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XP1020: Determination of Weak RWM Stability Rotation Profiles

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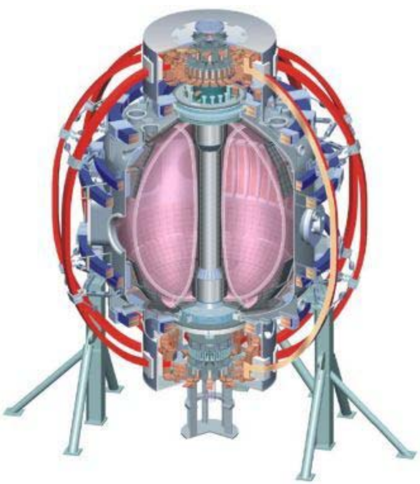

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RWM passive stability vs. rotation at low ℓ_i

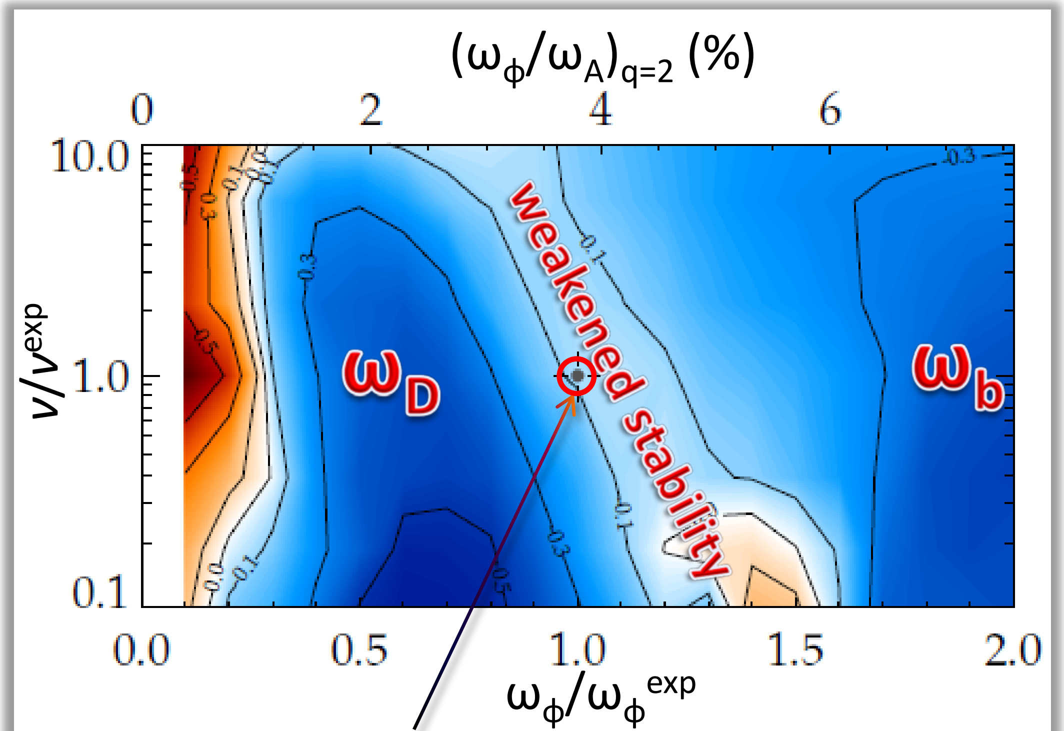
- Motivation
  - It is key to understand passive stability in regimes of high importance to the future of the ST (low ℓ_i).
  - Kinetic theory indicates that plasmas with ω_ϕ in between ω_D and ω_b resonances have weakened stability. *(Berkery et al., PRL, 2010)*
  - NSTX has the capability to test the importance of various effects in the theory.
- Goals
  - Verification of a unified, quantitative physics model for RWM stability based on variations of key variables in plasma near marginal stability.
  - Compare stable γ and ω_r measured with MHD spectroscopy , and the marginally unstable points, as a function of ω_ϕ and other key parameters, and compare to kinetic theory prediction.
  - Provide input to the eventual goal of realtime stability limit detection via resonant field amplification (RFA) measurement.

