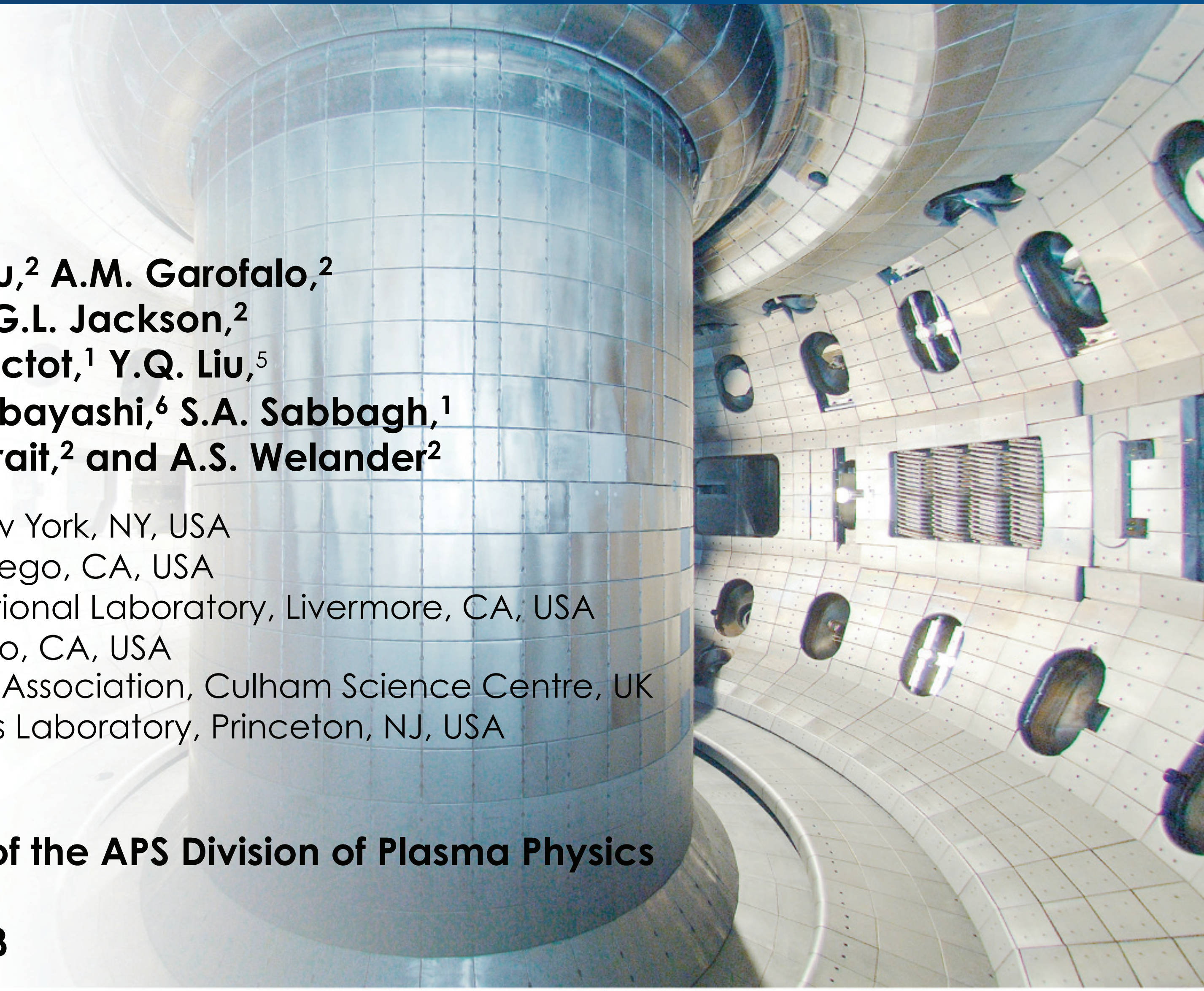
Wall-Stabilization and Its Limits in High Beta DIII-D Plasmas



