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Resistive Wall Mode Stabilization Physics in NSTX

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Long-Wavelength MHD Stability at High Pressure Required for ITER and Other Next-Step Devices

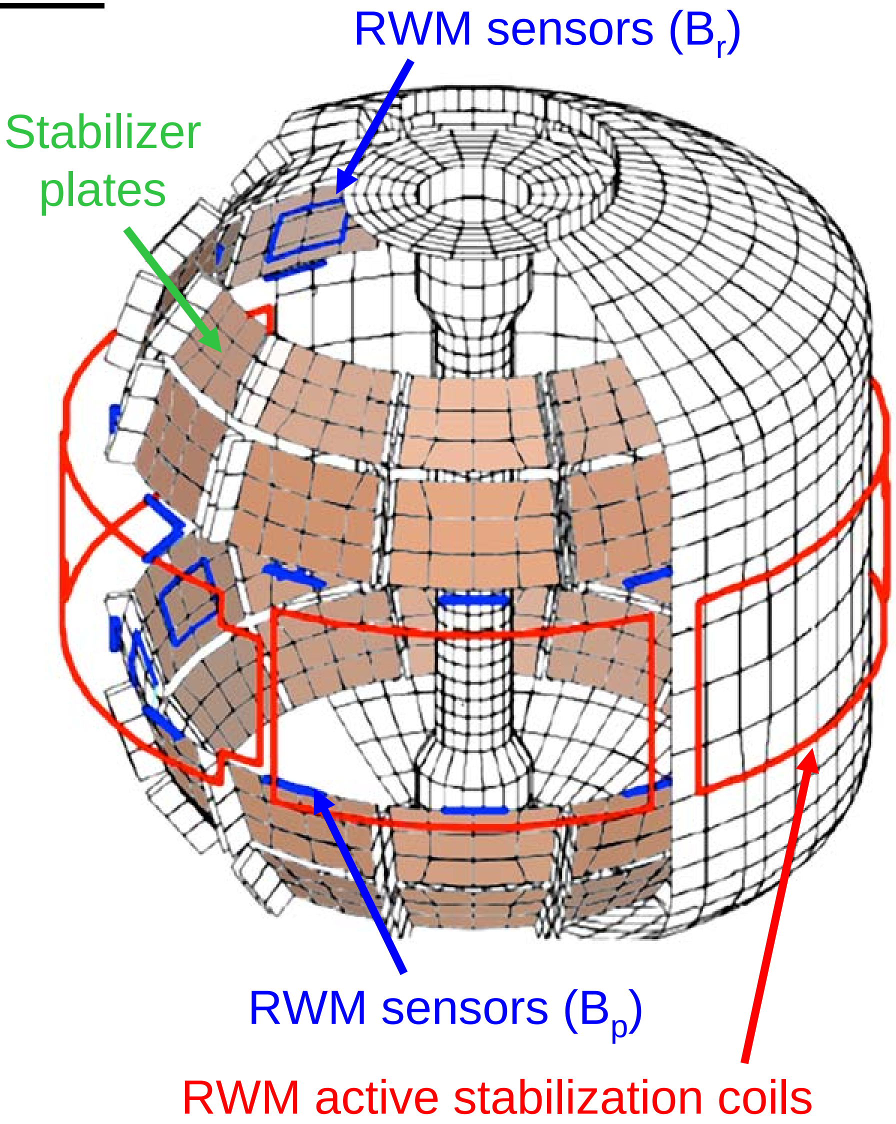
- ❑ Motivation
  - ❑ resistive wall mode (RWM) can cause plasma disruption at high β
  - ❑ RWM can be stabilized passively and/or actively
  - ❑ low rotation (ω_ϕ) in future devices increases susceptibility to RWMs

Understanding the passive stabilization physics that determines RWM stability is important to determine requirements for RWM active stabilization

