TH/P7-4

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FLR and rotation effects on low-n MHD modes at the QH-mode discharges with a flat q spot

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Outline

I. Motivations:

- — Experimental observations of edge harmonic oscillation (EHO)/ outer modes (OMs)
- — The differences between ELMs and EHO
- — Infernal (or low magnetic shear) modes vs EHO

II. Equilibrium with bootstrap current

III. Edge instabilities with FLR

IV. Summary

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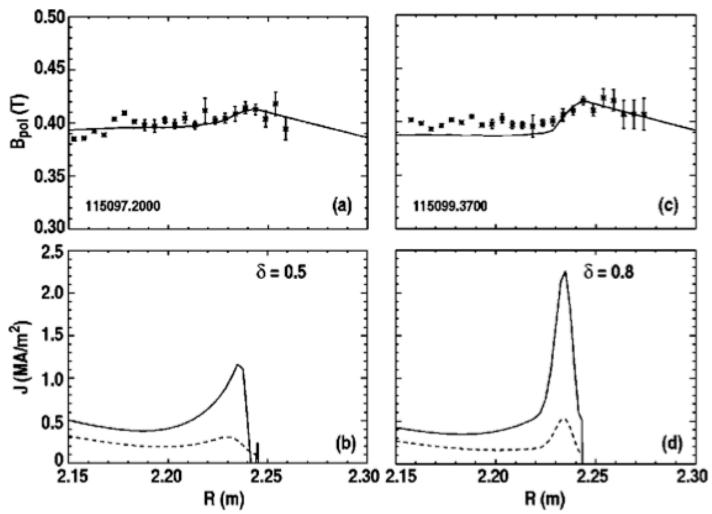
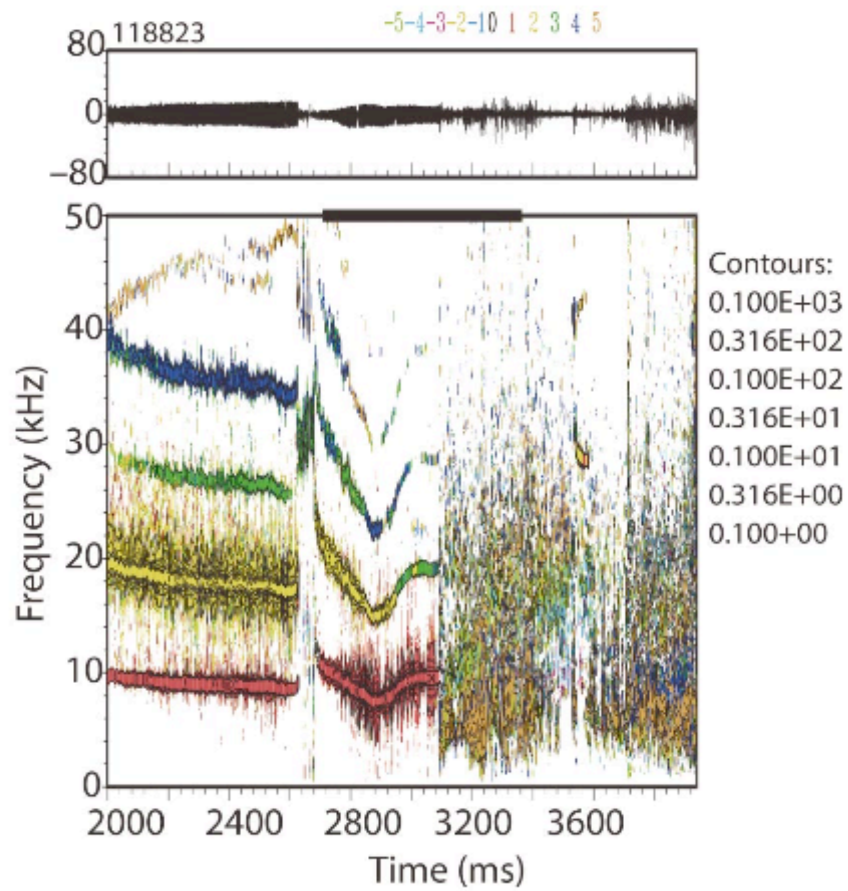
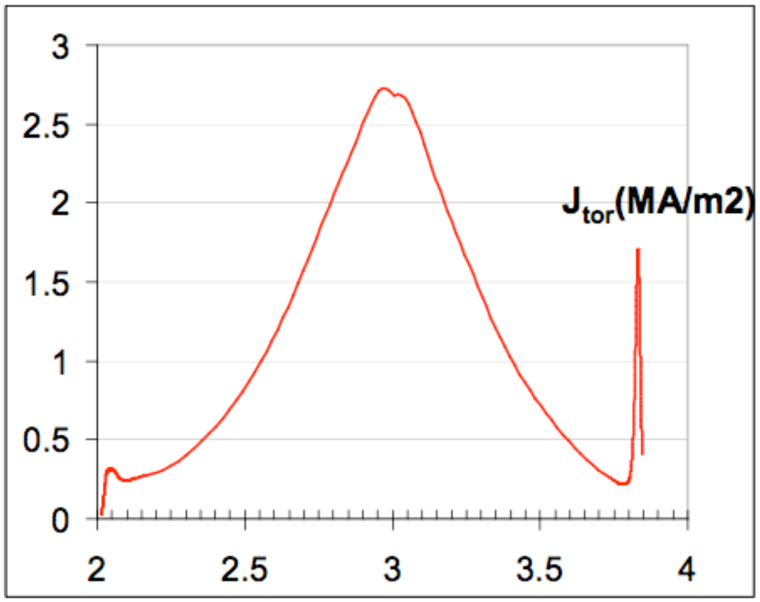
Observation of EHOs at DIII-3D



