APS 2009 Outline: The Role of Kinetic Effects, Including Fast Particles, in RWM Stability

Jack Berkery

Department of Applied Physics, Columbia University, New York, NY, USA

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Princeton, NJ

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Abstract

The Role of Kinetic Effects, Including Fast Particles, in Resistive Wall Mode Stability*

J.W. BERKERY, Columbia University**

Theoretically, the RWM is thought to be stabilized by energy dissipation mechanisms that depend on plasma rotation and other parameters, with kinetic effects being emphasized[1]. Experiments in NSTX show that the RWM can be destabilized in high rotation plasmas while low rotation plasmas can be stable, which calls into question the concept of a "critical" plasma rotation for stability. Also, recent results from JT-60U show that fast particle modes can trigger RWMs[2], indicating the importance of including kinetic fast particle resonances in the theory of RWM passive stabilization. The present work tests theoretical stabilization mechanisms against experimental discharges with various plasma rotation profiles created by applying either n=2 or 3 field configurations, and with various fast particle fractions. Kinetic modification of the ideal stability criterion is calculated with the MISK code, using experimental equilibrium reconstructions. Analysis of multiple NSTX discharges from just before RWM instability is observed, predicts near-marginal mode growth rates, with trapped ions providing the dominant kinetic resonances. Resonances with fast particles also provide an important stabilizing effect. Increasing or decreasing the rotation in the calculation drives the prediction farther from the marginal point in either the stable or unstable direction, showing that unlike simpler "critical" rotation theories, kinetic theory allows for a more complex relationship between plasma rotation and RWM stability. Kinetic theory also has the potential to explain how fast particle loss can trigger RWMs, through the loss of an important stabilization mechanism.

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**In collaboration with S.A. Sabbagh, H. Reimerdes, R. Betti, and B. Hu.

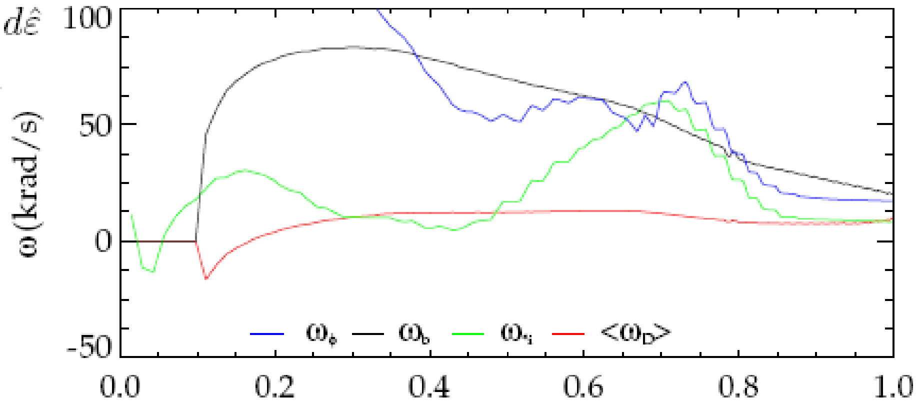
[1] B. Hu, R. Betti, and J. Manickam, *Phys. Plasmas* **12** (2005) 057301.
[2] G. Matsunaga et al., IAEA 2008.