RWM passive stability vs. rotation at low ℓ_i

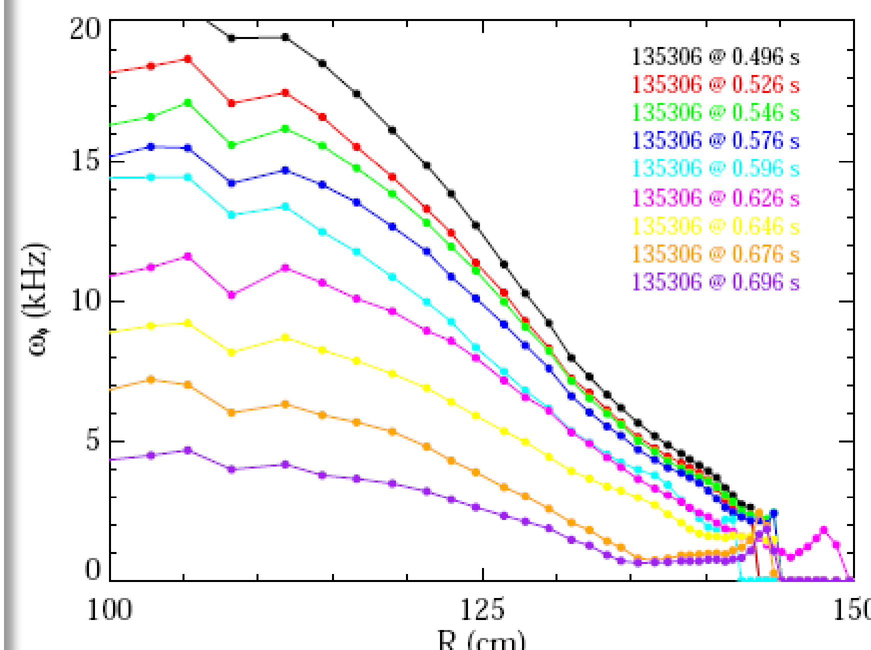
- Addresses:
  - NSTX Milestone R(10-1): Assess sustainable beta and disruptivity near and above the ideal no-wall limit.
  - ITPA: MDC-2: Joint experiments on resistive wall mode physics.
  - ITPA: MDC-12: Non-resonant magnetic braking.
  - ReNeW Thrust 16 proposed action: Implement and understand active and passive control techniques to enable long-pulse disruption-free operation in plasmas with very broad current profiles.

NSTX plasmas can go unstable at weakened stability rotation, or can navigate through to low rotation

- Weakened stability occurs at relatively high rotation when ω_ϕ is between ω_D and ω_b stabilizing resonances
  - Some shots are able to avoid RWM instability, make it to low ω_ϕ

