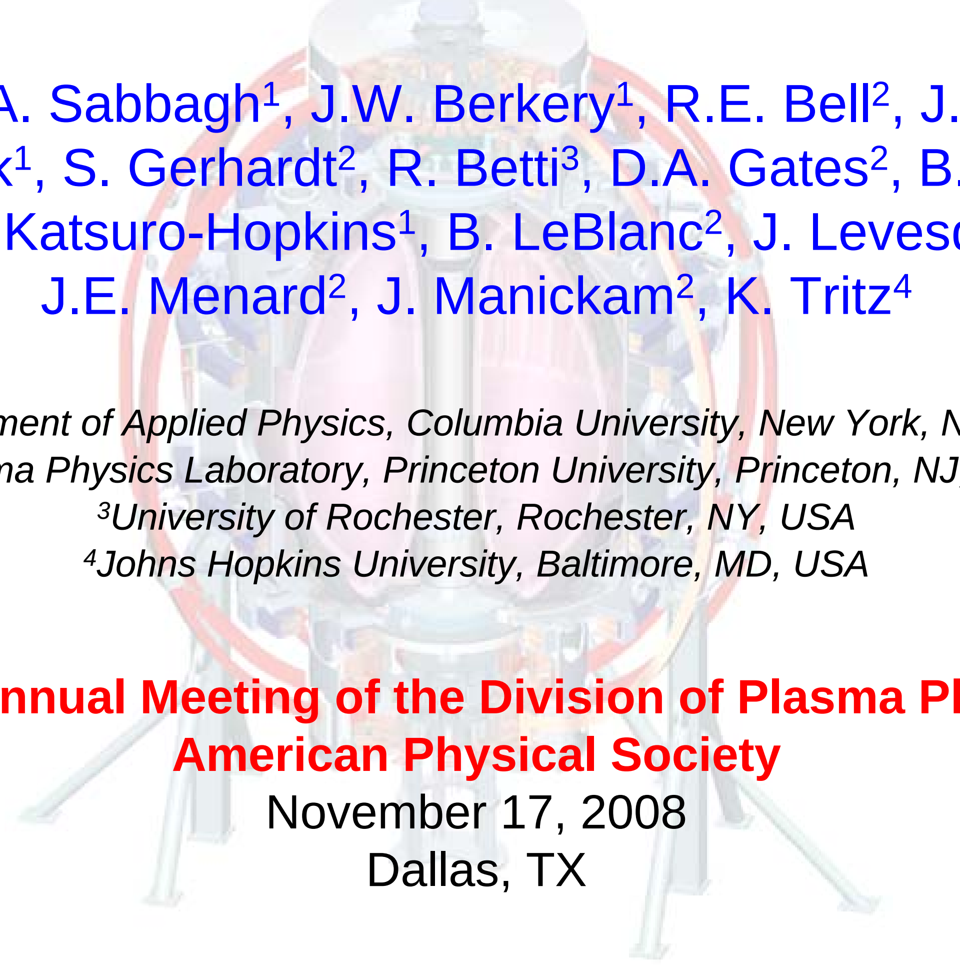
Global Mode Stability and Active Control in NSTX