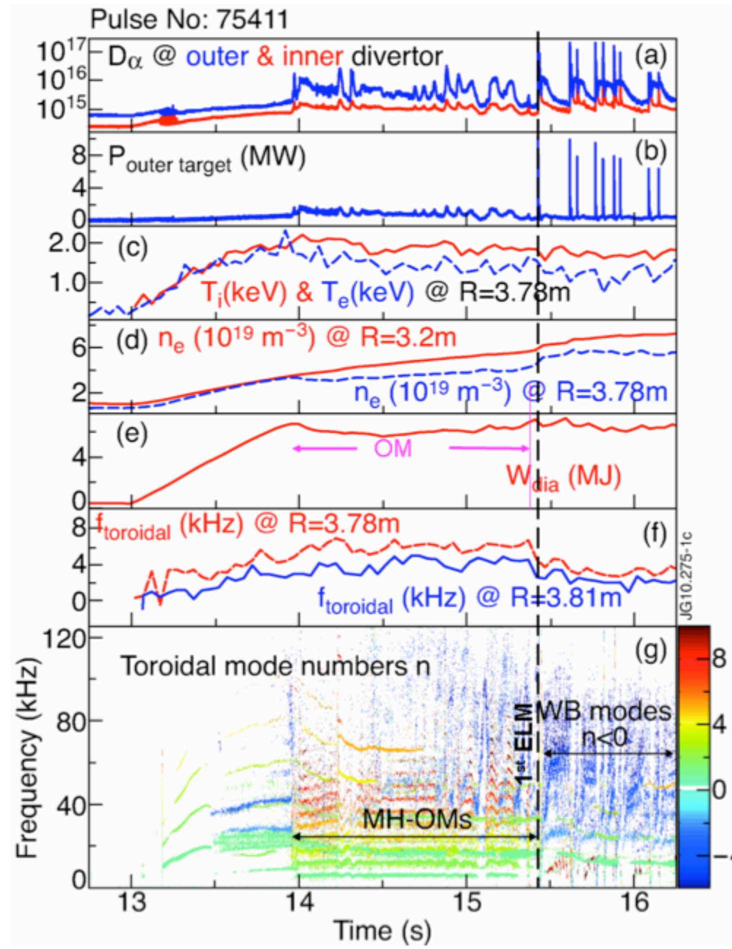
Burrell et al., Phys. of Plasmas 12, 056121 (2005)



