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Resistive Wall Mode Stabilization

Physics in NSTX

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A.C. Sontag¹, S.A. Sabbagh¹, R.E. Bell², J.M. Bialek¹,
D.A. Gates², A.H. Glasser³, J.E. Menard², K.L. Tritz⁴

¹Columbia University

²Princeton Plasma Physics Laboratory

³Los Alamos National Laboratory

⁴Johns Hopkins University

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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

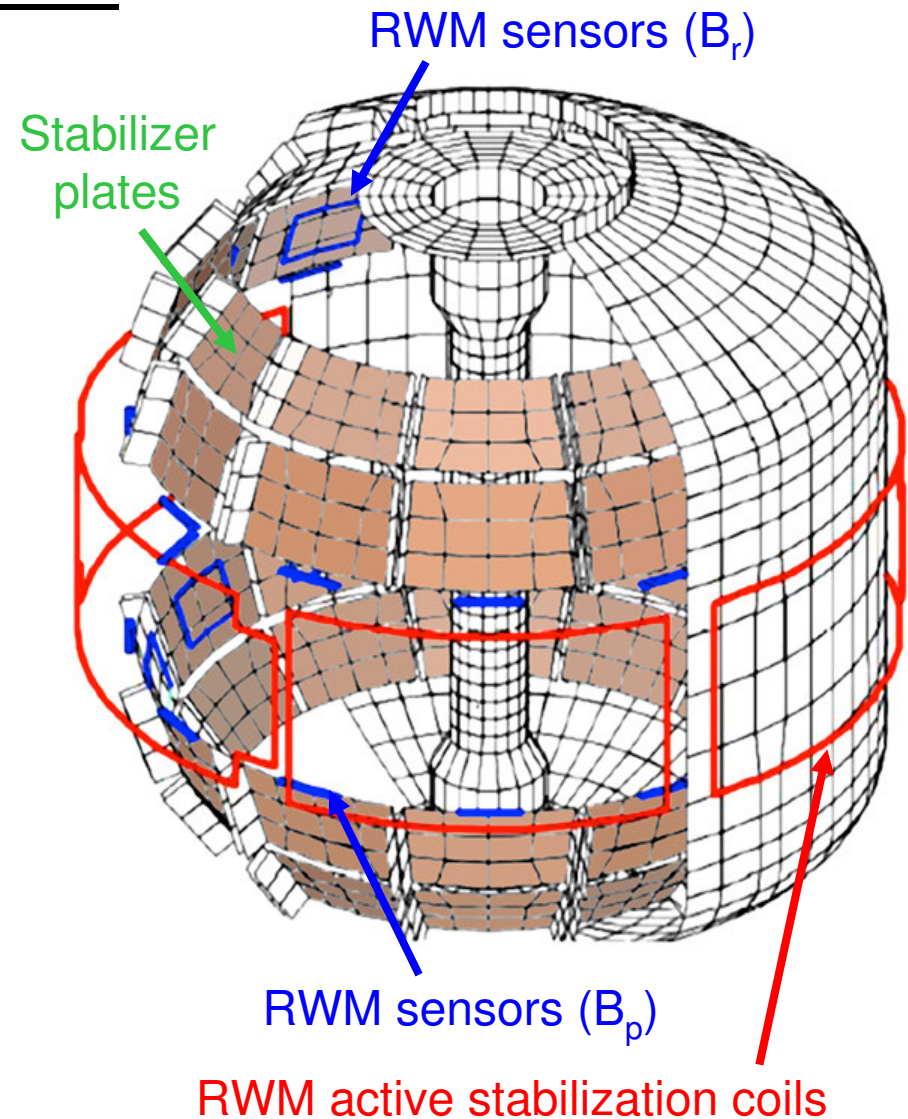
- ❑ Midplane control coil similar to ITER port plug designs