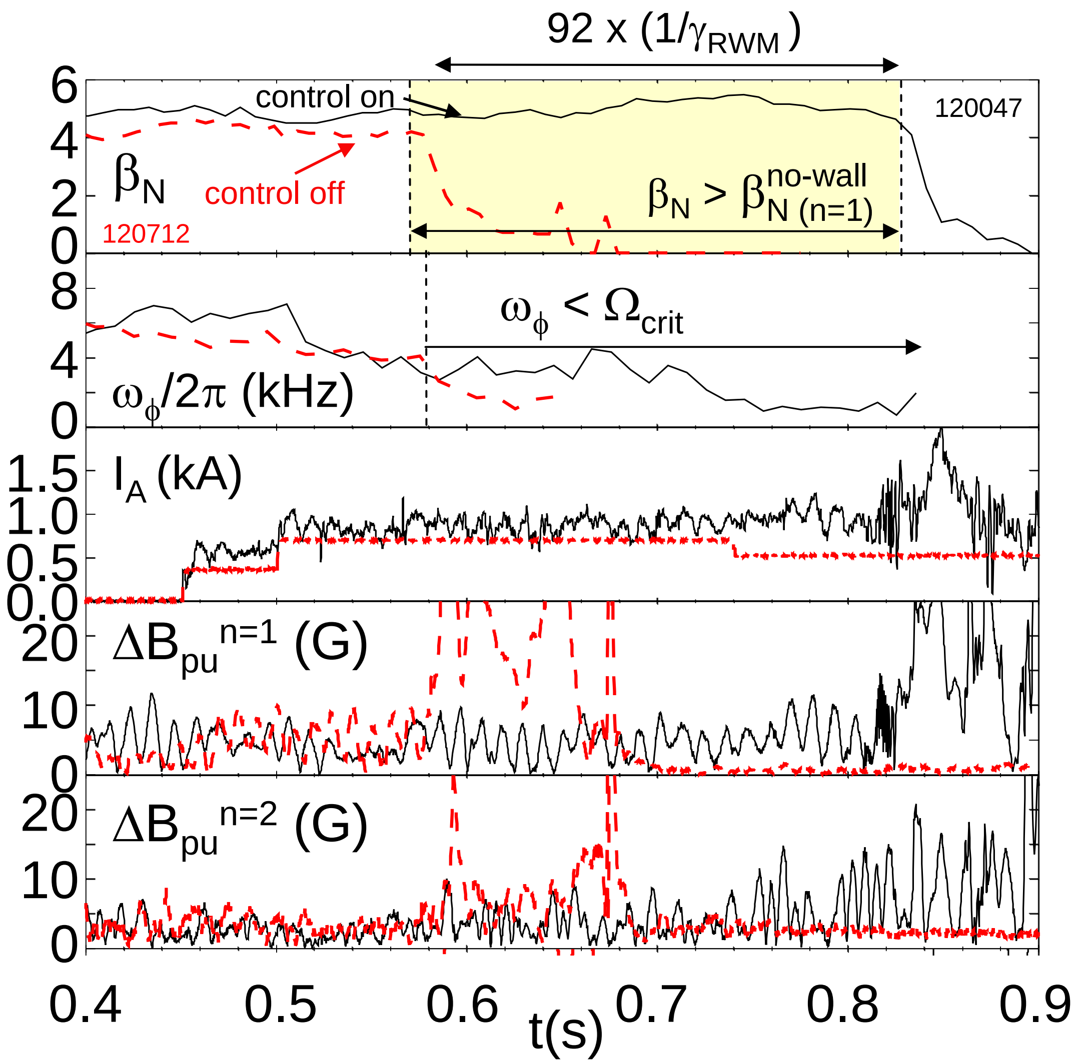
- ❑ NSTX is examining passive stabilization physics by applying n = 1 - 3 fields in order to study:
  - ❑ ω_ϕ at rational surface vs. ω_ϕ profile for stability determination
  - ❑ critical ω_ϕ for passive stability (Ω_{crit})
  - ❑ Ω_{crit} correlation with energy dissipation physics models

Non-axisymmetric coil enables key physics studies on NSTX

- RWM active stabilization
  - Midplane control coil similar to ITER port plug designs
- Plasma rotation control
  - A tool to slow ω_ϕ by resonant or non-resonant fields
- RWM passive stabilization
  - Plasma rotation profile, ion collisionality, ν_{ii}, important for stability
  - Non-resonant ω_ϕ braking preserves stability boundary



RWM actively stabilized at low, ITER-relevant rotation



- First such demonstration in low-A tokamak
  - Long duration > $90/\gamma_{RWM}$
  - Exceeds DCON $\beta_N^{no\text{-}wall}$ for *n* = 1 and *n* = 2
  - *n* = 2 RWM amplitude increases, remains stable while *n* = 1 stabilized
- *n* = 3 magnetic braking to reduce ω_ϕ
  - Non-resonant braking to accurately determine Ω_{crit}

