Fusion Reactor Technology I
(459.760, 3 Credits)

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Contents

Contents

Non-linear Plasma Activity

- **Fishbone Instability**

Study of High-Beta Magnetohyd

K. McGuire, R. Goldston, M. Bell, M. Bitte
F. Dylla, H. Eubank, H. Fishman, R. Fonc

- Oscillation frequency (usually not high, ~ 10^4 Hz) in each burst decreases almost two-fold from the beginning of a burst to its end.
- The oscillations grow rather fast, then decay somewhat more slowly and plasma is stabilized until the next burst.

"fishbone instability" from its cha

PACS numbers: 52.55.Gb, 52.35.]

On the PDX tokamak, large-amplitude ma
hydrodynamic (MHD) fluctuations have been
served during plasma heating by injection o

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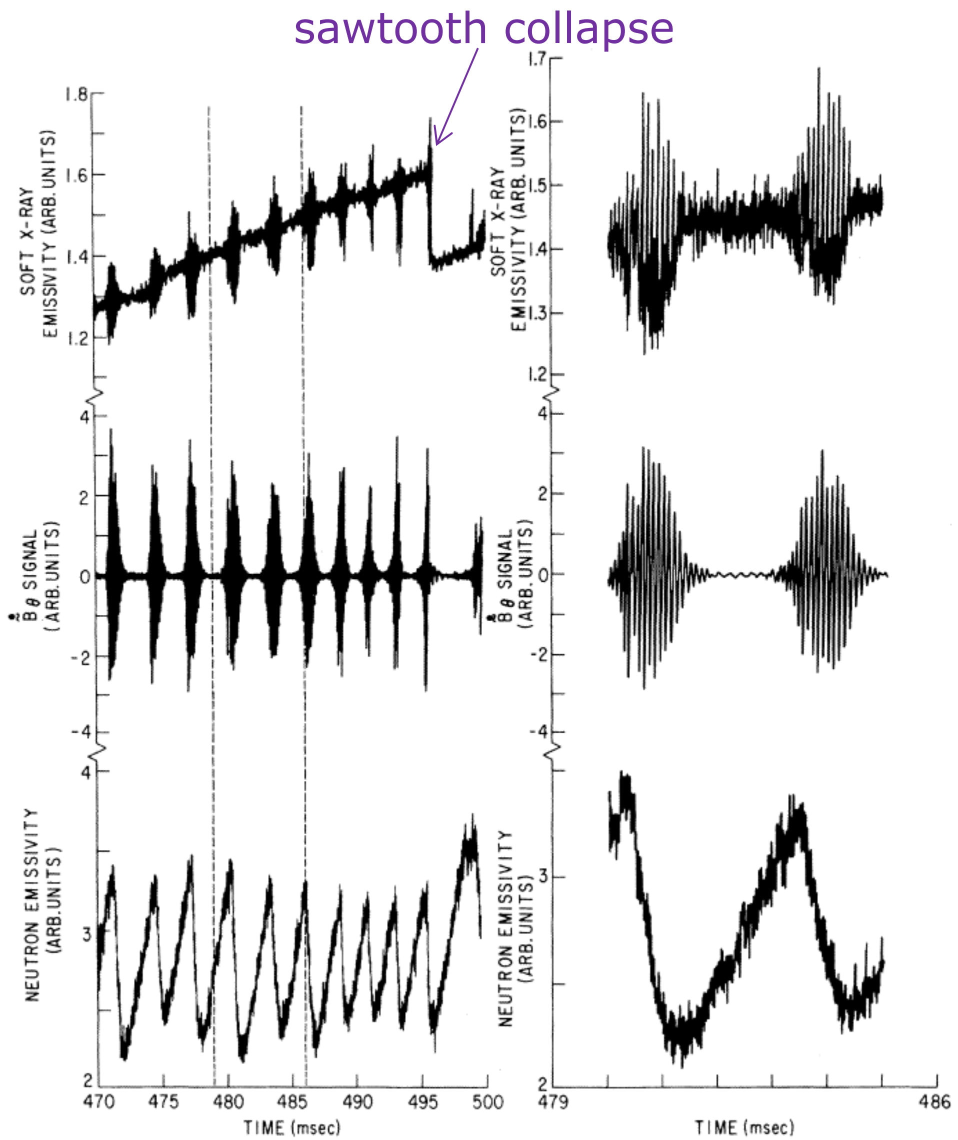


Non-linear Plasma Activity

- **Fishbone Instability**

- Occurring under certain conditions when a high energy neutral beam is injected to heat the plasma.
- Driven by $\partial f/\partial r$, the radial gradient in the fast particle distribution function: kinetic excitation of the internal helical mode by fast ions
- Due to an interaction between the injected particle and an $m = 1$, $n = 1$ MHD perturbation.

  Interaction of the resonance type characterized by Landau damping, but here causing growth

  Resonance between the toroidal wave velocity of the instability and the toroidal drift experienced by trapped energetic particles from the injected beam

  Cf. Fishbones would not occur for injection parallel to **B**.
- Oscillations dropping when the energy of resonant particles is exhausted until the next spike of fishbone activity.

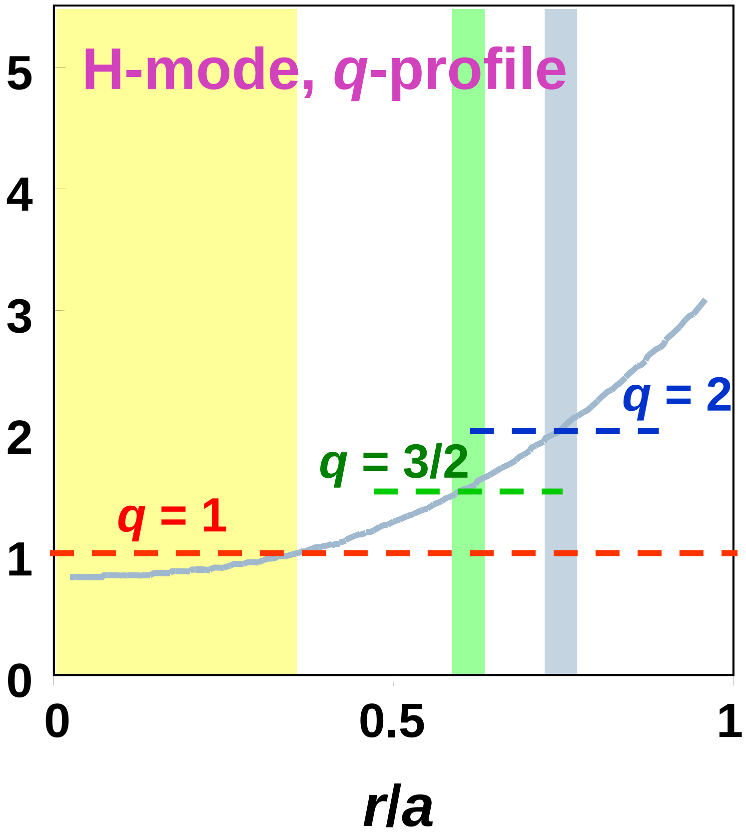
Non-linear Plasma Activity

- **Fishbone Instability**

- Leading to intensive loss of fast ions trapped in plasma
  → worsens the efficiency of additional heating
- Dangerous in fusion reactors:
  helical-mode destabilization may be excited by α-particle produced in the D-T reaction.

