Infernal modes at tokamak H-mode pedestal – a possible physics explanation for EHOs

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in collaboration with

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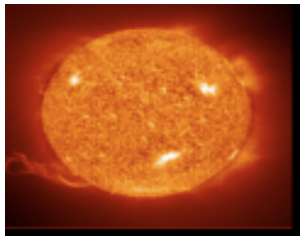

INSTITUTE FOR FUSION STUDIES

THE UNIVERSITY OF TEXAS AT AUSTIN

Outline

I. Introduction: fusion theory complicity vs simplicity
II. Experimental observations of EHOs/OMs
III. The differences between ELMs and EHOs
IV. Current interchange tearing modes (CITMs) and ELMs
V. Infernal (or low magnetic shear) modes vs EHOs
VI. Magnetic-surface-preserving RMPs
VII. Summary

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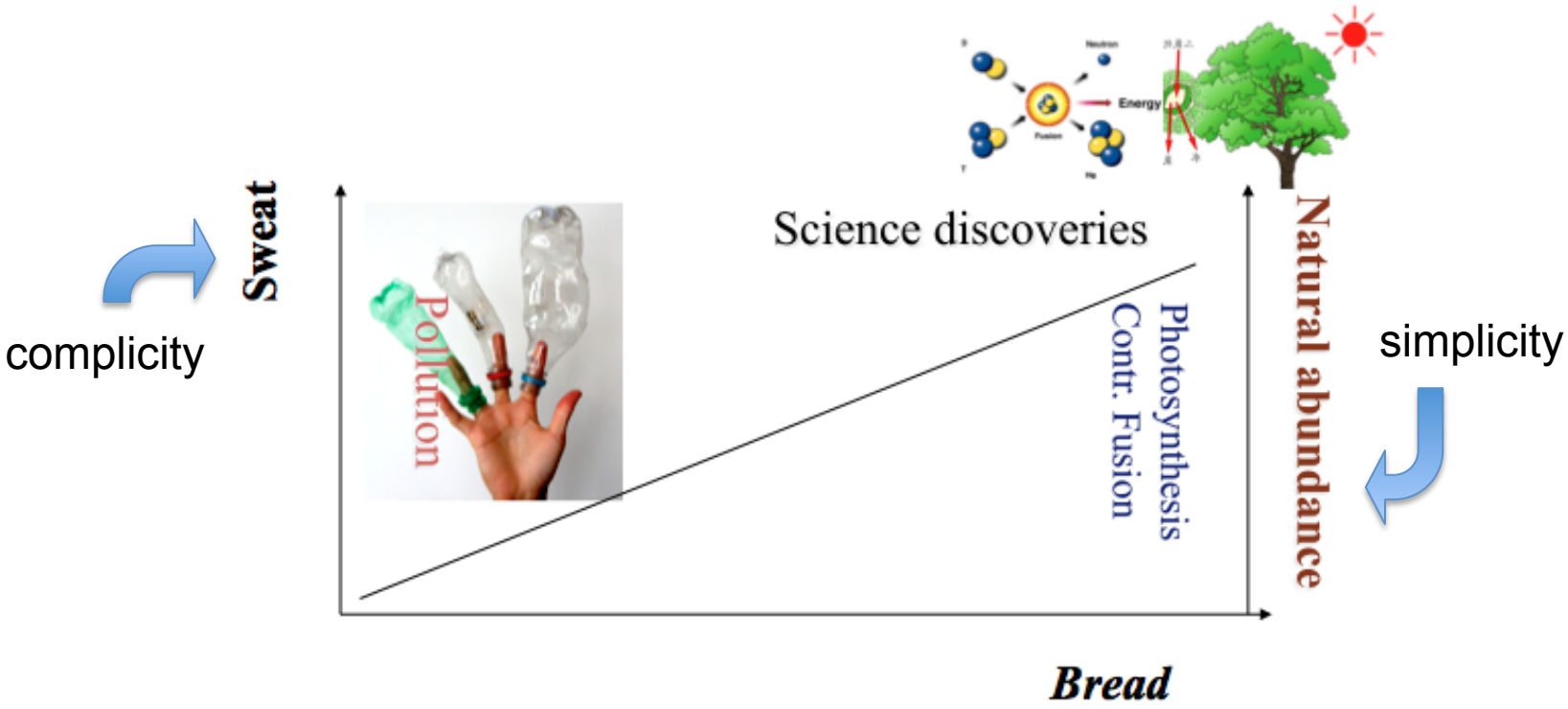
THE LAW OF LAWS

