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Behavior of magnetohydrodynamic modes of infernal type at H-mode pedestal with plasma rotation

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Outline

I. **Experimental observations of edge harmonic oscillation (EHO)/outer modes (OMs)**

   — The differences between ELMs and EHO

II. **Infernal (or low magnetic shear) modes vs EHO**

   — Numerical results

III. **Summary**

   — Magnetic-surface-preserving resonant magnetic perturbations (RMPs)

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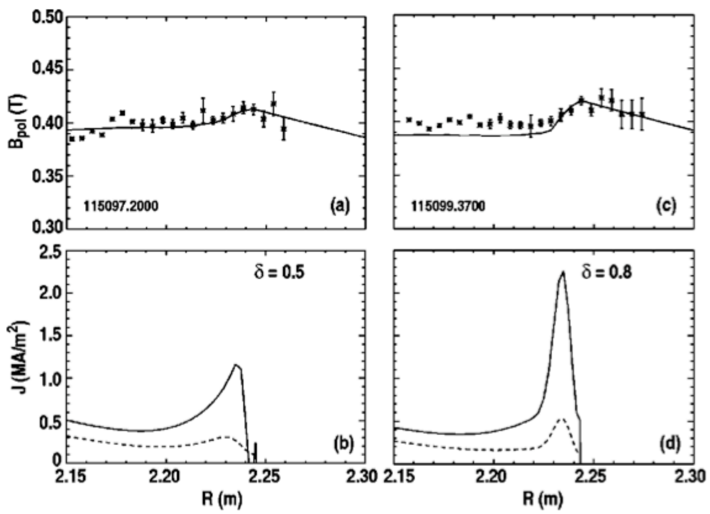
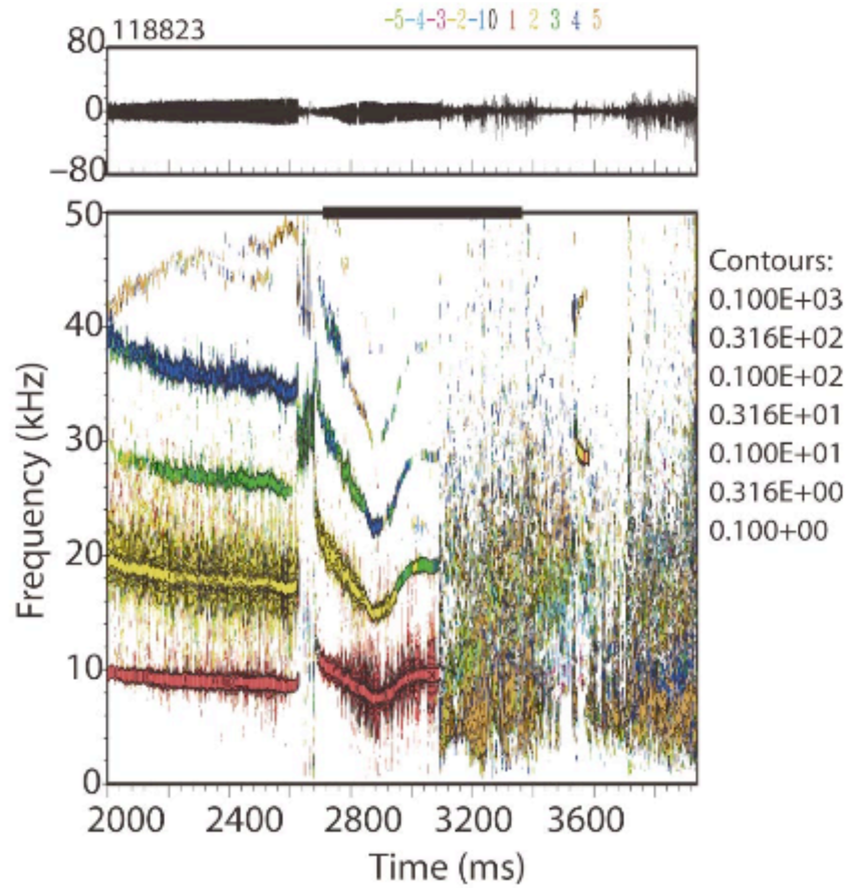
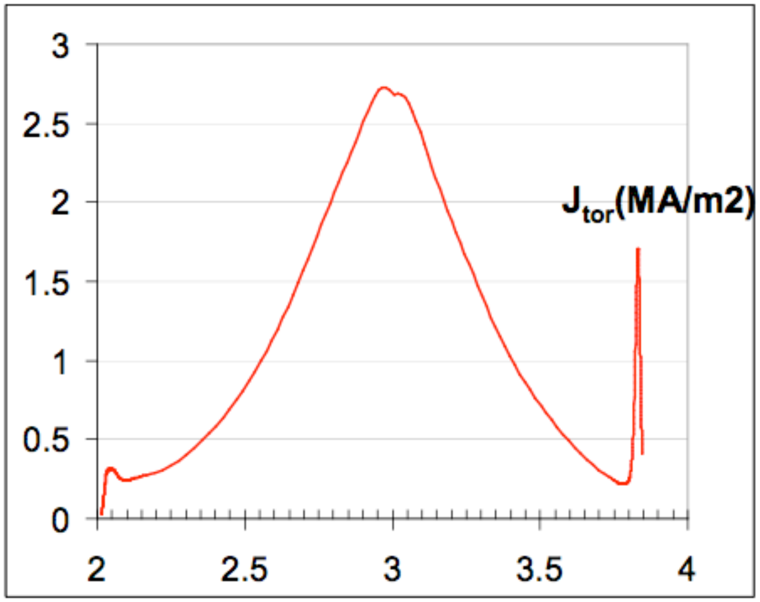
Observation of EHOs at DIII-3