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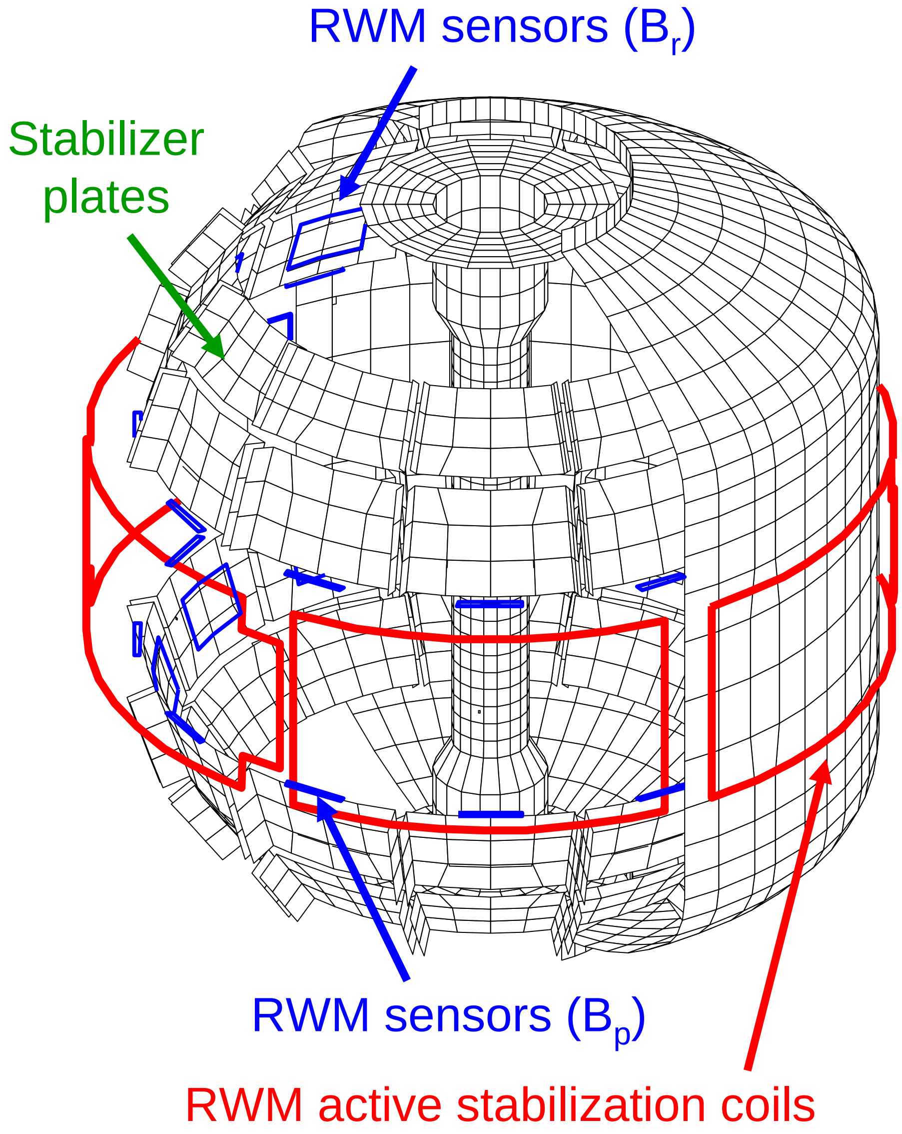
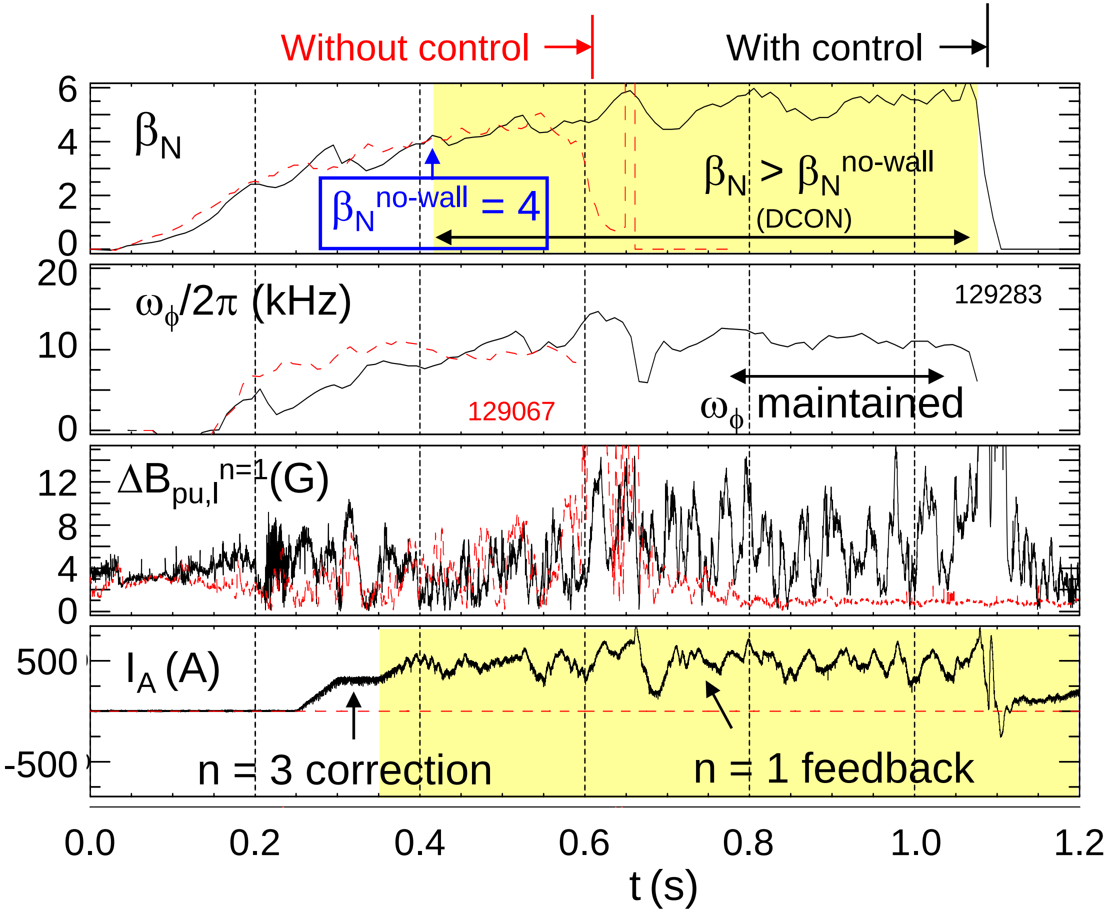
Research advances to understanding mode stabilization physics and reliably maintaining high beta plasmas

- **Outline**
  - Active control of beta amplified n = 1 fields / global instabilities
  - Mode dynamics during control
  - Kinetic effects on RWM stabilization
  - T_i influence on non-resonant magnetic braking