Genesis 3:19: In the sweat of thy face shalt thou eat bread



Controlled fusion is intrinsically complicated, but its physics should also have the nature of simplicity (Gen.1: "it was so") and beauty ("it was good").

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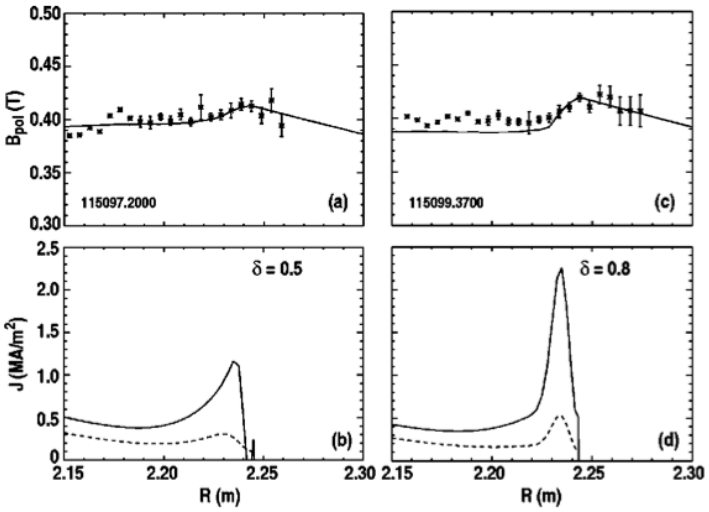
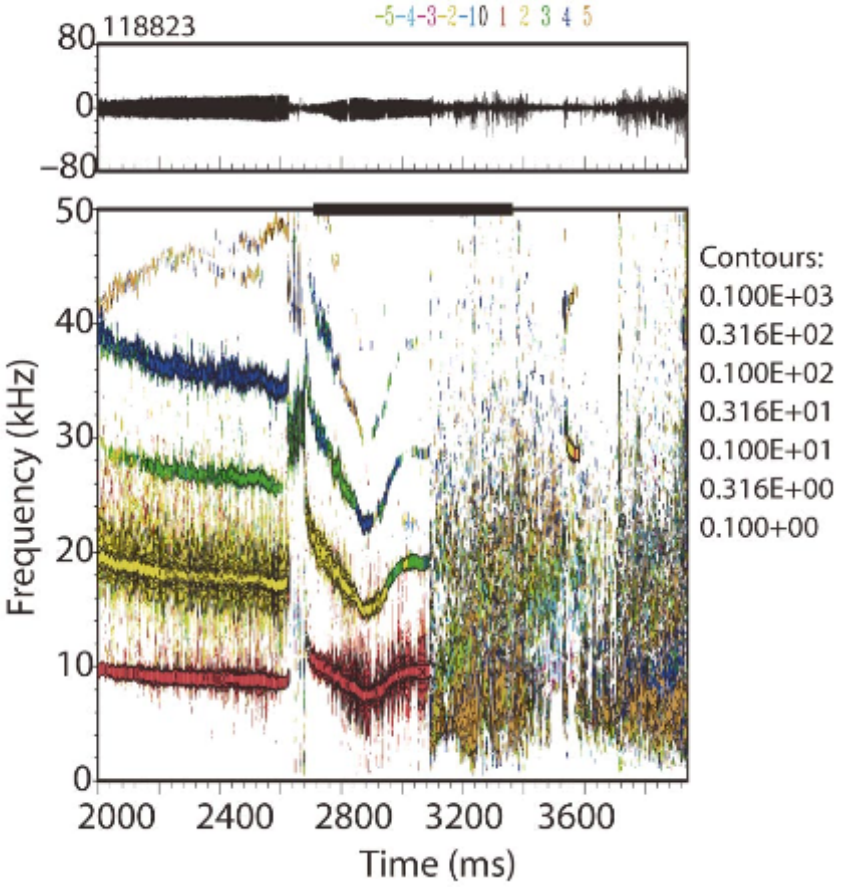
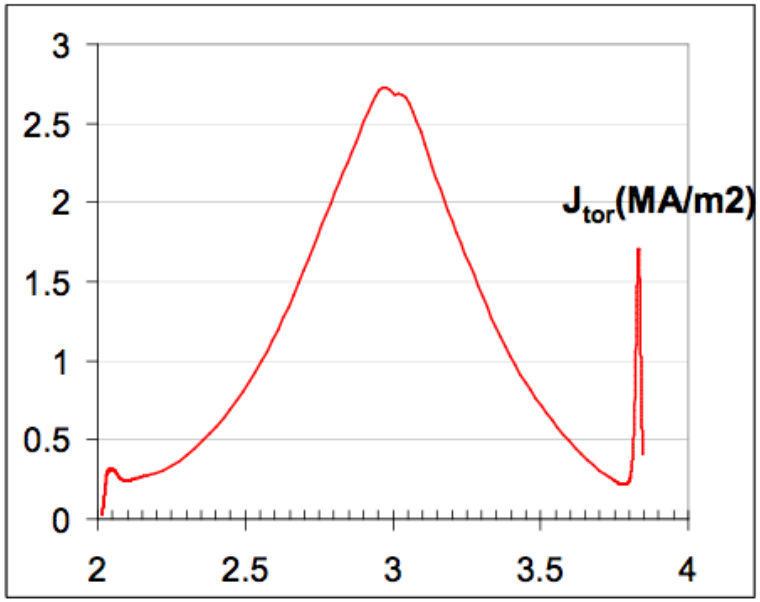
Observation of EHOs at DIII-3



