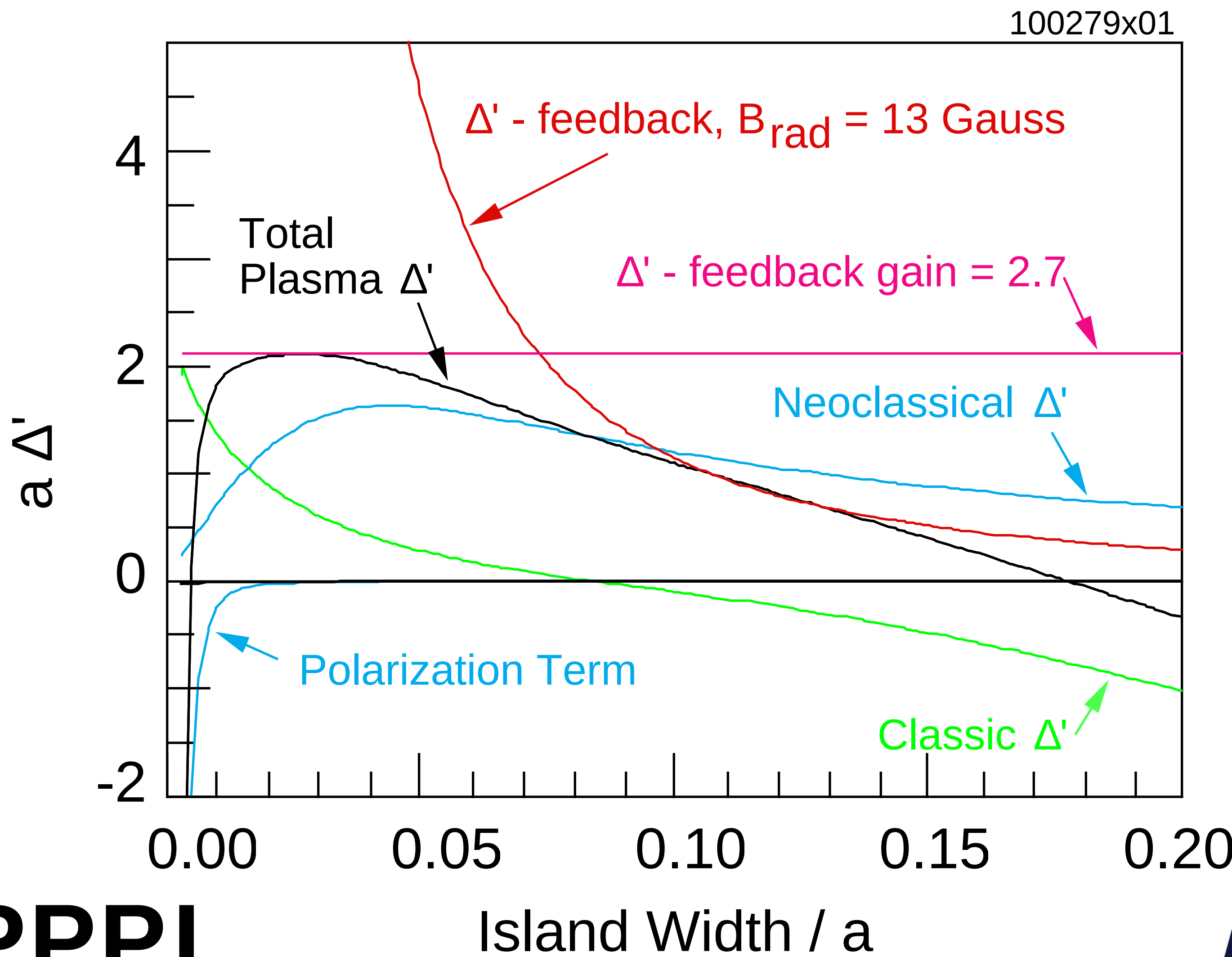
Feedback gain of 2.7, max. field 13 Gauss Needed to stabilize mode



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Many Simulation Options

1) $\Delta'nc$ from poloidal beta or actual bootstrap current.