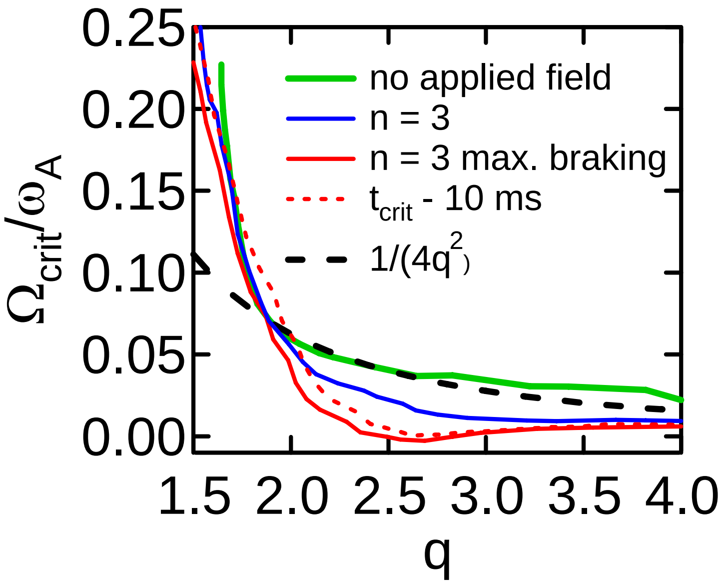
Sabbagh, et al., PRL **97** (2006) 045004.

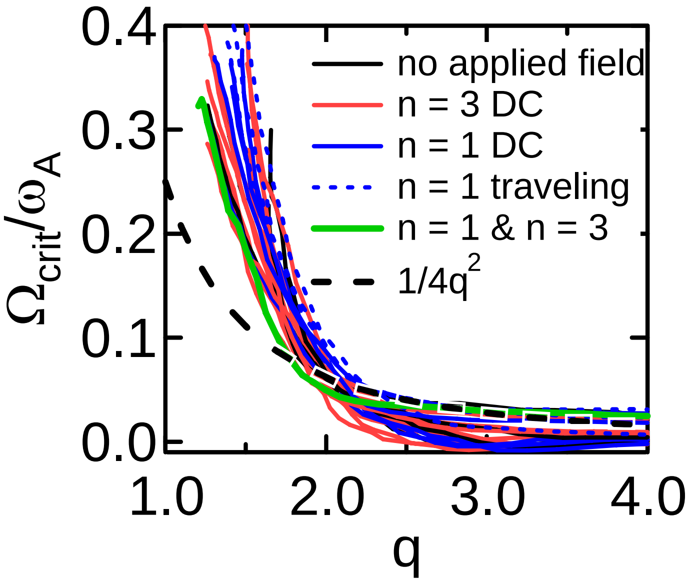
Rotation profile shape important for RWM stability

- Benchmark profile for stabilization is $\omega_c = \omega_A/4q^2$ *
  - predicted by semi-kinetic theory**
- Rotation outside *q* = 2.5 not required for stability
  - $n = 3$ used to brake stable ω_ϕ below ω_c
- Scalar Ω_{crit}/ω_A at $q = 2$, > 2 not a reliable criterion for stability
  - variation > $\Delta\omega_\phi$ in one time step
  - consistent with distributed dissipation

*A.C. Sontag, et al., Phys. Plasmas **12** (2005) 056112.