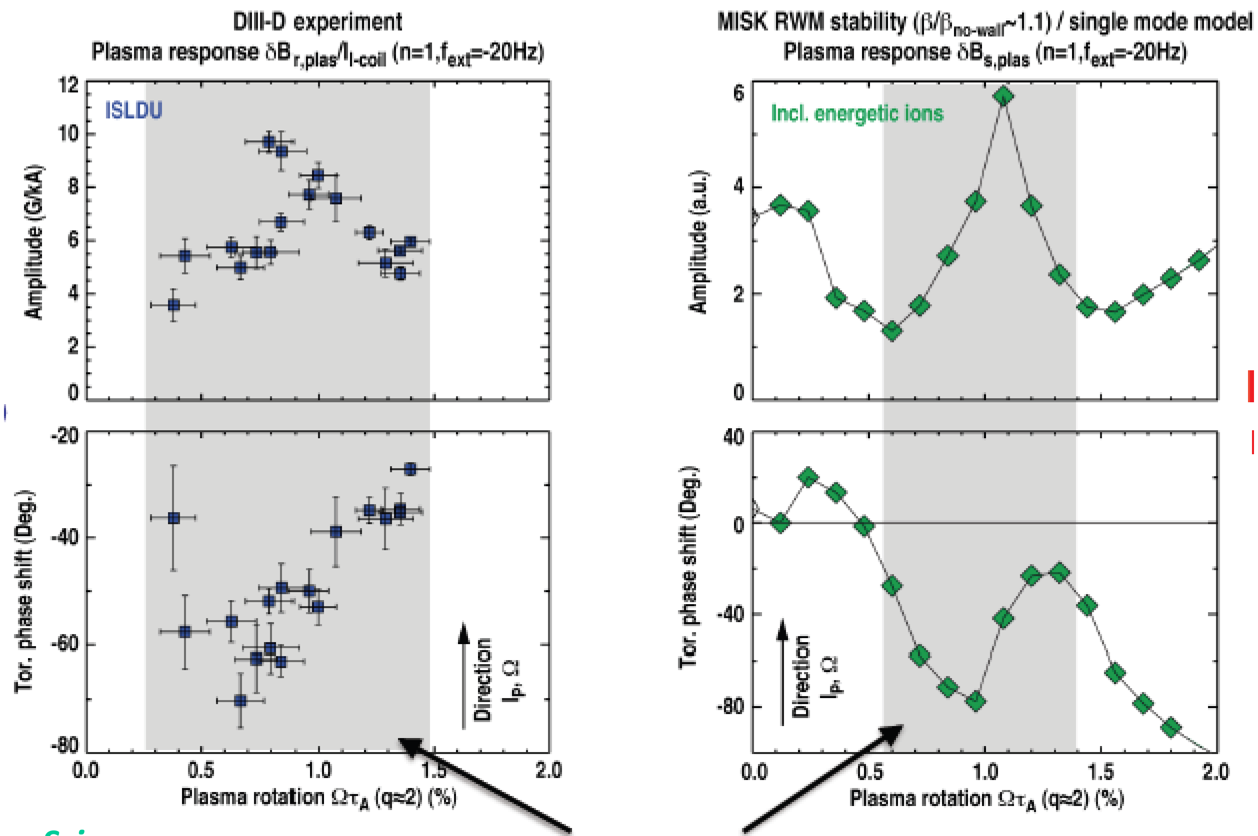


NSTX experimental instability



DIII-D results, Jan. 2010, are consistent with kinetic model

- Measured response to external n=1 fields (20 Hz) indicates that discharges were indeed least stable for $\Omega\tau_A$ ~ 0.8-1.0%.
  - Large plasma response to external (quasi-static) n=1 field indicates weakly damped RWM.
  - Key features of the kinetic modeling are duplicated.



Compare these rotation ranges

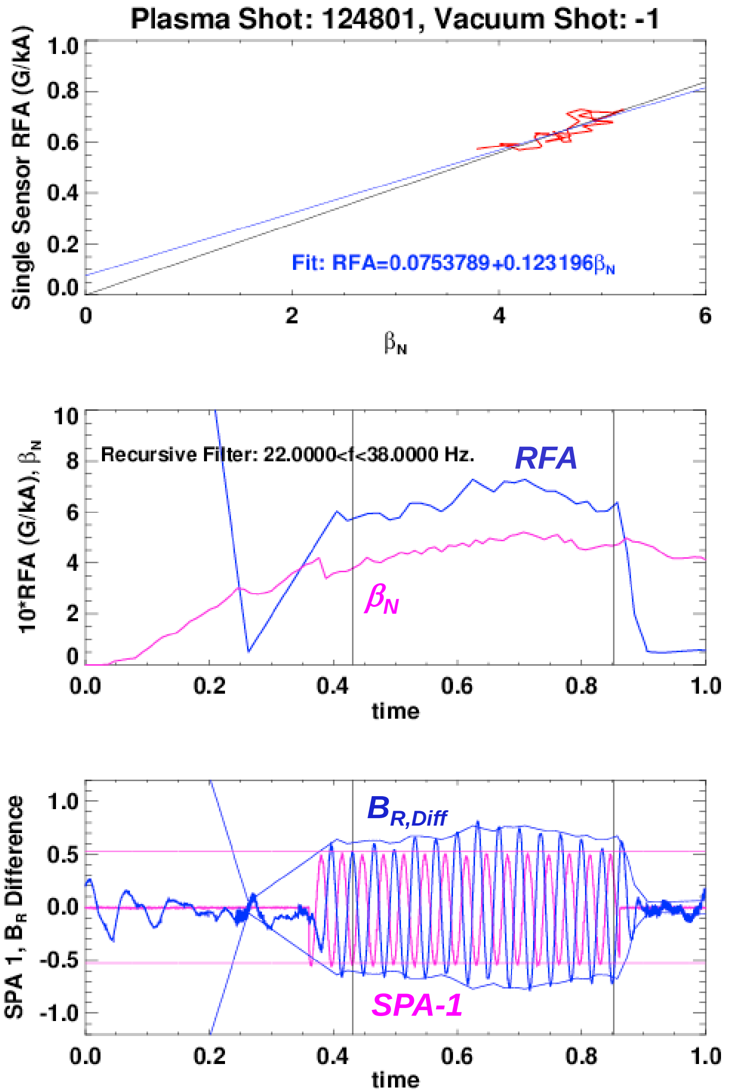
(Reimerdes, DIII-D Friday Science Meeting, February 12, 2010)