By

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Presented at

**50th Annual Meeting of the APS Division of Plasma Physics
Dallas, Texas
November 17-21, 2008**

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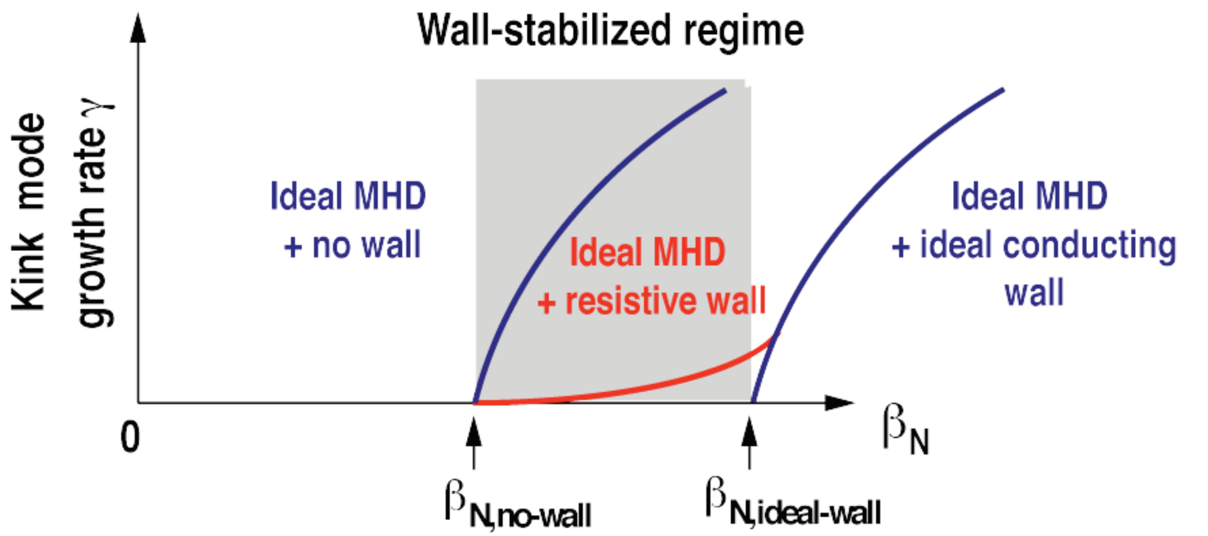
Columbia University

Wall-stabilization has the potential to significantly increase the attainable value of β_N

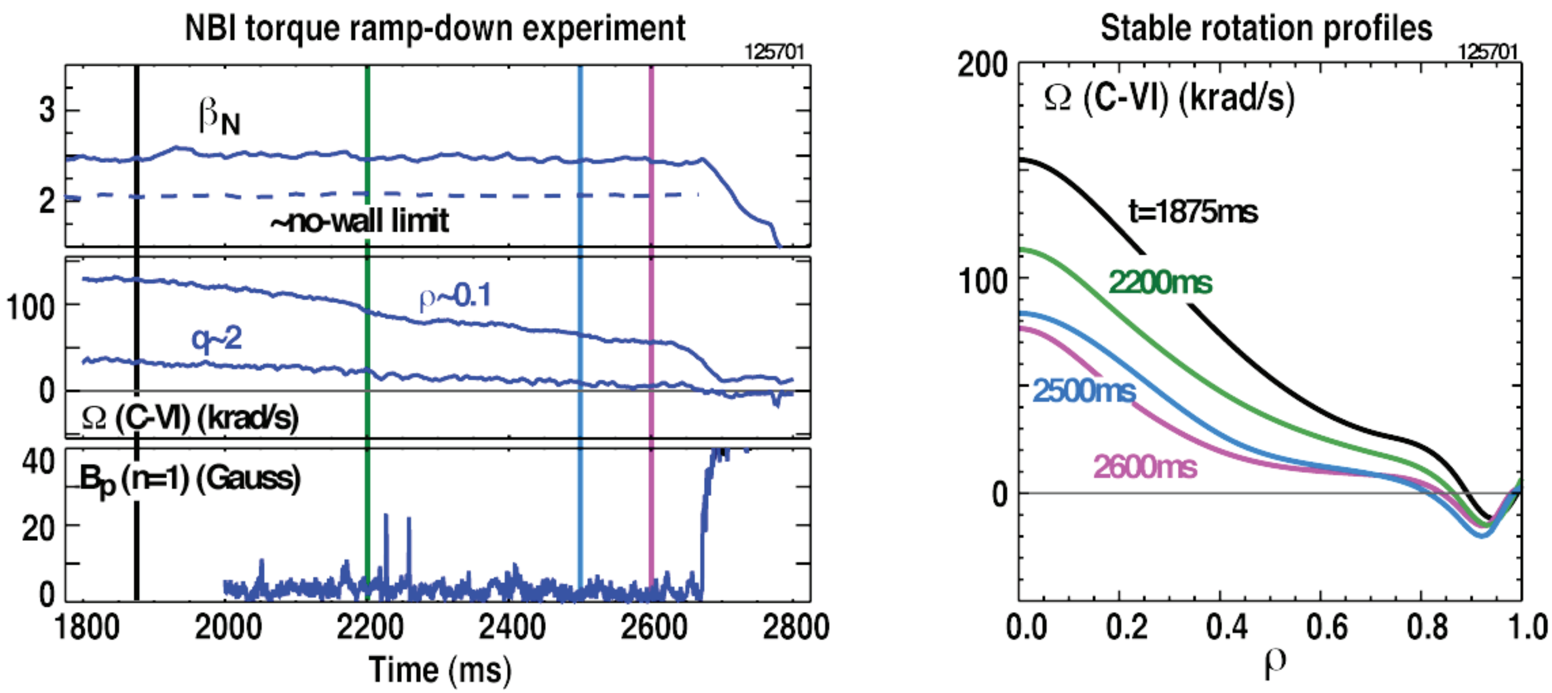
- **In ideal MHD β_N is usually limited by a long-wavelength (*n*=1) kink mode**
  - Marginal value of β_N increases when an ideal conducting wall imposes a constant flux boundary condition
    - In DIII-D $\beta_{N,ideal\text{-}wall}$ can be 2x as high as $\beta_{N,no\text{-}wall}$