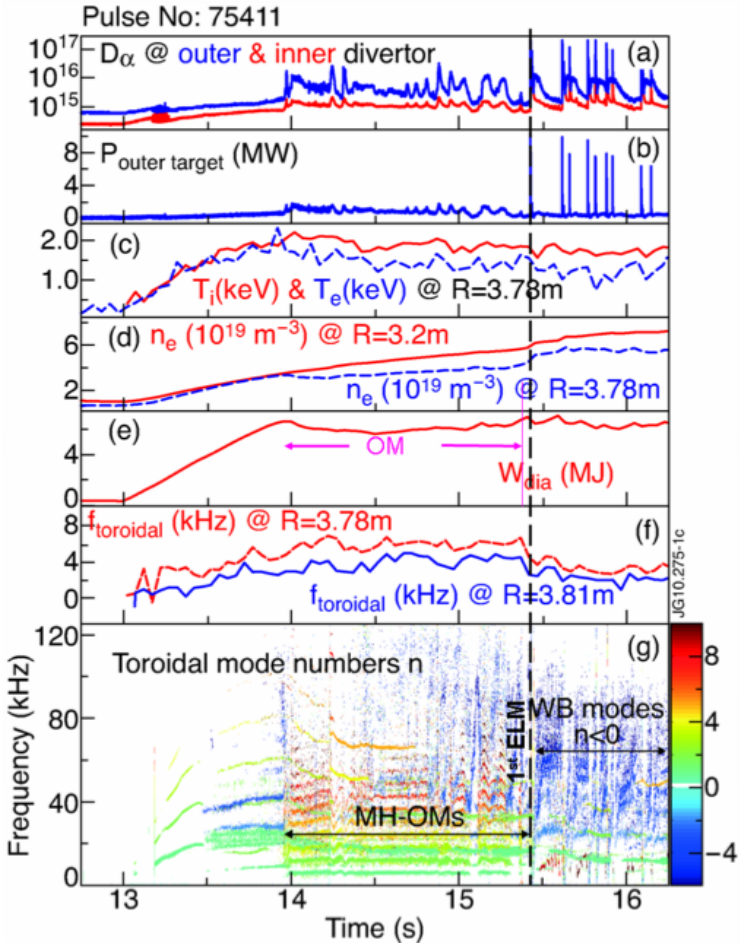
Burrell et al., Phys. of Plasmas 12, 056121 (2005)