2) Choice of collisional/collisionless parallel transport model.

3) With/without polarization current term.

4) Threshold simulation model.

5) Fudge factors in Δ'_{nc} definition.

- The threshold island size is ≈ 0.5% of the minor radius.

- The Δ’ feedback with constant amplitude also describes the effect of an external error field on Tearing Mode Stability.

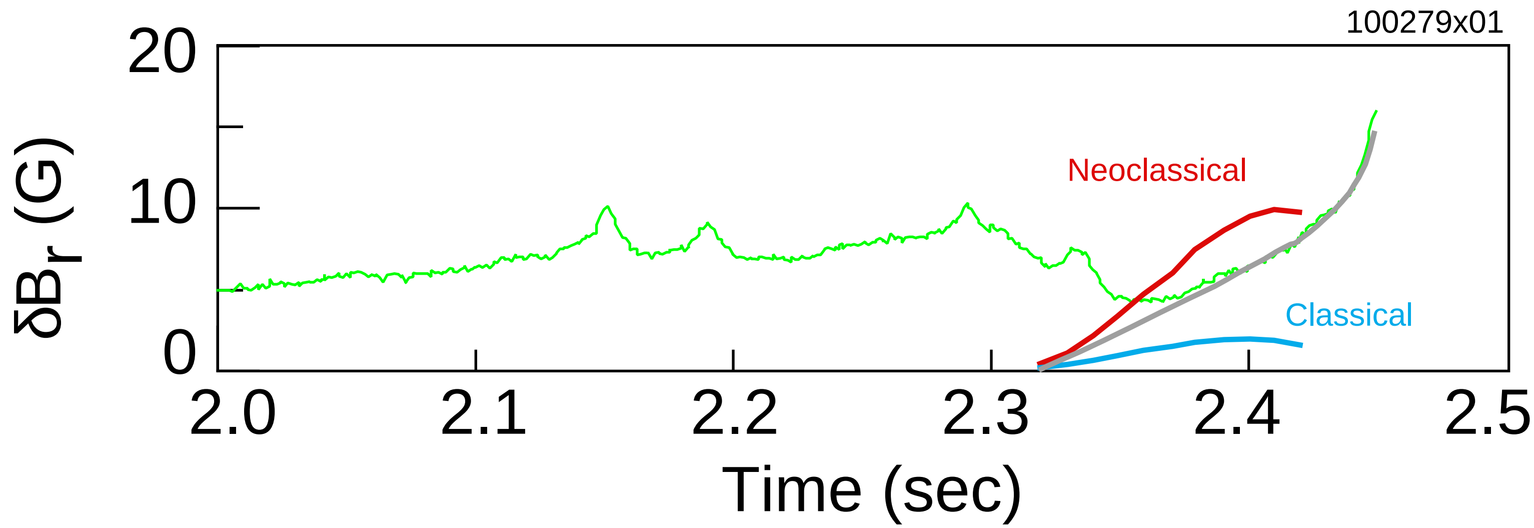
- The feedback system should be capable of applying up to 6 Gauss at the saddle loop location, with a gain of up to 6 to control mode.

- These calculations are very sensitive to modeling assumptions; they will be refined as the model is benchmarked against measurements.

Time dependent simulations of island width evolution provide insights

- Island growth rate from TRANSP resistivity results in reasonable agreement with data.

- This simulation requires assumption of threshold island model; the tearing mode is classically unstable.



- Rapid, non-linear growth at end not in standard model.

- MHD events may be modifying current profile.

1) Uncertainty in interpretation of saddle loop signals =>
uncertainty in physical model of disruption.

2) Standard Model:
Mode is unstable from 1.5 sec, amplitude varies with plasma
Conditions.

2) Conjecture:
Halo currents made non-axisymmetric by error field.
Saddle loop signal is from non-axisymmetric halo currents.
Amplified error field destabilizes tearing mode at 2.32 sec.
Thermal quench leads to disruption.