- **Finite wall resistivity allows modes above $\beta_{N,no\text{-}wall}$ to grow on characteristic wall time scales $\tau_W >> \tau_A$ → Resistive Wall Modes**
  - Plasma flow/particle resonances can modify RWM stability

RWM remains stable over a wide range of plasma rotation profiles

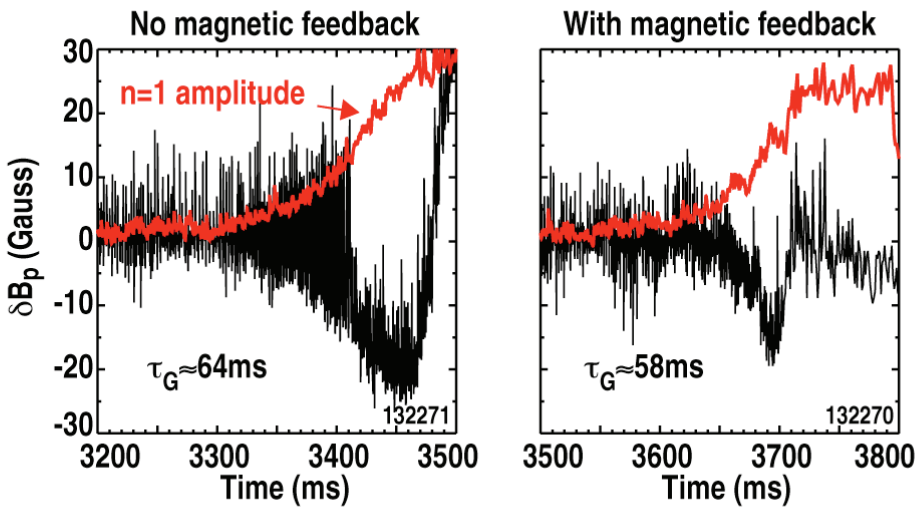
- **Good error field correction is essential to maintain wall-stabilization down to very low plasma rotation** [H. Reimerdes, et al, *Phys. Rev. Lett.* (2007)]
  - Rotation controlled by varying the NBI torque



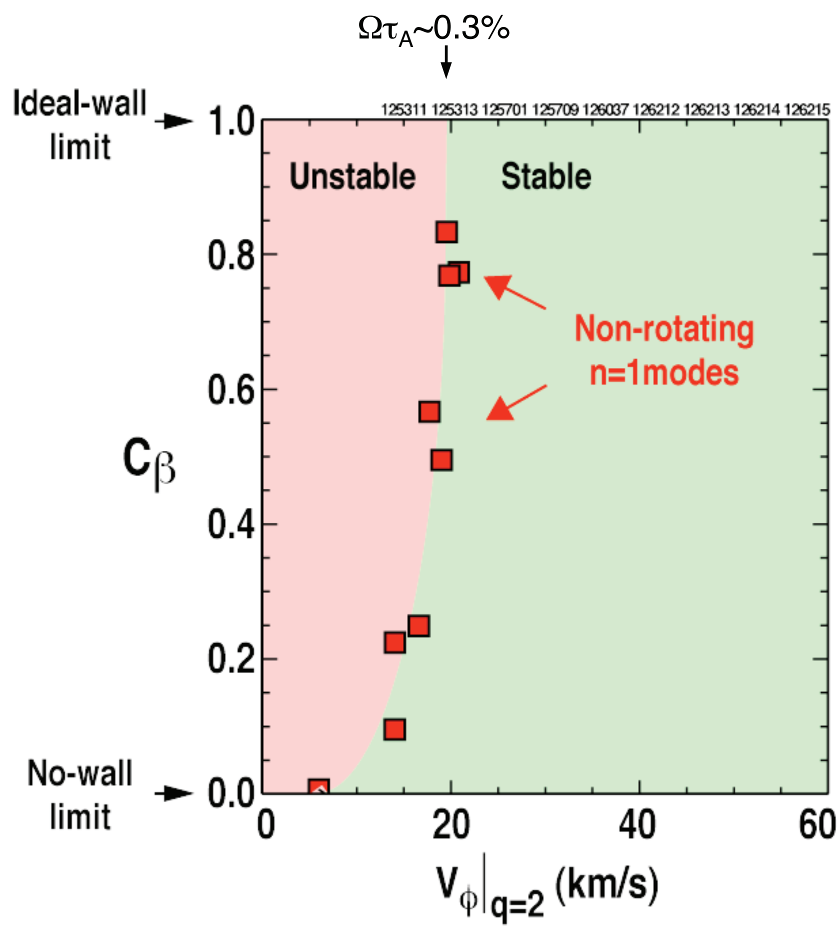
- **Operation limited by the onset of a rotating or locked growing *n*=1 mode**