Observation of OMs (EHOs) at JET

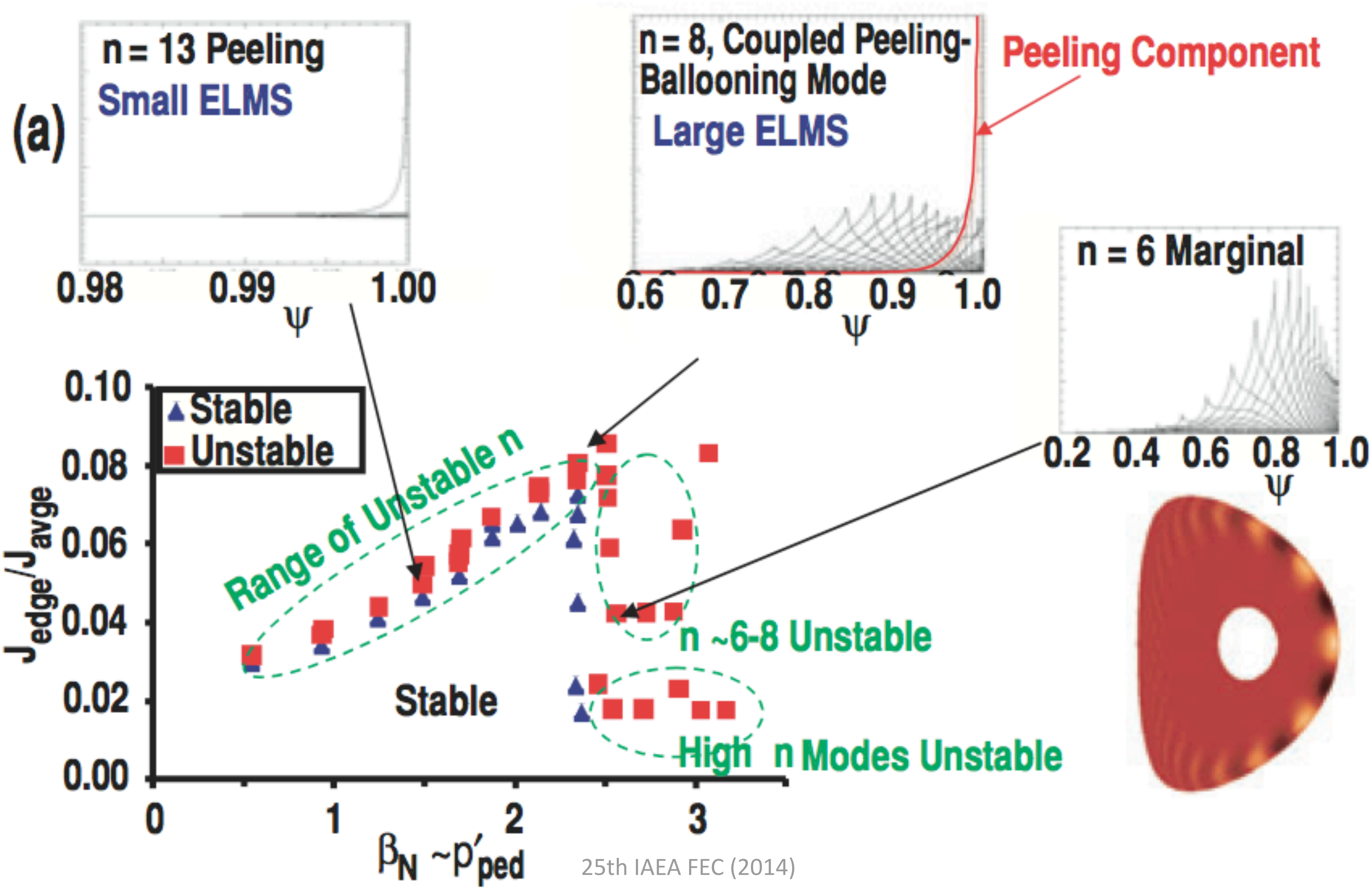


E.R. Solano, IAEA FEC, 2010



Existing peeling ballooning theory

Snyder et al. Nucl. Fusion 44 (2004) 320

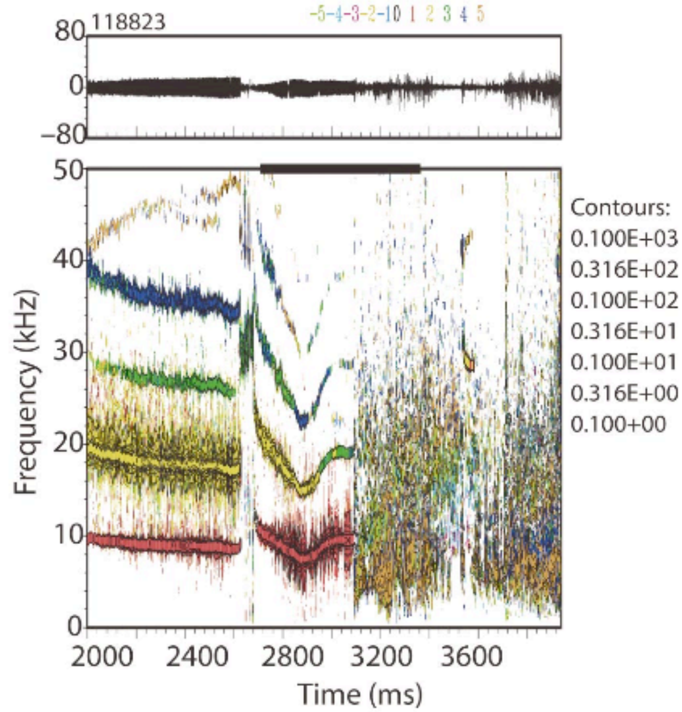


25th IAEA FEC (2014)

EHO/OMs are not peeling ballooning modes

Experimental observations:

1. Modes resonate at the pedestal top
2. Mode frequencies are n-multiple of rotation frequency at pedestal top

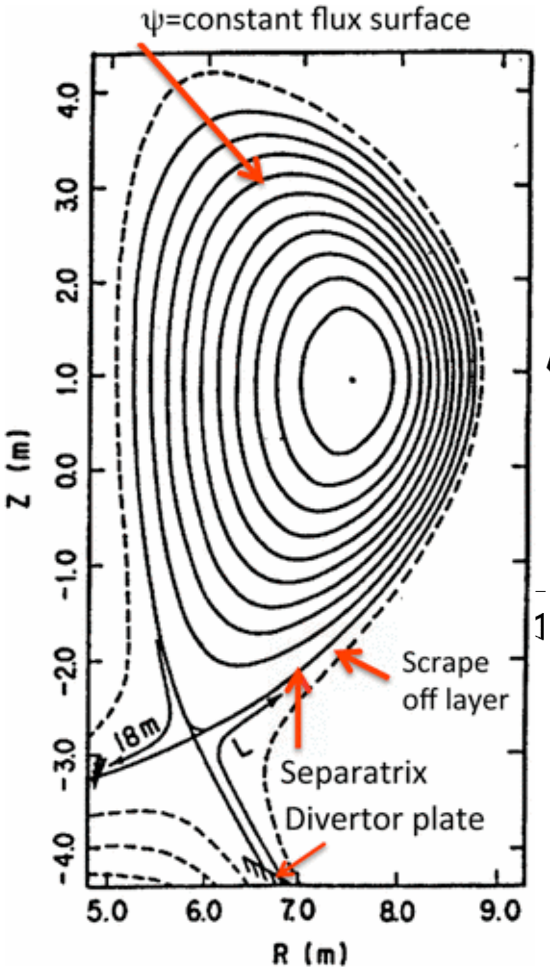


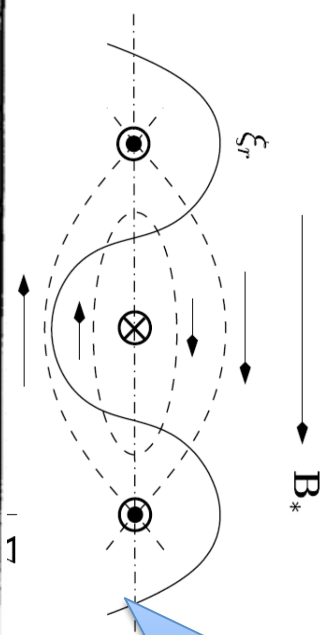
Peeling mode has resonance in the vacuum region and therefore does not fit the frequency of experimentally observed modes.

Peeling-off modes

- Current interchange

  $\Rightarrow$ tearing mode or symmetry breaking





Extended Rutherford equation:

$$\Delta' = \frac{2\sqrt{2}\mu_0}{\eta}\frac{\partial x_T}{\partial t}A_0 - \frac{2\sqrt{2}}{x_T}A_c,$$

There is current jump at plasma edge:
Peeling modes => peeling-off modes
(Zheng & Furukawa, PoP)

Conventional peeling mode
does not peel off plasma, only tearing mode does

ELM physics: positive feedback process between ELMs and SOL current

Physics:

- Edge MHD instability
- Radial transport to SOL
- SOL current surge
- Enhanced edge MHD instability

Formulation:

$$\tau_w \frac{\partial \delta B_r}{\partial t} - \Delta' \delta B_r = i \mu_0 w k_\theta \delta J_{||}$$

with $\delta J_{||}$ Related to δB_r

by transport process

L.J. Zheng et al, PRL (2008)

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Equilibrium: Reduced magnetic shear profile due to the bootstrap current

Equilibrium pressure and safety factor profiles computed by VMEC.
Rotation and density have same profiles as pressure