❑ Plasma rotation control

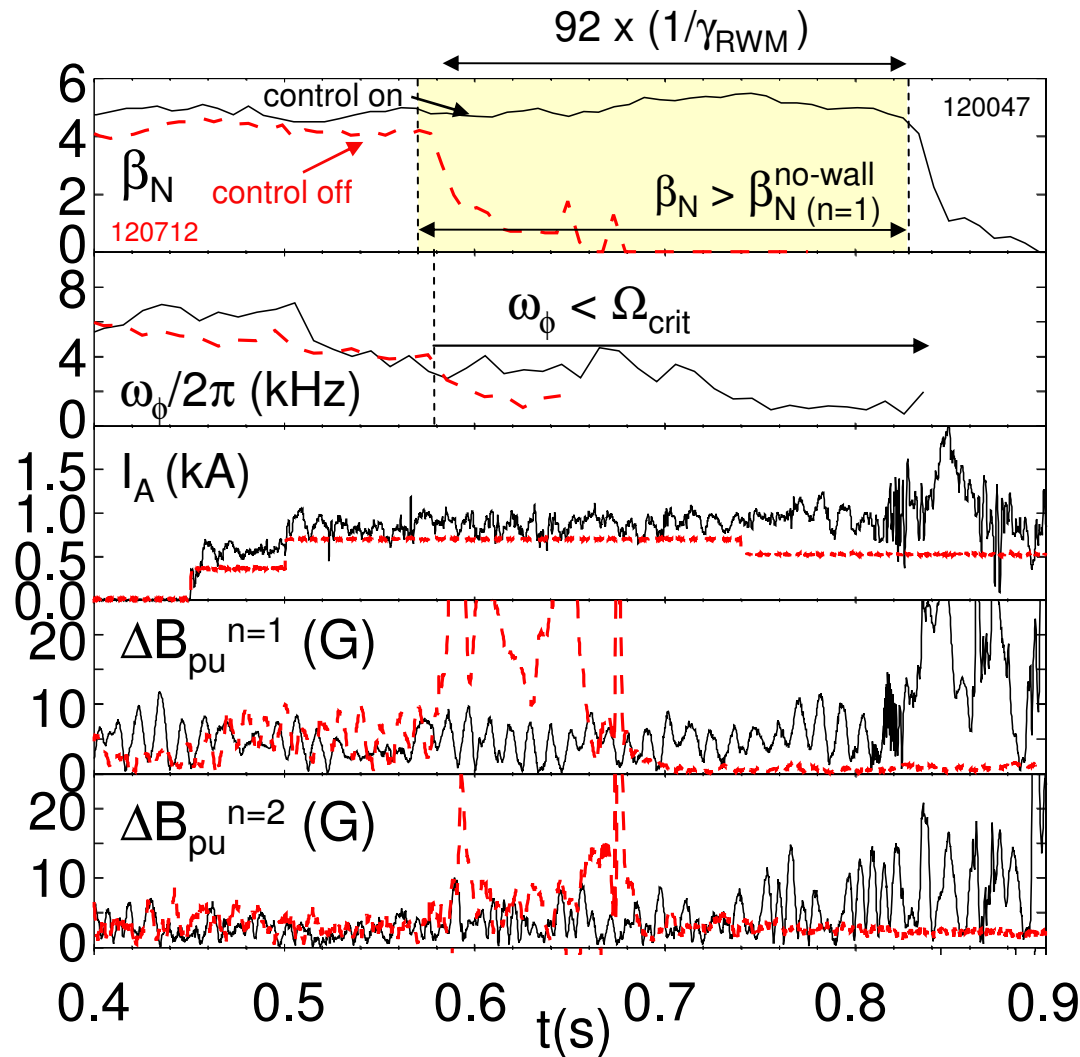
- ❑ A tool to slow ω_ϕ by resonant or non-resonant fields

❑ RWM passive stabilization

- ❑ Plasma rotation profile, ion collisionality, ν_{ij} , 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 $\beta_N^{no-wall}$ 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}