H–modes: Limitations

Stability of H-mode plasmas related safety factor profile: $q(r)$



$q_0 < 1$: Sawtooth instability, periodic flattening of the pressure in the core

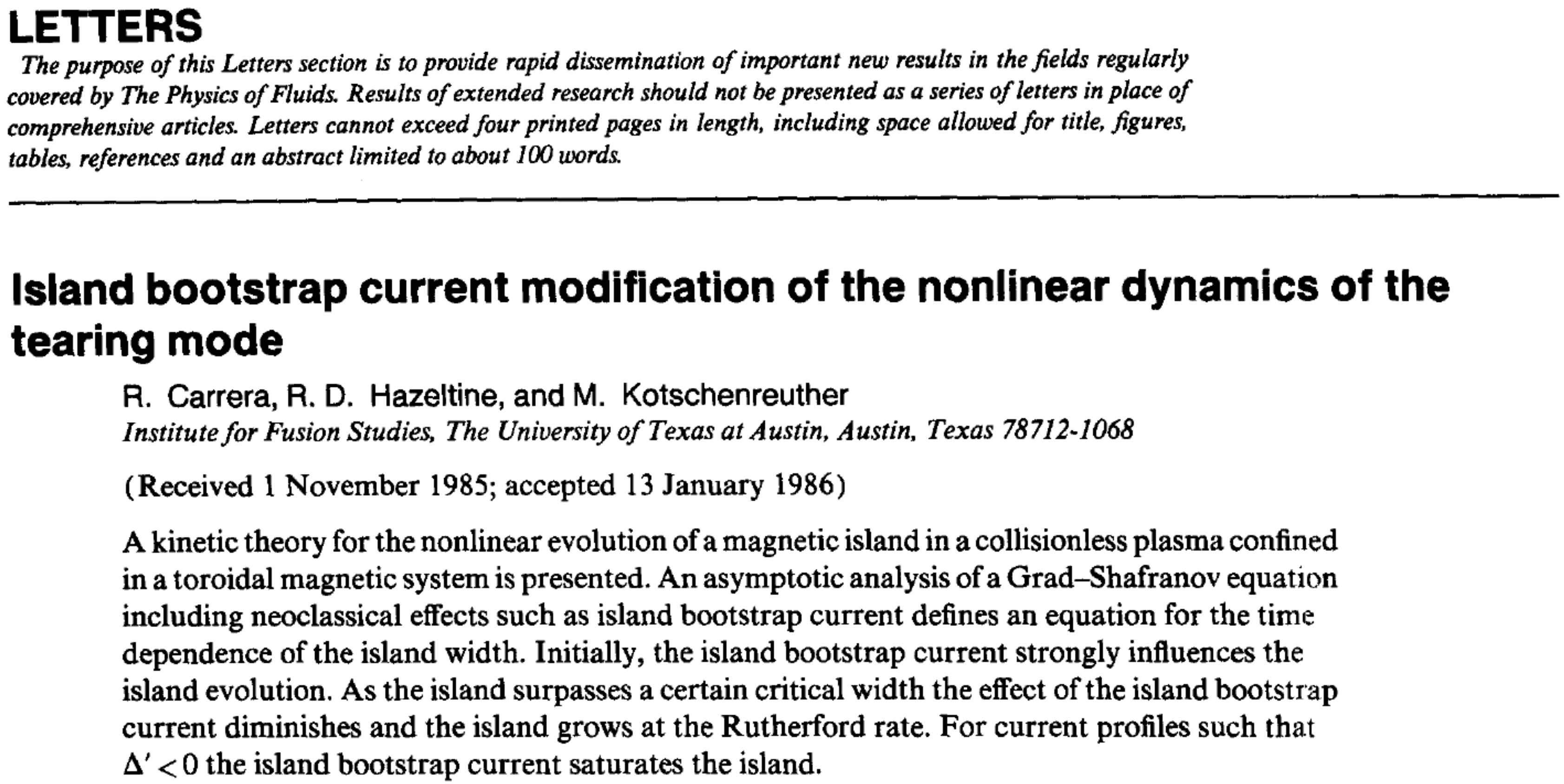
$q = 3/2$ and $q = 2$:

Neoclassical Tearing Modes (NTMs):

- limit the achievable $\beta \equiv 2\mu_0 p/B^2$
- degrade confinement (+ disruptions)
- often triggered by sawteeth.

- ITER work point is chosen conservatively: $\beta_N \leq 1.8$!

Neoclassical Tearing Mode (NTM)



LETTERS

The purpose of this Letters section is to provide rapid dissemination of important new results in the fields regularly covered by The Physics of Fluids. Results of extended research should not be presented as a series of letters in place of comprehensive articles. Letters cannot exceed four printed pages in length, including space allowed for title, figures, tables, references and an abstract limited to about 100 words.

Island bootstrap current modification of the nonlinear dynamics of the tearing mode

R. Carrera, R. D. Hazeltine, and M. Kotschenreuther
Institute for Fusion Studies, The University of Texas at Austin, Austin, Texas 78712-1068

(Received 1 November 1985; accepted 13 January 1986)

A kinetic theory for the nonlinear evolution of a magnetic island in a collisionless plasma confined in a toroidal magnetic system is presented. An asymptotic analysis of a Grad–Shafranov equation including neoclassical effects such as island bootstrap current defines an equation for the time dependence of the island width. Initially, the island bootstrap current strongly influences the island evolution. As the island surpasses a certain critical width the effect of the island bootstrap current diminishes and the island grows at the Rutherford rate. For current profiles such that $\Delta' < 0$ the island bootstrap current saturates the island.

R. Carrera et al, Physics of Fluids ***29*** *899 (1986)*

- One of the earliest theoretical paper

Neoclassical Tearing Mode (NTM)