Experimental Observations of Disruption:

1) Low density is correlated with:

   non-axisymmetric magnetic perturbations.

   a series of Partial Disruptions

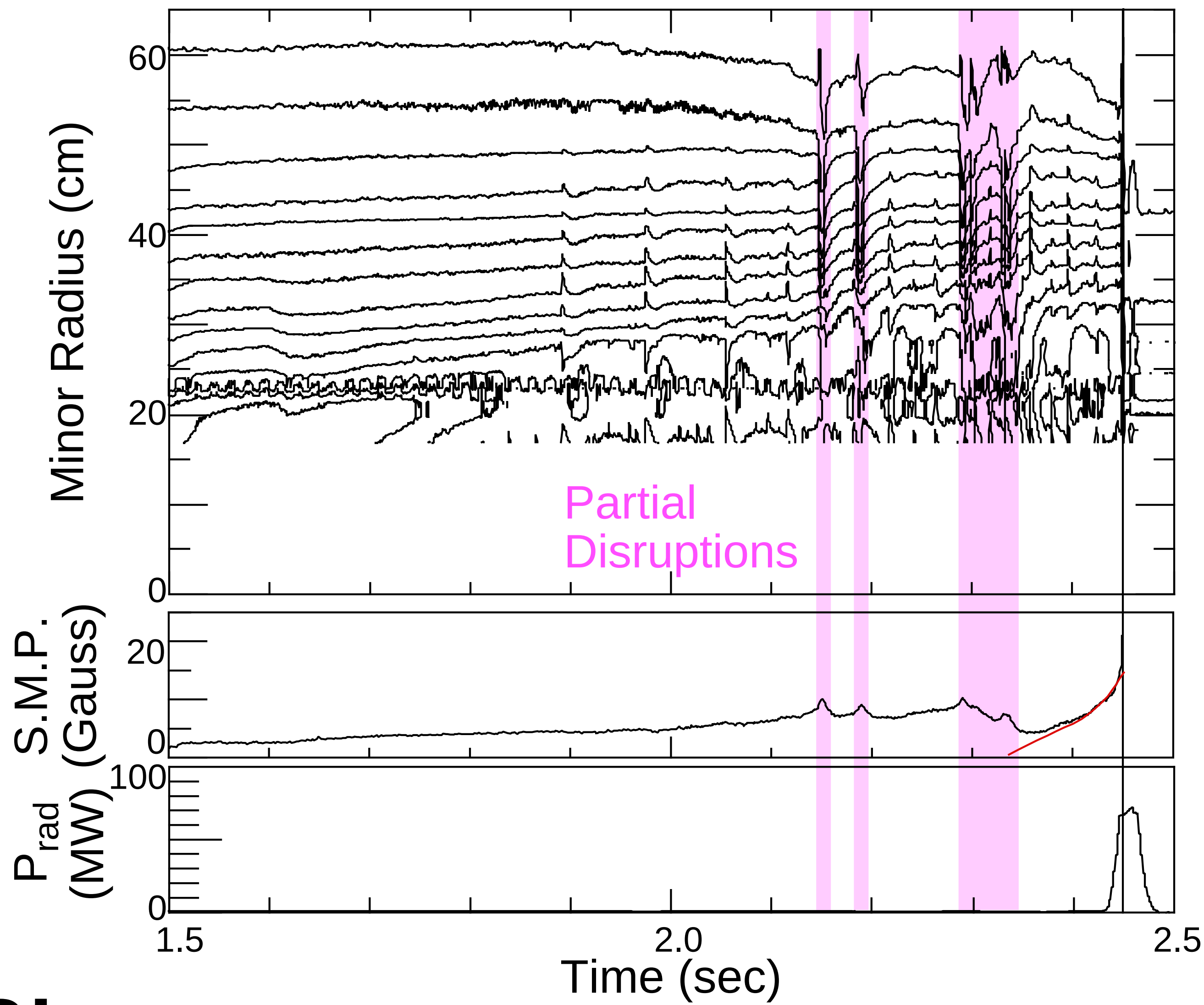
2) Strongly growing n=1 perturbation

3) Big Partial Disruption, Minor Disruptions

4) Thermal quench to q=1 surface

5) Probable m=1, n=1 external kink linked to disruption