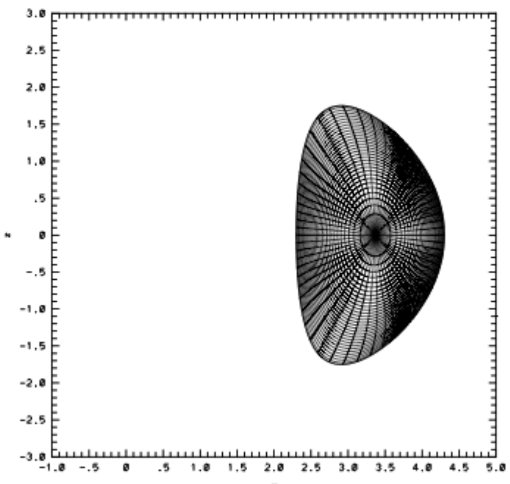
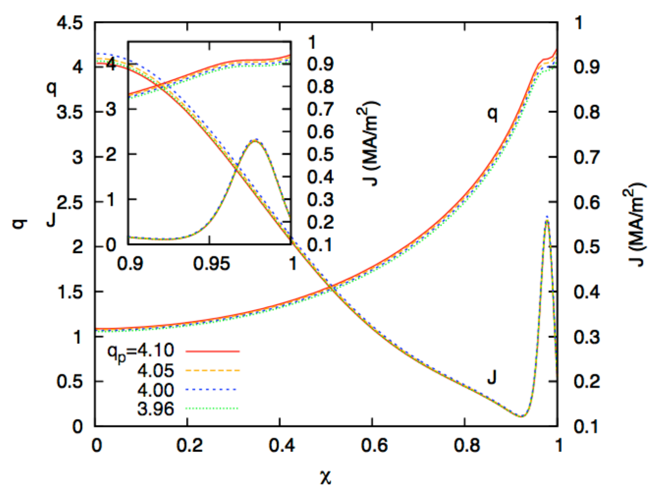
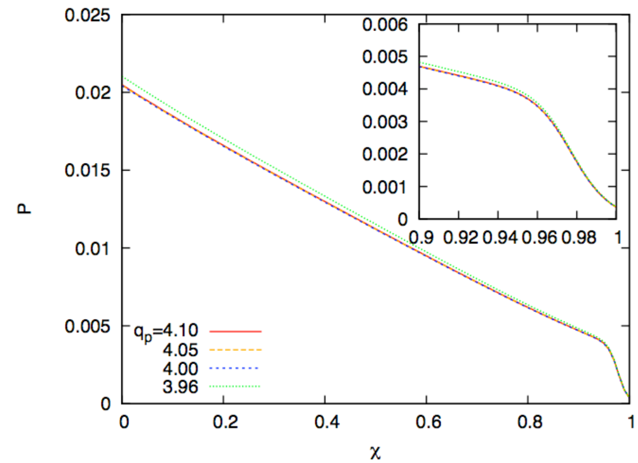


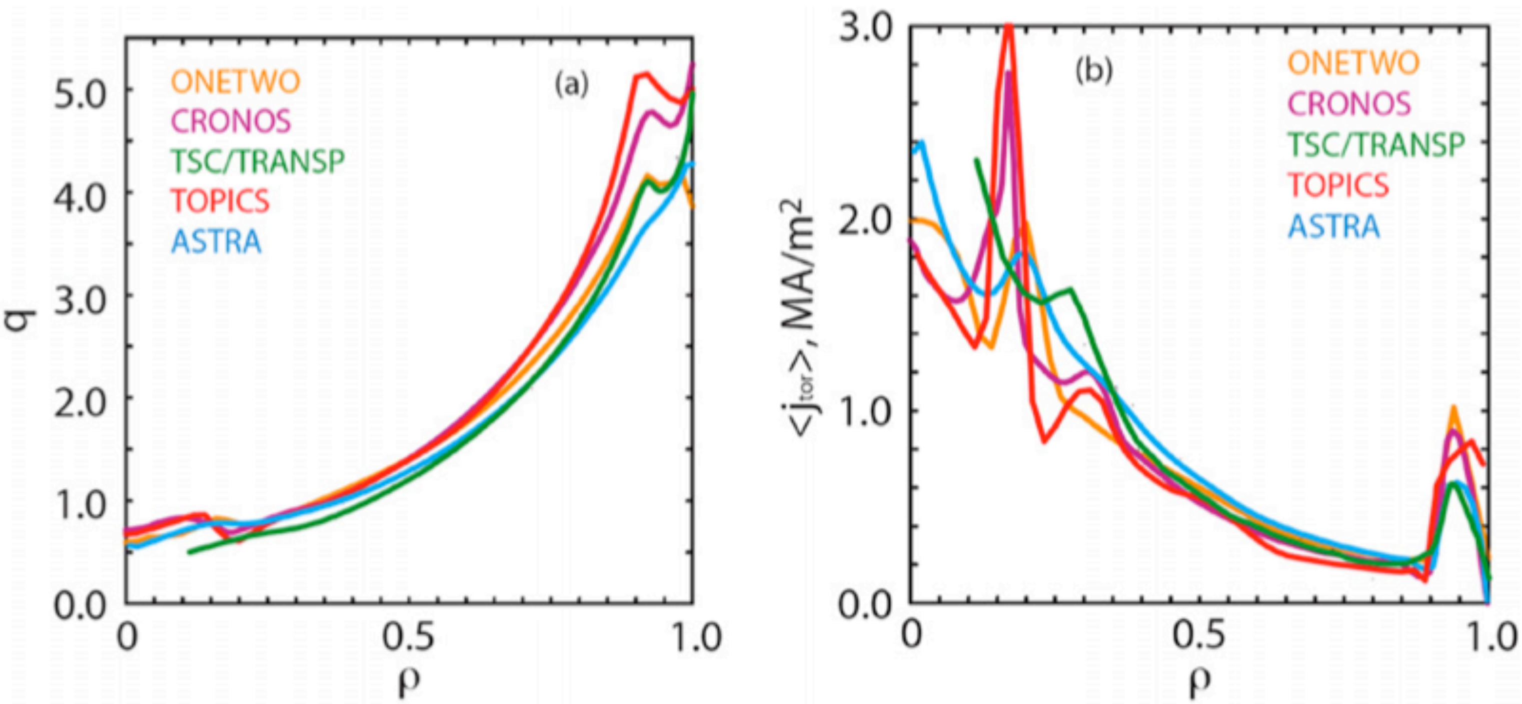
FIG. 1: JET equilibrium





Five cases: q_plateau = 4.1, 4.05, 4., 3.96, 3.92

Current and safety factor reconstruction



C.E. Kessel et al., Nucl. Fusion 47 (2007) 1274

There is a safety factor maximum q_{max} (or reduced magnetic shear) near plasma edge

