Stabilization of Tearing Modes by Electron Cyclotron Current Drive in the DIII–D Tokamak

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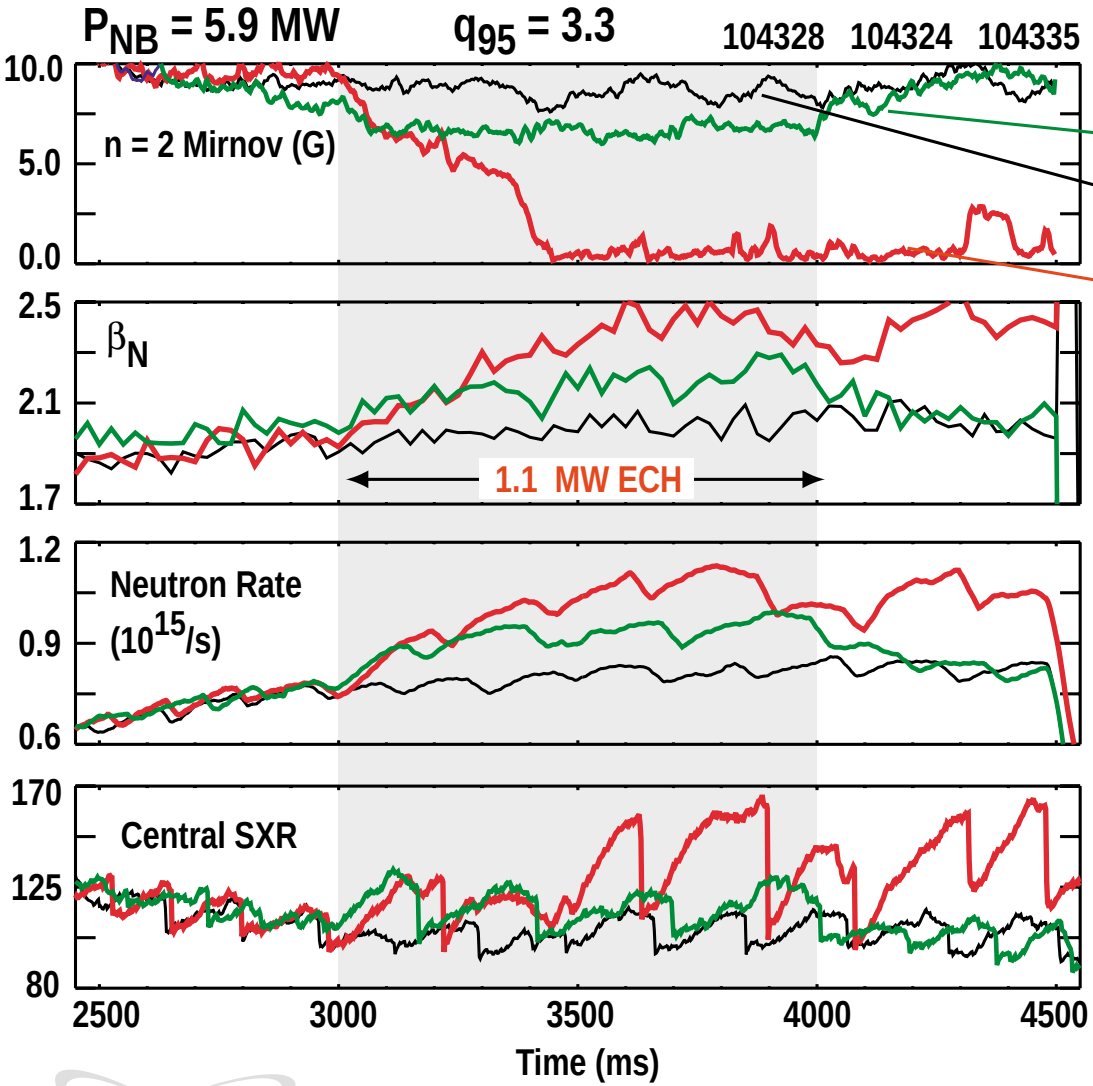
GENERAL ATOMICS