Active RWM control and error field correction maintain high β_N plasma

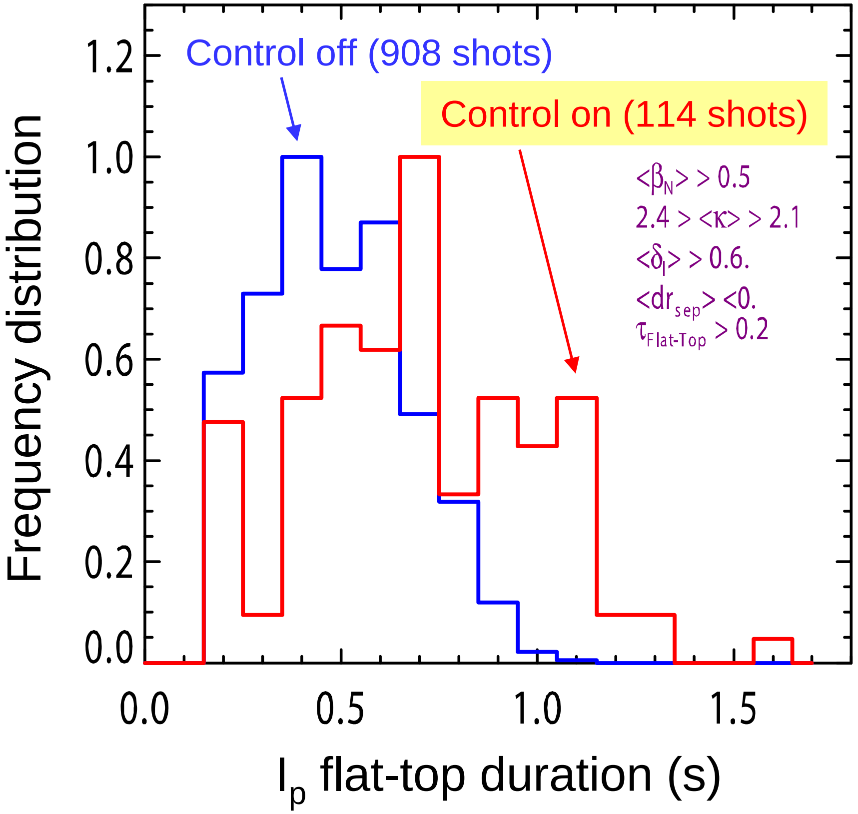


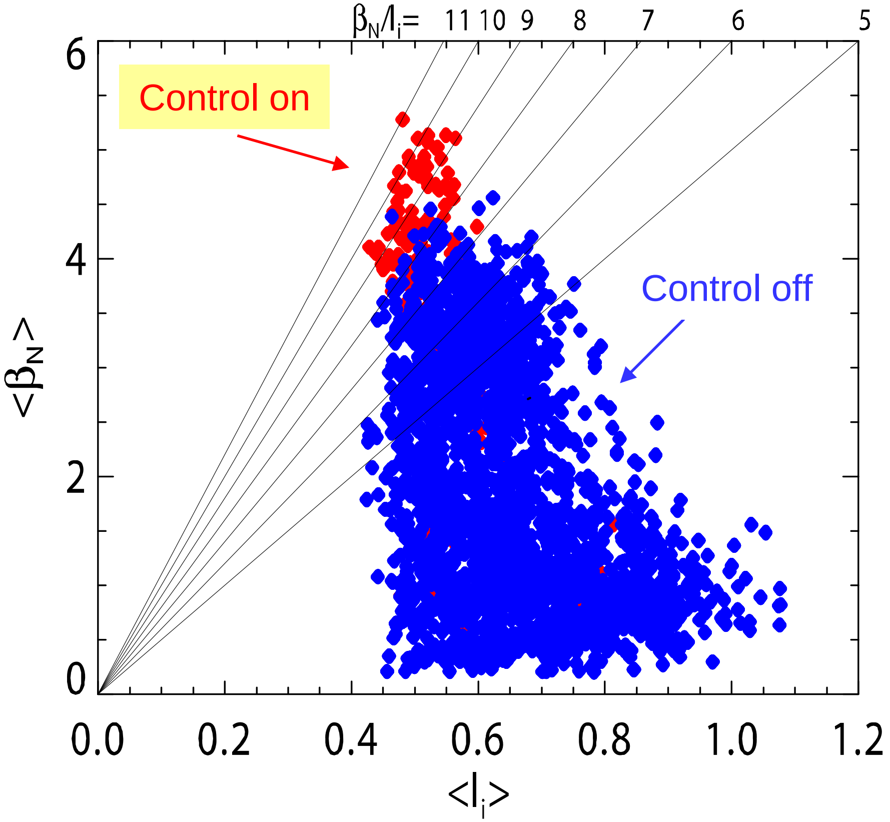
- n = 1 active, n = 3 DC control
  - n = 1 response ~ 1 ms < $1/\gamma_{RWM}$
  - $\beta_N/\beta_N^{no\text{-}wall} = 1.5$ reached
  - best maintains ω_ϕ
- NSTX record pulse lengths
  - limited by magnet systems
  - n > 0 control first used as standard tool in 2008
- Without control, plasma more susceptible to RWM growth, even at high ω_ϕ
  - Disruption at $\omega_\phi/2\pi$ ~ 8kHz near q = 2
  - Factor of 2 higher than marginal ω_ϕ with n = 3 magnetic braking