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Basic set of equations and the AEGIS code

- Basic set of equations:

$$-\rho_m \hat{\omega}^2 \boldsymbol{\xi} = \delta \mathbf{J} \times \mathbf{B} + \mathbf{J} \times \delta \mathbf{B} - \nabla \delta P,$$

where

$$\hat{\omega}^2 = (\omega + n\Omega)(\omega + n\Omega - \omega_{*i})$$

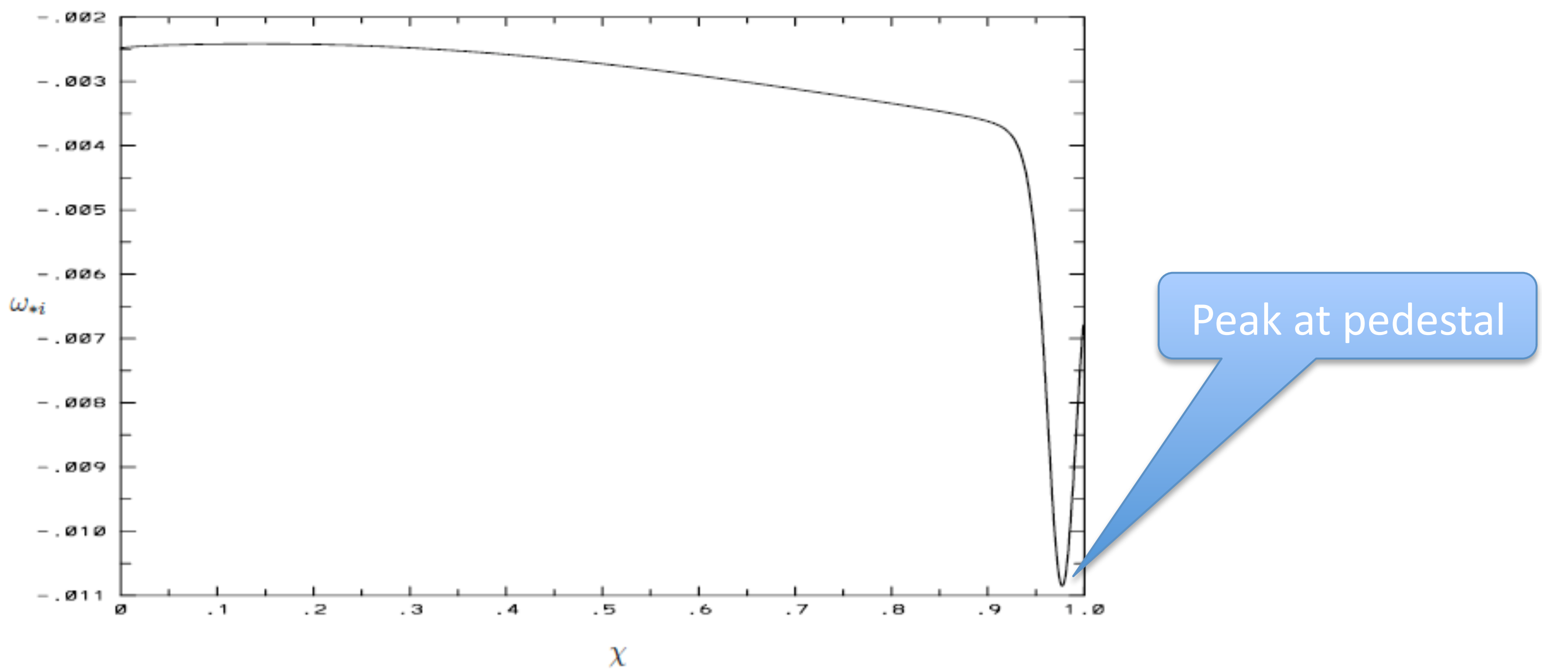
- Generalized energy principle

$$\delta W = \delta W_{mhd} + \delta W_{flr}$$

where

$$\begin{aligned}
\delta W &= \frac{1}{2} \int d\tau \ \rho_m (\omega + n\Omega - \omega_{*i}/2)^2 \, |\boldsymbol{\xi}|^2 , \\
\delta W_{mhd} &= -\frac{1}{2} \int d\tau \ \boldsymbol{\xi}^* \cdot \left[\delta \mathbf{J} \times \mathbf{B} + \mathbf{J} \times \delta \mathbf{B} - \nabla \delta P \right] , \\
\delta W_{flr} &= \frac{1}{8} \int d\tau \ \rho_m \omega_{*i}^2 \, |\boldsymbol{\xi}|^2 .
\end{aligned}$$

Diamagnetic frequency at pedestal



Diamagnetic drift frequency profile:

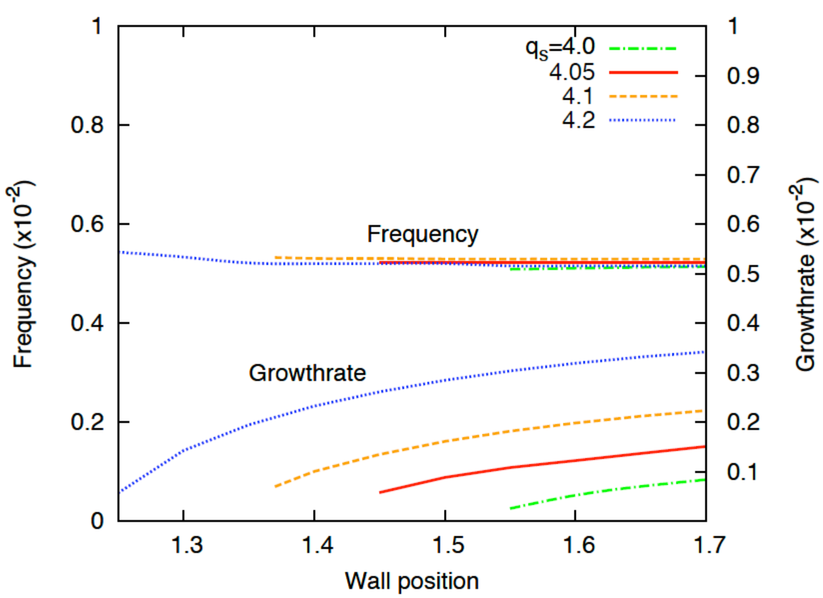
— Directly proportional to pressure gradient