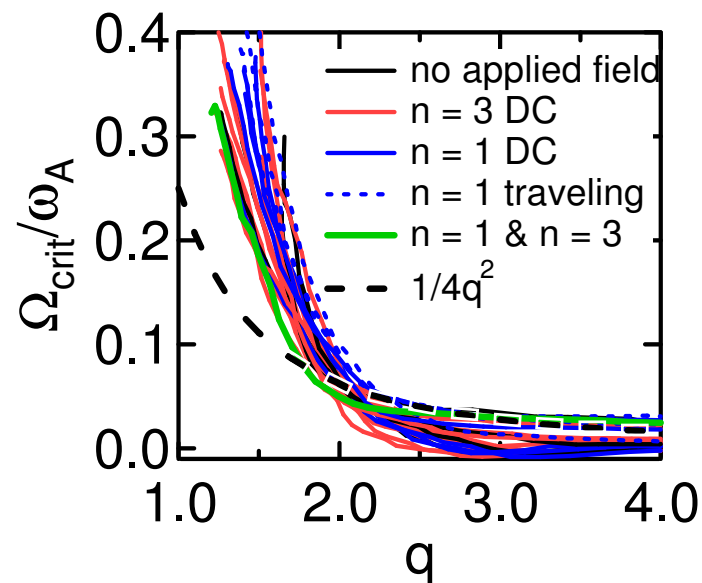
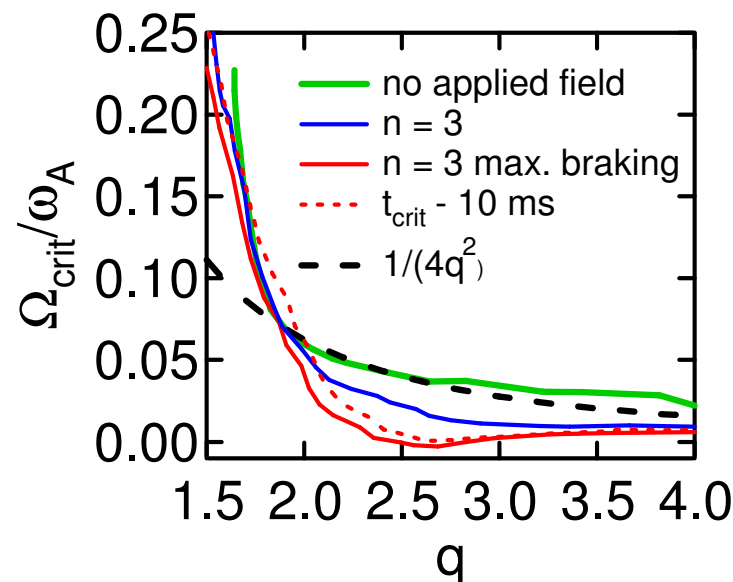
VI2.1 Thurs. PM - S. Sabbagh