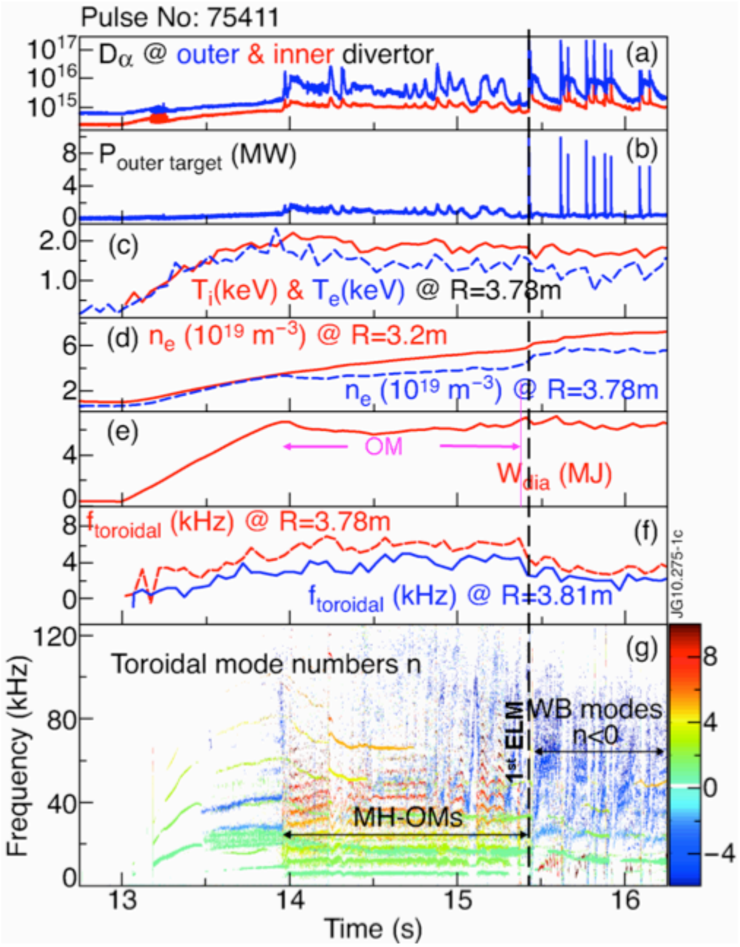
Burrell et al., Phys. of Plasmas 12, 056121 (2005)