VOLUME 74, NUMBER 23 PHYSICAL REVIEW LETTERS 5 JUNE 1995

Observation of N … **Modes in TFTR**

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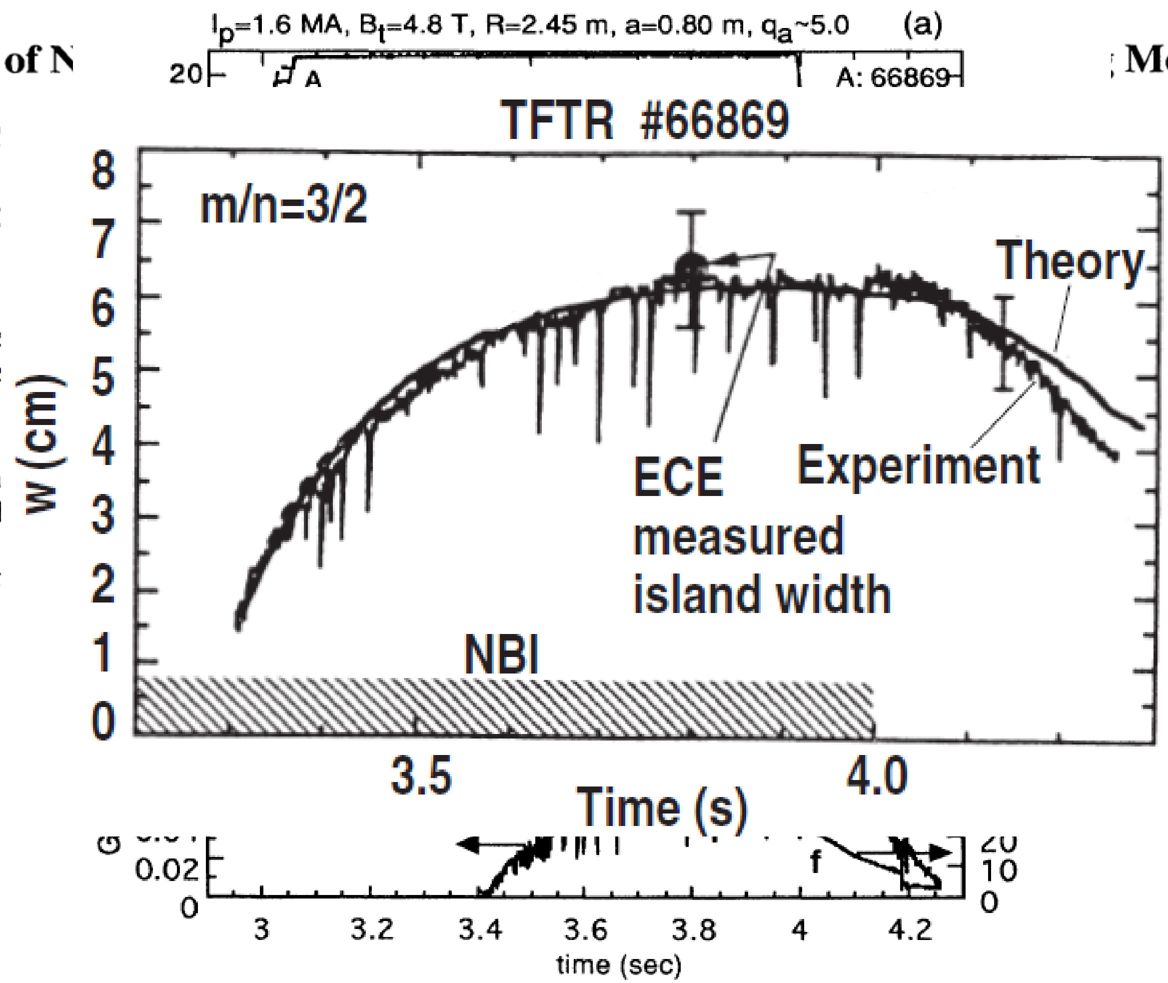
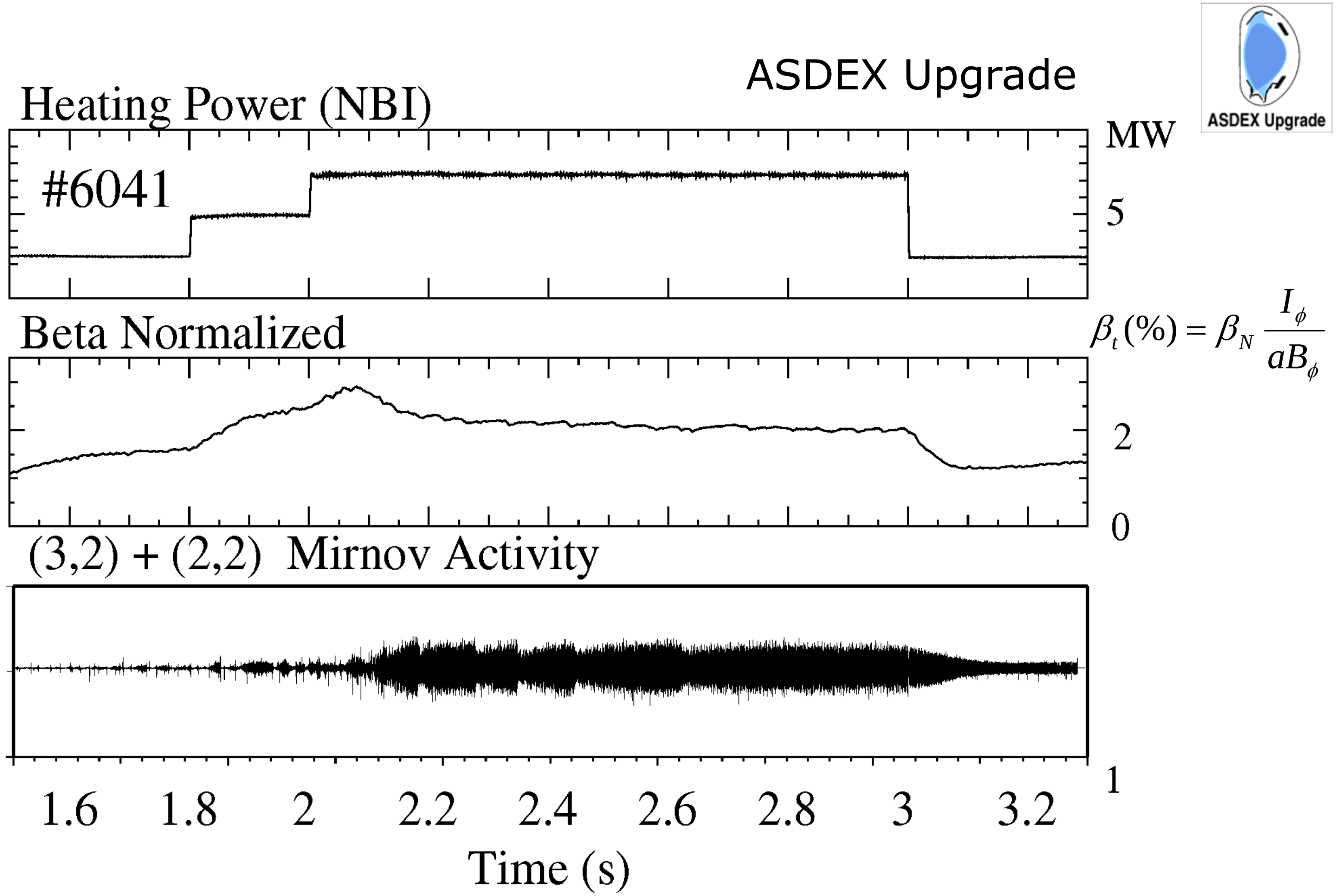
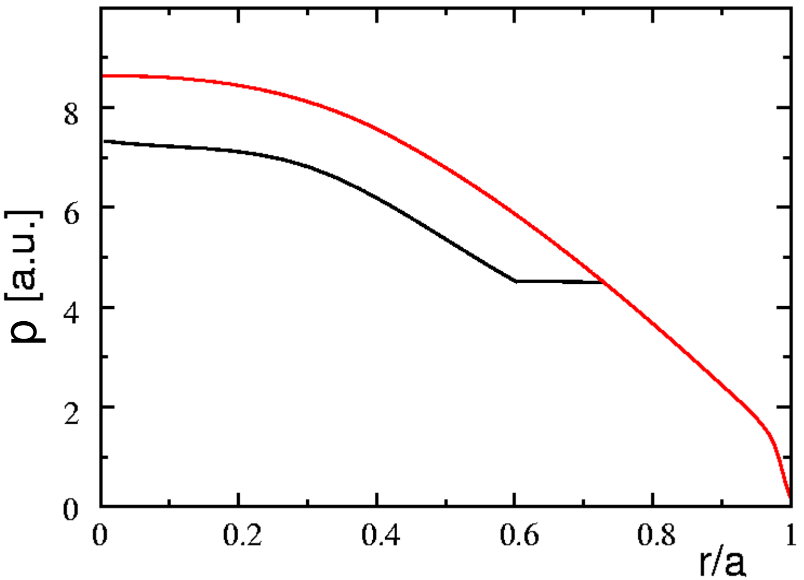


Neoclassical Tearing Mode (NTM)



