NSTX

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Recent Resistive Wall Mode Kinetic Stabilization Theory and Experiment Results

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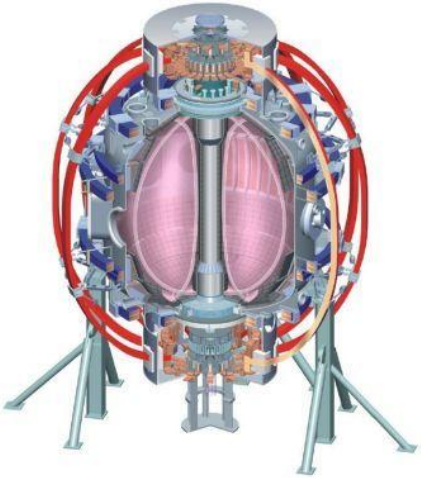

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Kinetic theory, including thermal and energetic particles, can explain experimental results

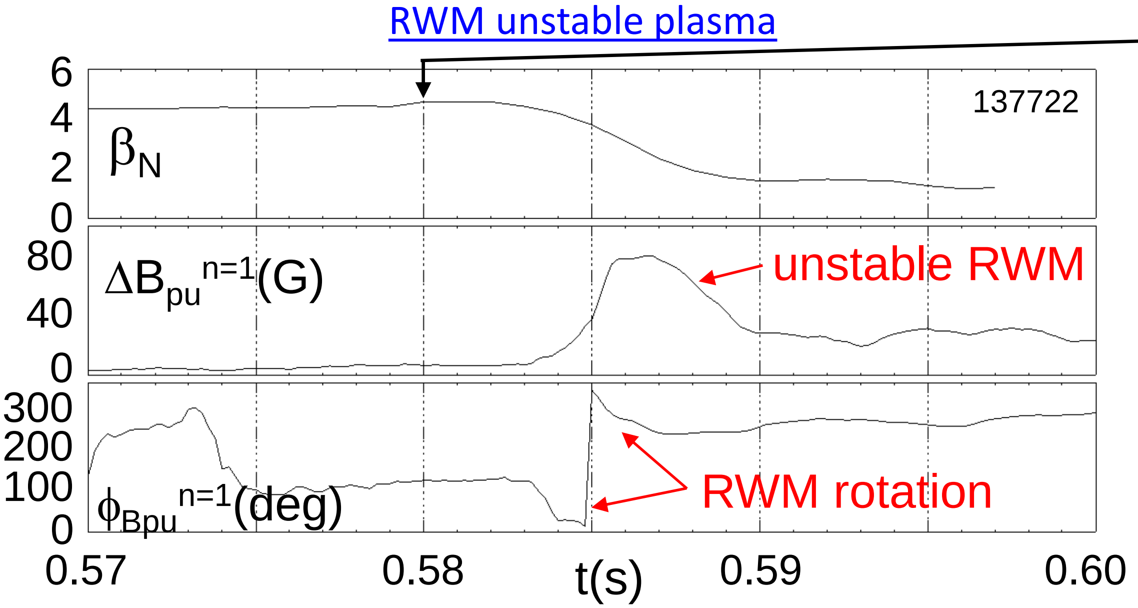
Motivation

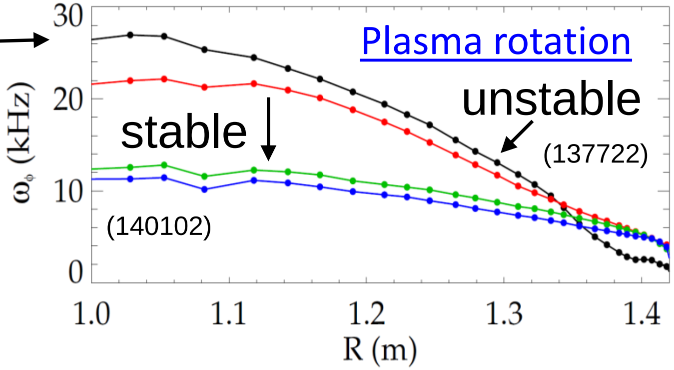
RWM stabilization is key for disruption-free operation of a low rotation, low collisionality, low l_i future devices