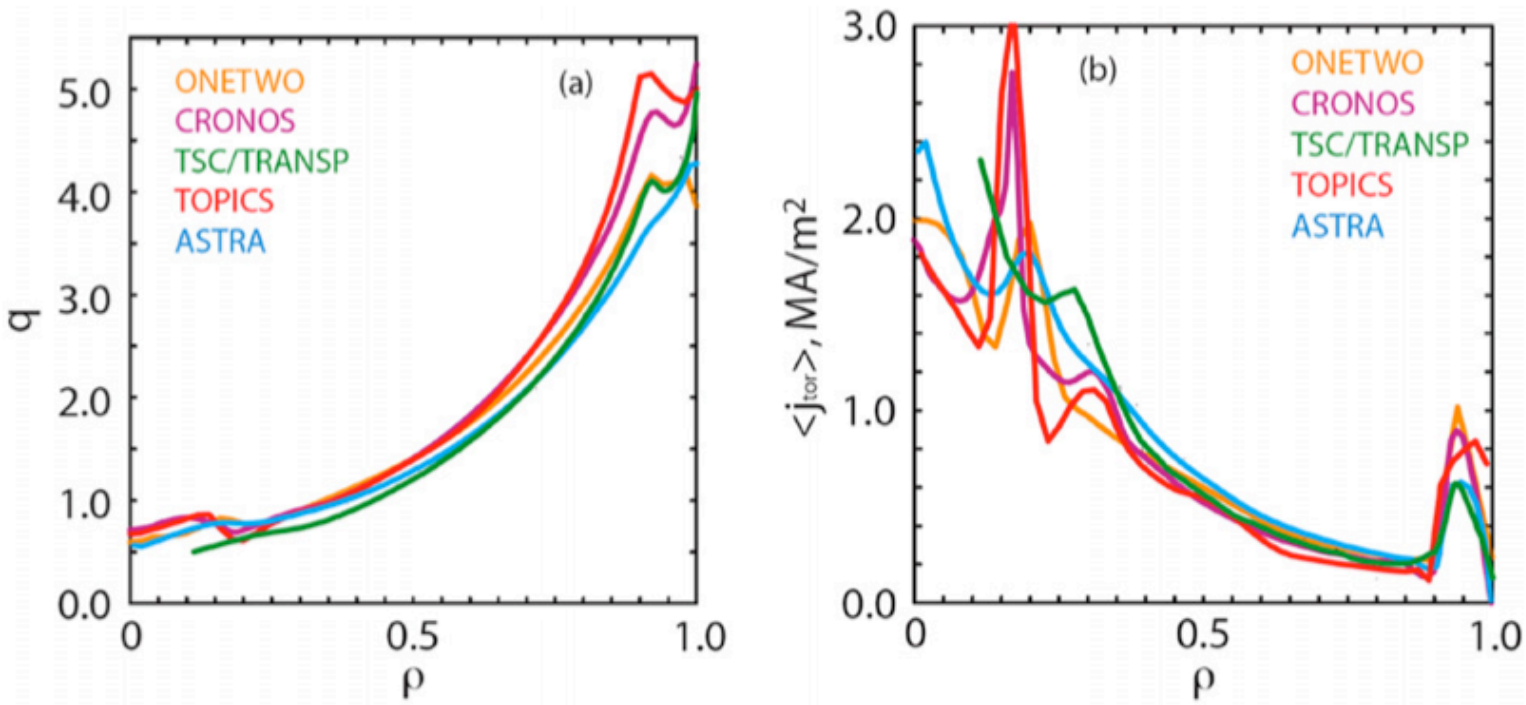
Observation of OMs (EHOs) at JET



E.R. Solano, IAEA FEC, 2010



Current and safety factor reconstruction

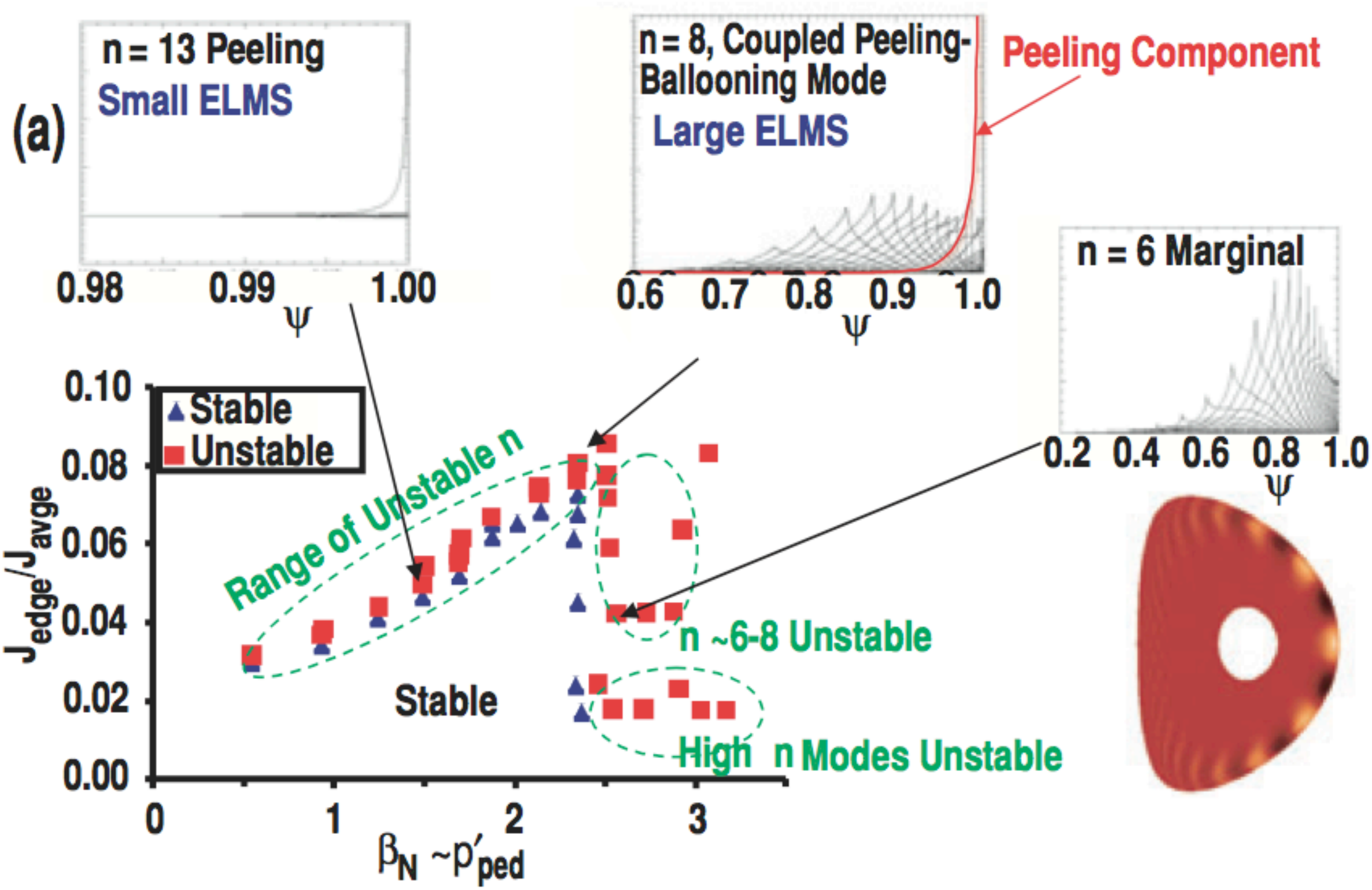


C.E. Kessel et al., Nucl. Fusion 47 (2007) 1274

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

Existing peeling ballooning theory

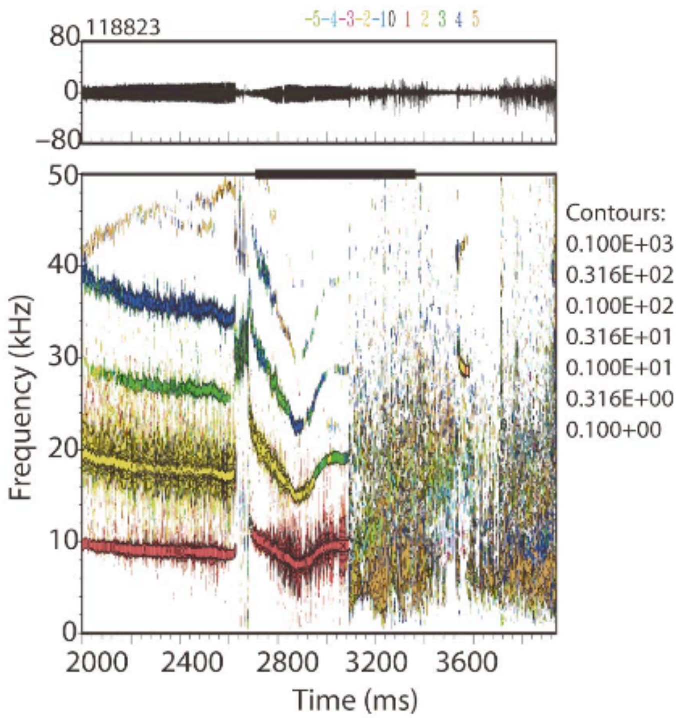
Snyder et al. Nucl. Fusion 44 (2004) 320



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.