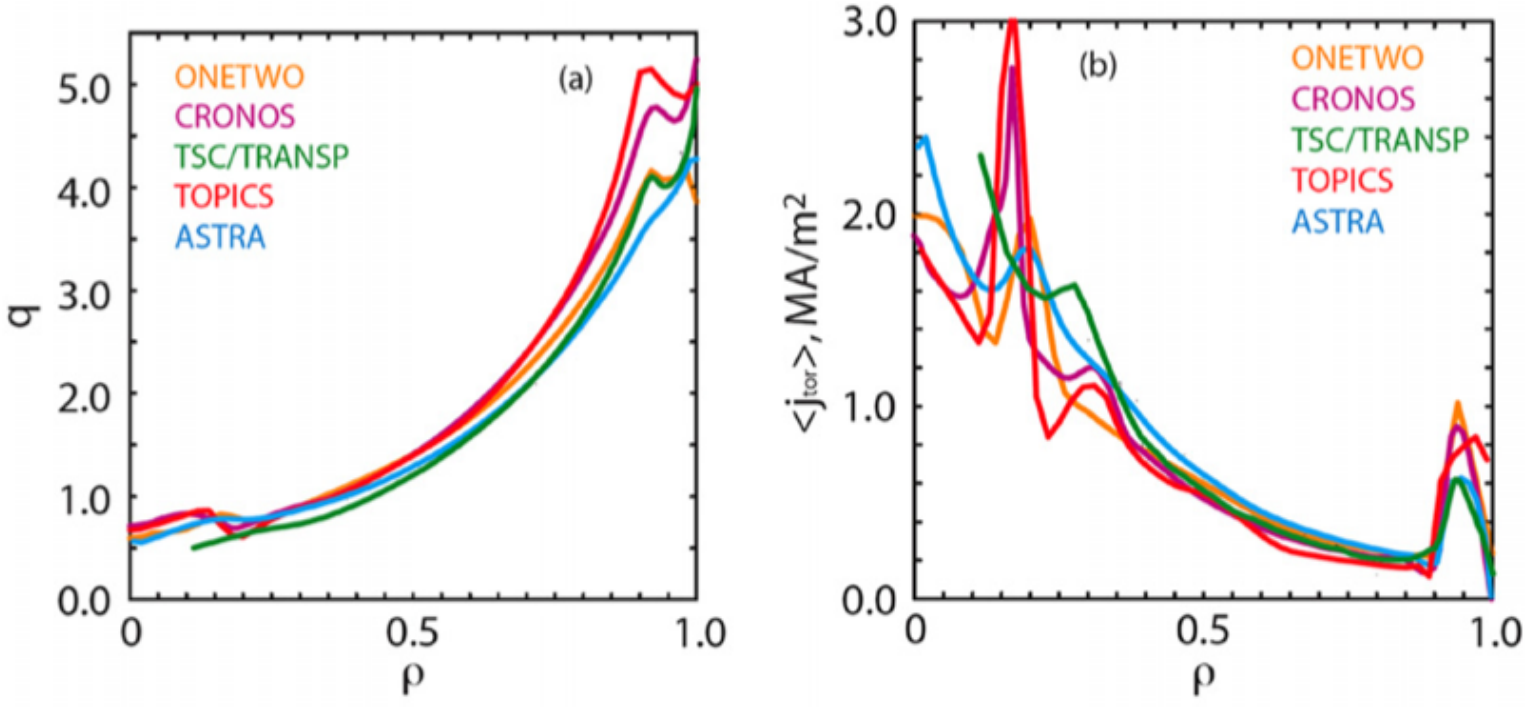
Observation of OMs (EHOs) at JET



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

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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