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

NP6.00082 Menard - Optimized EFC

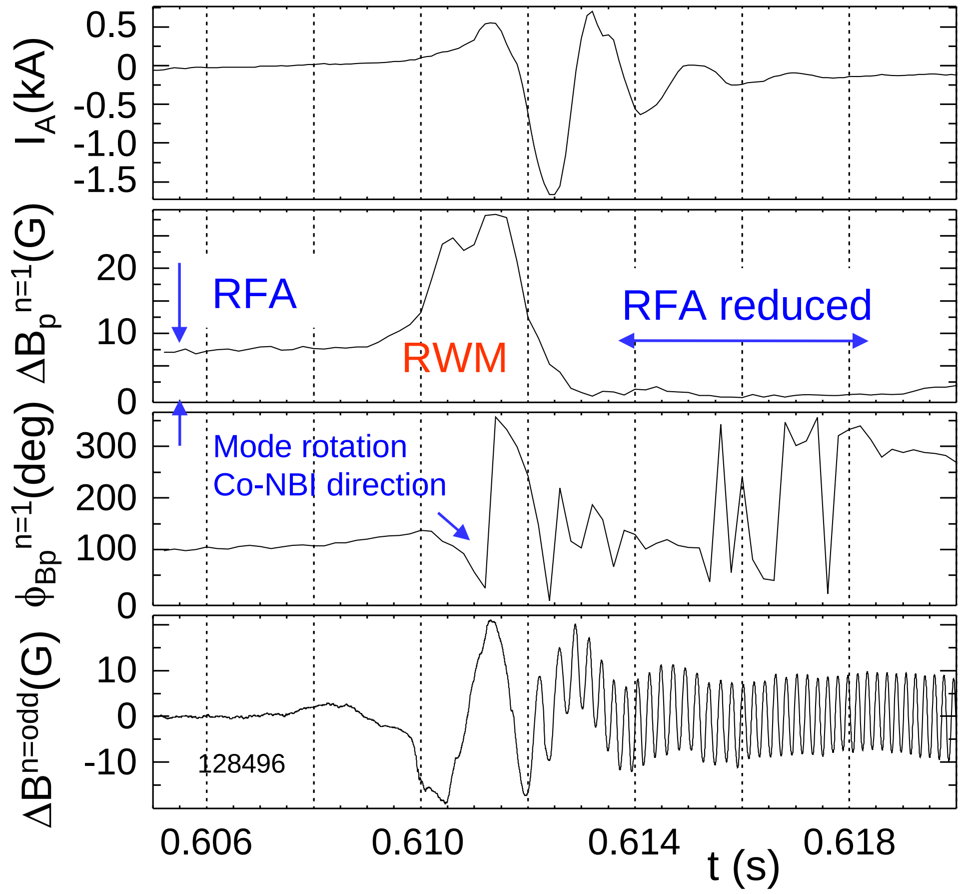
Probability of long pulse and $<\beta_N>_{pulse}$ increases significantly with active RWM control and error field correction