— Inversely proportional to density

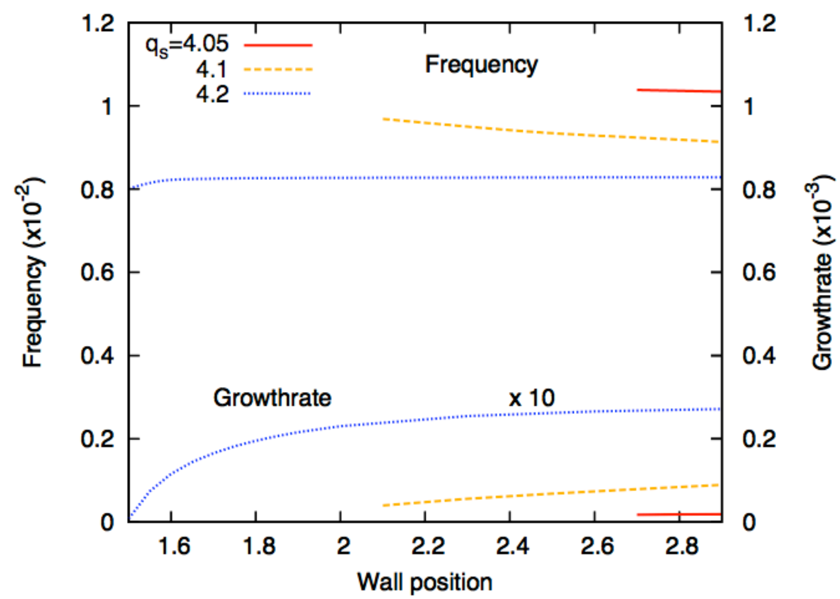
FLR stabilization and q-plateau

- FLR stabilization effects are much stronger when the q-plateau is closer to or lower than an integer

  — This is because the infernal harmonic shifts to the edge, where the diamagnetic frequency is bigger.