Ampere's law:

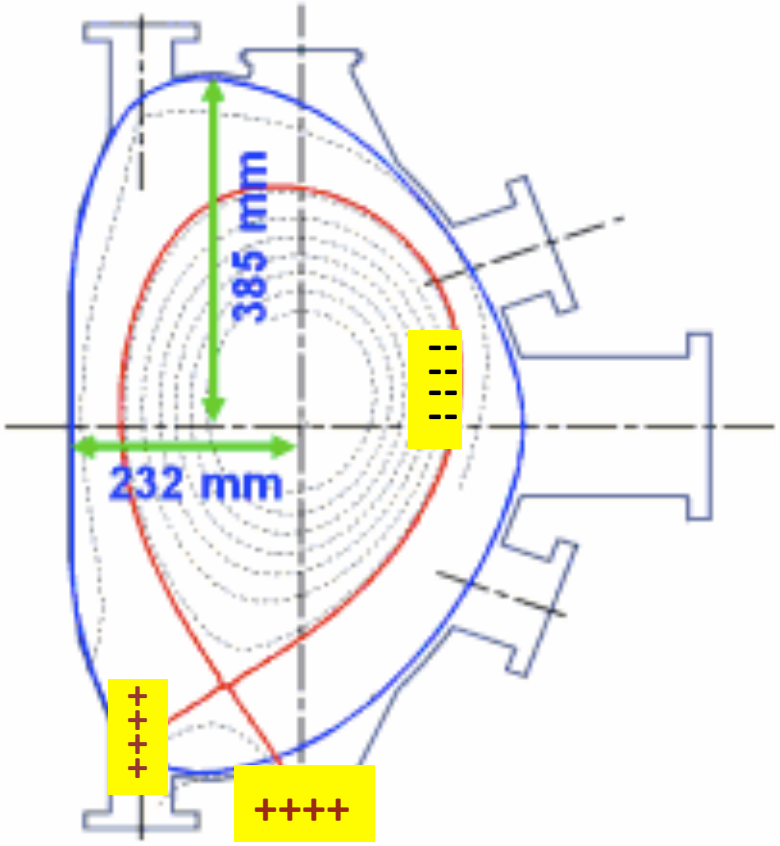
$$\tau_w \frac{\partial \delta B_r}{\partial t} - \Delta' \delta B_r = i \mu_0 w k_\theta \delta J_{||}$$

with $\delta J_{||}$ Related to δB_r by transport process

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

Charge recombination at plasma edge region

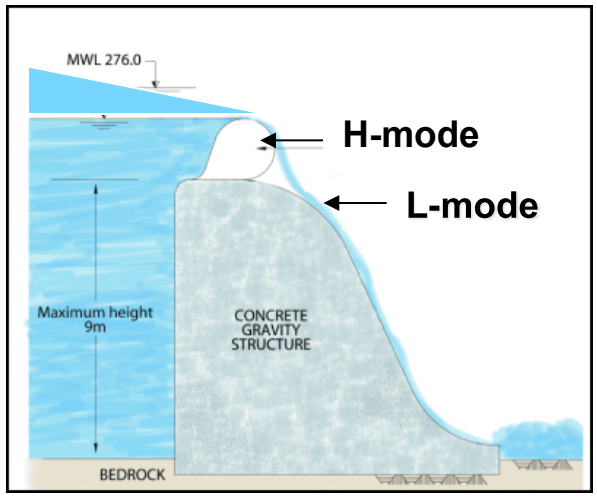
Charge recombination between the negative charges at plasma edge and the positive charges at divertor sheath can excite a surge of the SOL saturated current and consequently trigger the positive feed back process, i.e., ELMs