A. Bondeson, M.S. Chu, Phys. Plasmas **3 (1996) 3013.

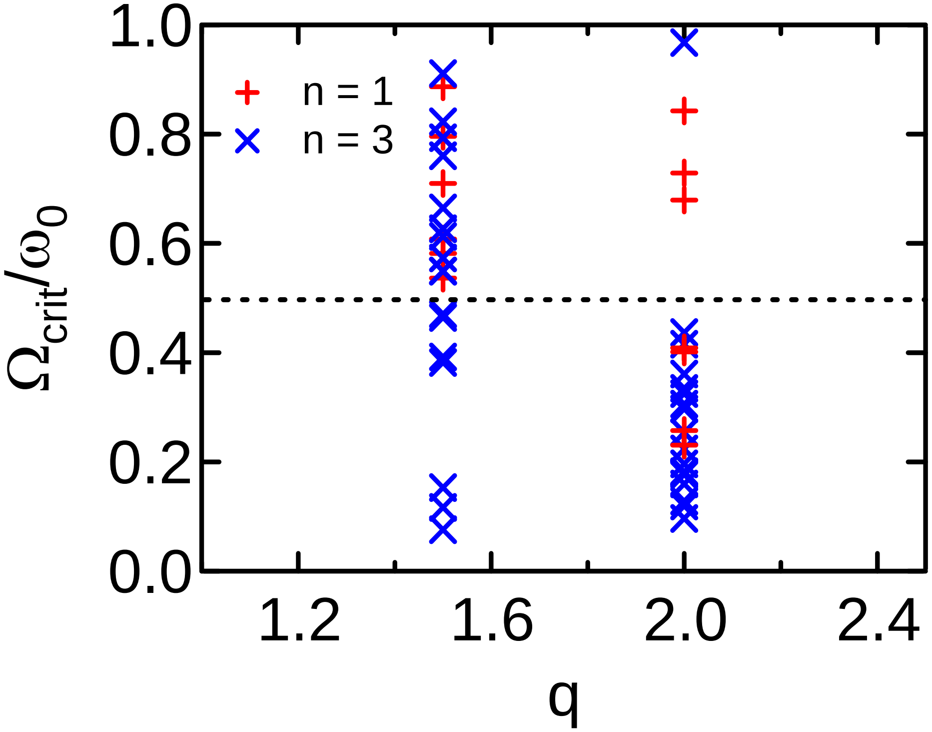




Ω_{crit} not correlated with Electromagnetic Torque Model

- Rapid drop in ω_ϕ when RWM unstable may seem similar to 'forbidden bands' theory
  - model: drag from electromagnetic torque on tearing mode*
  - Rotation bifurcation at $\omega_0/2$ predicted
- No bifurcation at $\omega_0/2$ observed
  - no correlation at q = 2 or further into core at q = 1.5
  - Same result for n = 1 and 3 applied field configuration

NSTX Ω_{crit} Database



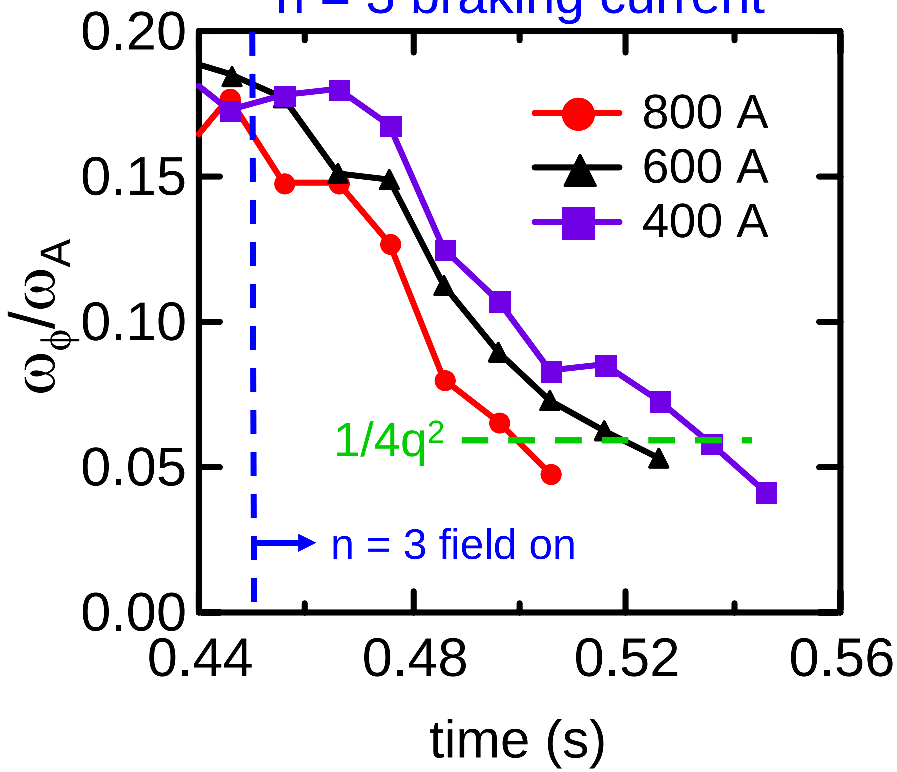
($\omega_0 \equiv$ steady-state plasma rotation)