High Level Outline

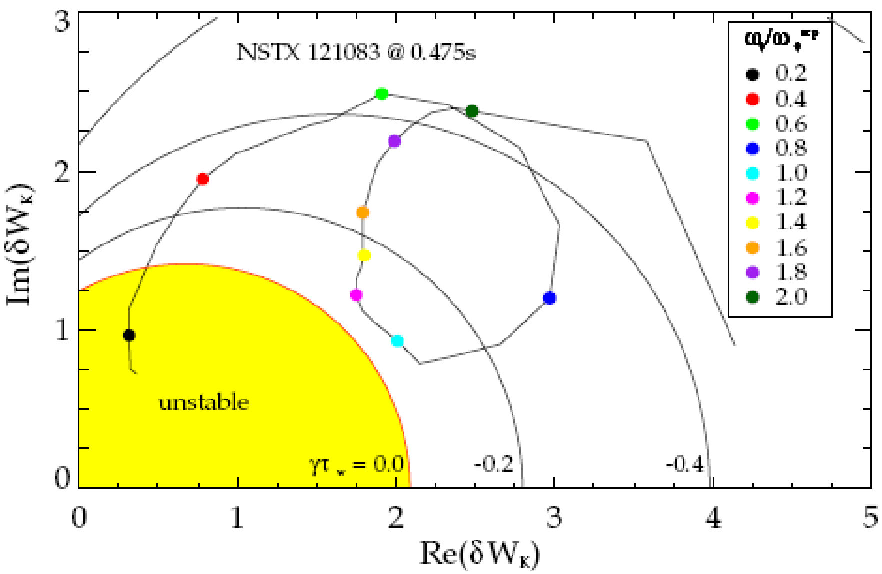
- RWM Kinetic Stability Theory:
  - Resonances of plasma rotation with precession drift and diamagnetic frequencies allow stability at low rotation and instability at intermediate rotation.
- Comparison to NSTX Experiments:
  - NSTX experimental results of instability at various plasma rotation profiles could not be explained by simple theories, but can be explained by kinetic theory.
- Including energetic particles adds a stabilizing effect
  - Could help explain the difference between NSTX and DIII-D RWM stability, and JT-60U observations of energetic particle mode RWM triggers.
  - Predicts that alpha particles can help ITER remain stable to RWM.
  - Presently this overpredicts stability compared to NSTX experiments.
  - Improvements to the treatment of energetic particles are possible, and are being implemented.

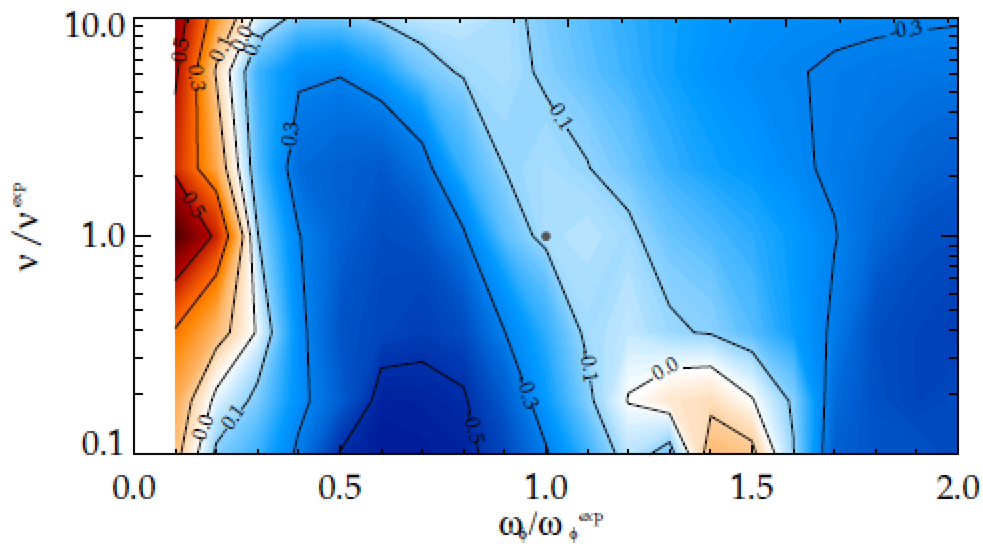
Kinetic theory and comparison to NSTX experiments

$$\delta W_K \sim \int_0^\infty \left[\frac{\omega_{*N} + \left(\hat{\varepsilon} - \frac{3}{2}\right)\omega_{*T} + \omega_E - \omega - i\gamma}{\langle \omega_D \rangle + l\omega_b - i\nu_{\text{eff}} + \omega_E - \omega - i\gamma} \right] \hat{\varepsilon}^{\frac{5}{2}} e^{-\hat{\varepsilon}} d\hat{\varepsilon}$$