Outline

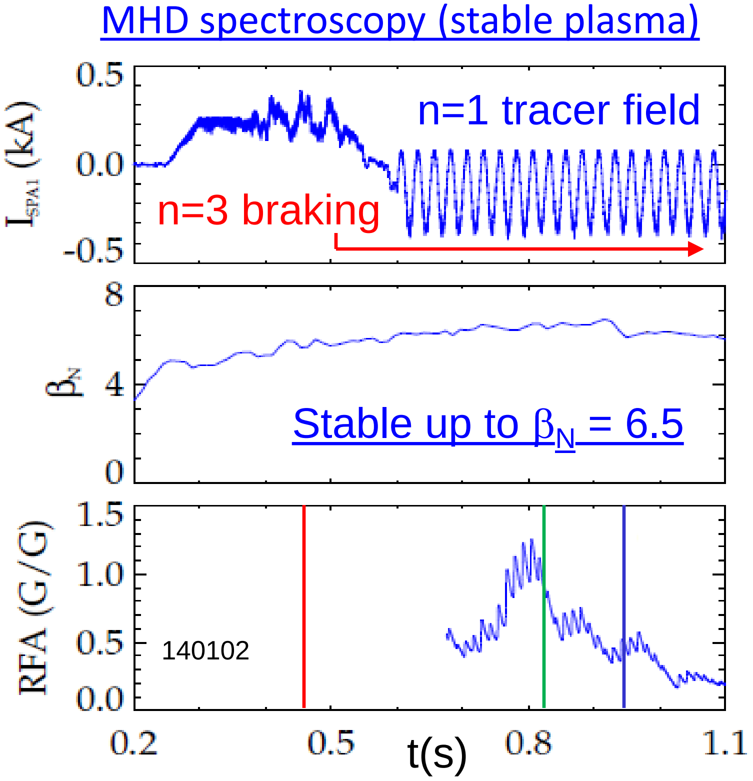
- XP1020 Results
  - RFA indicates weakened stability at intermediate ω_ϕ
  - Reduced l_i plasmas more stable?
- Towards unification of theory and experimental results
  - NSTX and DIII-D results consistent with kinetic theory
- New analysis of the effect of collisionality on stability
  - Important for future devices, NSTX-U

A scalar critical plasma rotation model can not explain RWM stability; it depends on the ω_ϕ *profile*





[S. Sabbagh *et al.*, IAEA FEC 2010, EXS/5-5]