*R. Fitzpatrick, Nucl. Fusion **33** (1993) 1061

Ω_{crit} Not Determined By *n* = 3 Braking Field Magnitude

- Applied *n* = 3 braking field varied in similar discharges
  - non-resonant field should not perturb RWM stability boundary
- Ω_{crit}/ω_A unchanged within $\Delta\omega_\phi$ during one time step
  - time of RWM onset delayed at lower field

Rotation @ q = 2 varying n = 3 braking current



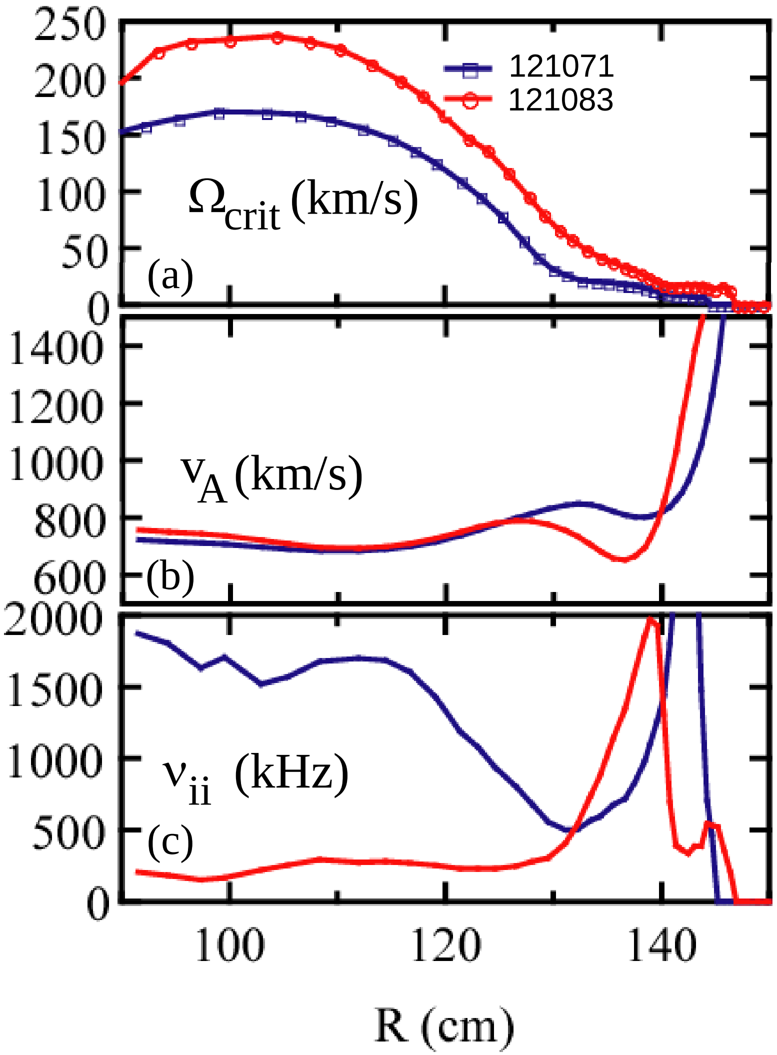
Consistent with RWM stability boundary that is unaffected by applied field

Increased ν_{ii} Leads to Decreased Ω_{crit}

- Plasmas with similar Alfven velocity, v_A, compared
  - I_p & B_t scaled for constant q
- Consistent with neoclassical viscous dissipation model
  - at low γ, increased ν_{ii} leads to lower Ω_{crit}
  - modification of Fitzpatrick "simple" model