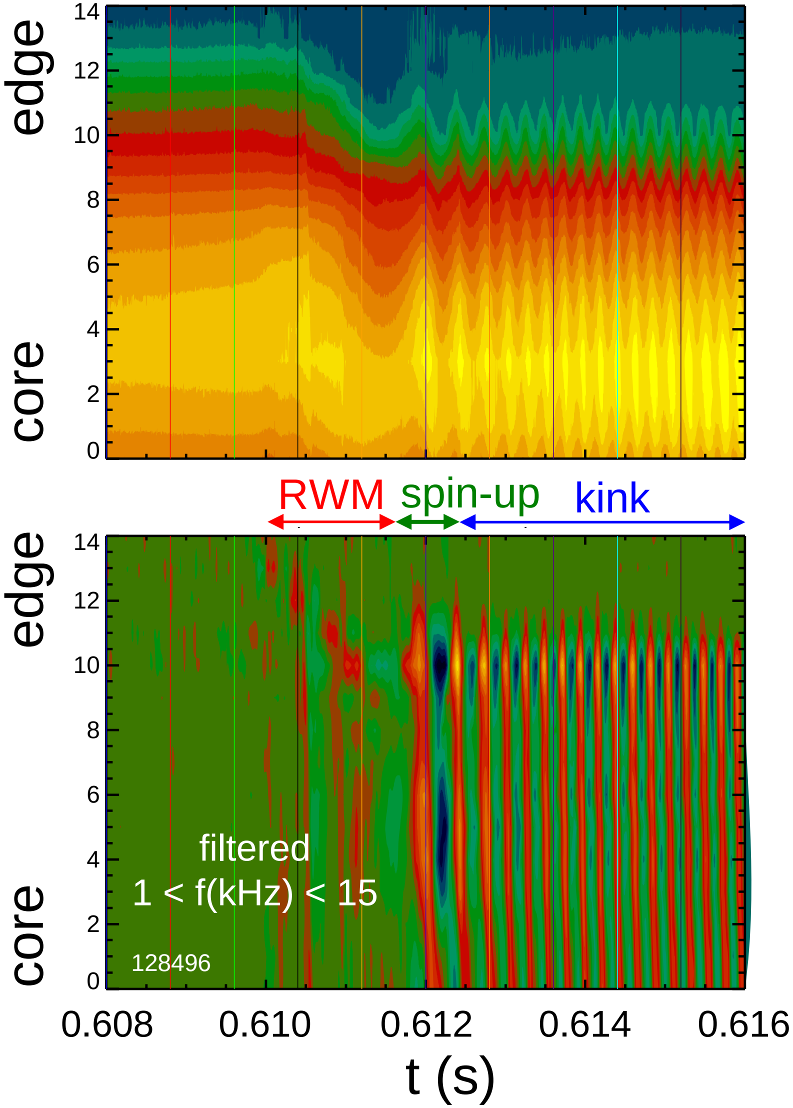


- Standard H-mode operation shown
  - I_p flat-top duration > 0.2s (> 60 RWM growth times)
- Control allows $<\beta_N>_{pulse} > 4$
  - β_N averaged over I_p flat-top