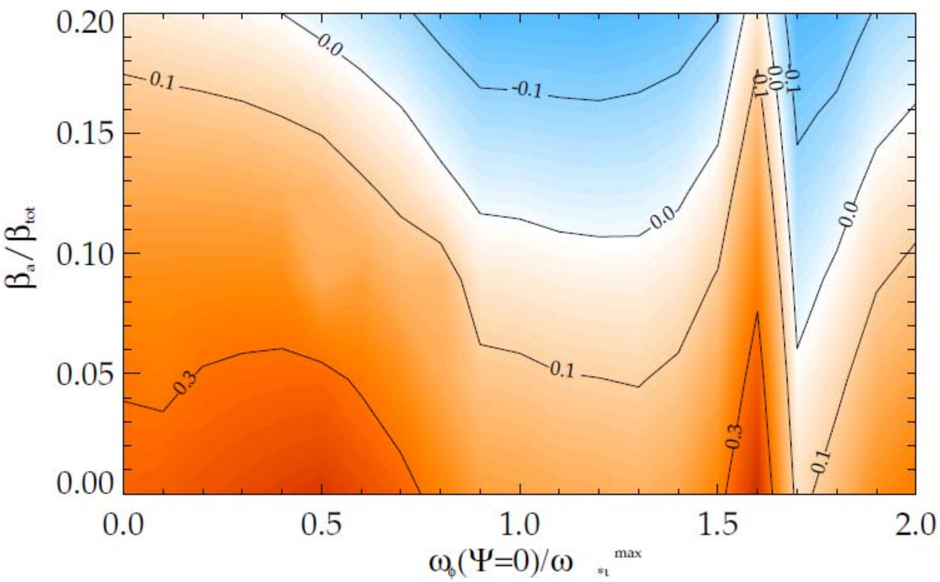


In kinetic theory there are multiple wave-particle resonances. Between the stabilizing precession drift and bounce frequency resonances, ω_ϕ can cancel with ω_{*i}, leaving $\omega_E = 0$ and reducing stability. This can explain RWM instability at relatively high rotation seen in NSTX.





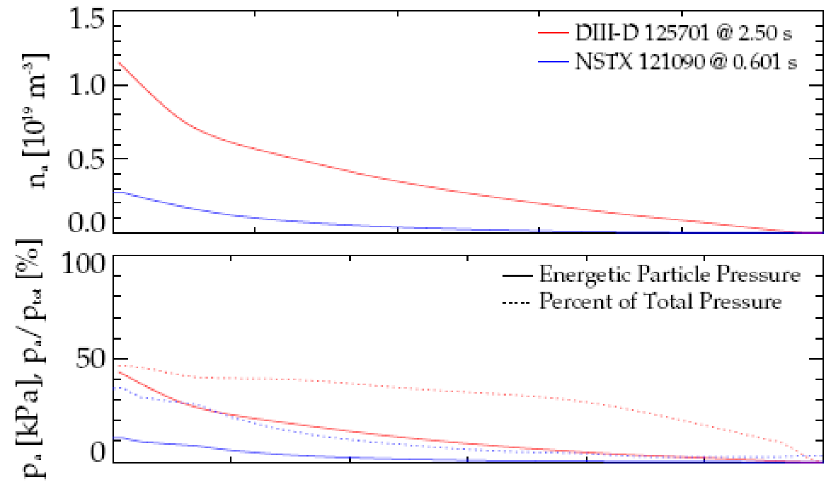
Energetic particles: ITER, DIII-D, and NSTX