MOTIVATIONS

- **Resistive instabilities known as tearing modes:**
  - Set a soft limit to fusion performance in conventional ELMing H–mode scenarios by degrading confinement
  - Can cause the plasma rotation to stop. Subsequent growth often leads to disruption with significant potential for damage to future devices at high current
- **Stabilization of these modes:**
  - Is critical safety issue for burning plasmas due to the potential for disruptions
  - Has the potential to allow increased fusion performance above present predictions
- **Tearing modes have been detected and stabilized using a closed-loop feedback scheme for the first time in the DIII–D tokamak using electron cyclotron current drive (ECCD)**

COMPLETE STABILIZATION OF A 3/2 TEARING MODE IS OBTAINED WITH MODEST ECH POWER



Resonance 2 cm off optimum

No ECCD

Full Stabilization

- β_N and neutron rate increase during stabilized phase
- Mode does not return despite large sawteeth
- Sharp drop in mode amplitude indicates a threshold condition
- Sawtooth after EC pulse produces a seed slightly too small to trigger the mode

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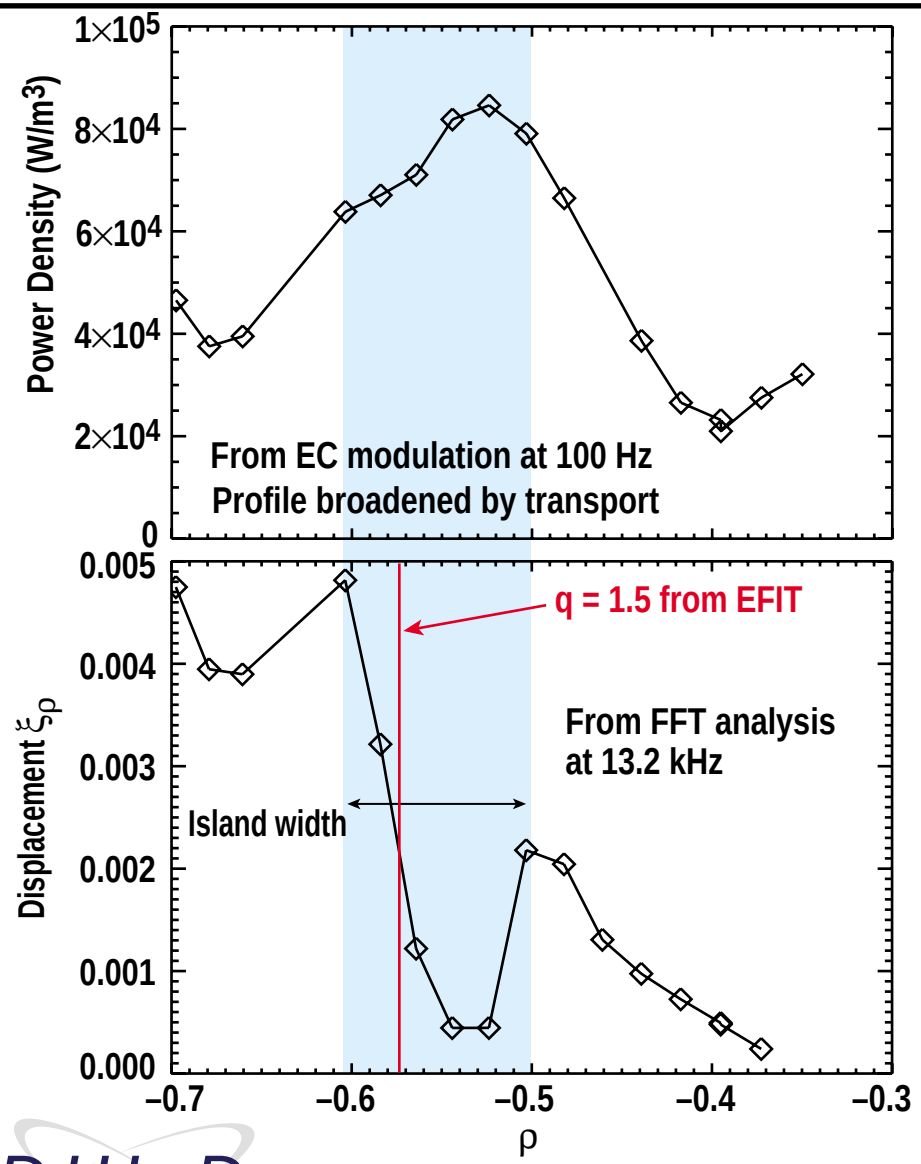
ECH MODULATION VERIFIES THAT EC DEPOSITION IS WITHIN THE ISLAND