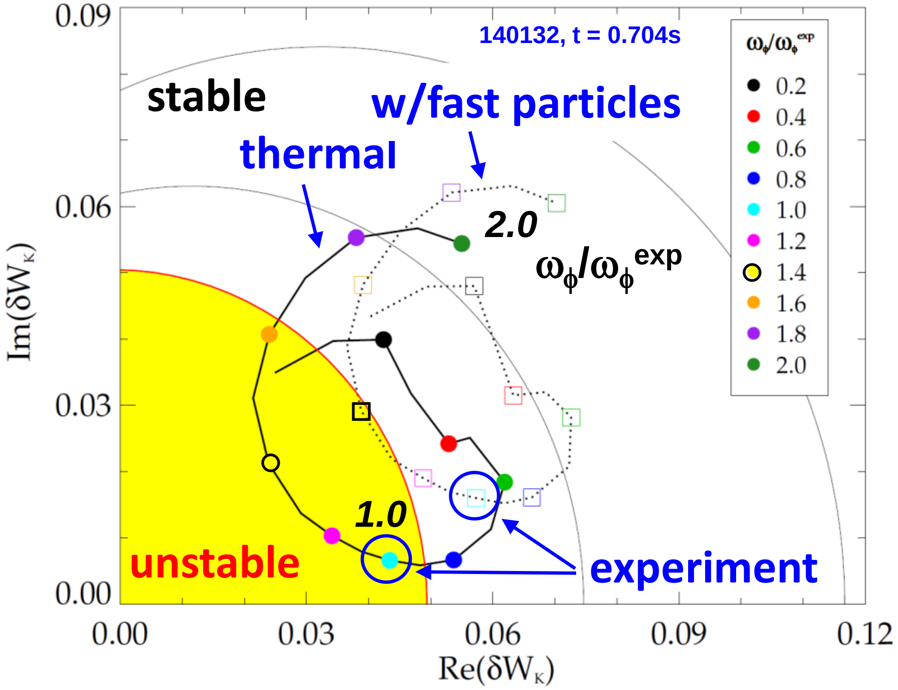


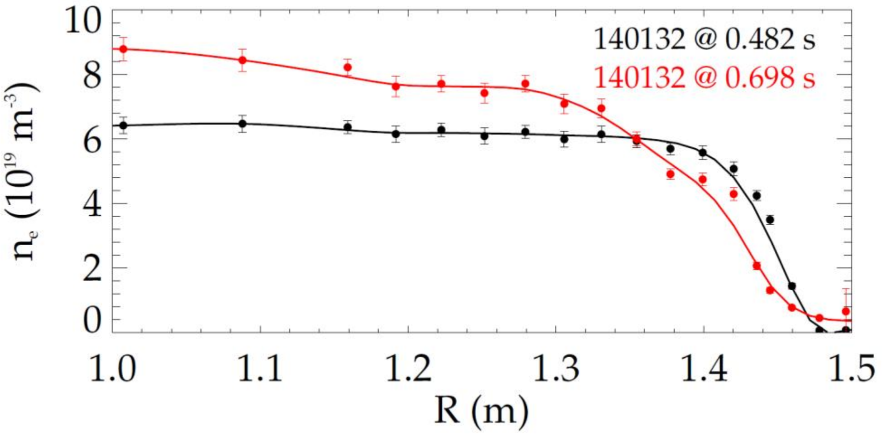
- RWM unstable plasma
  - Instability occurs at relatively high rotation level, and not at highest β_N (4.7)
- RWM stable plasma
  - MHD spectroscopy: increased resonant field amplification (RFA) indicates reduced stability
  - Plasma moves to more stable regime (lower RFA) at lower rotation (β_N up to 6.5)

MISK calculations show reduced stability in low l_i target plasma as ω_ϕ is reduced, RWM instability is approached

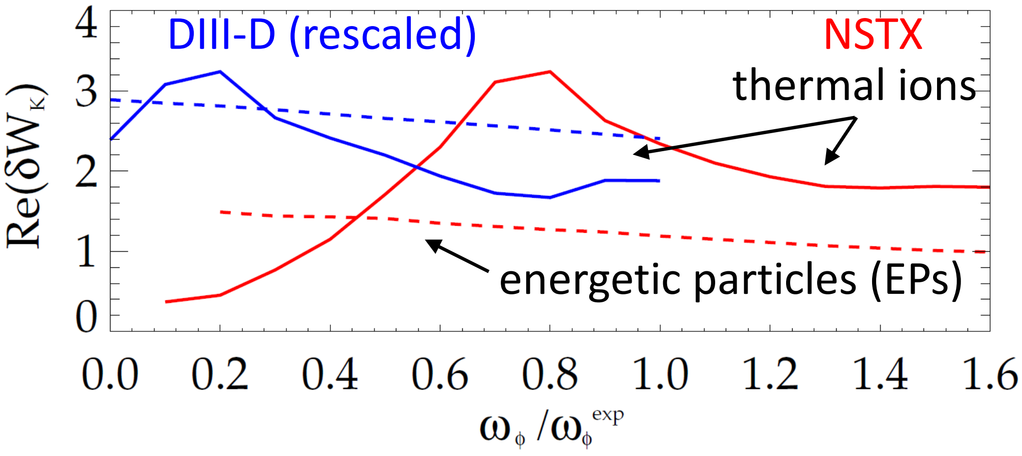
- Stability evolves
  - l_i increases in time as RWM instability is approached, but remains low (l_i = 0.42)
  - MISK computation shows plasma to be stable at time of minimum l_i
  - Region of reduced stability vs. ω_ϕ found before RWM becomes unstable (l_i = 0.49)
    - Co-incident with a drop in edge density gradient – reduces kinetic stabilization →