During n=1 feedback control, unstable RWM evolves into rotating global kink

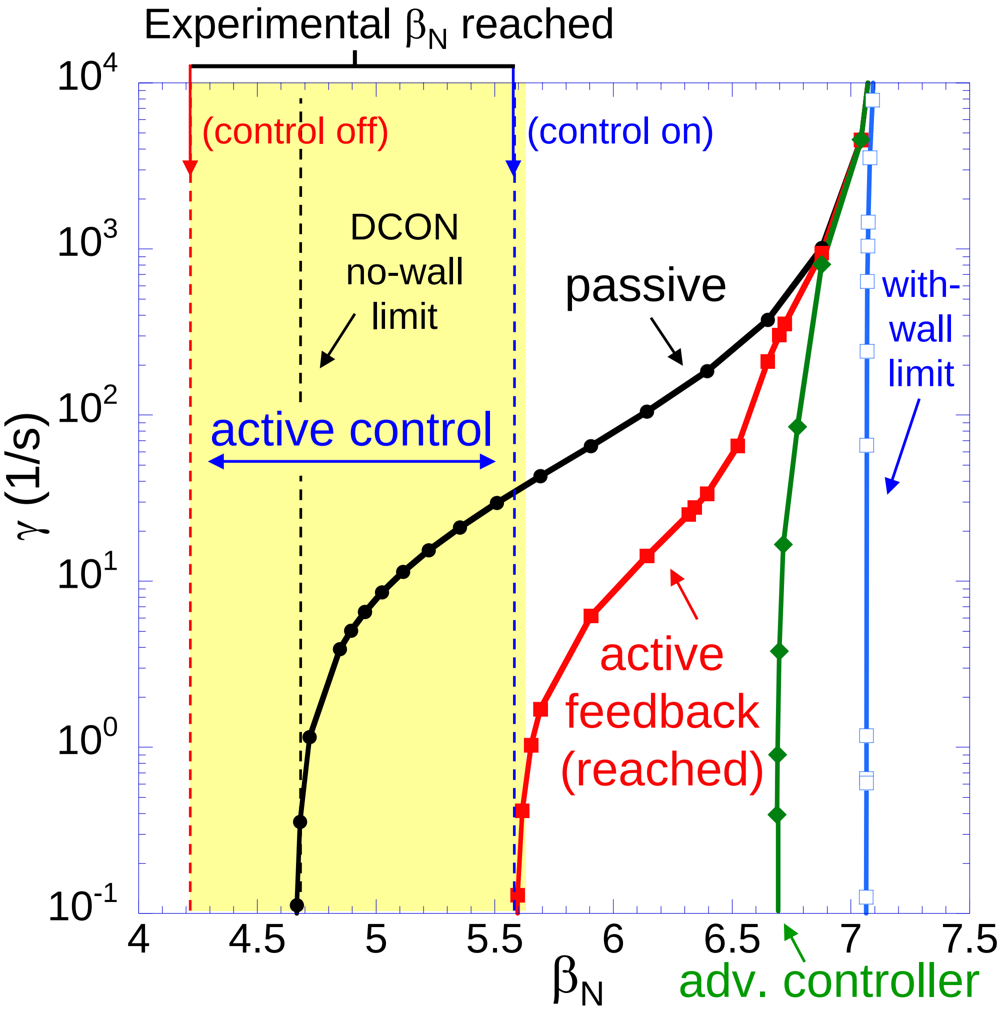


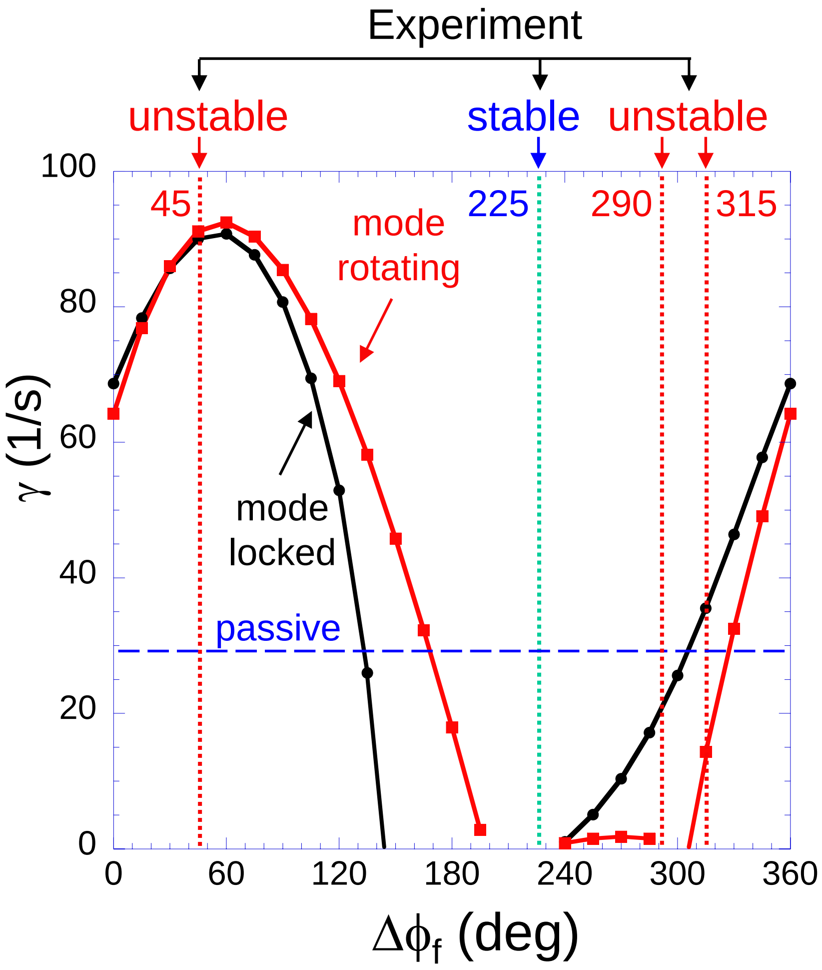
Soft X-ray emission contours



- RWM unlocks without disruption
- Kink either damps away, or saturates
  - Tearing mode appears after 10 RWM growth times; modes stabilize

Experimental RWM control performance consistent with theory





- ❑ VALEN code with realistic sensor geometry, plasmas with reduced V_ϕ
- ❑ Feedback phase scan shows superior settings

Katsuro-Hopkins JP6.00108 – adv. controller

Bialek NP6.00103 – NSTX upgrade, ITER VAC02 results

Modification of Ideal Stability by Kinetic theory (MISK code) investigated to explain experimental stability

- ❑ Simple critical ω_ϕ threshold stability models or loss of torque balance do not describe experimental marginal stability

Sontag, et al., Nucl. Fusion **47** (2007) 1005.

- ❑ Kinetic modification to ideal MHD growth rate
  - ❑ Trapped and circulating ions, trapped electrons
  - ❑ Alfven dissipation at rational surfaces

$$\gamma\tau_w = -\frac{\delta W_\infty + \delta W_K}{\delta W_b + \delta W_K}$$

Hu and Betti, Phys. Rev. Lett **93** (2004) 105002.

- ❑ Stability depends on
  - ❑ Integrated ω_ϕ profile: resonances in δW_K (e.g. ion precession drift)
  - ❑ Particle collisionality

ω_ϕ profile (enters through ExB frequency)

Trapped ion component of δW_K (plasma integral)

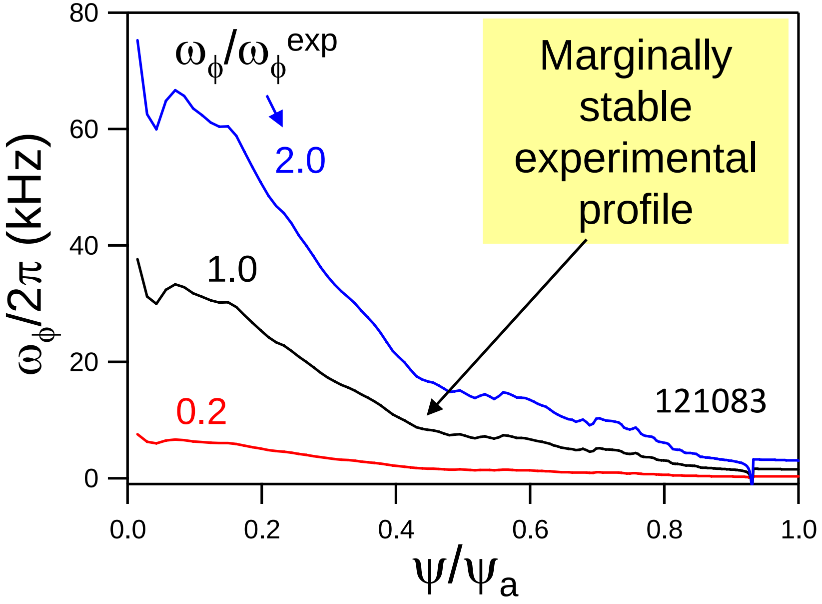
$$\delta W_K \propto \int \left[\frac{\omega_{*N} + \left(\hat{\varepsilon} - {}^{3}\!/_{2}\right)\omega_{*T} + \omega_E - \omega - i\gamma}{\underset{\substack{\uparrow\\ \text{precession drift}}}{\langle\omega_D\rangle} + l\underset{\substack{\uparrow\\ \text{bounce}}}{\omega_b} - i\underset{\substack{\uparrow\\ \text{collisionality}}}{\nu_{eff}} + \omega_E - \omega - i\gamma}\right]\hat{\varepsilon}^{\frac{5}{2}} e^{-\hat{\varepsilon}}\, d\hat{\varepsilon}$$