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

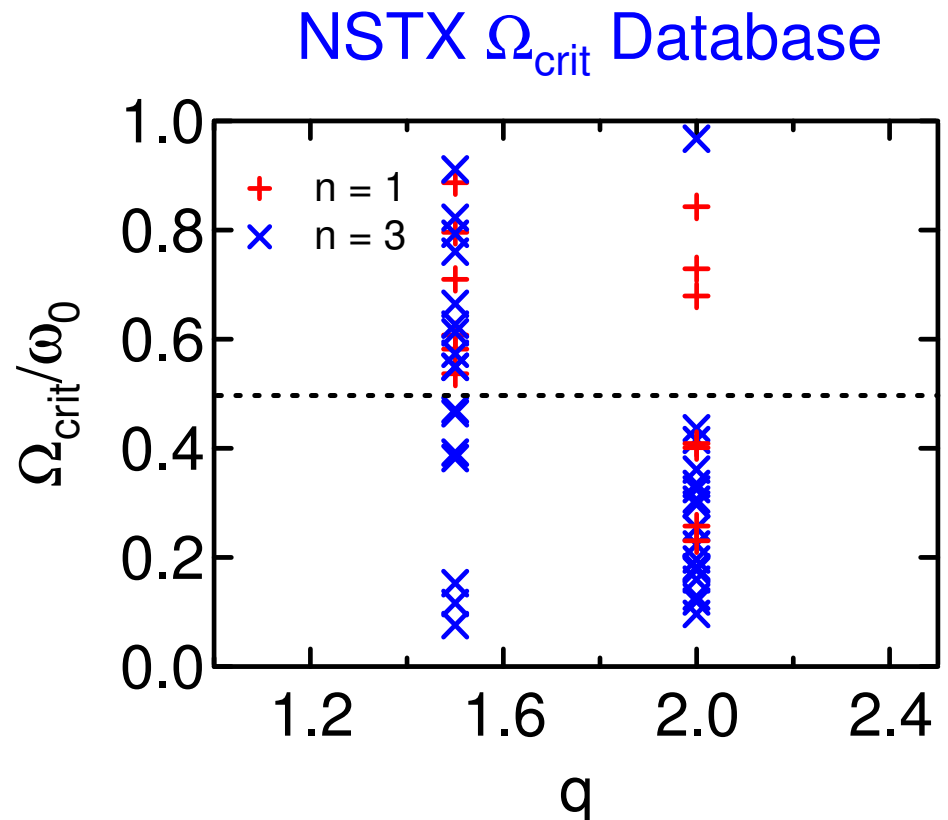


*A.C. Sontag, et al., Phys. Plasmas **12** (2005) 056112.

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

Ω_{crit} not correlated with Electromagnetic Torque Model

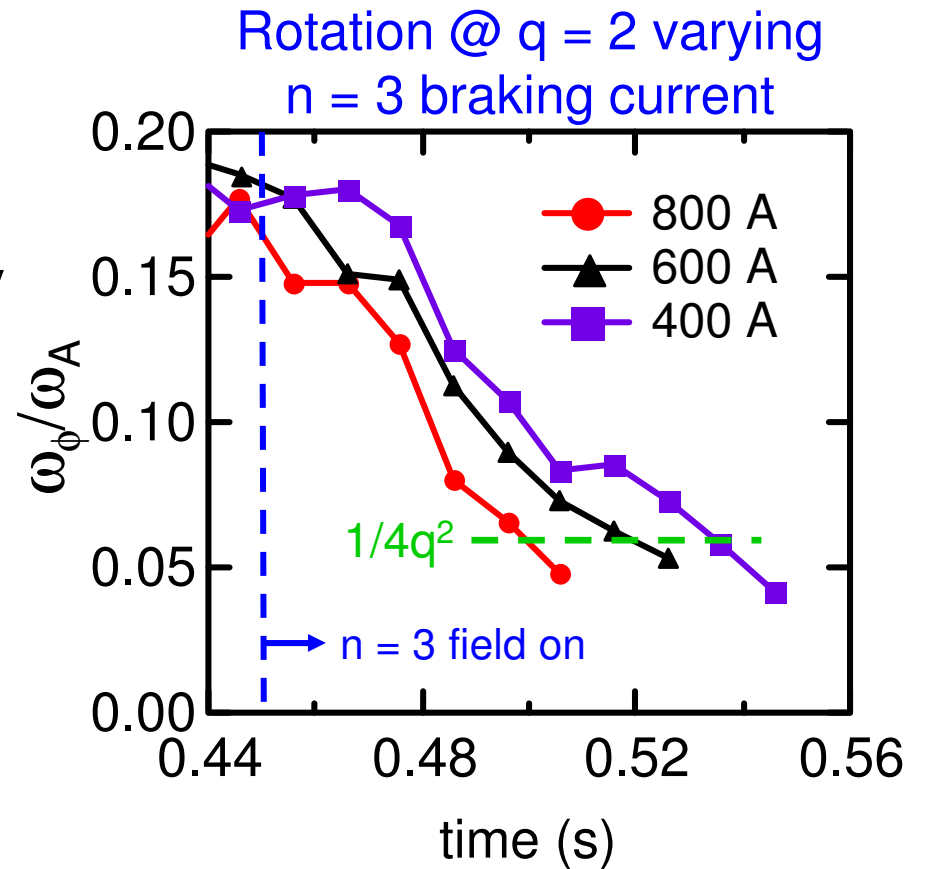
- ❑ Rapid drop in ω_ϕ when RWM unstable may seem similar to 'forbidden bands' theory
 - ❑ model: drag from electromagnetic torque on tearing mode*
 - ❑ Rotation bifurcation at $\omega_0/2$ predicted
- ❑ No bifurcation at $\omega_0/2$ observed
 - ❑ no correlation at $q = 2$ or further into core at $q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