- Slow modulation by ECH and fast modulation by island measured by the same ECE system ⇒ no mapping for comparison
- Island width estimates from ECE and magnetics agree (~7 cm before ECH)

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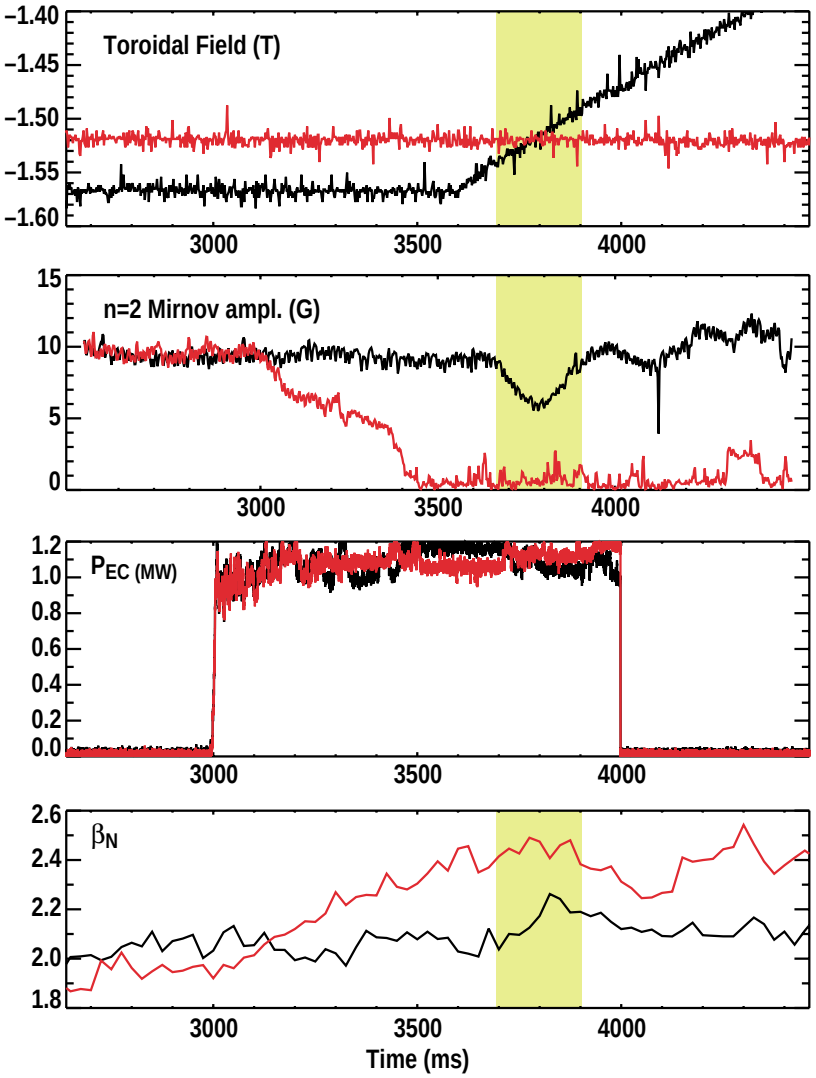
RADIAL EXTENT OF ECCD INFLUENCE ON THE MODE AMPLITUDE IS SMALL AS EXPECTED



- Full width at half maximum of the change of mode amplitude in the B_T ramp case is ~4 cm, which is consistent with estimates of the island width and calculations of the ECCD profile width
- Full suppression at steady B_T is achieved using the B_T value at the minimum mode amplitude point of the B_T ramp
- β_N increases in the B_T ramp case coincident with the mode amplitude drop. This implies the β_N rise in the steady case is due to the mode suppression, not simply additional heating