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Equilibrium

Reversed or reduced magnetic shear profile

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

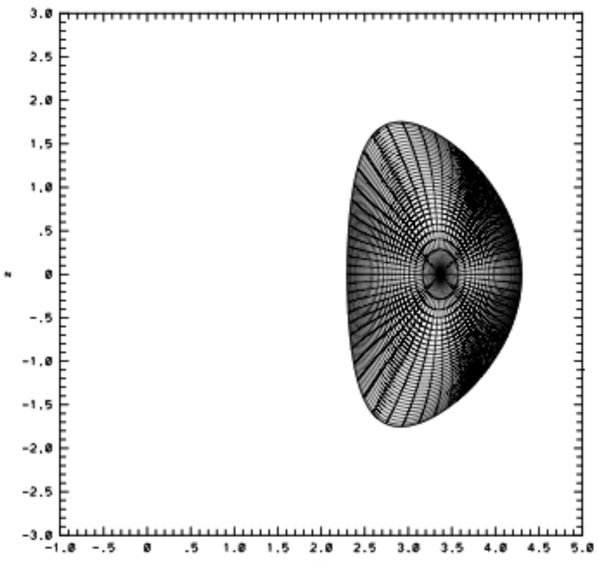

FIG. 1: JET equilibrium

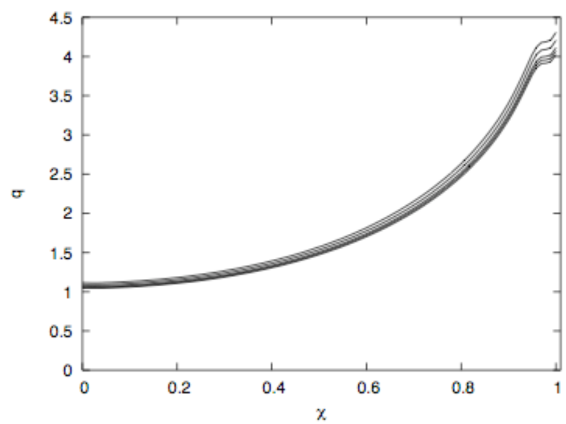

FIG. 2: Safety factor profiles

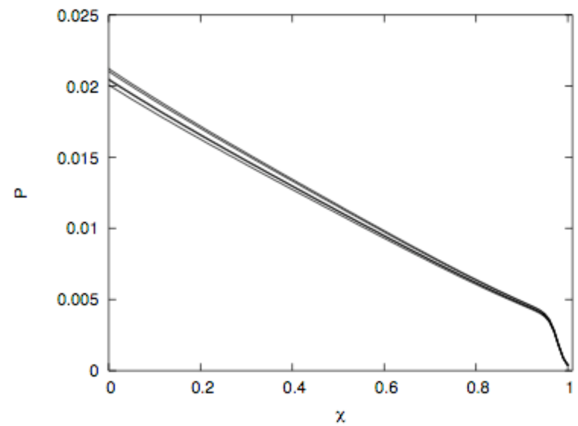

FIG. 3: Pressure profiles

Five cases: q_plateau = 4.2, 4.1, 4., 3.96, 3.92

MHD stability computed by AEGIS code

The case with

q-plateau > 4

is more unstable, because higher pressure gradient meets with low magnetic shear.

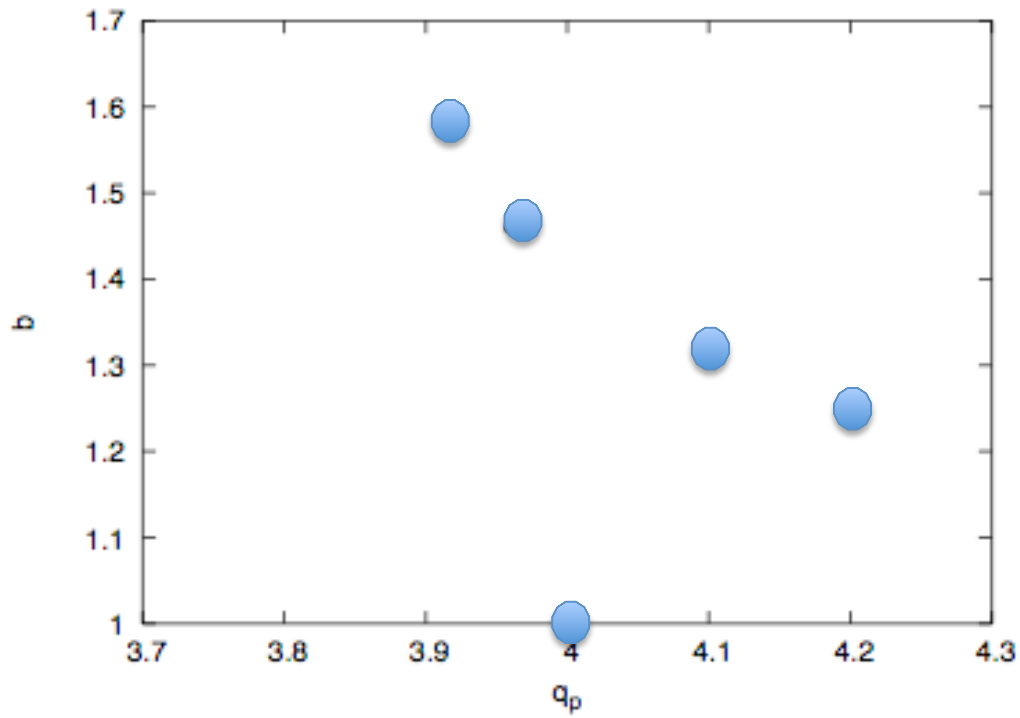

FIG. 4: Critical wall position vs q-plateau: q_p.