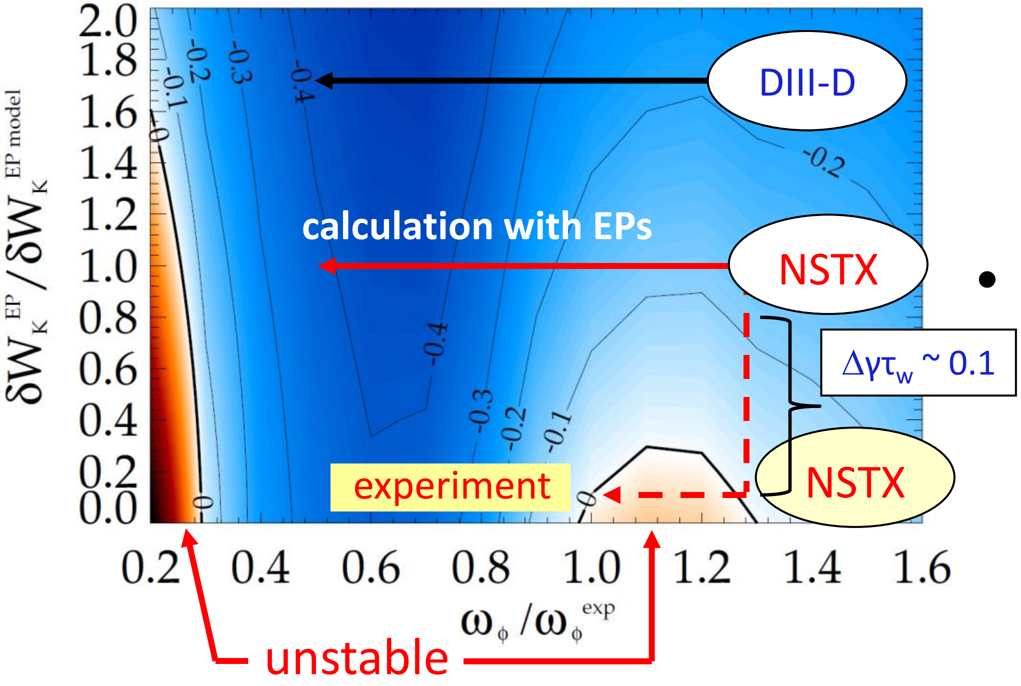
RWM stability vs. ω_ϕ (contours of $\gamma\tau_w$)





Model of kinetic modifications to ideal stability can unify RWM stability results between devices





- Observed, NSTX:
  - RWM can cross marginal point as ω_ϕ is varied
  - RFA can increase in stable plasmas at intermediate ω_ϕ
- Observed, DIII-D:
  - RWM stable at all ω_ϕ, but RFA can increase in at intermediate ω_ϕ
  - RWM destabilized by events that reduce EP population

  [M. Okabayashi *et al.*, Nucl. Fusion (2009)]
- Explanation:
  - Both have rotational resonances between the mode and thermal ion precession drift.
  - DIII-D has a higher EP fraction than NSTX, leading to higher stability.

  [S. Sabbagh *et al.*, IAEA FEC 2010, EXS/5-5]

Advancements in the theoretical model continue

Electrostatic effect

The electrostatic component of the perturbed distribution function contributes to δW. This effect is likely to be small, however.

$$\delta W_{\Phi} = -\frac{1}{2}\int e^2 \left|\tilde{\mathbf{\Phi}} + \boldsymbol{\xi}_{\perp}\cdot\boldsymbol{\nabla}\Phi_0\right|^2 \sum_j Z_j^2 \frac{n_j}{T_j} d\mathbf{V}$$

[B. Hu *et al.*, Phys. Plasmas **12**, 057301 (2005)]

Additional anisotropic term

In addition to the effect of anisotropy on δW_K, when *f* is anisotropic an additional term arises that is proportional to $\tilde{\mathbf{B}}_{\|}$:

$$\delta W_{\tilde{B}} = \sum_j \frac{1}{2}\int\int \langle HT_j\rangle^* \mu \frac{\tilde{\mathbf{B}}_{\|}}{B}\frac{\partial f_j}{\partial \mu} d^3\mathbf{v} d\mathbf{V}.$$

Centrifugal destabilization

This fluid force term is usually neglected, but it is always destabilizing, and could be important if the plasma rotation Mach number is significant, or for alpha particles rotating at higher frequency ~ $\omega_{*\alpha}$.

$$\delta W_C = -\frac{1}{2}\sum_j \int \boldsymbol{\xi}_{\perp}^* \cdot \left[\tilde{\rho}\mathbf{v_0}\cdot\boldsymbol{\nabla}\mathbf{v_0}\right] d\mathbf{V}$$

Other possibilities:

- Inclusion of plasma inertia term in the dispersion relation.
- Effect of poloidal rotation on ω_E (small?).
- Use of a Lorentz collisionality model instead of current ad-hoc inclusion of collisionality.

$$C\left(\tilde{f}\right) = \frac{1}{2}\nu\Pi_{\varepsilon}\frac{\partial}{\partial\chi}\left(1-\chi\right)^2\frac{\partial\tilde{f}}{\partial\chi}$$

Collision frequency is very high for electrons, very low for energetic particles, but in the right range for ions