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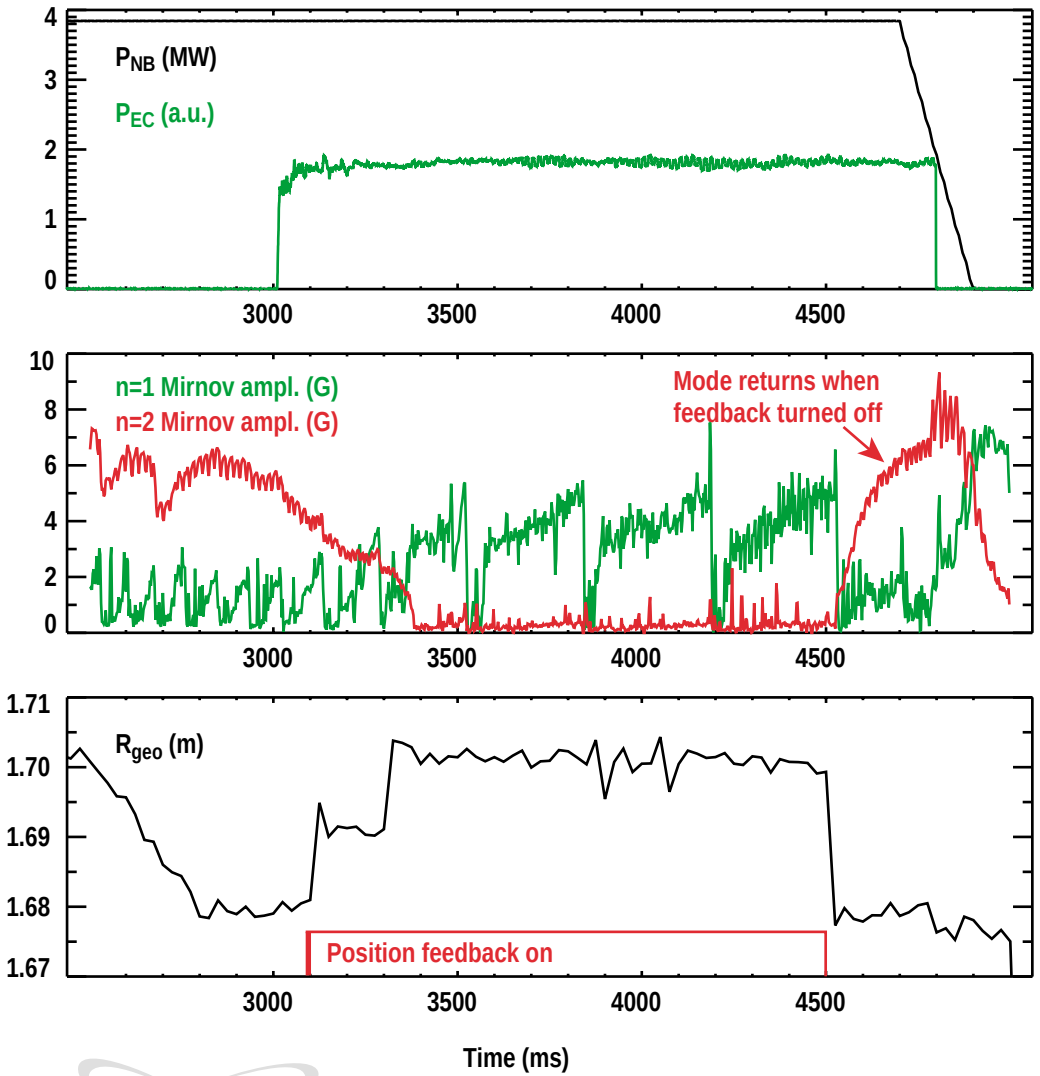
ACTIVE MODE CONTROL WITH CLOSED-LOOP FEEDBACK HAS BEEN SUCCESSFULLY IMPLEMENTED TO OPTIMIZE THE STABILIZATION