Rotation threshold in wall-stabilized discharges is NOT imposed by an unstable RWM

- **Rotation at the *n*=1 mode onset has only a weak β dependence**
  [E.J. Strait, et al, *Phys. Plasmas* (2007)]



  – Growth on resistive rather than wall time-scale (τ_W~3ms)
  – Mode unaffected by feedback

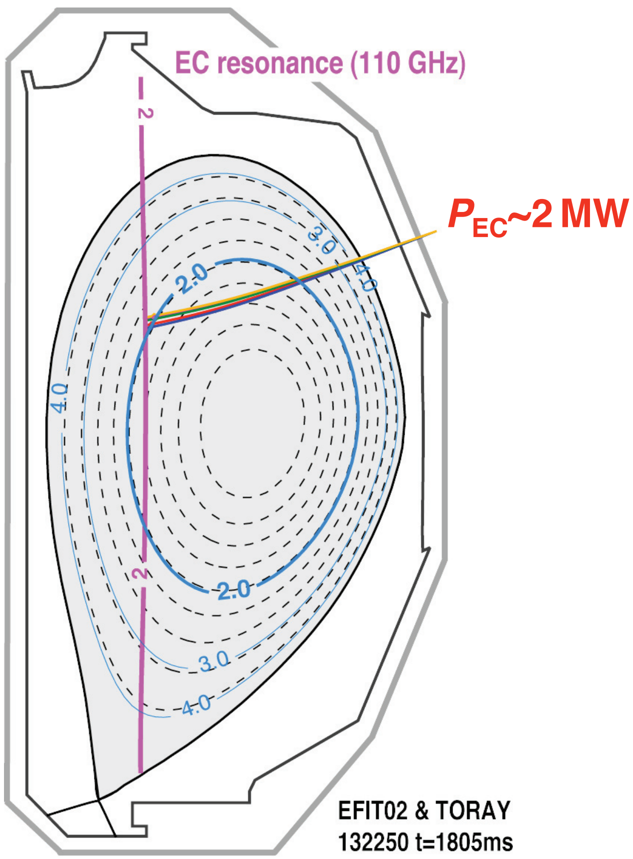


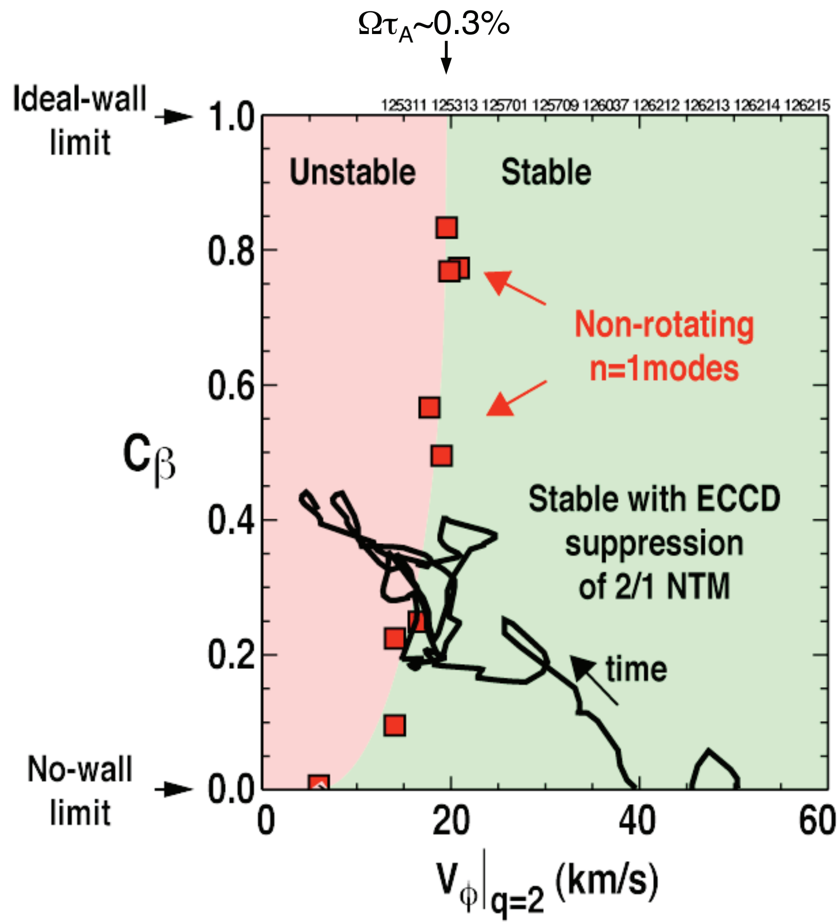
→ Perturbation evolution consistent with a locked growing 2/1 NTM