Any effects that reduce the coupling to SOL can help ELM mitigation, e.g., RMPs: reduce edge charge, increase connection length

Tokamak confinement

- Tokamak: overflowed reservoir for sticky water



Heating:
Flooding water

EHOs and RMPs:
Overflow to reduce pressure on dam

ELMs:
Dam failure

Elm mitigation or suppression are conditional, subject to heating power, etc.

Conclusion of Sec. III

1. Peeling ballooning can trigger ELMs, but ELMs are not peeling ballooning modes

– ELM frequency shoots up dramatically. This indicates ELMs are highly nonlinear positive feedback process
– No ELM-like modes are tied to ITB. This shows coupling to SOL is critical.

2. EHOs/OMs are not tearing modes

– Otherwise, they will be coupled to SOL current and lead to ELMs.
– JET experiments show that OMs are of kink type (E.R. Solano, IAEA FEC, 2010)
– No frequency chirping

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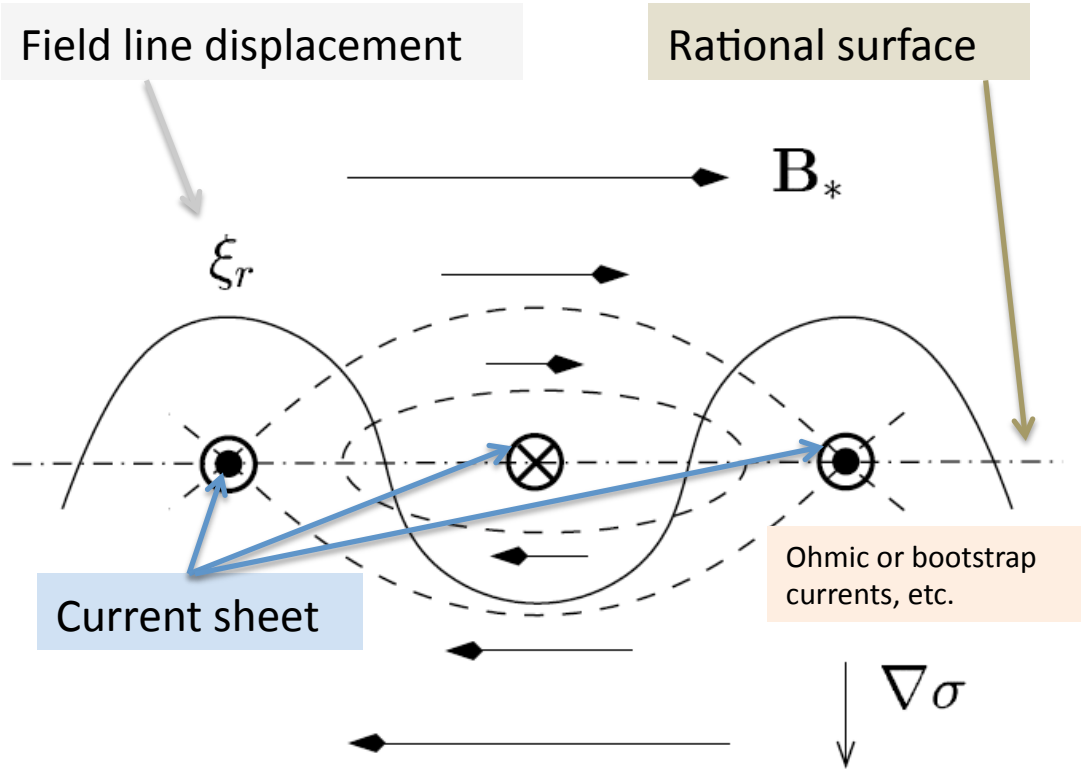
Current interchange tearing modes