The S.M.P./Locked Mode disruption is similar to density limit disruption



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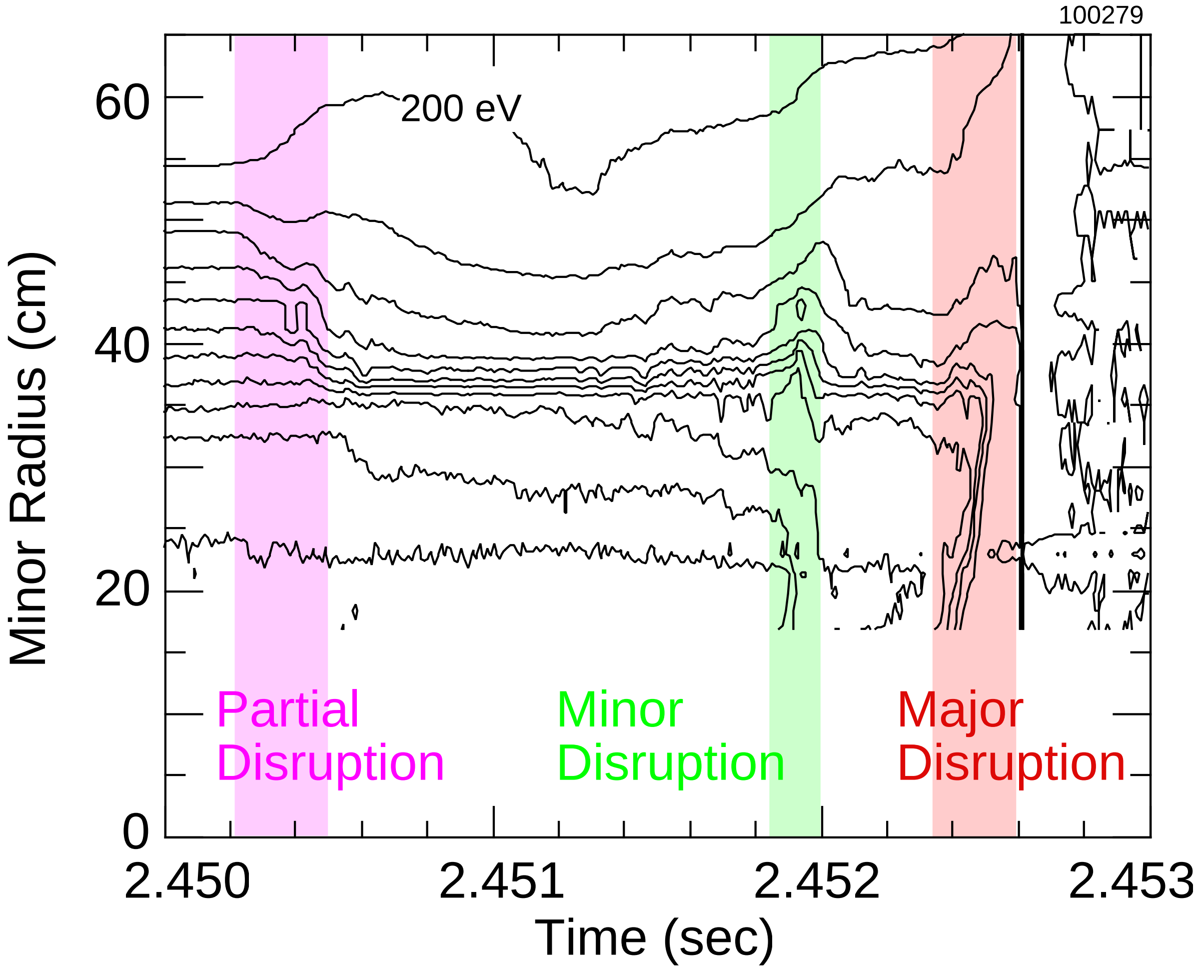
Disruption follows classic density limit disruption pattern:

- Thermal collapse (radiation, stochasticity)
- Partial disruptions (2,1 tearing?)
- Minor disruptions (1,1 kink)
- Major disruption (1,1 external kink)
- Thermal and current quenches.