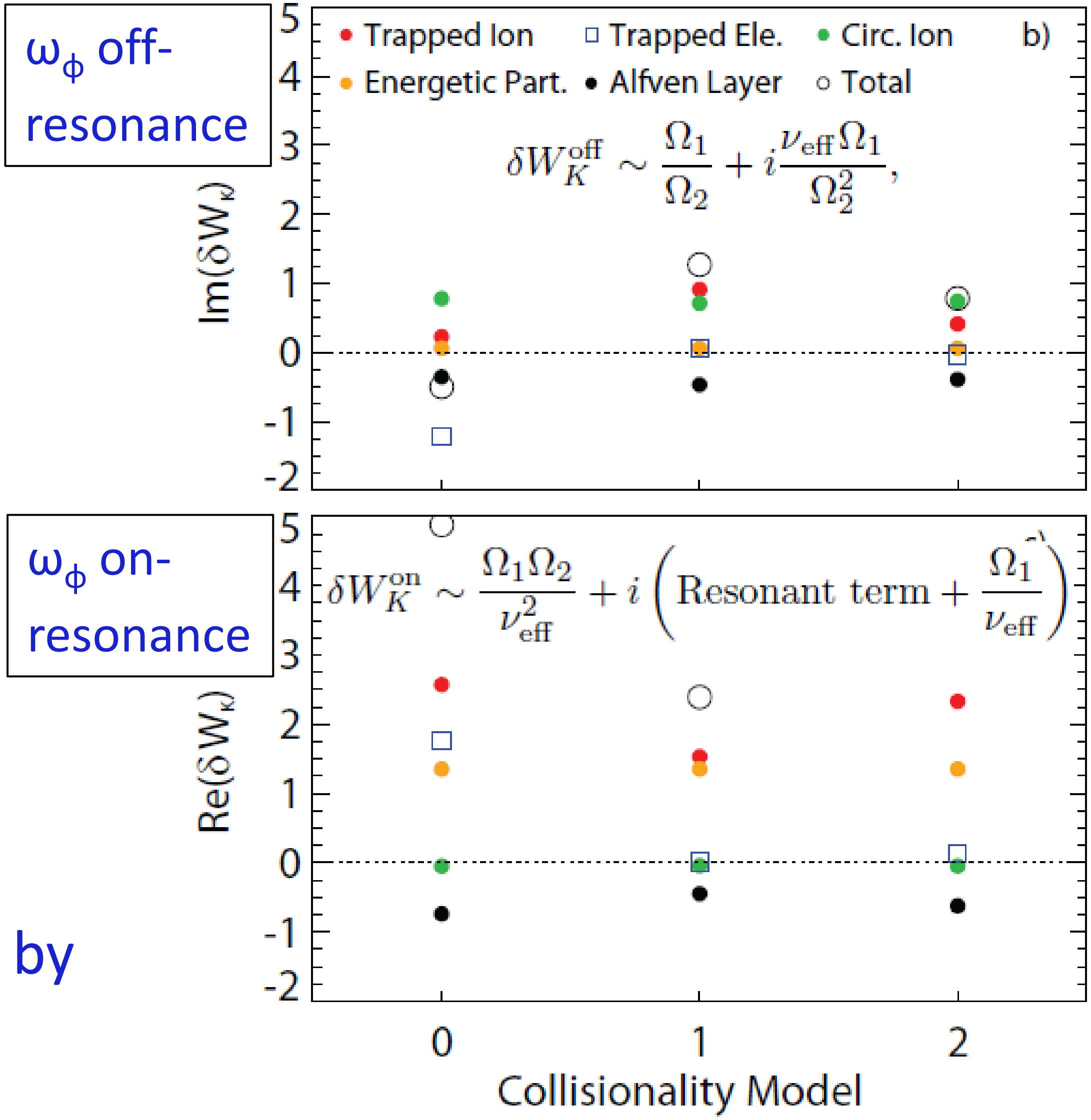
Three collisionality models:

$\nu_0 = 0$ (MARS)

$$\nu_1(\Psi) = \frac{\sqrt{2} n_i m_{ji}^{\frac{1}{2}} Z_i^2 Z_j^2 e^4 \ln \Lambda}{12 \pi^{\frac{3}{2}} \epsilon_0^2 m_j T_j^{\frac{3}{2}}} \epsilon_r^{-1}$$