  – Critical β_N reduced at low rotation **→ R. Buttery, PO3.00003, We-PM**

NTM suppression can extend operating regime even below the previously reported rotation threshold

- **Apply preemptive ECCD *at q*=2 surface to suppress 2/1 NTM**
  [R. Prater, et al., *Nucl. Fusion* (2007)]



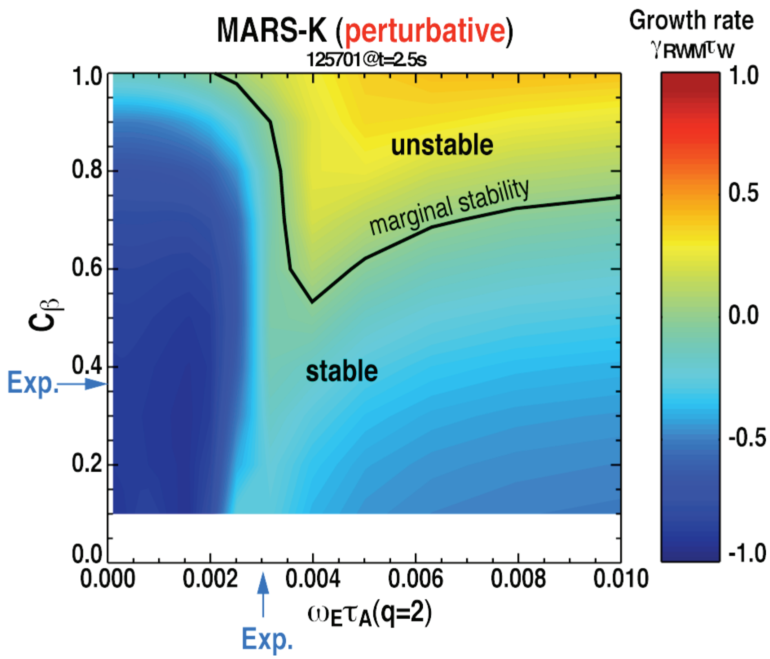


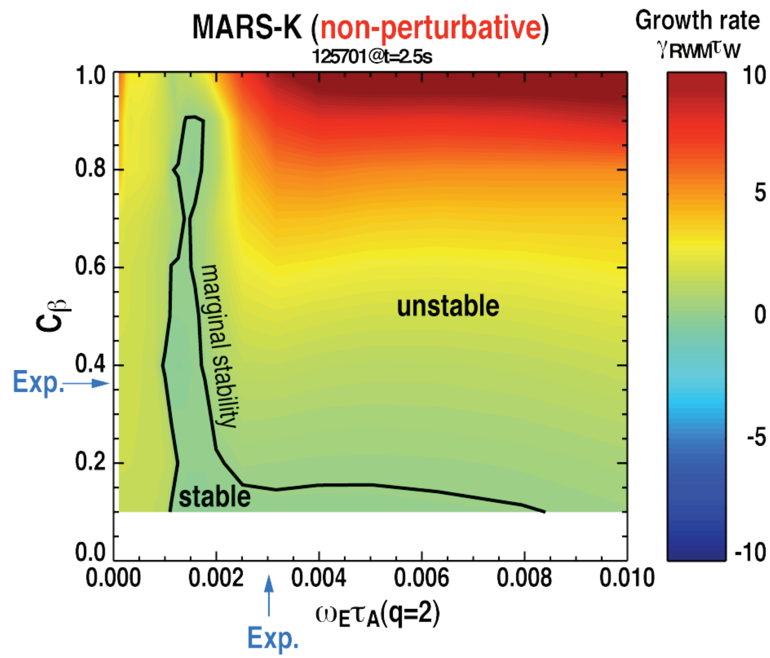
- **Operational constraints limit $C_\beta \leq 0.5$**

New MARS-K code shows the importance of a non-perturbative formulation of kinetic damping

- **MARS-K: Perturbative and non-perturbative formulation of kinetic damping including particle bounce and precession drift frequencies** [Y.Q. Liu, IAEA (2008)]
  – Thermal particles only

- **Compare perturbative and non-perturbative predictions for DIII-D plasma**





- **Non-perturbative formulation significantly reduces kinetic stabilization**
  → Additional physics needed to describe DIII-D experiments