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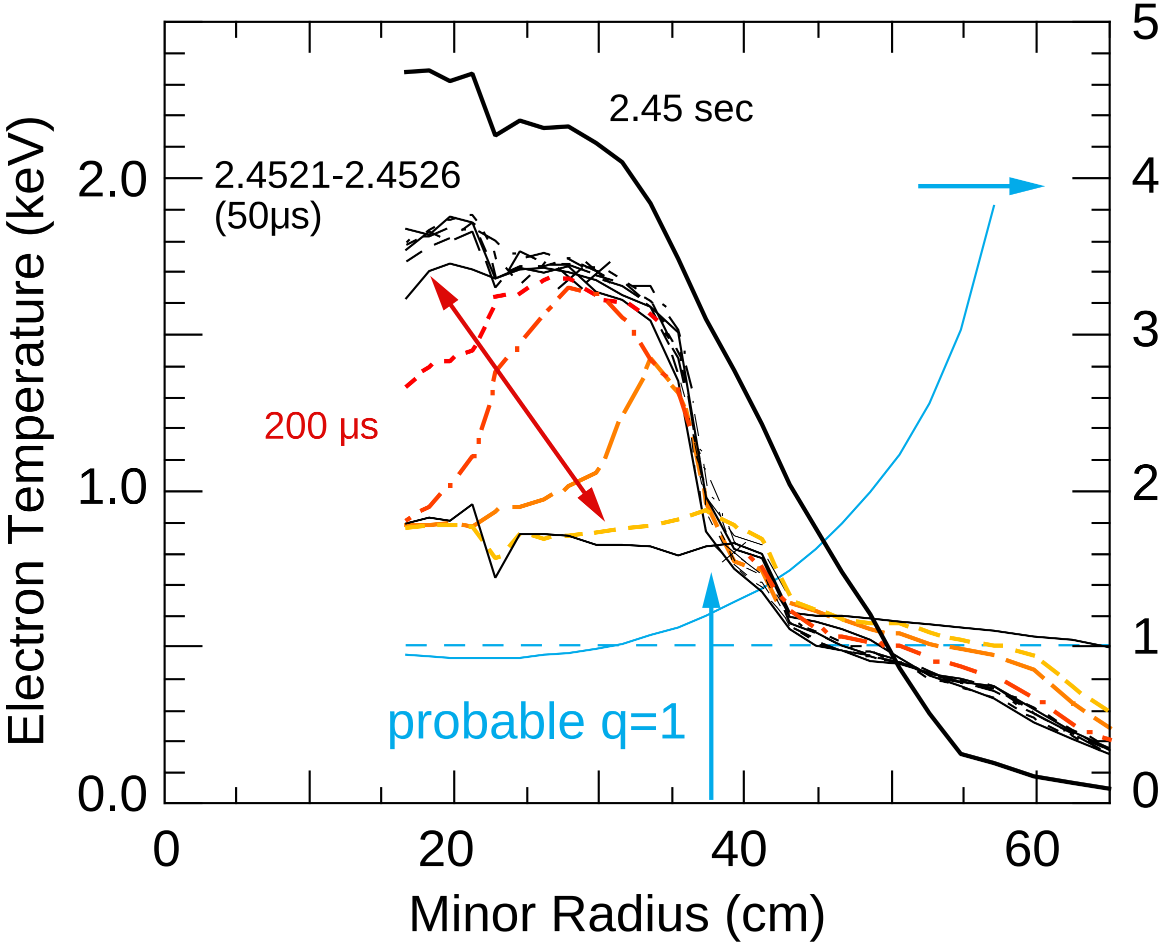
Disruption caused by "Kadomtsev cold bubble" following thermal collapse.