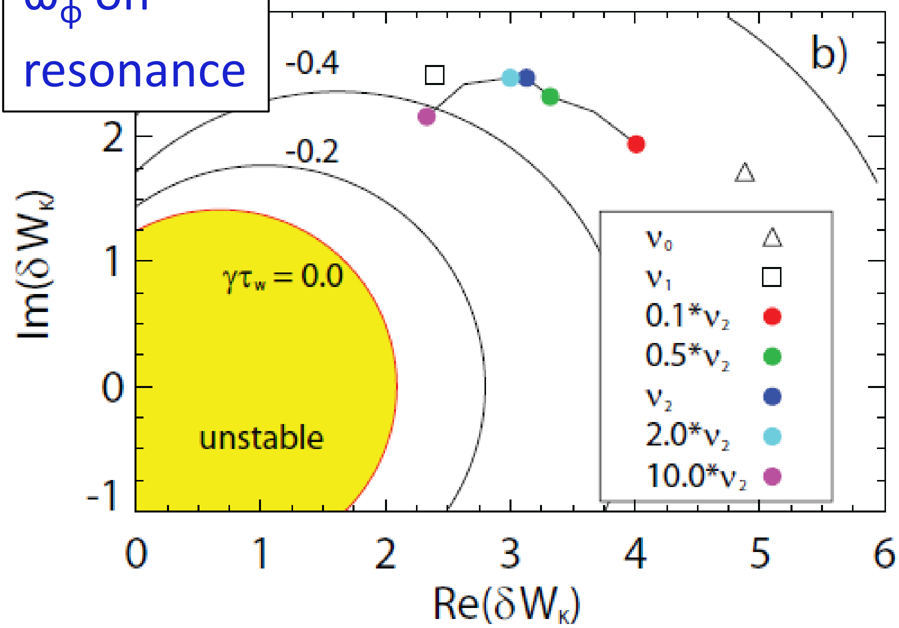
$\nu_2(\Psi, \varepsilon) = \nu_1 \hat{\varepsilon}^{-\frac{3}{2}}$ (MISK)

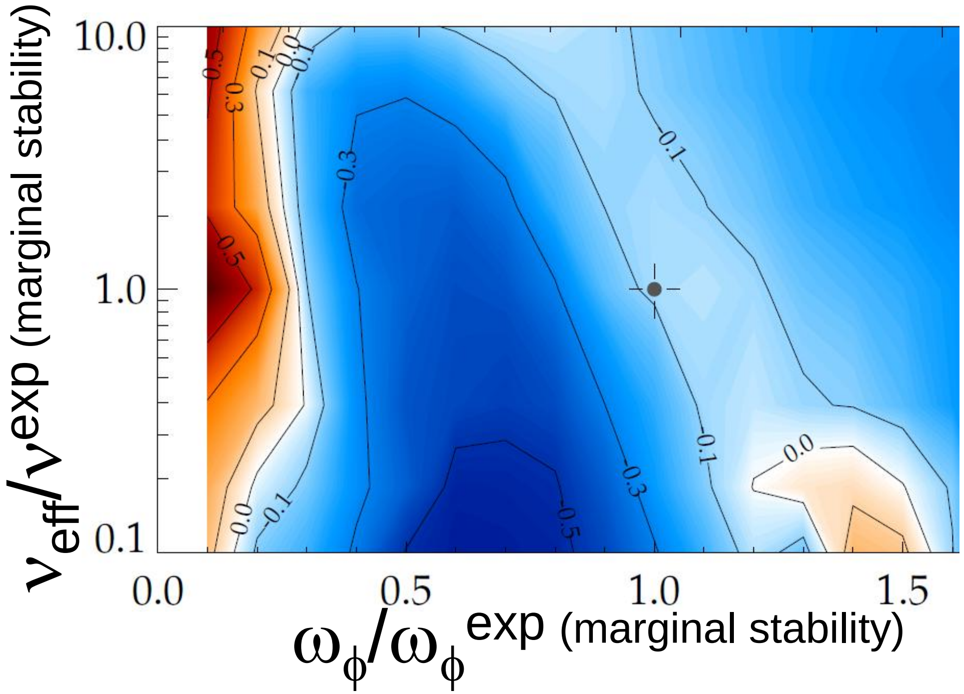
- Energetic Particles are unaffected by collisionality.
- As soon as ν ≠ 0, Electron component → 0.
- Trapped Ions *are* affected by collisionality model.



Reduced collisions allow resonant kinetic stabilizing effects to be more powerful, but also reduce collisional dissipation

ω_ϕ on-resonance





- The effect of reduced collisionality in future machines:
  - Lower stability off-resonance plasmas even less stable
  - Higher stability on-resonance plasmas even more stable
  - Makes it all the more important to mitigate the effects of reduced stability at off-resonance ω_ϕ.

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