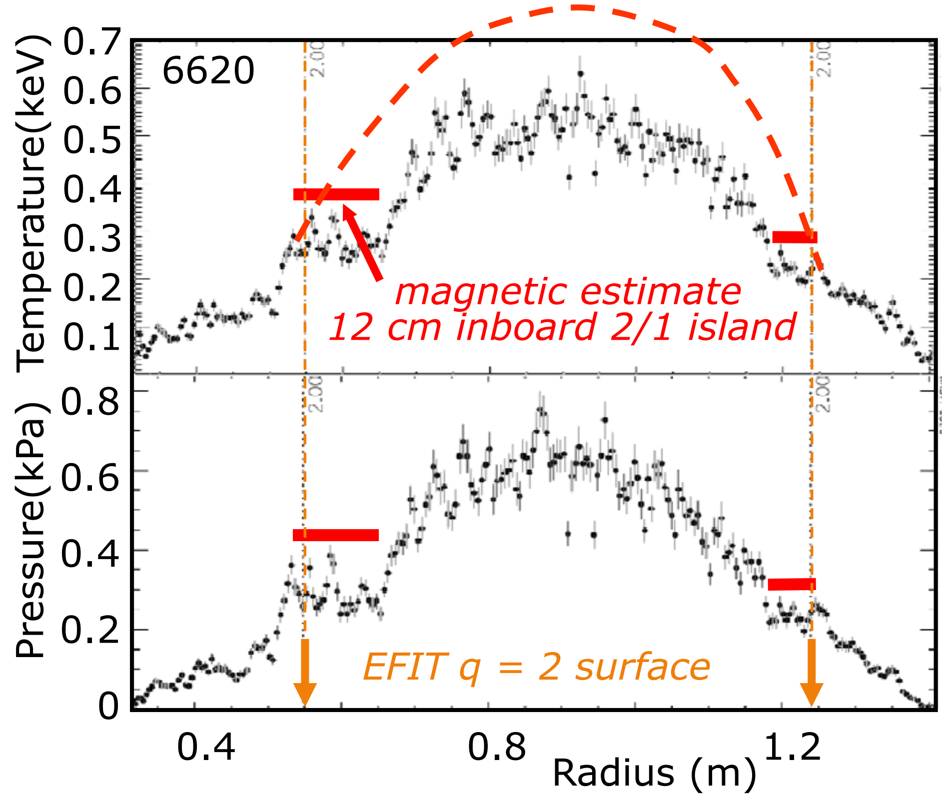
$$\beta_t(\%) = \beta_N \frac{I_\phi}{aB_\phi}$$

Neoclassical Tearing Mode (NTM)



- Pressure flattening across magnetic islands due to large transport coefficients along magnetic field lines

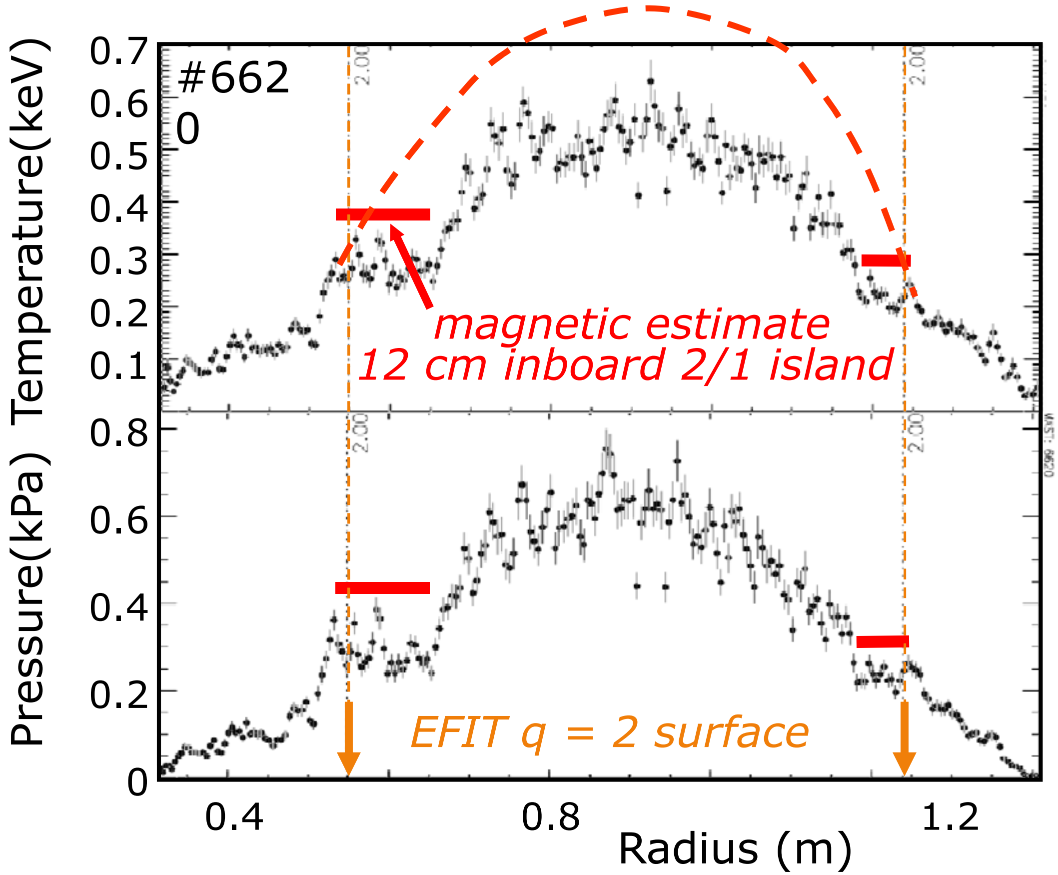
Neoclassical Tearing Mode (NTM)



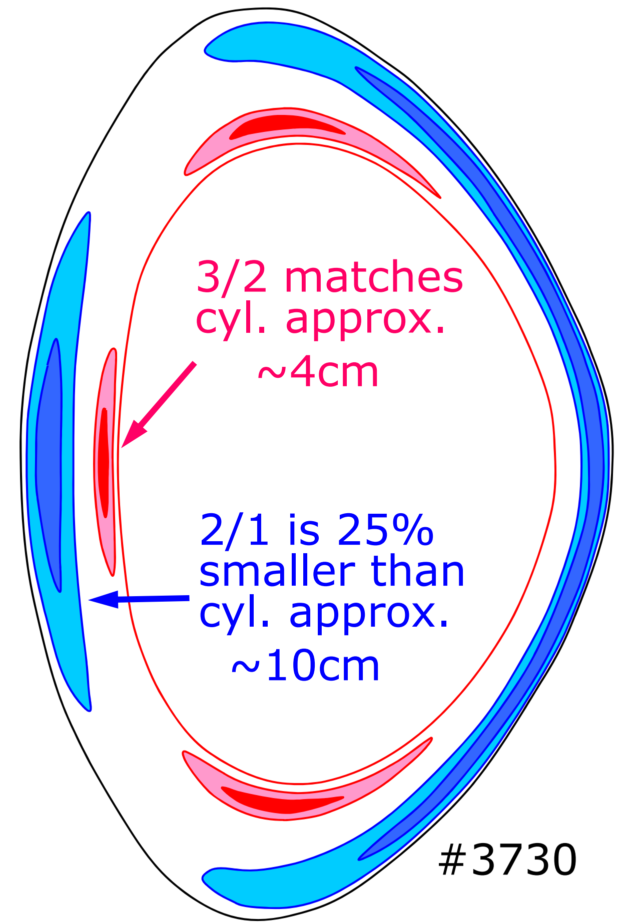
- Pressure flattening across magnetic islands due to large transport coefficients along magnetic field lines

Neoclassical Tearing Mode (NTM)