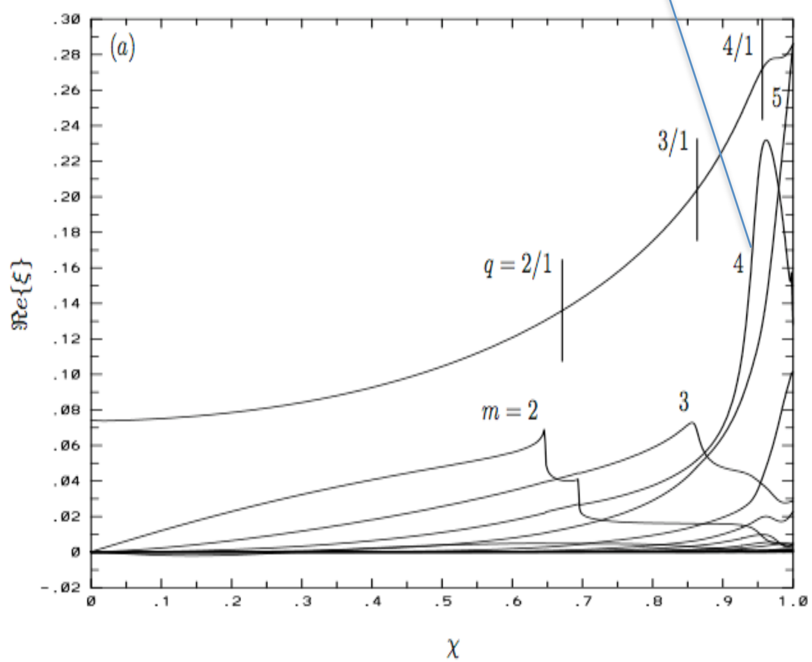
Without FLR



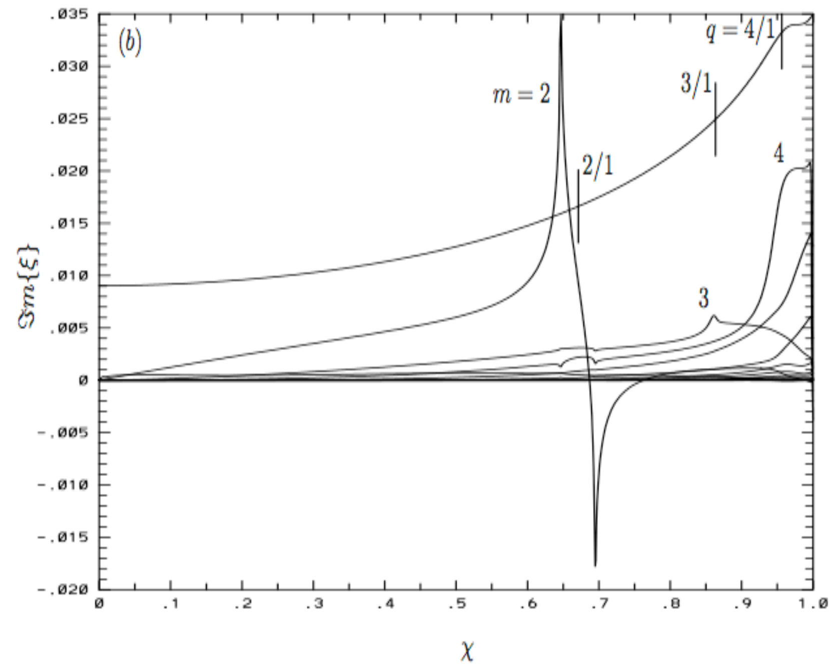
With FLR

Infernal mode eigenfunction

Fat m = 4 infernal branch



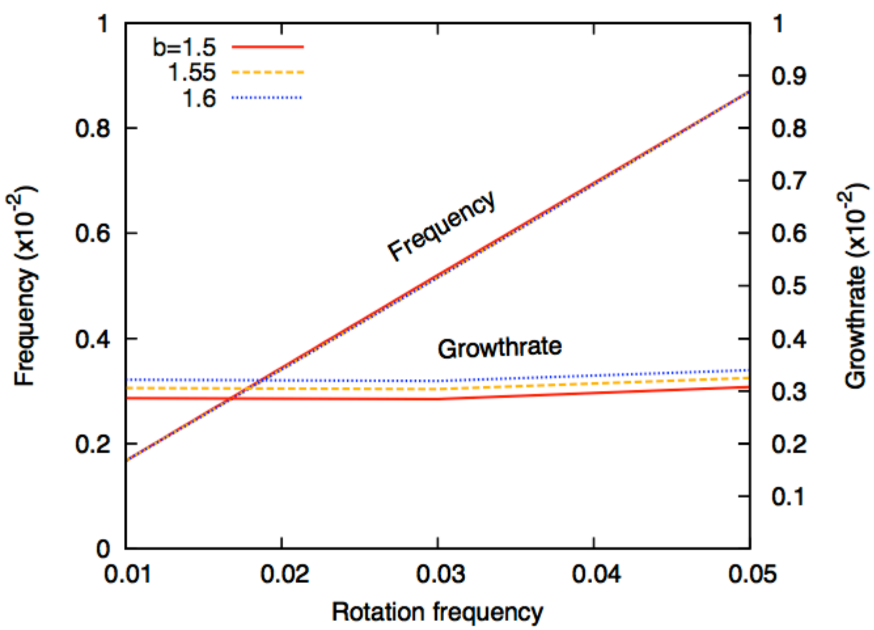
Real part



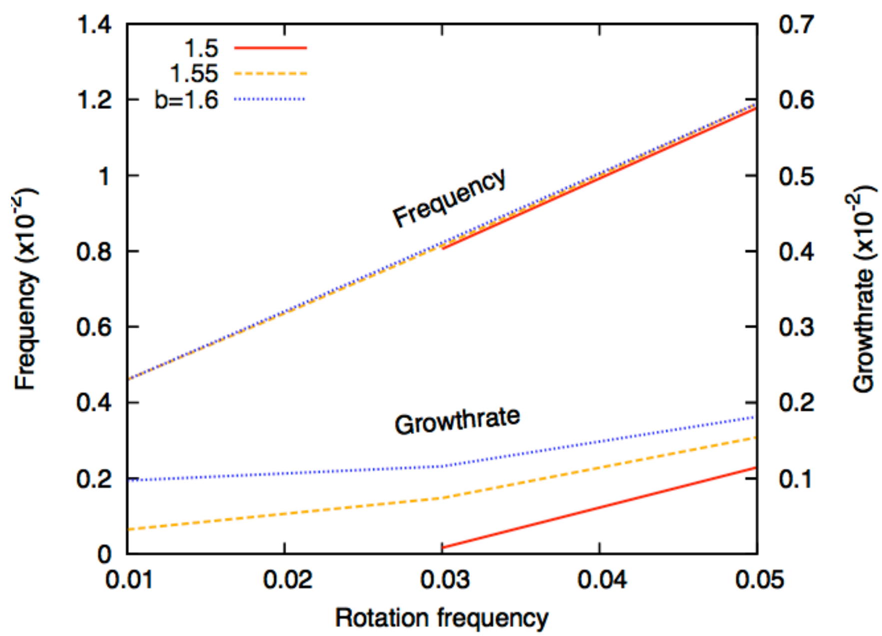
Imaginary part

Rotation effects with FLR

- Without FLR, growthrate is insensitive to the rotation frequency
- With FLR, growthrate becomes sensitive to the rotation frequency in the marginally stable case, while is still not very sensitive for the deeply unstable case.