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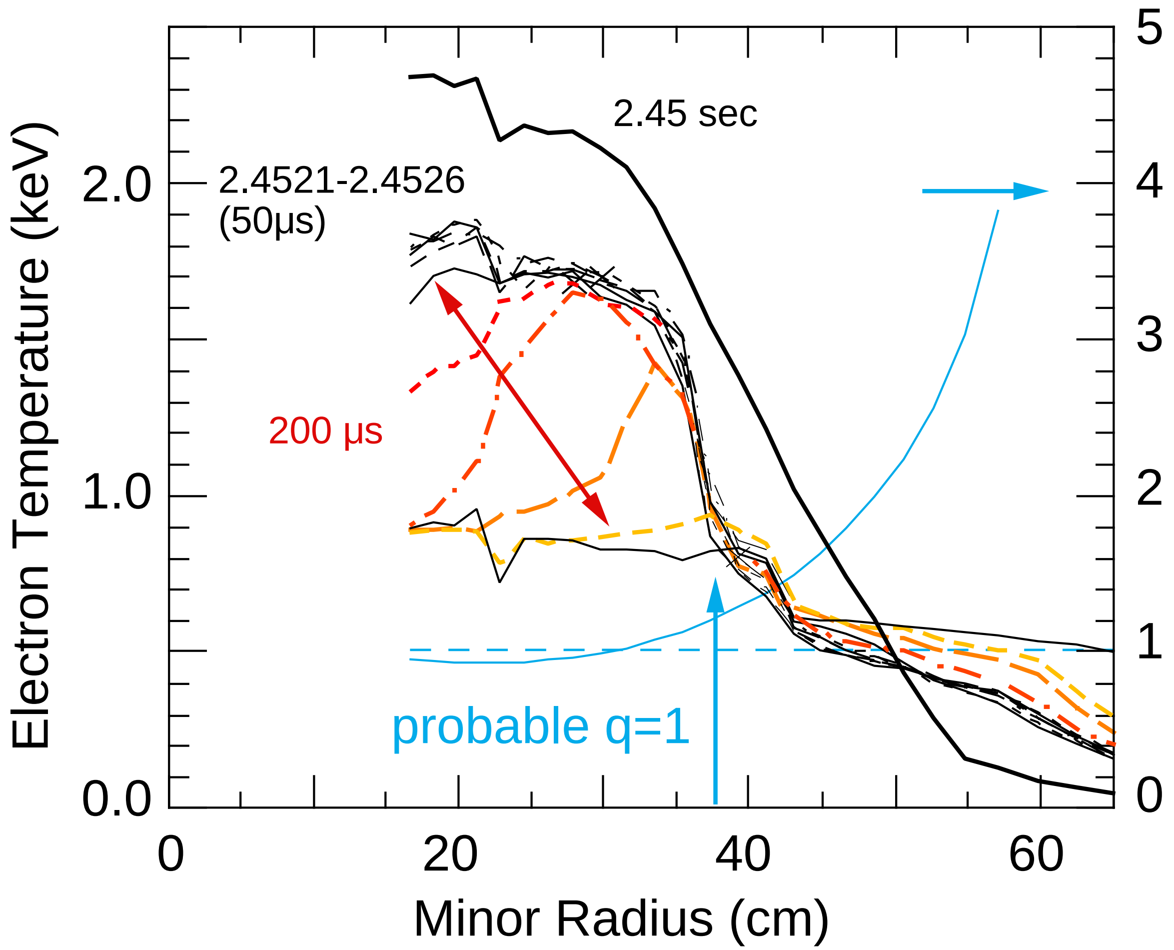