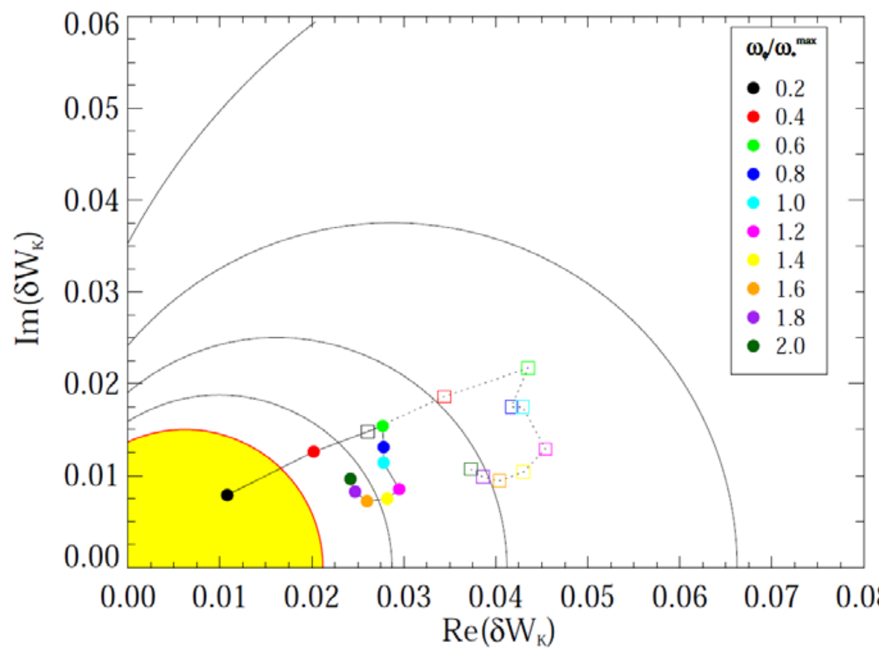


Alpha particle effects for ITER are correctly included and show the ability to stabilize the RWM.

DIII-D beam ion pressure profile is larger than NSTX. Efforts were made in a half-day XP to reduce the energetic particle content in DIII-D, but the RWM remained stable.

For NSTX, MISK seems to overpredict stability, especially with energetic particles included.





"Issues and Needs from the Group"

- For experiment/theory comparison *without* E.P.:
  - Complete. Currently writing a draft paper with Sabbagh and Betti.
- For energetic particles:
  - More analysis of present data (help with equilibria from Sabbagh).
  - Need better "experimental" profiles for ITER calculation (Sabbagh).
  - Would be good to compare FIDA simulated density profiles to TRANSP (Podesta, Heidbrink).
  - Would like to implement TRANSP beam ion distribution function in MISK analysis. Not 100% sure I can do this in time. Could use help with translation of TRANSP f into the form I need: $f_a(\Psi,\varepsilon,\Lambda)$. (???)

"Issues and Needs from the Group"

$$\delta W_K = -\sqrt{2}\pi^2 \sum_{\pm\sigma} \int d\hat{\varepsilon} \int d\Lambda \int d\Psi \frac{T^{\frac{5}{2}}\hat{\tau}}{m^{\frac{3}{2}}B_0} \frac{T\left((\omega + i\gamma)\frac{\partial f}{\partial \varepsilon} + \frac{\partial f}{\partial \Psi}\right)}{\langle\omega_D\rangle + l\omega_b - i\nu_{\text{eff}} + \omega_E - \omega - i\gamma} \hat{\varepsilon}^{\frac{5}{2}} \left[\langle H/\hat{\varepsilon}\rangle\right]^2$$

Using a Maxwellian leads to the familiar form for δW_K for thermal particles. For energetic particles, I currently use:

$$f_a(\varepsilon, \Psi) = \frac{3n_a}{8\sqrt{2}\pi}\left(\ln\left(1 + \hat{\varepsilon}_c^{-\frac{3}{2}}\right)\right)^{-1}\left(\frac{m_a}{\varepsilon_a}\right)^{\frac{3}{2}} \frac{1}{\hat{\varepsilon}^{\frac{3}{2}} + \hat{\varepsilon}_c^{\frac{3}{2}}}$$

But, it would be better to use $f_a(\Psi,\varepsilon,\Lambda)$ directly from TRANSP.

"Issues and Needs from the Group"

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 N=    10000 Emin= 0.000000E+00   rng_seed=    1208957313
 "AC" FILE 121083A11.DATA1 TIME =  4.7000E-01 +/-  5.0000E-03 sec.
  tokamak: NSTX NLSYM=F #= 1 A= 2.0 Z= 1.0 NEUTRAL BEAM
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  R(cm)  Z(cm)  vpll/v  E(eV) -- 4(1x,1pe13.6)  (get_fbm)
  1.201988E+02  2.980755E+00  7.359741E-01  6.304164E+04
  9.379746E+01 -3.445899E+00  1.841772E-01  3.036160E+04
  1.013430E+02  2.231355E+01  2.240487E-01  4.833252E+04
  1.195976E+02  4.239142E+00  1.937160E-01  2.104600E+04
  8.827346E+01  9.050176E+00  1.352235E-01  3.435382E+04
  1.232774E+02  1.015873E+01  5.842287E-01  1.267039E+04
  1.234808E+02  1.684721E+01  1.212909E-01  9.116948E+03
  9.886298E+01  6.585267E+00  4.554875E-01  5.348661E+04
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$\Lambda = \mu B_0/\varepsilon = (v_\perp/v)^2 B_0/B$