- Feedback uses a rigid body radial shift of the plasma to align the ECCD position with the island at the inboard midplane
- The same technique using control of the toroidal magnetic field has also been demonstrated successfully
- Gyrotron turn on/off is not yet available in real time

For more details, see Poster RP1.010 Thursday p.m., D.A. Humphreys

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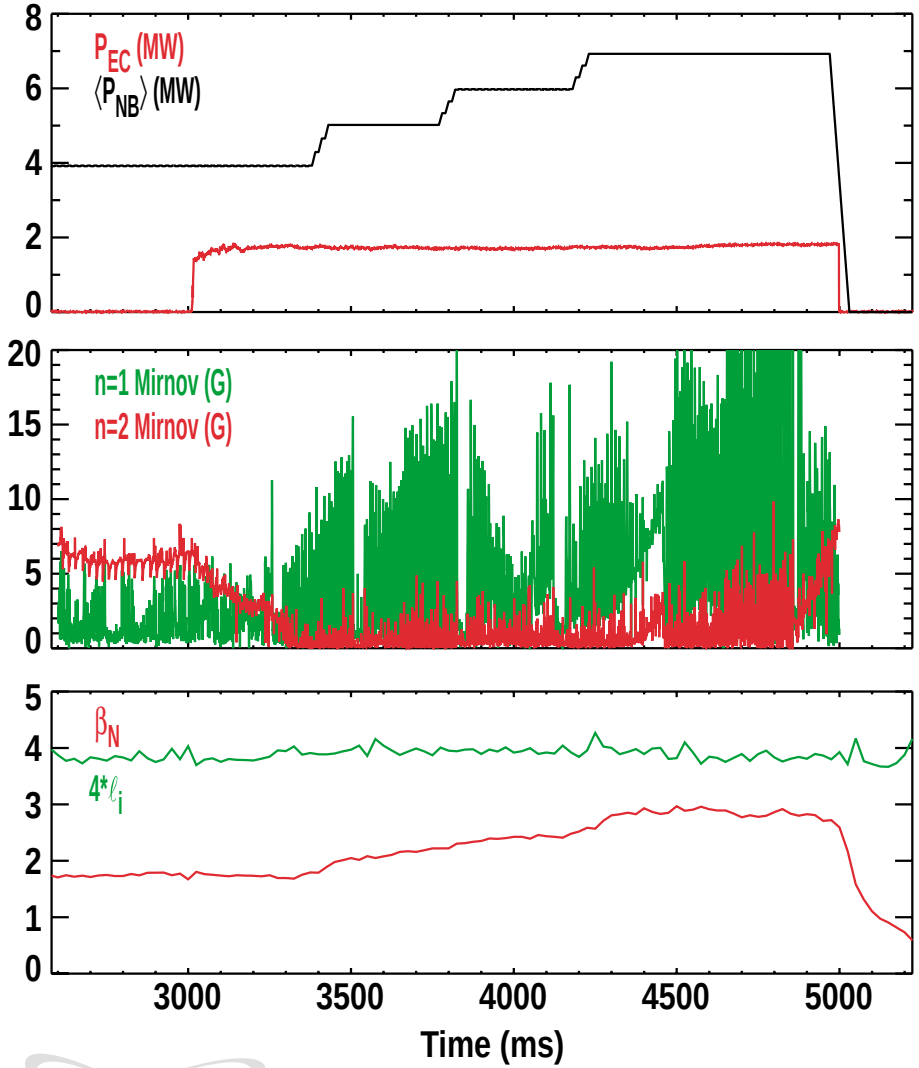
3/2 TEARING MODE STABILIZED BY ECCD REMAINS STABLE DURING 50% INCREASE IN β



- Fishbone and sawtooth amplitudes increase significantly during the stabilized phase
- A 3/2 mode does recur at 4850 ms at a sawtooth crash. This is consistent with a growing mismatch between the ECCD location and the q = 3/2 surface due to increased Shafranov shift and evolution of the current profile
- Real-time tracking of the q = 3/2 surface will be attempted in 2002. The goal will be β at the no-wall β limit, which should be $\beta_N \sim 4$