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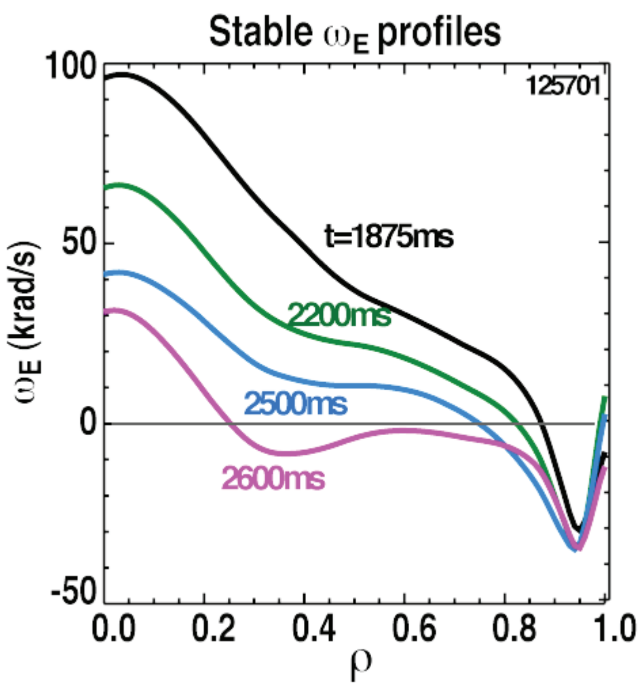
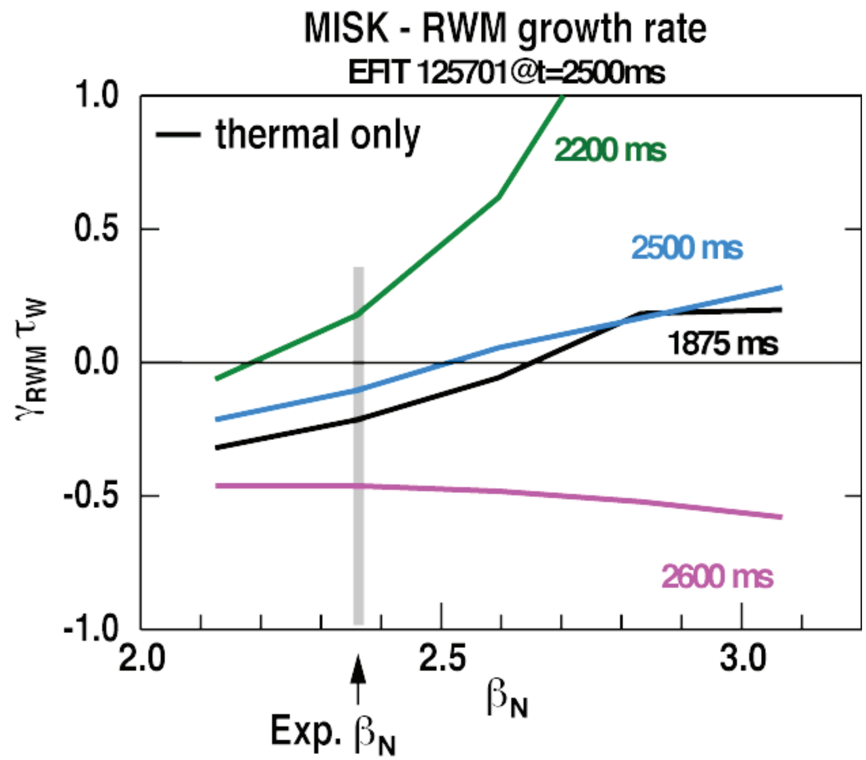
→ Y.Q. Liu, BI2.00003, Mo-AM

H. Reimerdes, 50th DPP Meeting, Nov. 2008

Perturbative calculations using the MISK code indicate the importance of hot ions for the observed RWM stability

- **MISK: Perturbative formulation of kinetic damping based on the PEST mode structure** [Hu, Betti, *Phys. Rev. Lett.* (2004), Sabbagh, et al., IAEA FEC (2008)]





→ **J.W. Berkery, NP6.00101, We-AM**

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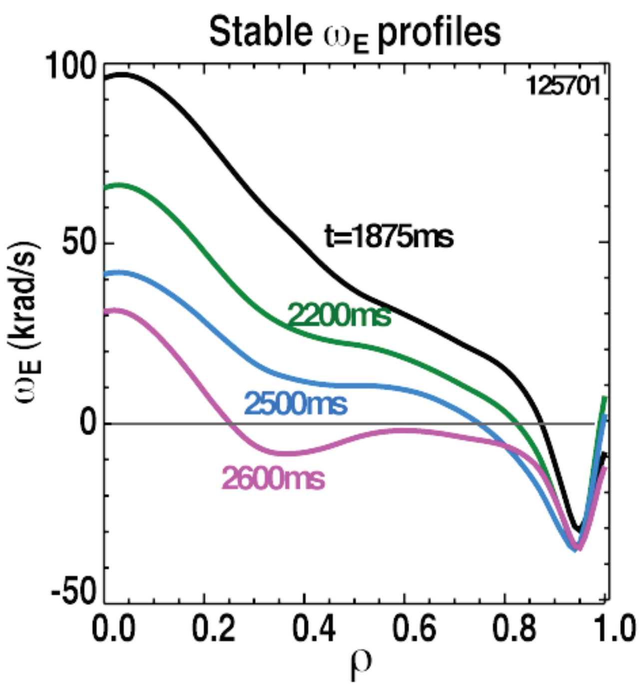