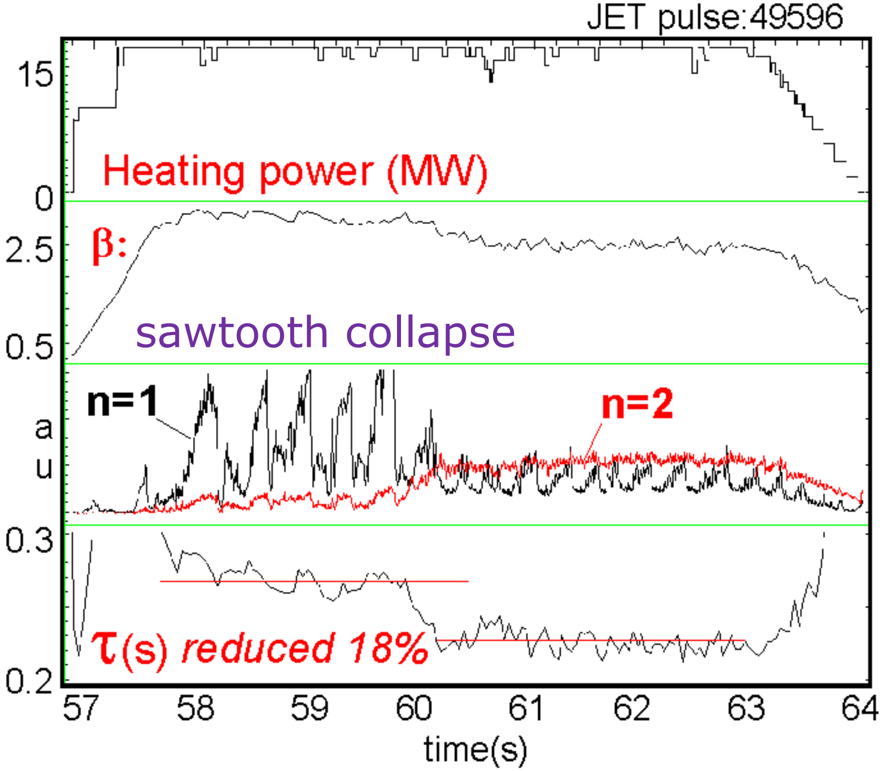
Pressure flattening due to island



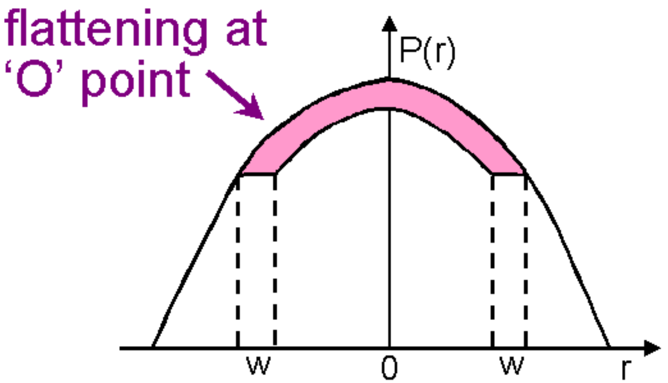
MAST (300 point Thomson scattering)



Neoclassical Tearing Mode (NTM)



- 3,2 NTM reduces β
- confinement reduced ~15-20%
- explained by 'Belt model':

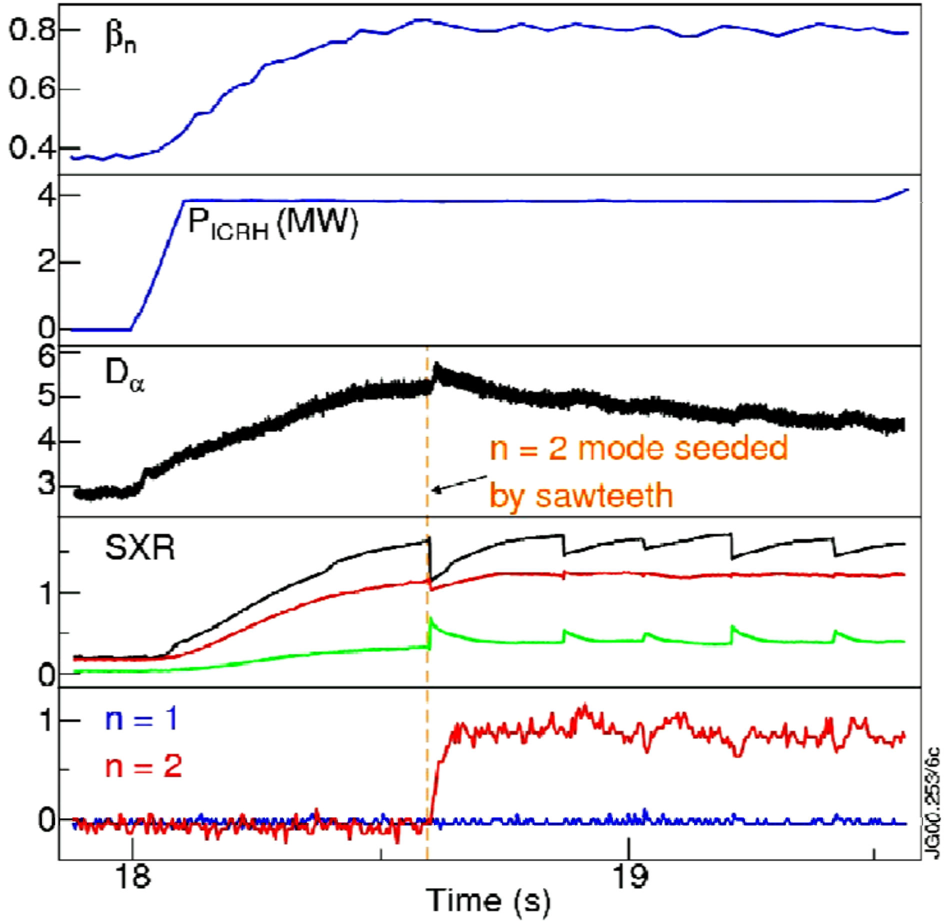


[Chang and Callen 1990]

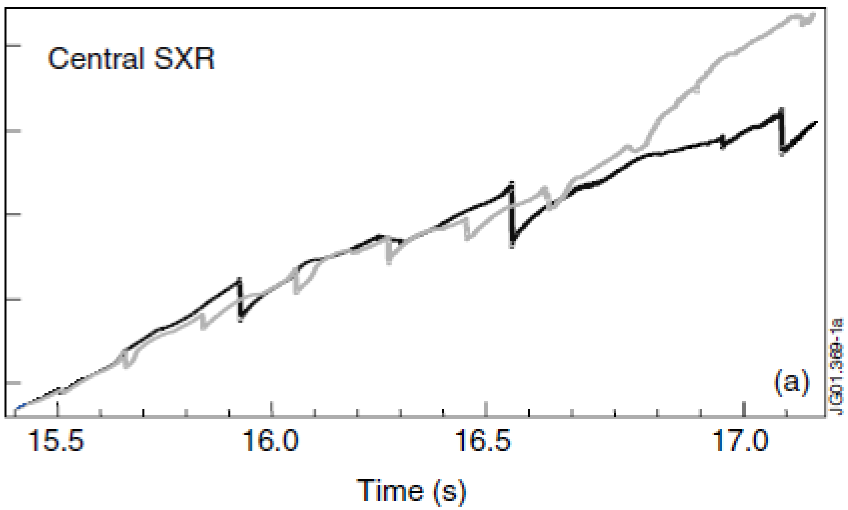
R. Buttery et al, Plasma Physics and Controlled Fusion (2000)