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

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



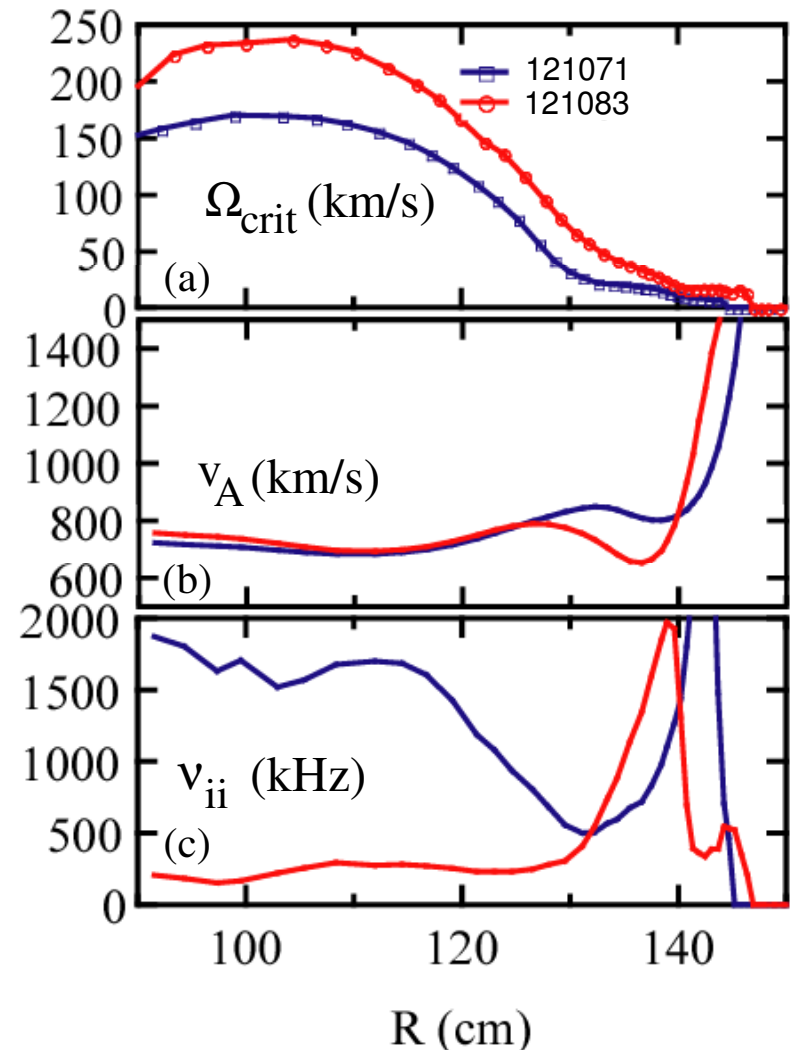
Consistent with RWM stability boundary that is unaffected by applied field

Increased v_{ji} Leads to Decreased Ω_{crit}

- Plasmas with similar Alfvén velocity, v_A , compared
 - I_p & B_t scaled for constant q
- Consistent with neoclassical viscous dissipation model
 - at low γ , increased v_{ji} leads to lower Ω_{crit}
 - modification of Fitzpatrick “simple” model
- Similar result for neoclassical flow damping model at high collisionality ($v_{ji} > 1/\tau_{transit}$)