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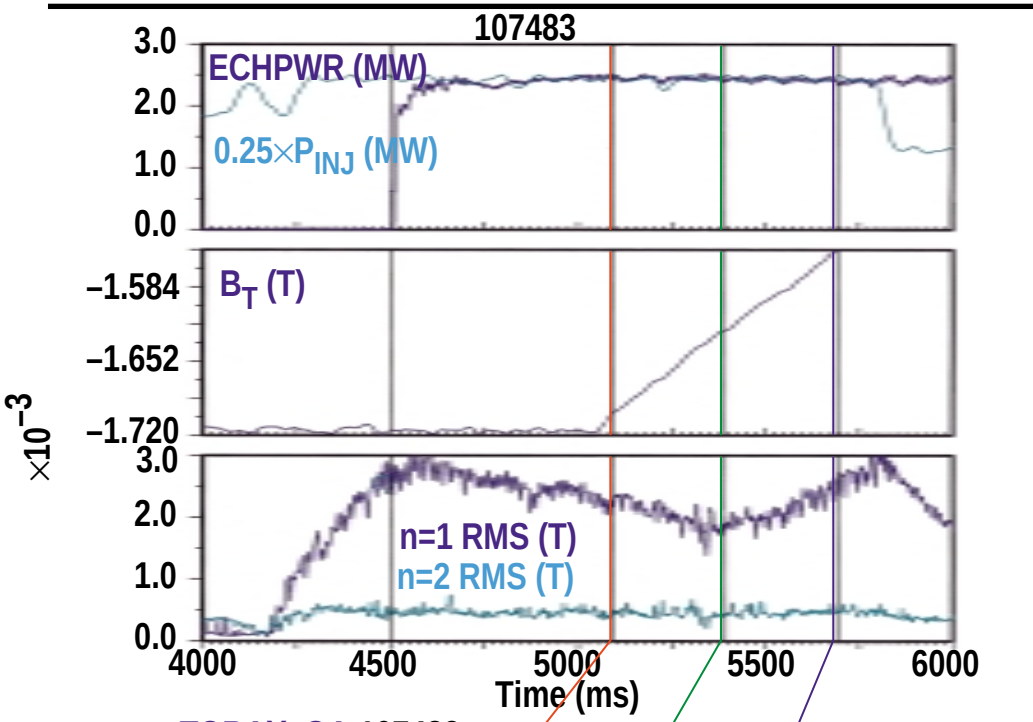
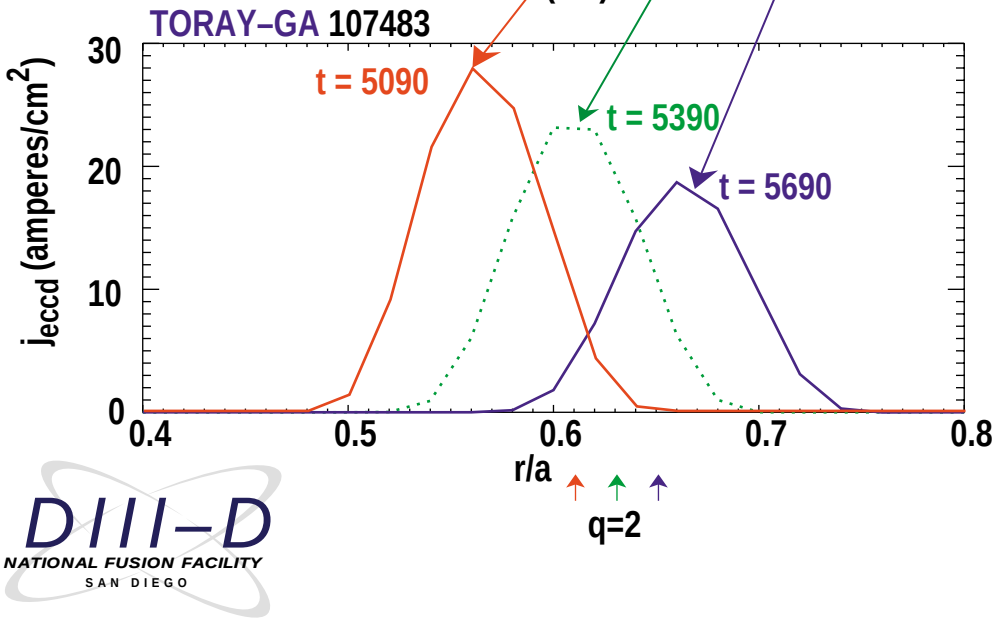
PARTIAL SUPPRESSION OF 2/1 TEARING MODE BY ECCD ACHIEVED