← Energy integral

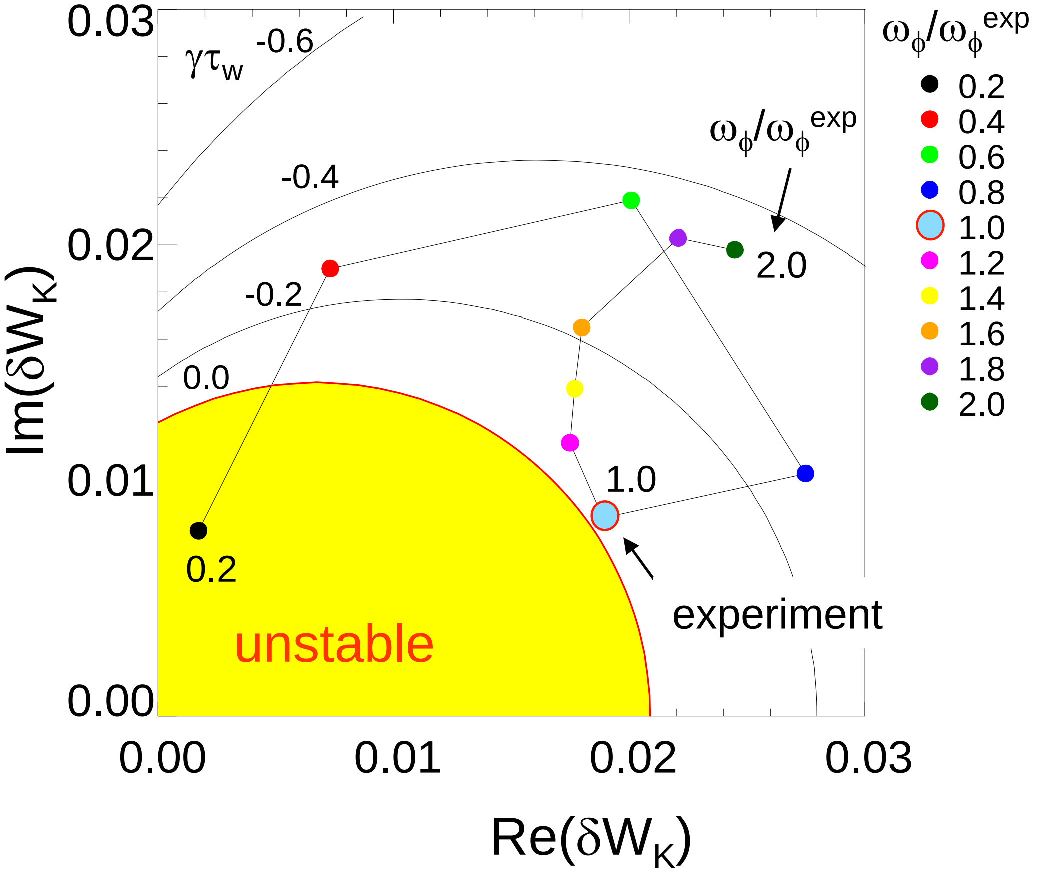
NP6.00101 Berkery

Kinetic modifications show decrease in RWM stability at relatively high V_ϕ – consistent with experiment

Theoretical variation of ω_ϕ



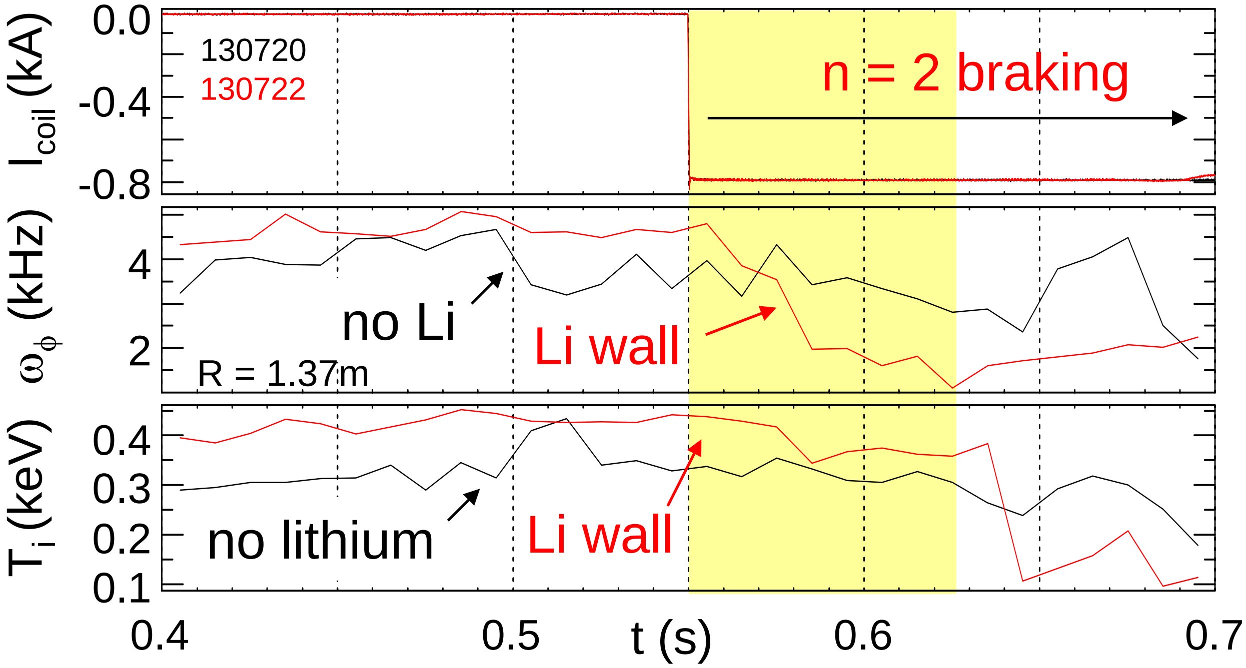
RWM stability vs. V_ϕ (contours of $\gamma\tau_w$)