Realtime stability limit detection via RFA is an eventual goal

- This experiment can also provide valuable data to the eventual goal of realtime stability limit detection via RFA.
  - Traveling waves will be applied for many shots that will approach, and reach, unstable conditions.

$$RFA = \frac{B_{R,Diff,Peak-to-Peak}}{I_{RWM,Peak-to-Peak}}$$

(Gerhardt, XP930 presentation, 2009)



XP1020: Determination of Weak RWM Stability Rotation Profiles

- Approach
  - Establish long pulse target plasmas at low ℓ_i.
    - If low ℓ_i target proves difficult, can use standard long pulse shot.
  - Use mild n=3 non-resonant magnetic braking to get a slow ramp to low rotation without RWM instability.
    - Use guidance from previous XPs and MISK to find conditions that are near marginal stability.
    - If disruption is unavoidable, optionally add n=1 feedback at crucial time
  - Add n=1, 30 Hz., 1kA peak to peak traveling wave for active MHD spectroscopy.
    - Will be used in the background of all shots, as a diagnostic.
  - Vary key parameters in the model that can alter RWM stability, to determine the effect on the plasma for comparison to theory.

XP1020: Determination of Weak RWM Stability Rotation Profiles

- Approach, continued
  - Vary key parameters in the model that can alter RWM stability, to determine the effect on the plasma for comparison to theory.

$$\delta W_K = \delta W_K^{\text{thermal}} + \delta W_K^{\text{energetic}} - \frac{1}{2}\sum_j \int \frac{n_j}{T_j} \left| e\tilde{\Phi} + \xi_\perp \cdot \nabla e\Phi_0 \right| dV$$

rotation resonances and collisionality effect	EPs add stability. New term from theory (asymmetric f): $\mu \frac{\tilde{B}_\parallel}{B} \frac{\partial f}{\partial \mu}$	Electrostatic effect: not previously included in calculation. Important with strong co-NBI.

XP1020: Determination of Weak RWM Stability Rotation Profiles

- Approach, continued
  - Vary key parameters in the model that can alter RWM stability, to determine the effect on the plasma for comparison to theory.
    1. Use extremes of energetic particle fraction.
    2. Use extremes of collisionality.
    3. Vary quantities related to the electrostatic term.
    4. Test the importance of $\tilde{B}_{||}/B$ with pulses of n = 3 field.