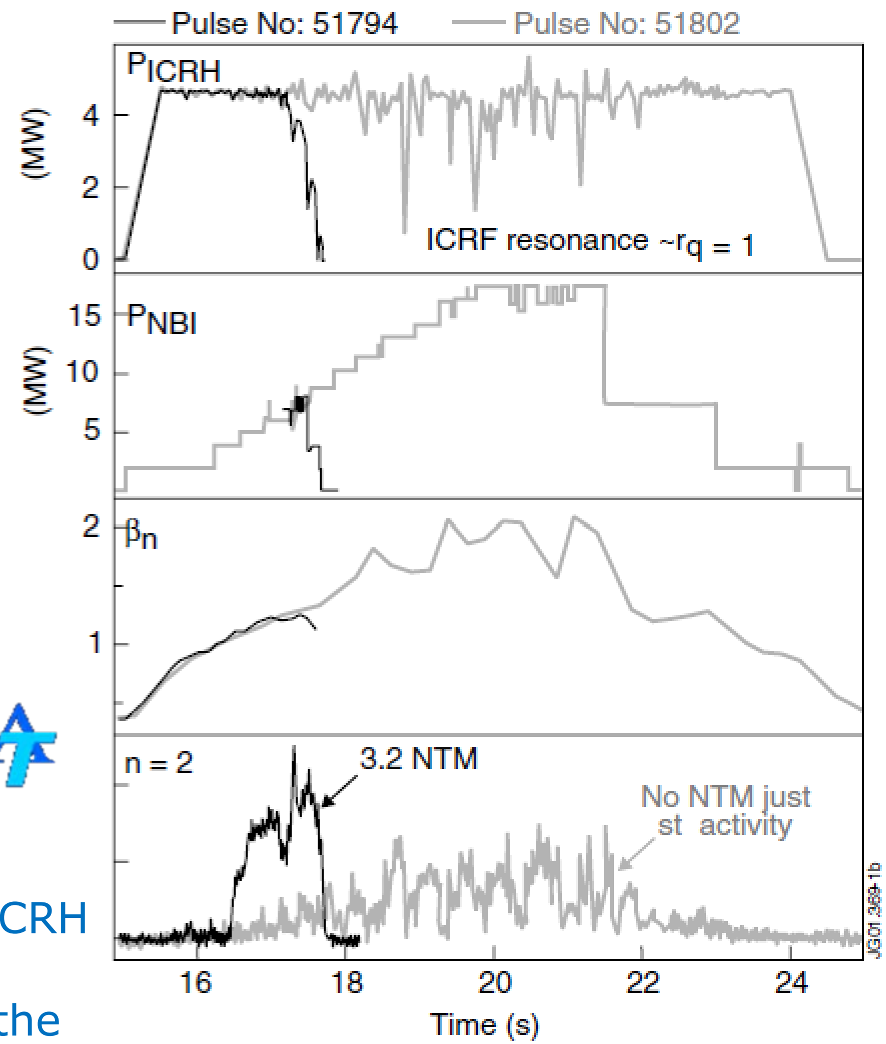
Neoclassical Tearing Mode (NTM)

JET



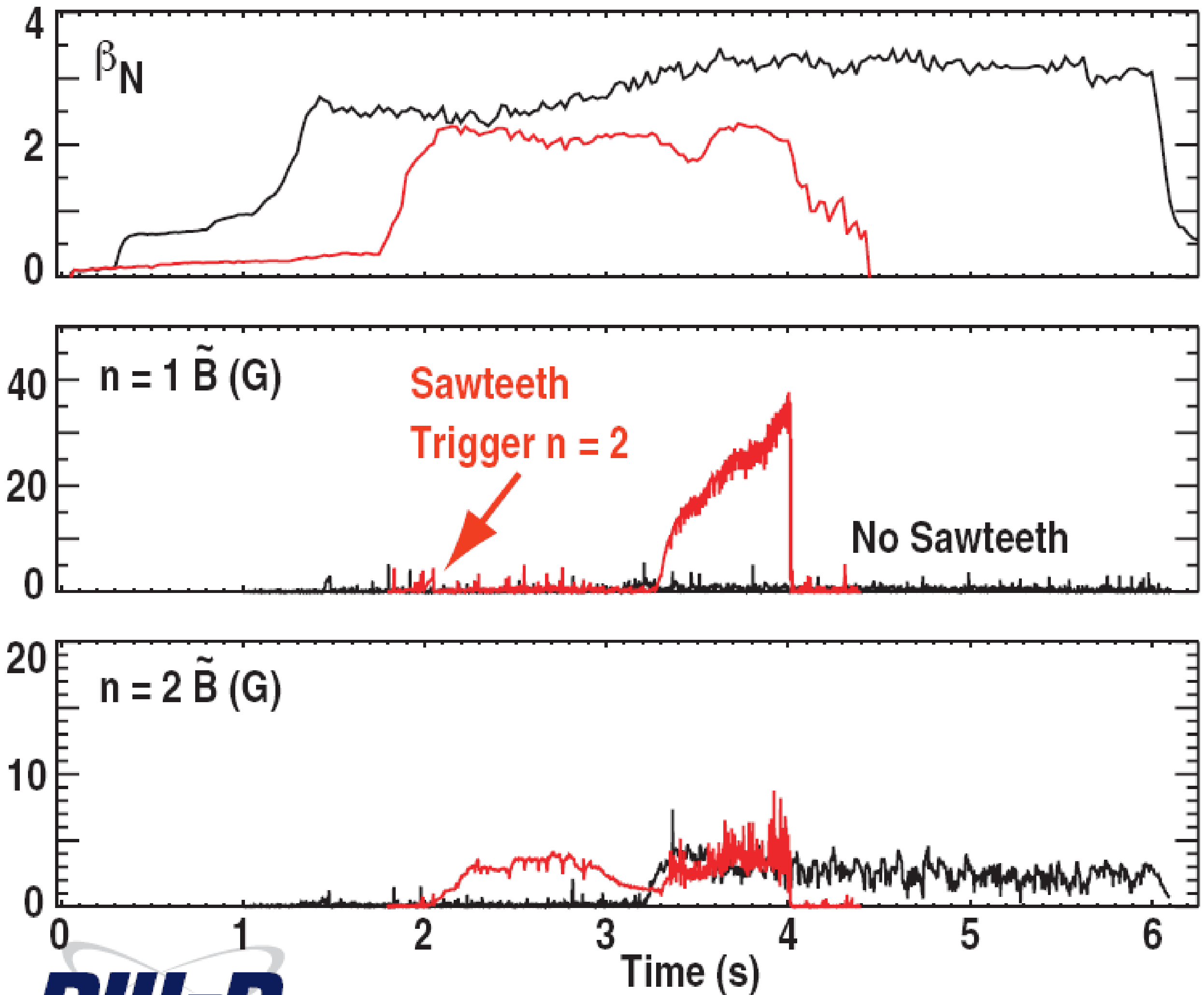
Neoclassical Tearing Mode (NTM)





- Increased sawtooth period due to stabilisation by fast ions produced by ICRH leads to the triggering of n = 2 NTM activity which causes a termination of the discharge.

Neoclassical Tearing Mode (NTM)



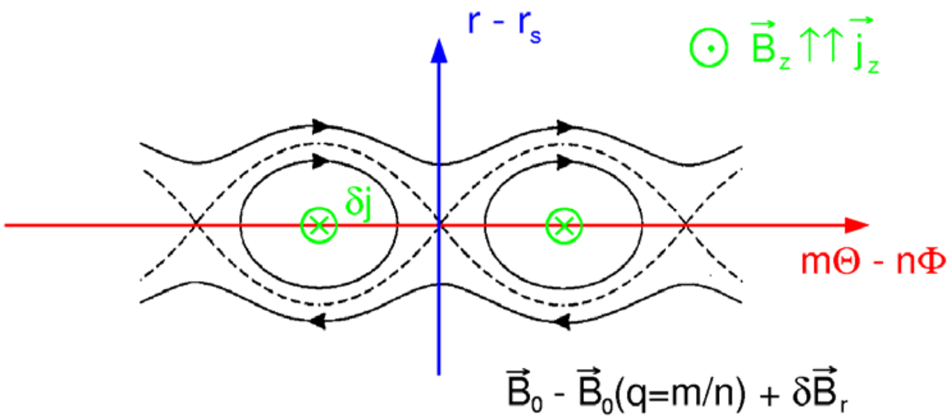
DIII-D
NATIONAL FUSION FACILITY
SAN DIEGO