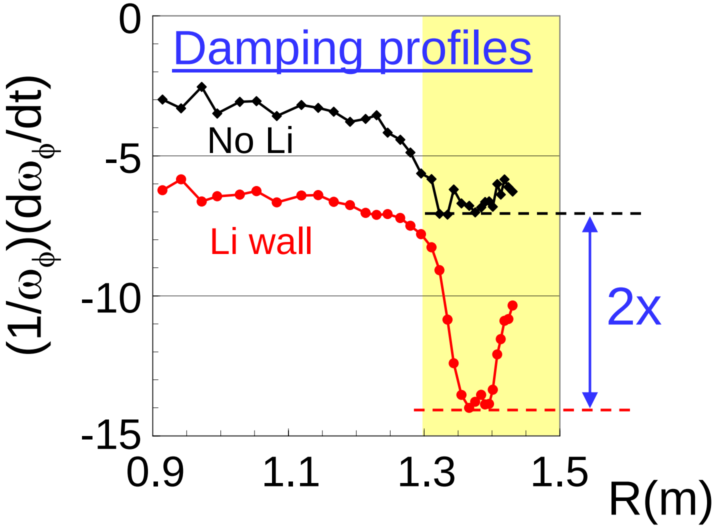


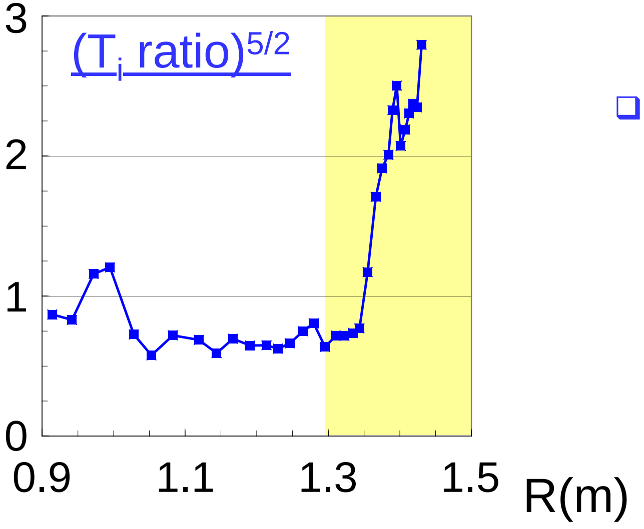
- Variation of ω_ϕ away from marginal profile <u>increases</u> stability
- Unstable region at low ω_ϕ
- Kinetic model also shows overall increase in stability as collisionality decreases

NP6.00101 Berkery

Stronger non-resonant braking at increased T_i







- ❑ Observed non-resonant braking using n = 2 field
- ❑ Li wall conditioning produces higher T_i in experiment
- ❑ Expect stronger neoclassical toroidal viscosity at higher T_i ($-d\omega_\phi/dt \sim T_i^{5/2}\,\omega_\phi$)
  - ❑ At braking onset, T_i ratio$^{5/2}$ = $(0.45/0.34)^{5/2} \sim 2$
  - ❑ Consistent with measured $d\omega_\phi/dt$ in region of strongest damping

NTV theory:
J-K. Park: GI1.00005
K. Shaing: JP6.00109

Advances in global mode feedback control, kinetic stabilization physics and magnetic braking research

- Active n = 1 control, DC n = 3 error field correction maintain high β_N plasma over ideal $\beta_N^{\text{no-wall}}$ limit for long pulse
  - Growing RWM converts to kink that stabilizes; can yield tearing mode
- Active control performance compares well to theory
  - Significant β_N increase expected for ITER with proposed internal coil
- Kinetic modifications to ideal stability can reproduce behavior of observed RWM marginal stability vs. V_ϕ
  - Simple critical rotation threshold models for RWM stability inadequate
- Non-resonant V_ϕ braking increases with increased T_i consistent with NTV
  - Braking observed using n = 2 applied field in 2008