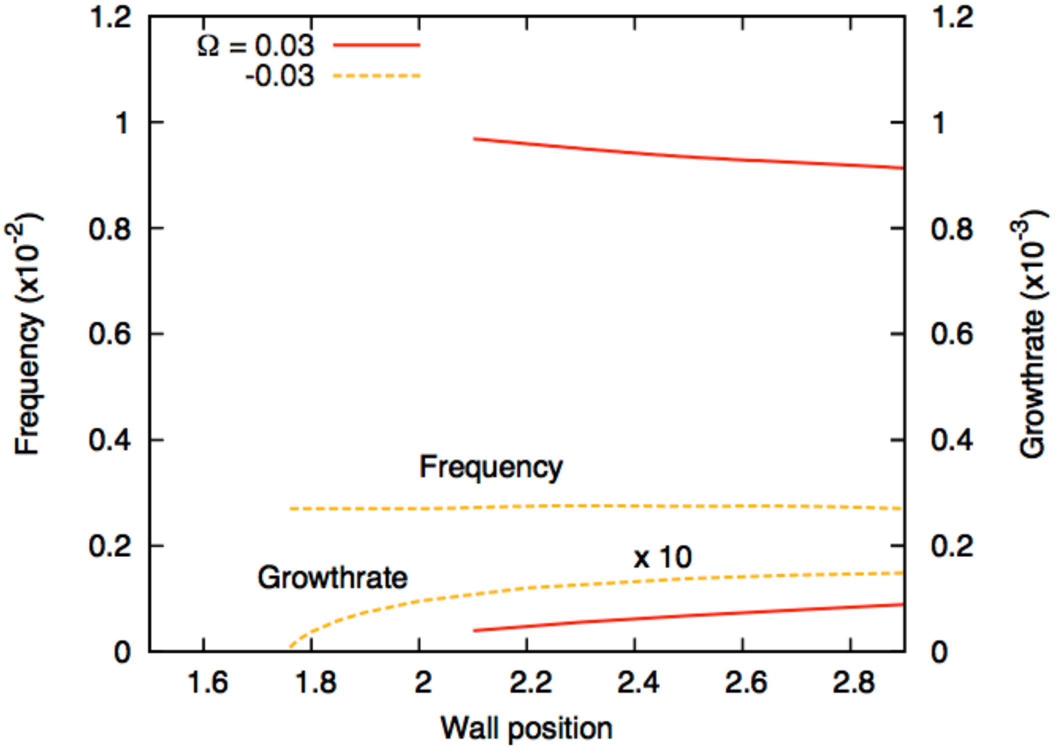
Without FLR



With FLR

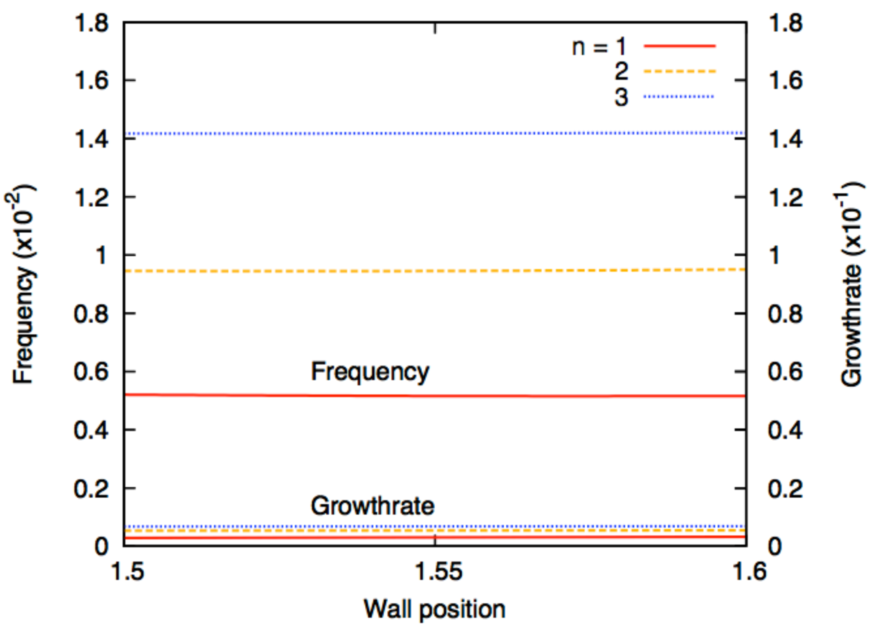
Rotation direction effects

- Co-rotation is more effective for stabilization

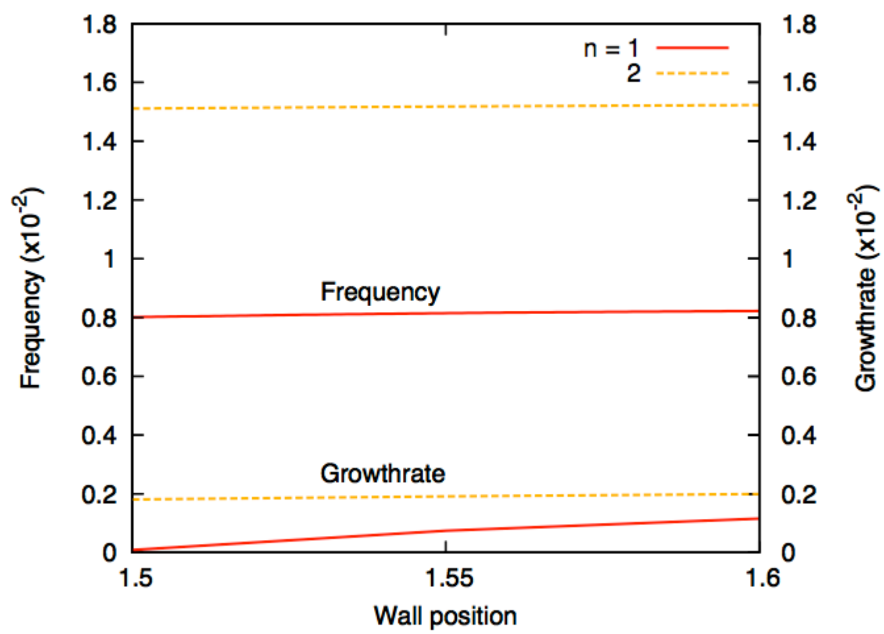


EHO-like frequency multiplying rule

- EHO-like frequency multiplying rule: $\omega = n\Omega$
  is still preserved with FLR effects.
- FLR or diamagnetic drift effects are important for not very high n modes



Without FLR



With FLR

Summary

FLR effects are investigated at the H-mode pedestal:

1. Bootstrap current leads q to reverse or to form a plateau at pedestal

2. Infernal modes have the edge harmonic oscillation (EHO) features:

— the mode frequency equals n multiple rotation frequency: $\omega = n\,\Omega$

— Peeling or kink modes are not easy to explain this frequency features of EHO/OMs.

3. The FLR effects can have big effects on the modes with mode number as low as $n \geq 3$.

4. Co-rotation with the ion diamagnetic drift velocity is much effective for stabilization.

References

[1] Linjin Zheng, M. T. Kotschenreuther, P. Valanju, "*Behavior of n = 1 magnetohydrodynamic modes of infernal type at high-mode pedestal with plasma rotation*", Phys. Plasmas 20, 012501 (2013).

[2] Linjin Zheng, M. T. Kotschenreuther, P. Valanju, "*Low-n magnetohydrodynamic edge instabilities in quiescent H-mode plasmas with a safety-factor plateau*", Nucl. Fusion 53, 063009 (2013).

[3] Linjin Zheng, M. T. Kotschenreuther, P. Valanju, "*Diamagnetic drift effects on the low-n magnetohydrodynamic modes at the high mode pedestal with plasma rotation*", Phys. Plasmas 21, 062502 (2014).