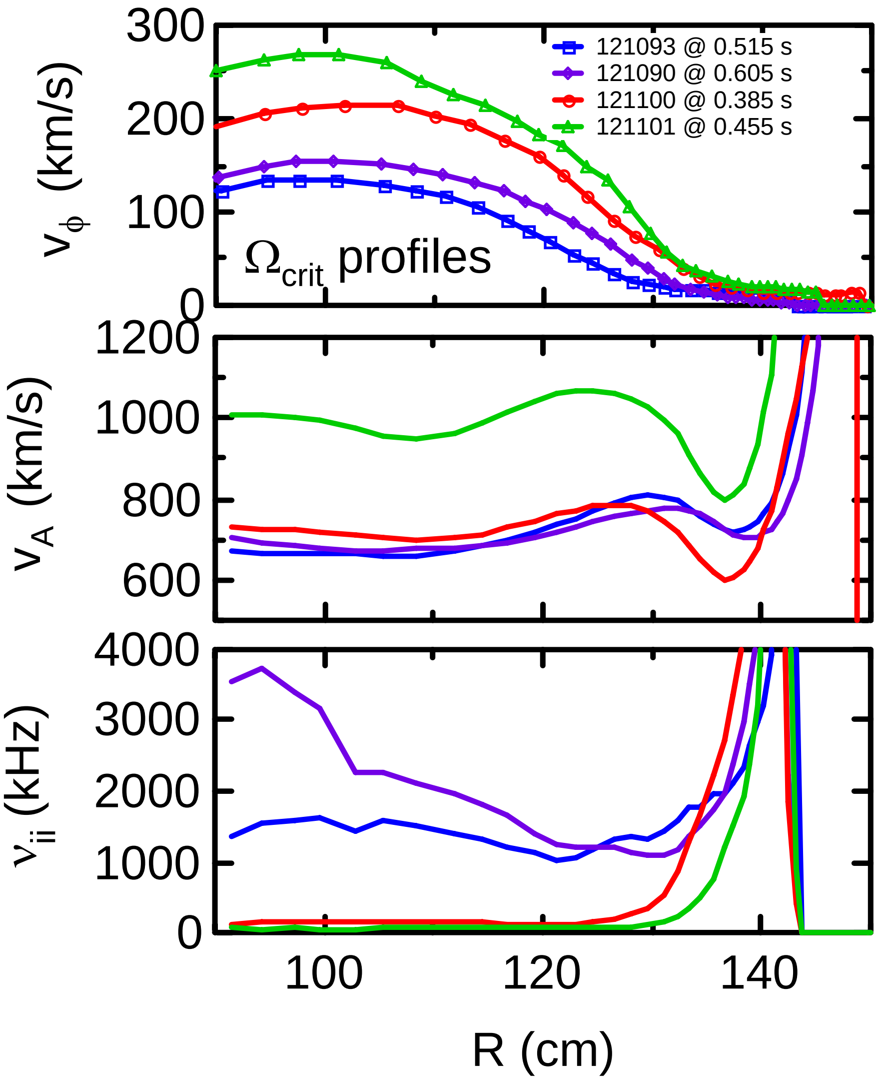
    (K. C. Shaing, Phys. Plasmas **11** (2004) 5525.)
- Similar result for neoclassical flow damping model at high collisionality ($\nu_{ii} > 1/\tau_{transit}$)

(R. Fitzpatrick, et al., Phys. Plasmas **13** (2006) 072512.)



Weak Correlation Between Ω_{crit} and v_A

- Scan performed at constant q
  - v_A, T_i, ρ all varying
- General trend with ν_{ii} remains consistent
  - higher ν_{ii} cases have lower Ω_{crit}
- Need to account for ν_{ii} effects to accurately determine v_A dependence
  - when does ν_{ii} effect saturate?