- ECCD is above the inboard midplane, so localization and efficiency are lower
- Mode onset is at β_N ~ 3.5
- Will have more power in 2002

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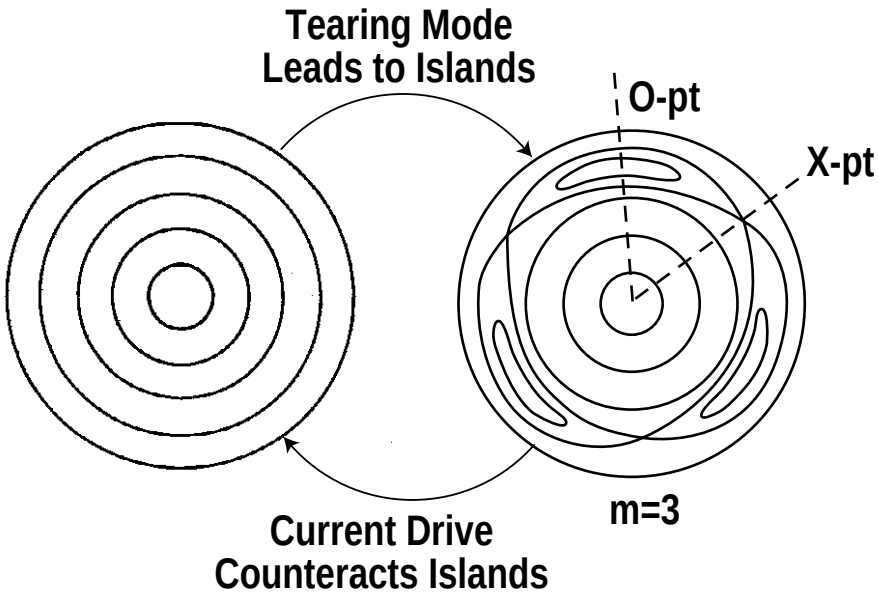
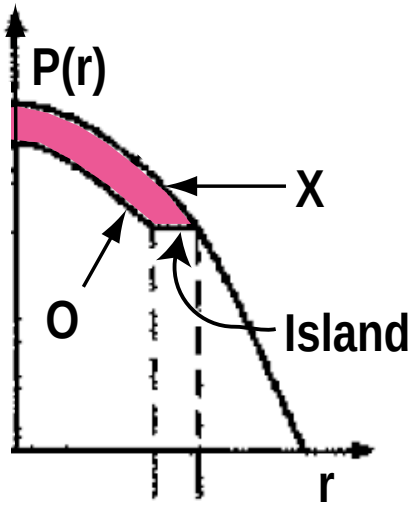
CONCEPTUAL PICTURE OF TEARING MODE STABILIZATION BY CURRENT DRIVE





- For classical tearing modes, it is energetically favorable for the current on a rational surface to clump, with current perturbations in the direction opposite to the total current
- An additional destabilizing term occurs if the pressure is flattened in the island O point, leading to a local deficit in the bootstrap current
- Stabilization by current drive is achieved by replacing the "missing" current by a non-inductive source

SUMMARY

- Complete suppression of 3/2 tearing modes achieved by ECCD in the presence of sawteeth
- ECCD must be localized and coincident with the island for suppression
- Closed-loop feedback has been implemented to optimize the relative location of the ECCD and the island
- β has been increased >50% during suppression
- Partial stabilization of the 2/1 tearing mode has been obtained