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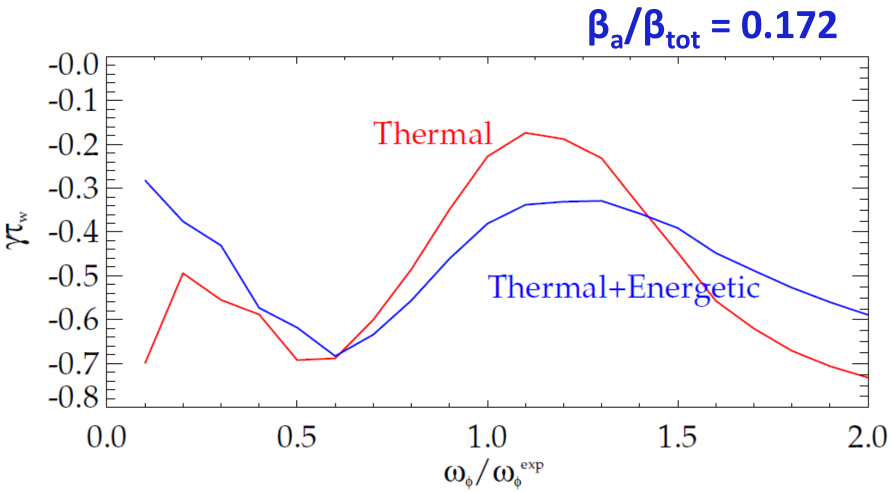
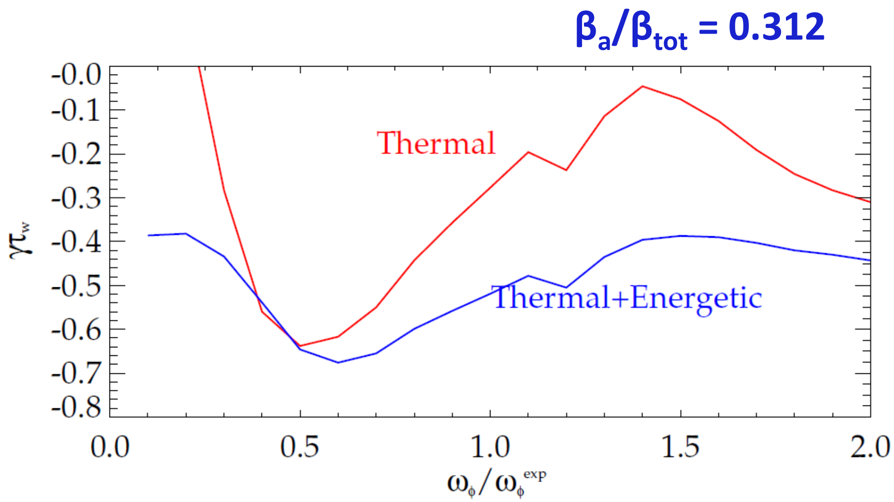




Shot Plan

Task	Number of Shots
1) Establish target with slow rotation ramp down and AC fields	
A) Developed or improved in XP1023 (or LLD survey XP) start n=3 error field correction at 0.250 s, ramping to full amplitude at 0.300 s. Backup position: long pulse, low to moderate l_i target.	1
B) During the period devoid of n=1 rotating mode activity, vary the n=3 DC field from correcting phase to braking phase, and vary the SPA current ramp rate and timing to optimally change plasma rotation, to find the marginal point. Attempt to navigate through the marginal point to low rotation without an unstable RWM, as slowly as possible.	2
C) Add n=1, 30 Hz, 1kA peak to peak AC field. (Use setup from XP935)	1
D) Come back to B, using RFA as a metric of how close the approach to instability is. Optimize rotation ramp to get as close as possible.	2

2) Vary key parameters in the model that can alter RWM stability, to determine the effect on the plasma for comparison to theory.

A) Energetic particle content

Several shots at each condition for reproducibility.

Condition	I_p (MA)	B_t (T)	Shots
1	1.1	0.55	3
2	0.8	0.4	3

Shot Plan, continued

B) Collisionality

Using LLD and gas puffing, change the density profile, which will change the collisionality. Use results from initial LLD XPs, LLD survey XP, and XP1023 to most efficiently generate different collisionality conditions.

Condition	ν	Shots
3	High	3
4	Low	3

C) Electrostatic effect

Use the high and low collisionality conditions 3 and 4 to get high/low n_i/T_i. Within those variations, probe low and intermediate ω_E at the time of peak beta. 8

D) "Error field"

Use short ($\sim\tau_{momentum} \sim$ 10 ms), relatively high amplitude n=3 pulses to examine the possible effect due to the $\tilde{B}_{||}$ term, while not entering very low rotation states. Start with 1kA at the desired time, and double until the braking effect gets too large. 4