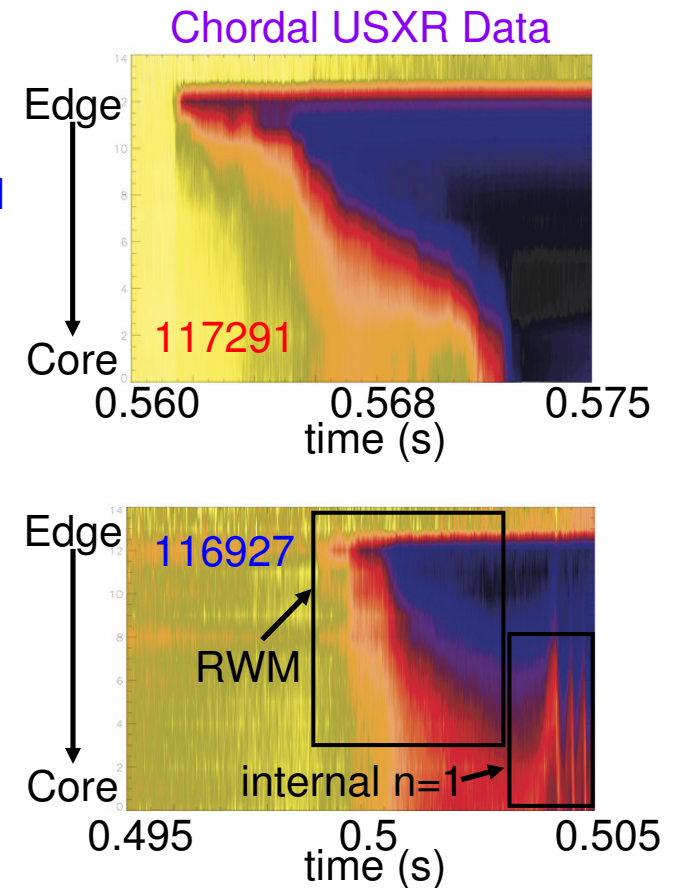
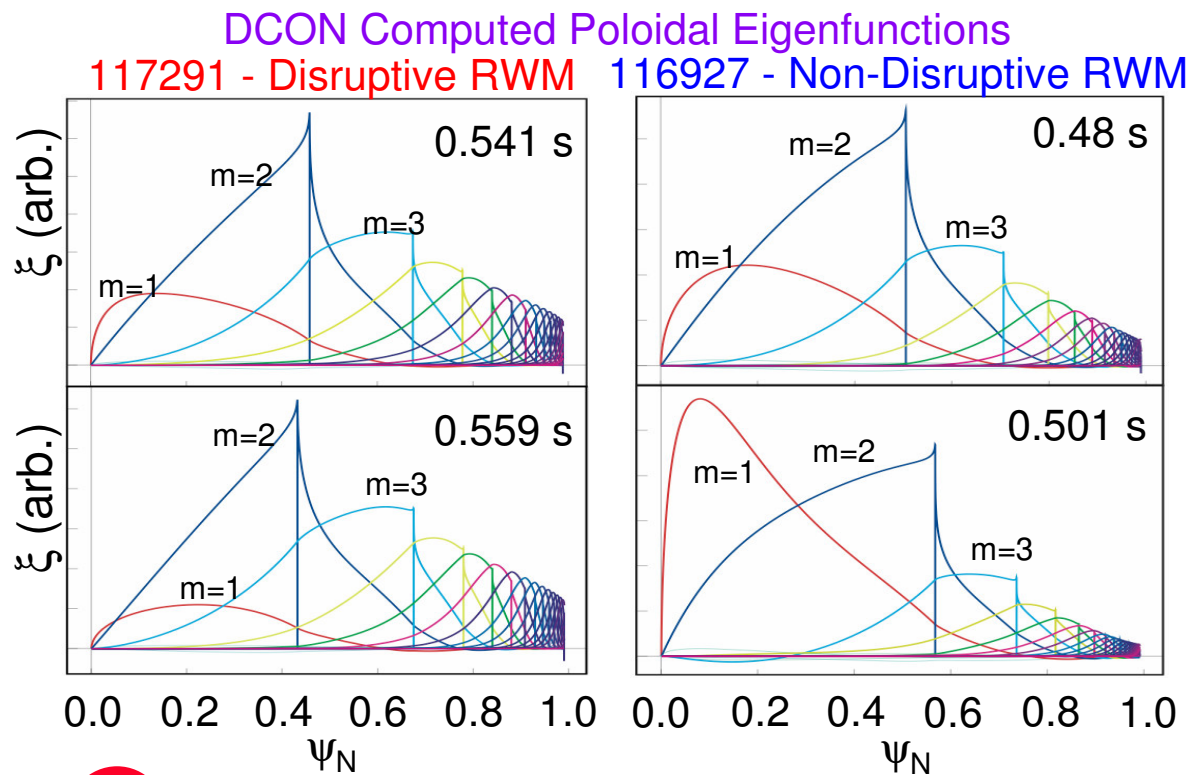
(K. C. Shaing, Phys. Plasmas **11** (2004) 5525.)

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



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: $q_0 \sim 1.15$ at collapse
 - ❑ 117291: $q_0 \sim 1.45$ at collapse



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 v_{ij} leads to increased Ω_{crit}
 - ❑ increased rotation required for RWM stability in ITER