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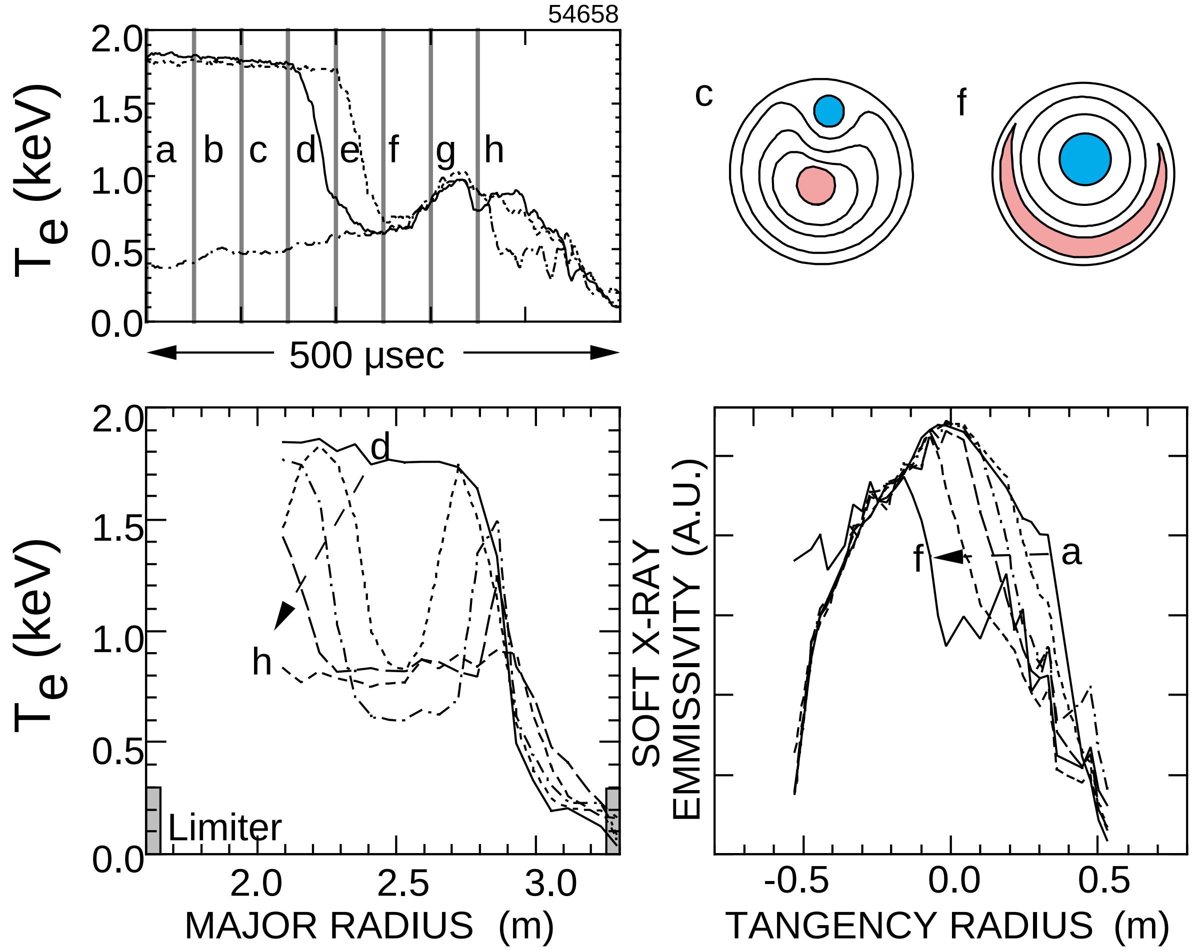
Disruption is similar to density limit disruption on TFTR

TFTR



- The kink has a ballooning topology, probably reflecting low magnetic shear in the core.

Nucl. Fusion 33, p 141 (1993)

Summary

- The feedback system was capable of preventing flux leakage through the wall.
- This was not sufficient to stabilize the tearing mode.
- Calculations made assuming the mode was a 2/1 suggest that the system could feedback stabilize the mode with an improved algorithm.
- The locked mode disruptions showed many similarities to density limit disruptions, including 1/1 cold bubble.

Future plans:

1) Rotate locked mode with C-coil to allow measurement of island width with ECE radiometer.

2) Start “smart shell” feedback earlier to prevent growth of SMP.

3) Improved feedback algorithm for “mode control”.

4) Lower single null plasma to allow halo current measurements (instrumentation only in lower divertor).