The n = 1 MHD eigen modes

Infernal mode harmonic: m = 4

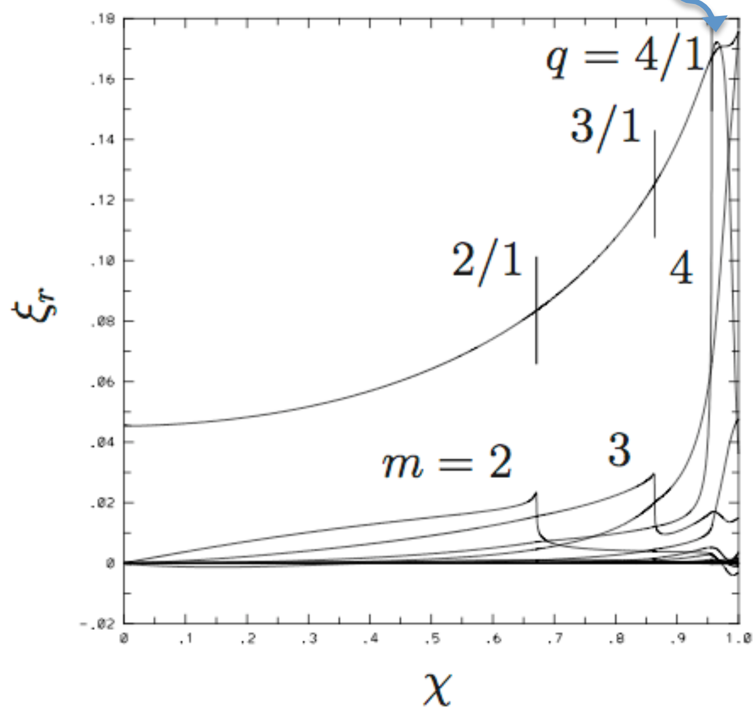

FIG. 5: MHD eigenfunction for the case with q-plateau = 4.1 and wall position b=1.33.

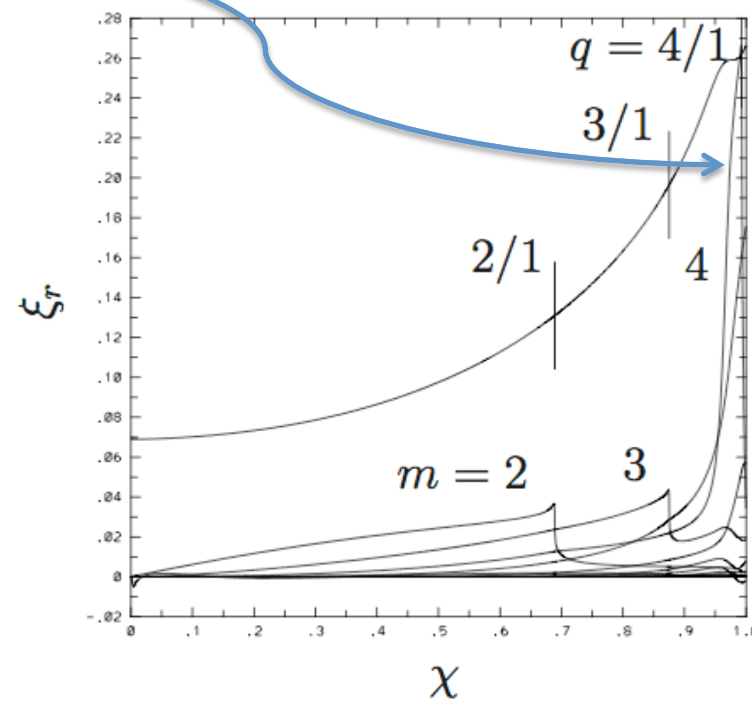

FIG. 6: MHD eigenfunction for the case with q-plateau = 3.96 and wall position b=1.47.

Stability diagram with rotation q_plateau = 4.1

Infernal mode features:

- Frequency is independent of wall position
- Growthrate is independent of rotation frequency

Mode frequency is close to the rotation frequency at pedestal top

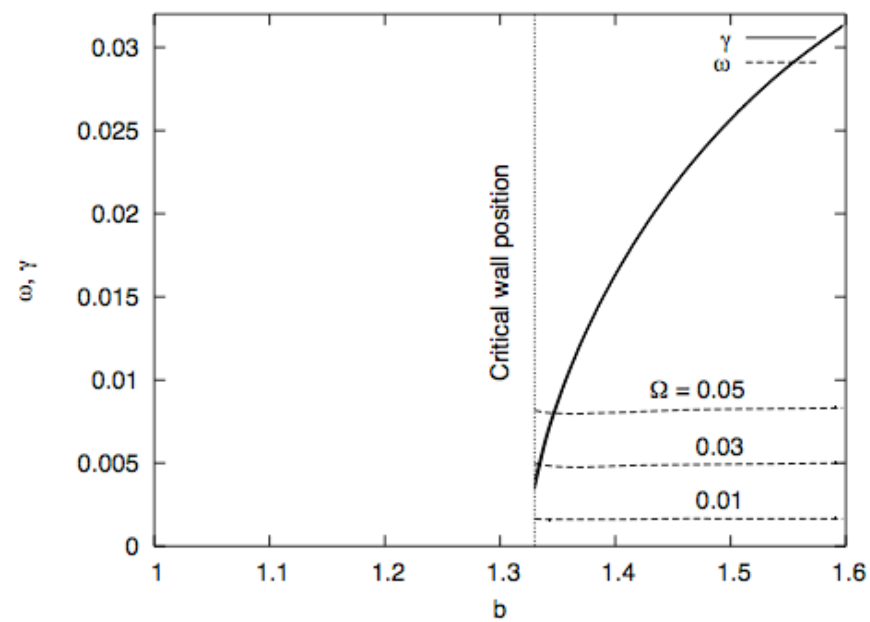

FIG. 7: Eigen frequency and growth rate for the case with q-plateau = 4.1.