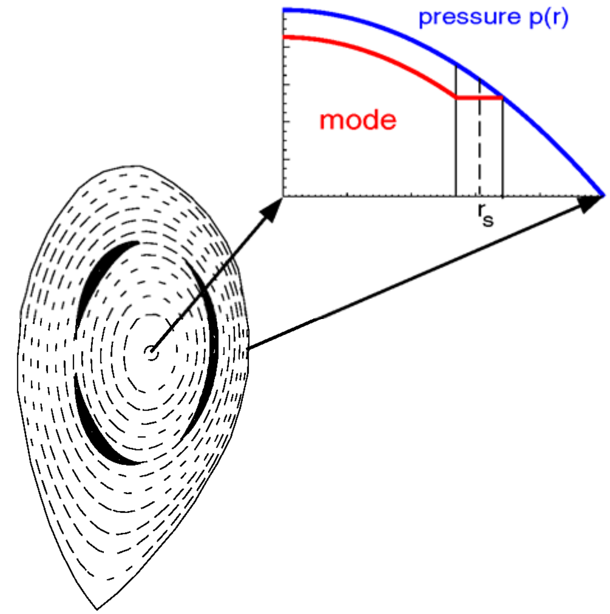
Neoclassical Tearing Mode (NTM)

- At high β_p, pressure gradient drives plasma current by thermo-electric effects (Bootstrap current):

$$j_{BS} \propto \nabla p$$

- Inside islands ∇p and thus j_{BS} vanish





- Loss of BS current inside magnetic islands (helical hole) acts as helical perturbation current driving the islands – so once seeded, island is sustained by lack of bootstrap current

Neoclassical Tearing Mode (NTM)

- **The Modified Rutherford Equation (MRE)**

$$\frac{\tau_R}{r_s}\frac{d\omega}{dt} = \Delta_0' r_s + \delta\Delta' r_s + a_2 \frac{j_{bs}}{j_{\|}}\frac{L_q}{\omega}\left[1 - \frac{\omega_{marg}^2}{3\omega^2} - K_1 \frac{j_{ec}}{j_{bs}}\right]$$

1st : Conventional tearing mode stability: assumed as $\Delta_0' r_s \approx -m$ for *m/n* NTM

2nd: Tearing mode stab. enhancement by ECCD: Westerhof's model with no-island assumption

$\delta\Delta' r_s \approx -\frac{5\pi^{3/2}}{32} a_2 \frac{L_q}{\delta_{ec}} F(e) \frac{j_{ec}}{j_{\|}} \tau$, where the misalignment function $F(e) = 1 - 2.43e + 1.40e^2 - 0.23e^3$

3rd: Destabilization from perturbed bootstrap current:

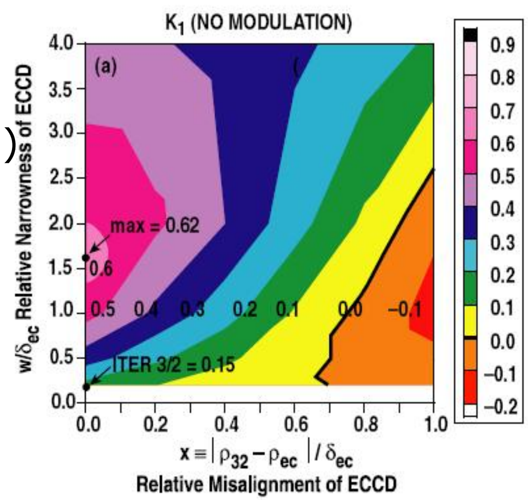
a_2 fitted by inferred size of saturated NTM island (e.g. ISLAND)

4th: Stabilization from small island & polarization threshold:

$w_{marg} \approx 2\varepsilon^{1/2}\rho_{\theta i}$ (= twice ion banana width)

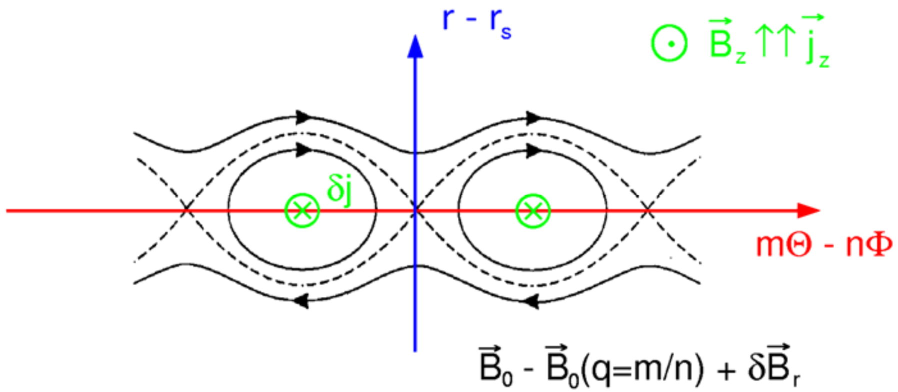
5th: Stabilization from replacing bootstrap current by ECCD:

K_1 calculated from improved Perkins' current drive model

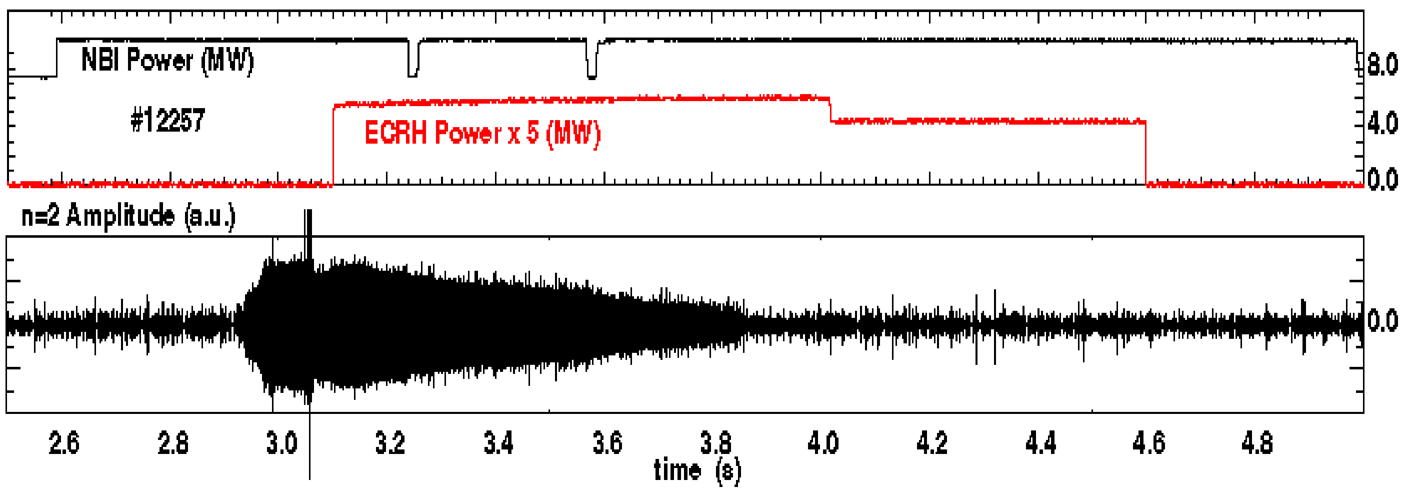


*R. J. La Haye et al, Nuclear Fusion **46** 451 (2006)*

Neoclassical Tearing Mode (NTM)