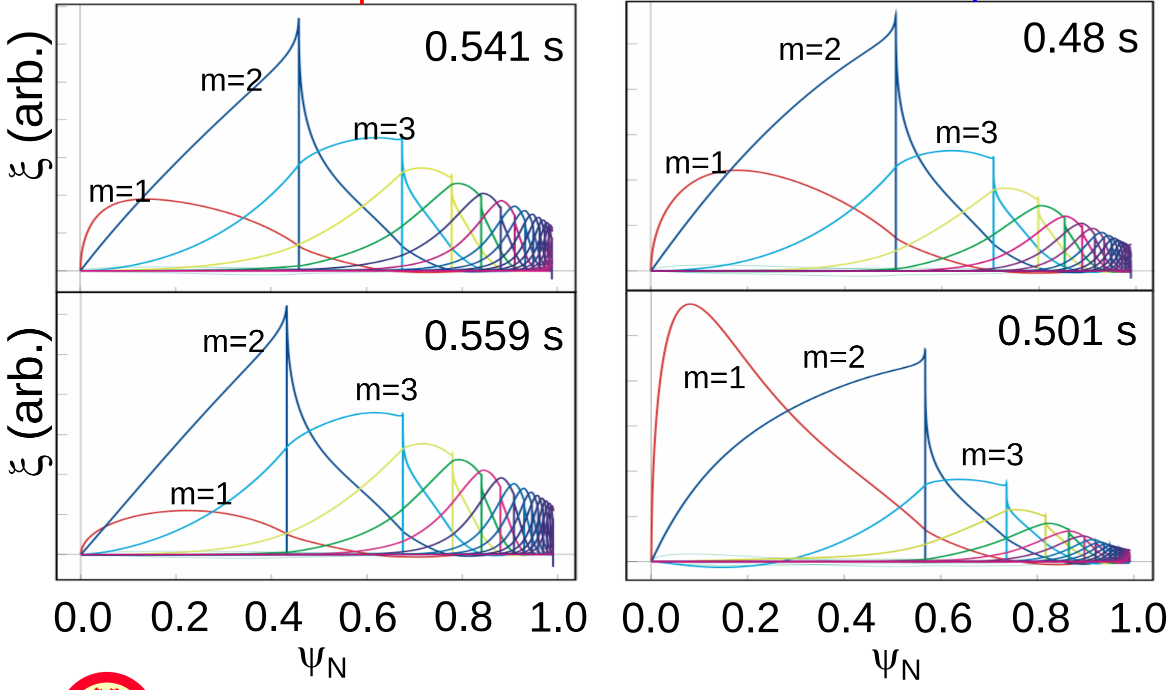


RWM Stabilized Upon Growth of Internal Mode

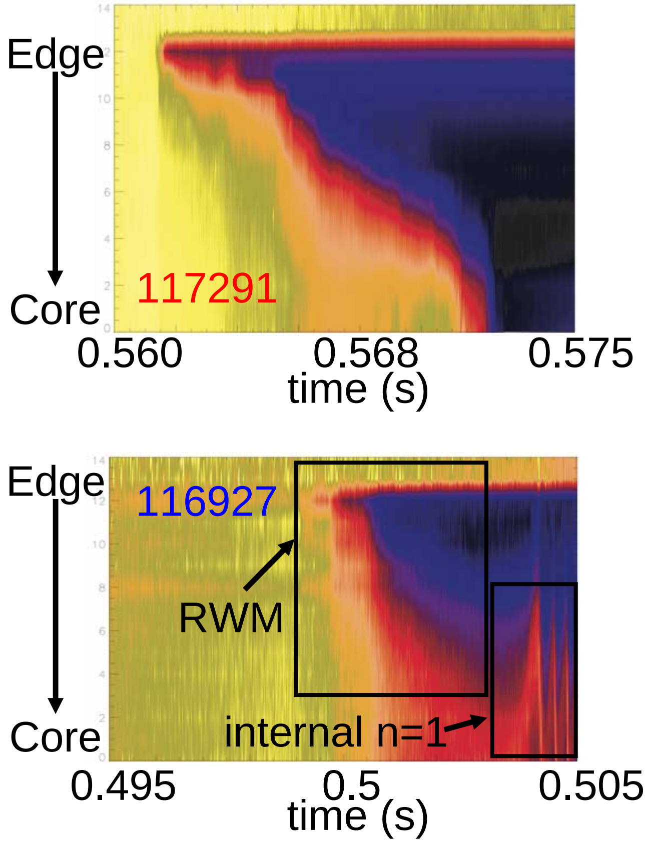
- RWM growth observed in magnetics and USXR *without* disruption
- Internal mode growth averts disruption, saturates β below $\beta_N^{\text{no-wall}}$
- DCON m = 1 component increases in time in non-disruptive cases
  - 116927: q_0 ~ 1.15 at collapse
  - 117291: q_0 ~ 1.45 at collapse

DCON Computed Poloidal Eigenfunctions

117291 - Disruptive RWM 116927 - Non-Disruptive RWM



Chordal USXR Data



Understanding RWM Passive Stability Physics Critical to Advanced Operation in Next-Step Toroidal Devices

- Scalar Ω_{crit} inadequate to define RWM passive stability boundary
  - significant variation in Ω_{crit} observed at $q = 2$ surface
  - large rotation at $q > 2$ not required for RWM passive stability
- NSTX Ω_{crit} data inconsistent with EM torque model
  - more complete RWM physics model needed for ITER predictions
- Applied n=3 field magnitude does not determine Ω_{crit}
  - Ω_{crit} from non-resonant braking extrapolates to other devices
- Decreased ν_{ii} leads to increased Ω_{crit}
  - increased rotation required for RWM stability in ITER