Eigen modes with rotation q_plateau = 4.1

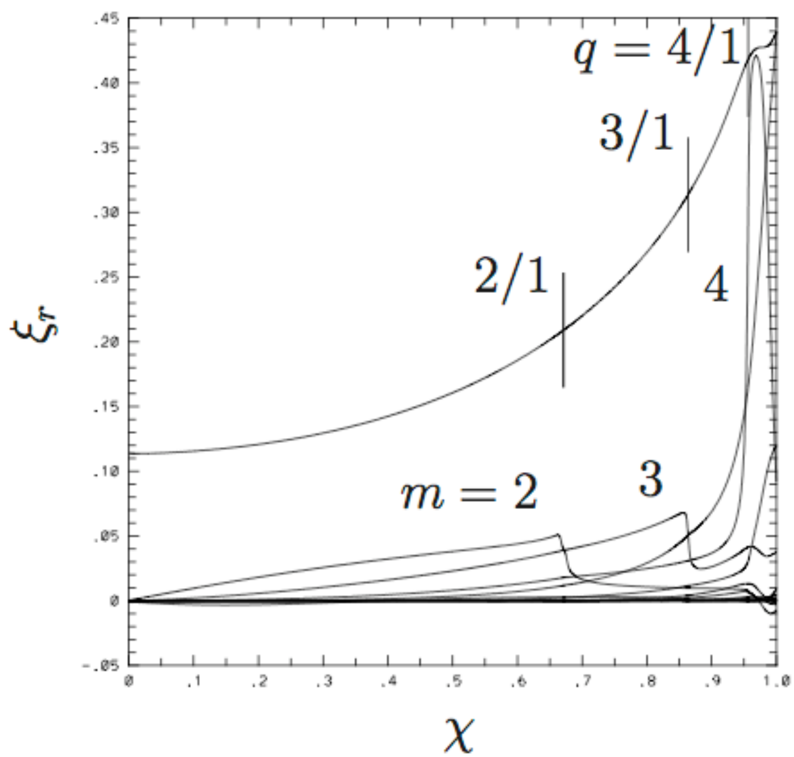

FIG. 9: Real eigenfunction for the case with q-plateau = 4.1.

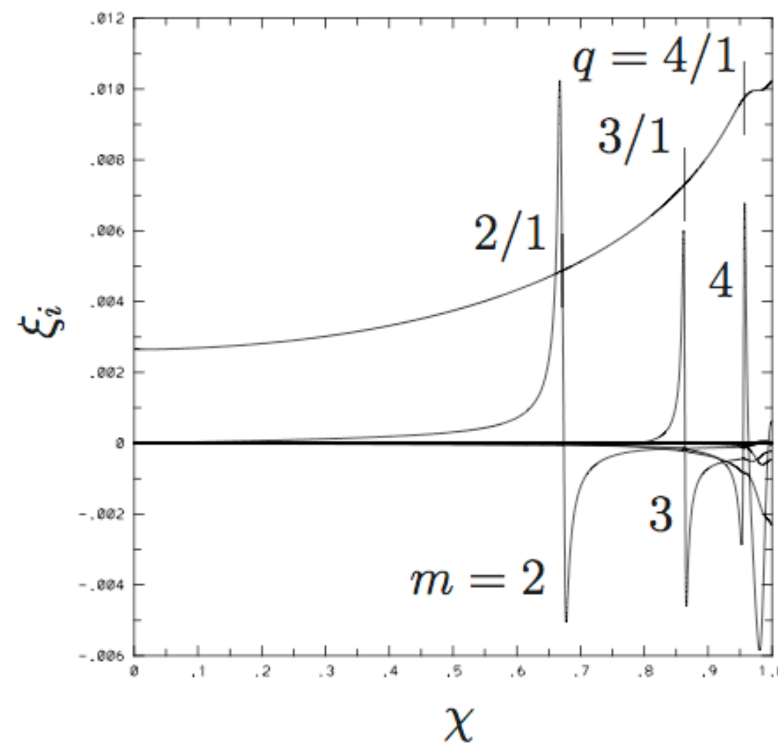

FIG. 10: Imaginary eigenfunction for the case with q-plateau = 4.1.

Stability diagram with rotation q_plateau = 3.96

- It is not as typical of infernal mode as the q_p = 4.1 case, due to peeling mode coupling --- q=4 surface is close to the plasma-vacuum interface.

- Infernal mode is still predominant:

  — Frequency is independent of wall position
  — Growthrate is independent of rotation frequency

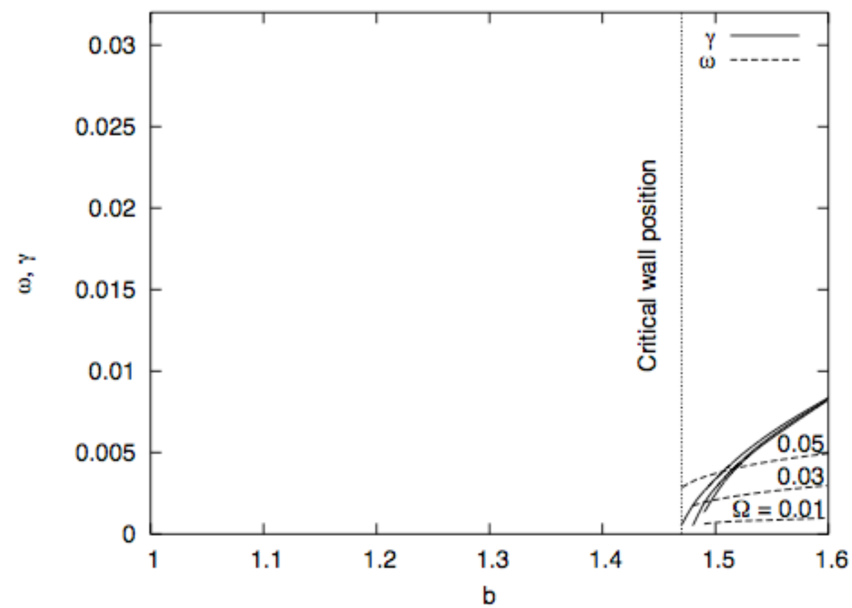

FIG. 8: Eigen frequency and growth rate for the case with q-plateau = 3.96.