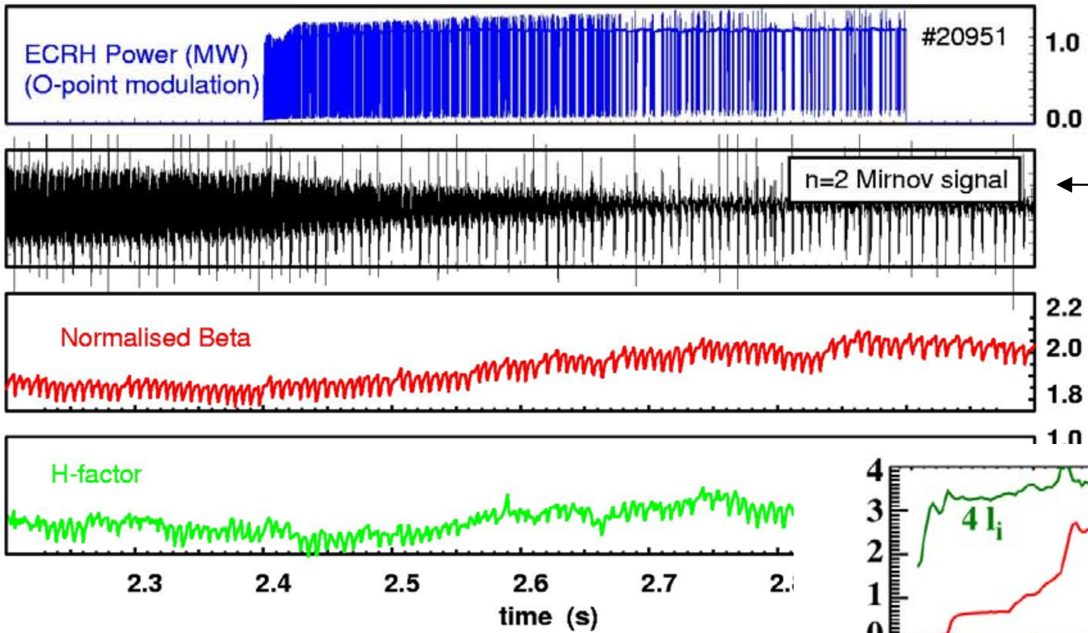
- Missing bootstrap current inside island can be replaced by localised external current drive.



- Complete stabilisation by searching the position of the magnetic island by scanning magnetic field in quantitative agreement with theory!

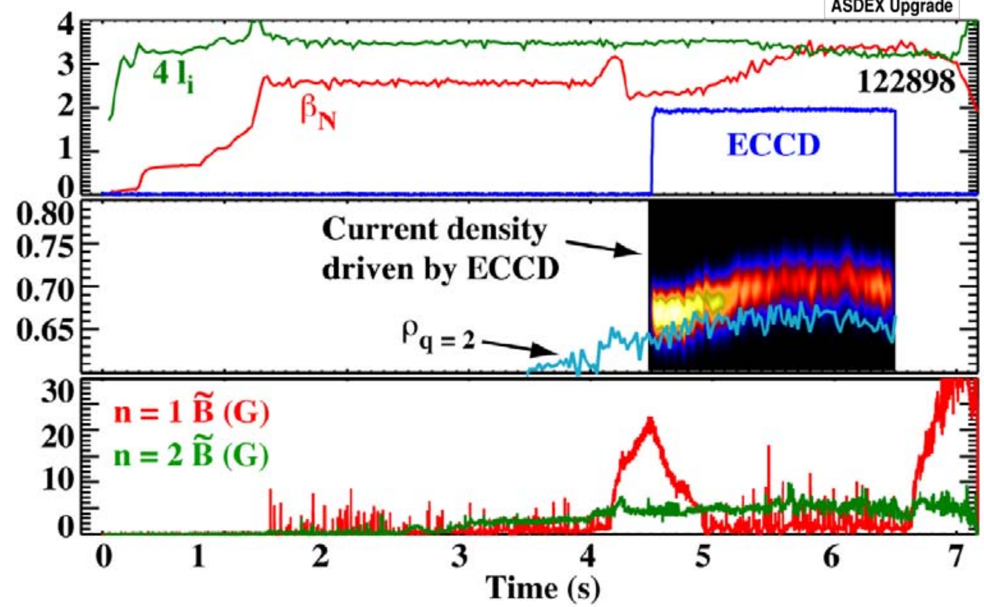
*1st Paper: G. Gantenbein et al, PRL **85** 1242 (2000)*

NTM Stabilisation by ECCD



NTM stabilisation with ITER relevant broad deposition in ASDEX Upgrade

ASDEX Upgrade

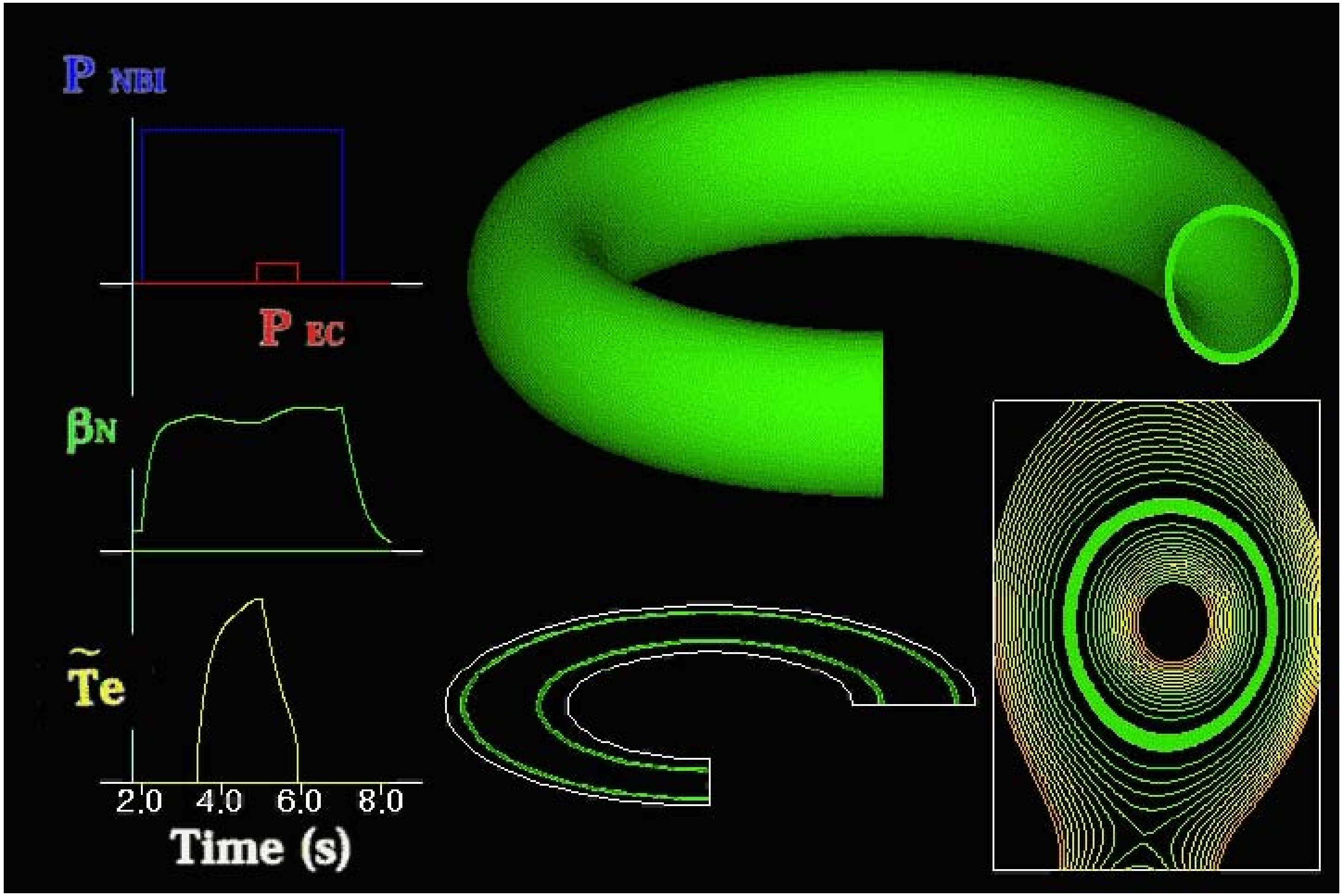


Feedback controlled Deposition in DIII-D

- Demonstration of individual elements as well as integrated feedback

NTM Stabilisation by ECCD

- JT-60U



NTM Stabilisation by ECCD

Courtesy from R. J. La Haye, APS (2005)