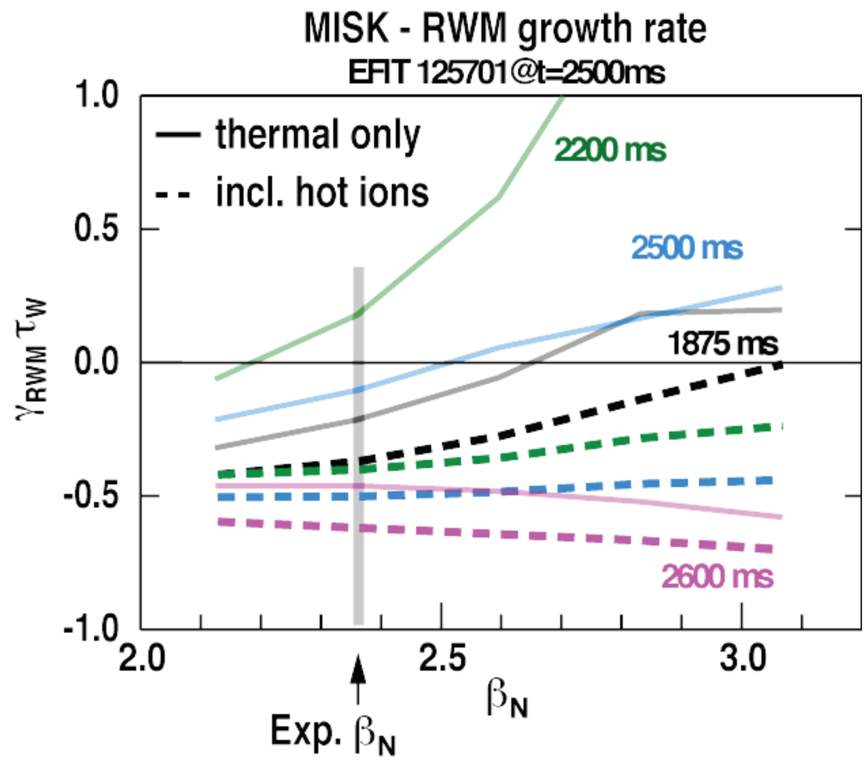

- **Kinetic effects sufficient to stabilize RWM over the entire range of observed rotation profiles**
  - Hot ions (~35% of total β) contribute significantly to the RWM stability

→ J.W. Berkery, NP6.00101, We-AM

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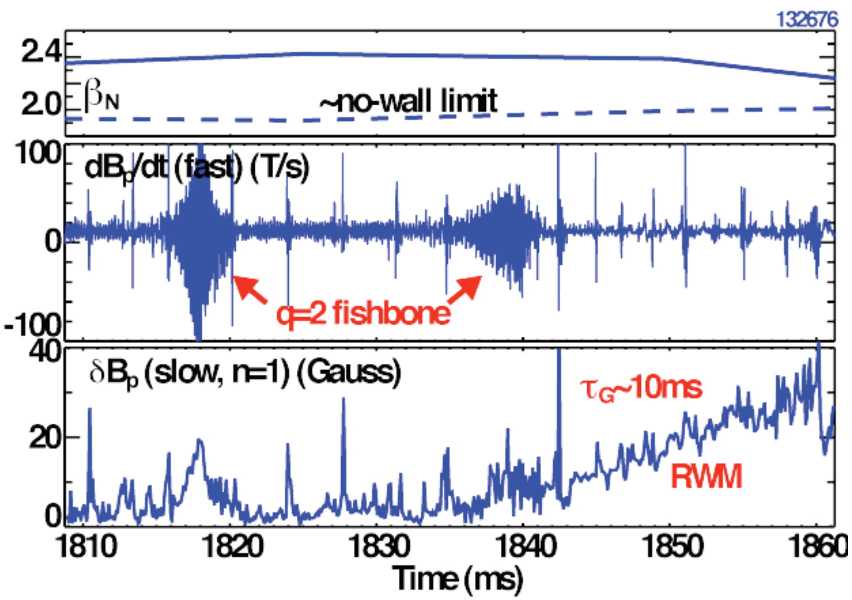
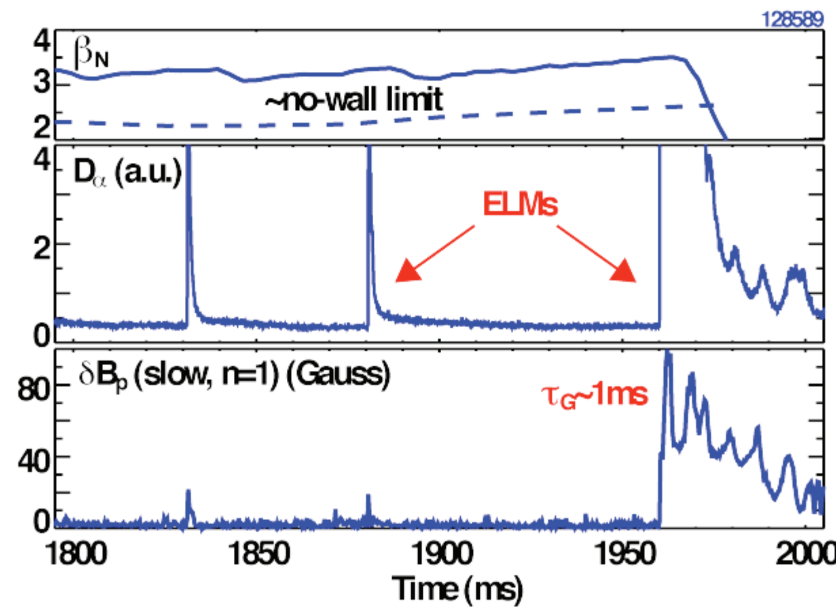
RWM can be triggered by localized instabilities such as q=2 fishbones and ELMs