Mode frequency/growthrate drops

Eigen modes with rotation
q_plateau = 3.96

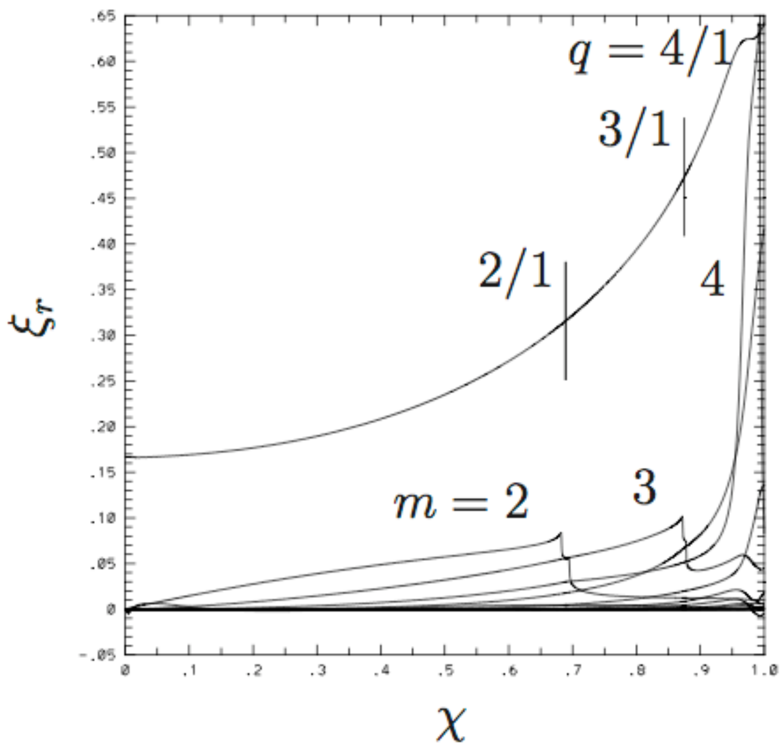

FIG. 11: Real eigenfunction for the case with q-plateau = 3.96.

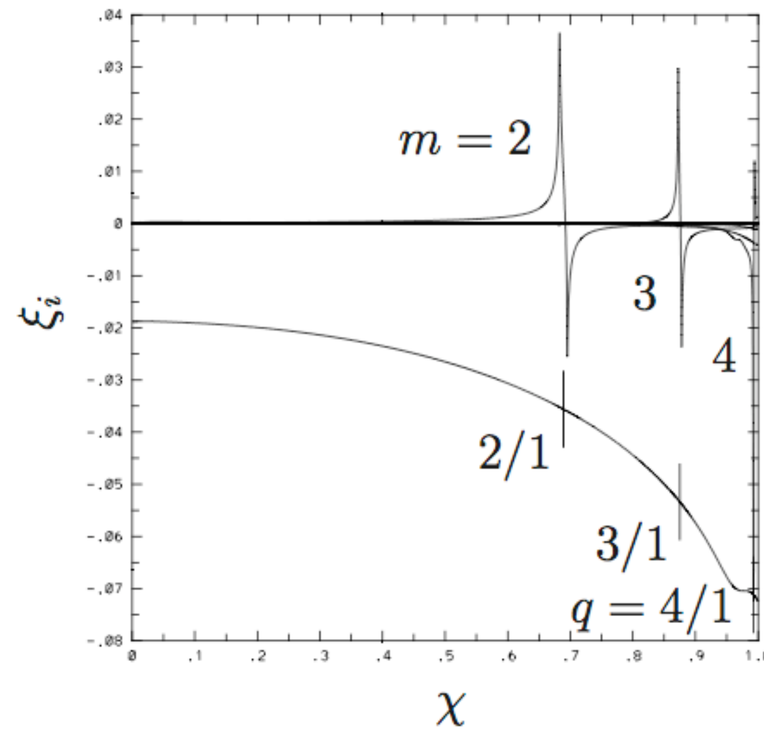

FIG. 12: Imaginary eigenfunction for the case with q-plateau = 3.96.

Numerical results by AEGIS code

Infernal mode features:

Mode frequency is linearly counter-matched with rotation frequency, while growthrate is about independent of rotation frequency