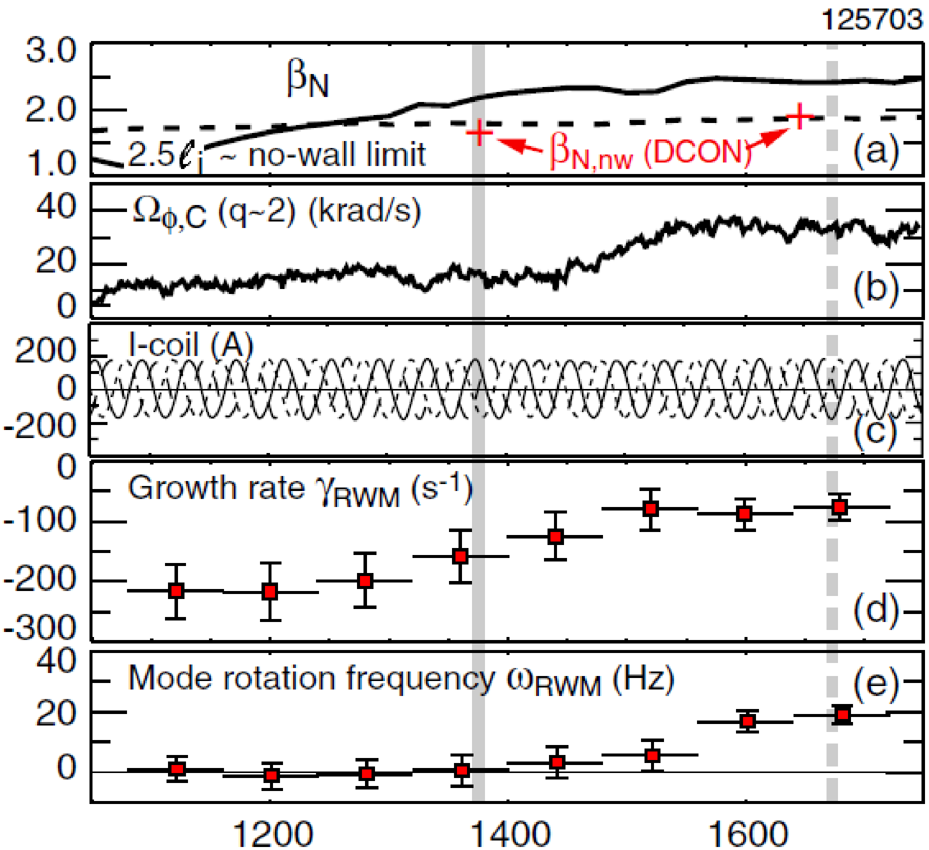
Total: 30

RWM Passive Stabilization Physics - Diagnostics

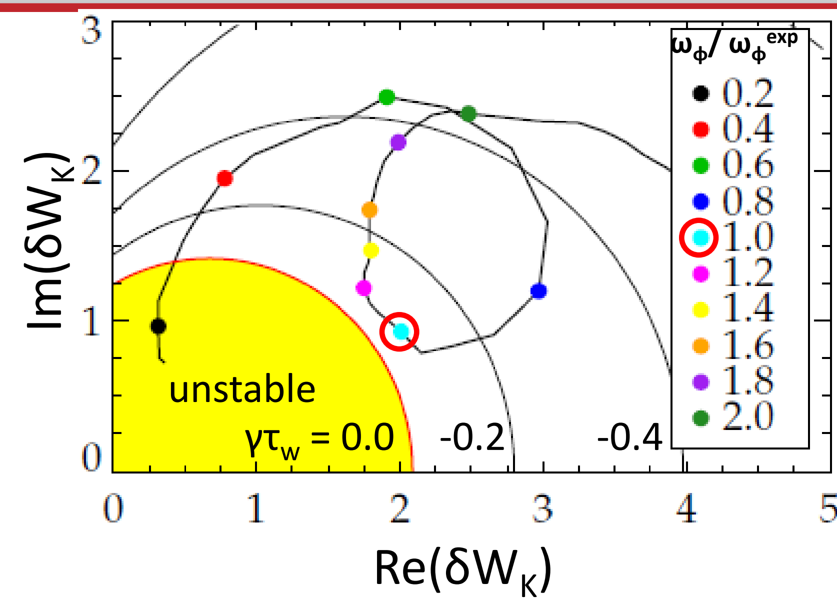
- Required diagnostics / capabilities
  - Ability to operate RWM coils in n = 3 configuration
  - RWM sensors
  - CHERS toroidal rotation measurement
  - Thomson scattering
  - USXR
  - MSE
  - Standard magnetics and diamagnetic loop
  - FIDA
- Desired diagnostics
  - FIReTip
  - Fast camera
  - CHERS poloidal rotation measurement

Active MHD spectroscopy can measure growth rate and mode rotation frequency

Comparing measured γ and ω_r to theory will improve understanding of RWM stability.



(Reimerdes, PPCF, 2007)



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