- **Fishbone driven RWM observed at low density and slow rotation when q_{min}~2**



- **ELM driven RWM can occur even at high rotation**



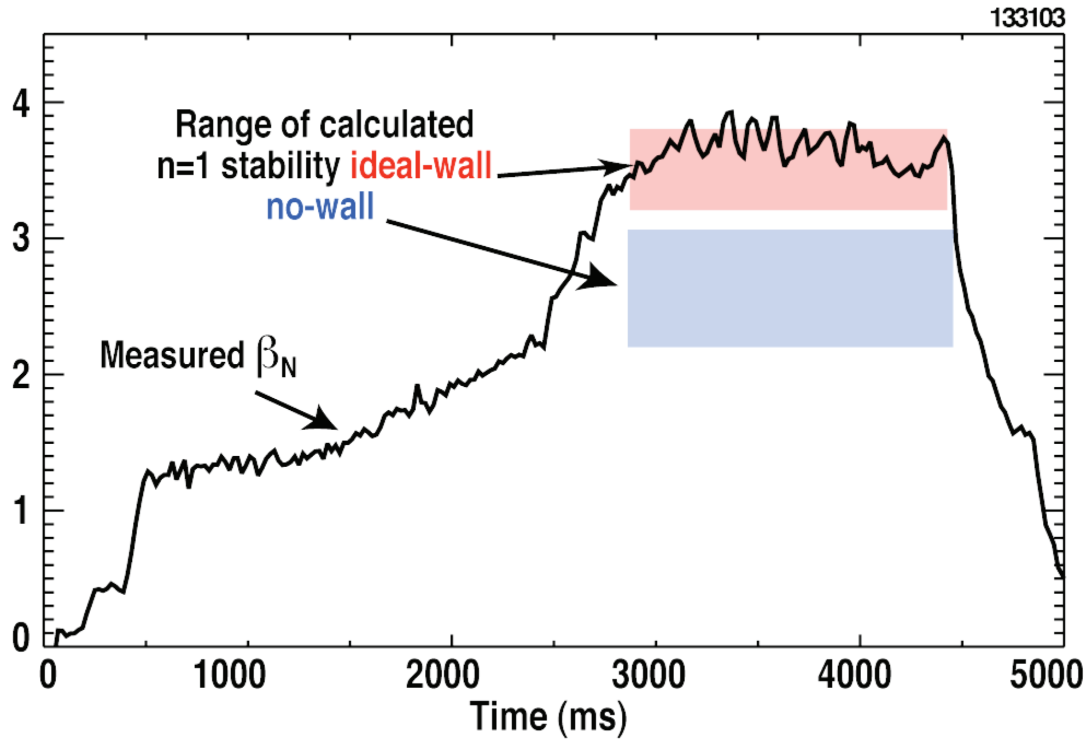
➔ **Requires a non-linear destabilization mechanism**

– Analyze evolution of δB in phase space → **E.J. Strait, YP6.00032, Fr-AM**

→ **M. Okabayashi, TP6.00005, Th-AM**

Optimized DIII-D steady-state AT scenario takes advantage of the full potential of wall stabilization

- **Sustained operation in the vicinity of the ideal wall limit achieved with**
  - Optimized error field correction
  - Broad ECCD deposition for 2/1 NTM suppression
  - Fast plasma rotation



→ C.T. Holcomb, CI1.00003, Mo-PM

Summary

- **RWM in DIII-D can remain stable over a wide range of plasma rotation profiles**
  - Suppressing 2/1 NTM with preemptive ECCD extends operating regime below the previously reported rotation threshold
- **Wall-stabilized plasmas test improved calculations of kinetic effects on linear RWM stability**
  - MARS-K calculations highlight importance of a non-perturbative approach, but predict weaker damping than observed in DIII-D
  - MISK calculations indicate the importance of hot ions (NBI), which have not yet been included in the MARS-K calculations
- **RWM can be triggered by other localized instabilities such as ELMs and *q*=2 fishbones suggesting the possibility of non-linear RWM destabilization mechanisms**