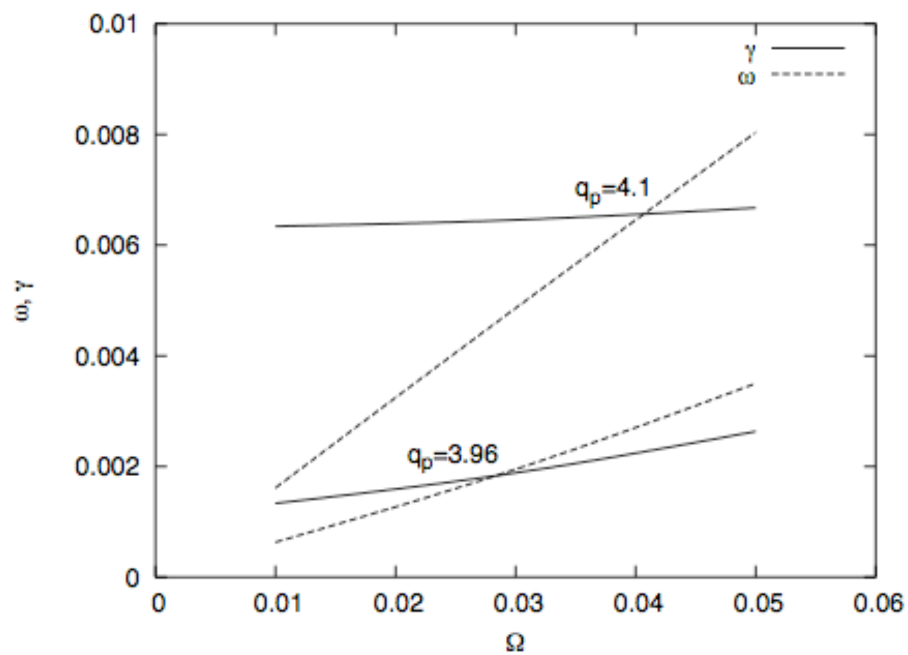

FIG. 13: Eigen frequency and growth rate vs rotation frequencies.

Localized mode theory

- **Singular layer equation with** $\omega_D = \omega + n\Omega$

$$\frac{d}{dx}\left(s^2x^2\frac{d}{dx}E_0\right) - \frac{r}{R}\alpha_p\left(1-\frac{1}{q^2}\right)E_0 - D_\Omega E_0 - \frac{d}{dx}\left(\frac{q^2\mathcal{M}}{m^2}\frac{\omega_D^2}{\gamma_A^2}\frac{d}{dx}E_0\right) = 0$$

- **Mercier criterion – no shear stabilization at** q_{max}

$$\frac{s^2}{4} + \frac{r}{R}\alpha_p\left(1-\frac{1}{q^2}\right) + D_\Omega > 0.$$

- **Inertia energy for explanation of mode frequencies being proportional to toroidal mode number: n**

$$\delta W_{inertia} \propto \int d^3x(\omega - n\Omega)^2\left|\frac{dE_0}{dx}\right|^2$$

Finite magnetic shear can result in different continuum damping.

Conclusion of Sec. II

Further support for infernal (or low magnetic shear) modes interpretation of EHO/OMs:

– Infernal (or low magnetic shear) modes are more unstable, but less damaging. Hence, they can be observed below ELM threshold, but not lead to loss of pedestal.

– Infernal (or low magnetic shear) modes are localized and tend to decouple from SOL

– Mode frequencies are proportional to toroidal mode number n.

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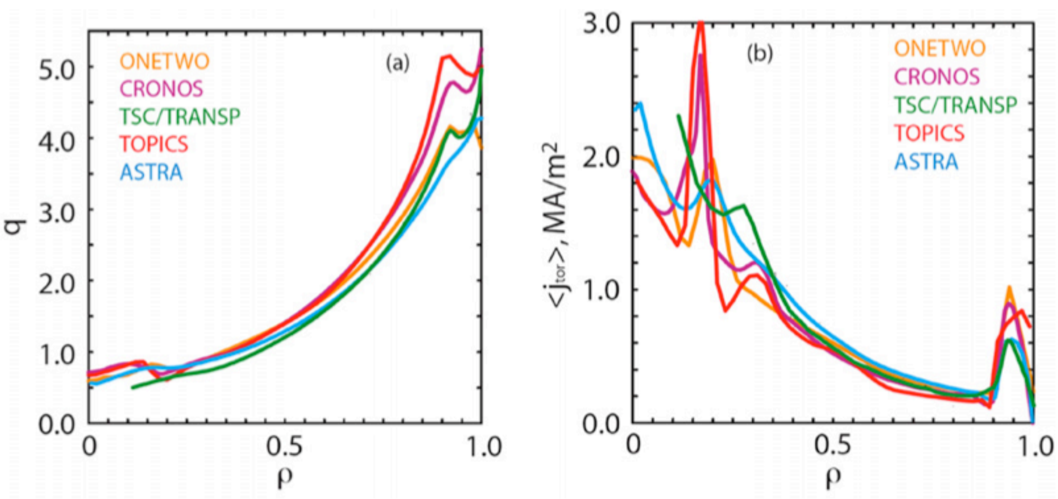
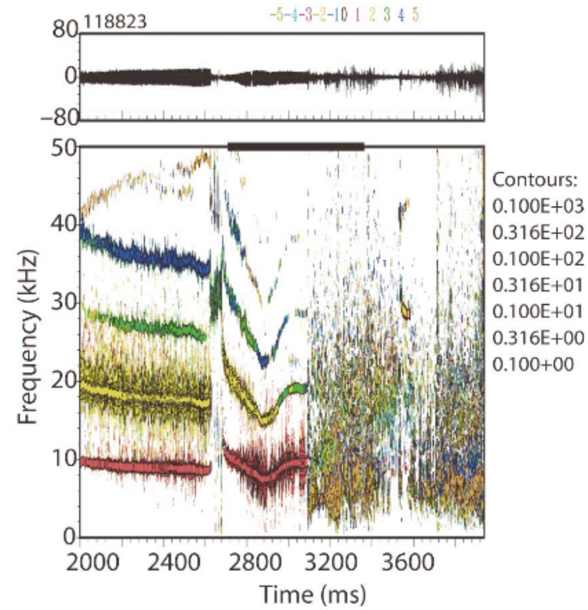
Magnetic-surface-preserving RMPs



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



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

Proposal: to apply RMPs which resonate with q_{max}, (or q with low magnetic shear) to pump out energy without causing the coupling to SOL modes

Summary

I. We find that there is possible correlation of infernal modes at q extremes or low magnetic shear modes with EHO/OMs observed experimentally.

II. Application of magnetic-surface-preserving RMPs can help to mitigate ELMs, without seriously damaging the magnetic surfaces.