(L.J. Zheng and M Furukawa, PoP 2010)

- **Interchange-type modes interchange not only plasma and magnetic energies, but also current.**
- **The induced current sheet leads to the excitation of the tearing modes (islands).**



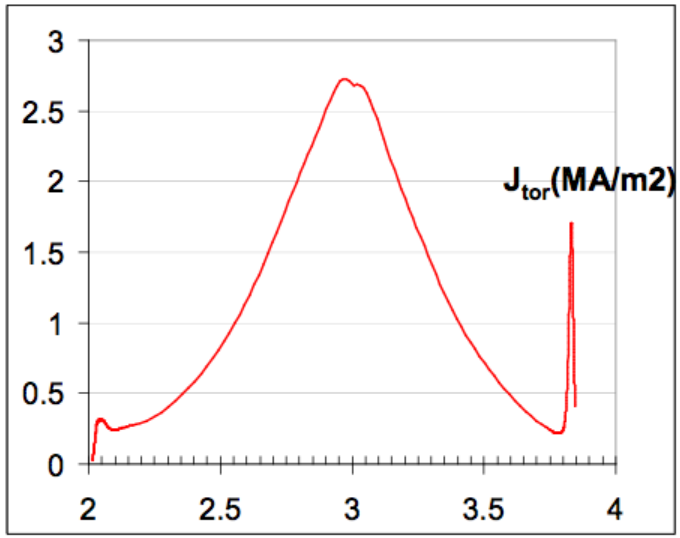
- **Both electrostatic (drift waves) and electromagnetic (MHD) modes can convert to CITMs**

Conclusion of Sec. IV

Conclusion:

EHOs/Oms tends to be infernal modes at q_{max} or low magnetic shear modes

– Otherwise, CITMs will be excited, which connect pedestal to SOL and lead to possible positive feedback Process – ELMs.



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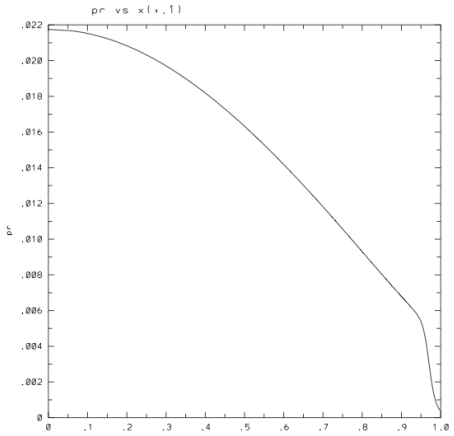
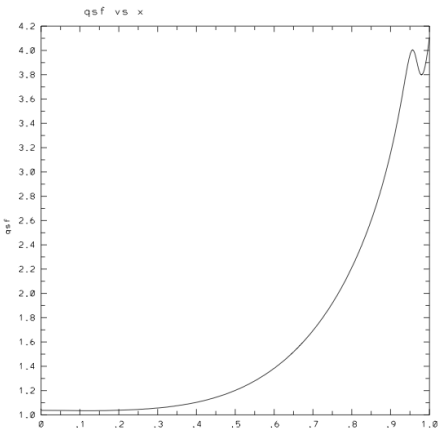
Reversed or reduced magnetic shear profile

Equilibrium pressure and safety factor profiles computed by VMEC:





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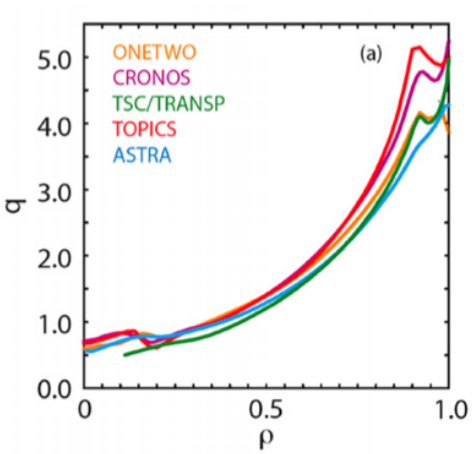
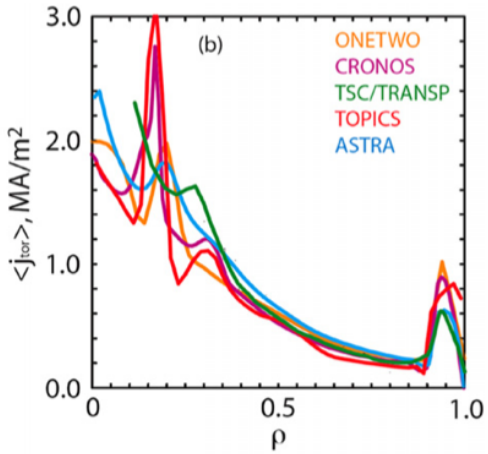
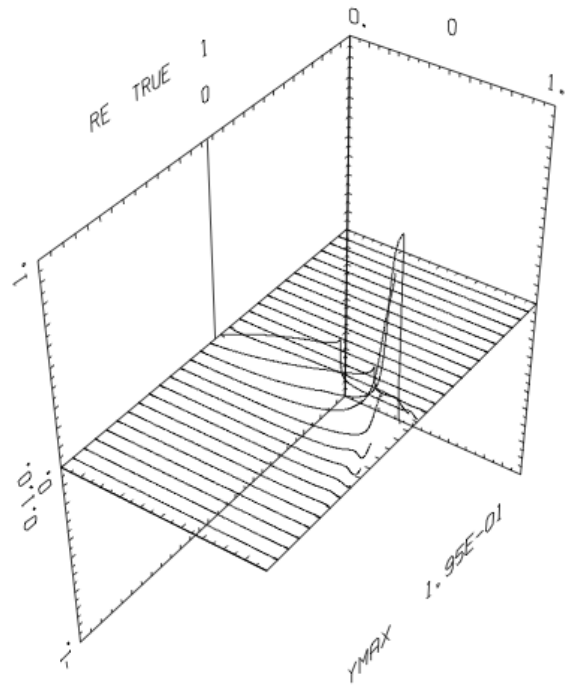
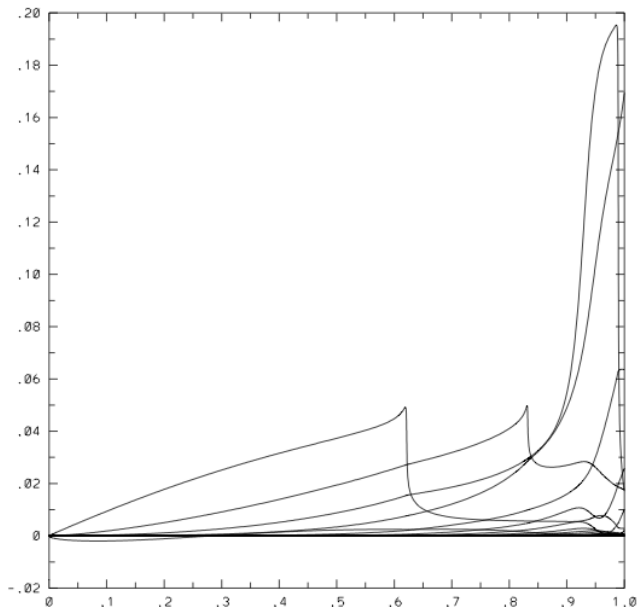




Theoretical origin for CITMs

n = 1 eigen mode structure – peak at q_{max}= 4 surface:





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. V

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

– Infernal (or low magnetic shear) modes are more unstable, but less damaging.

– 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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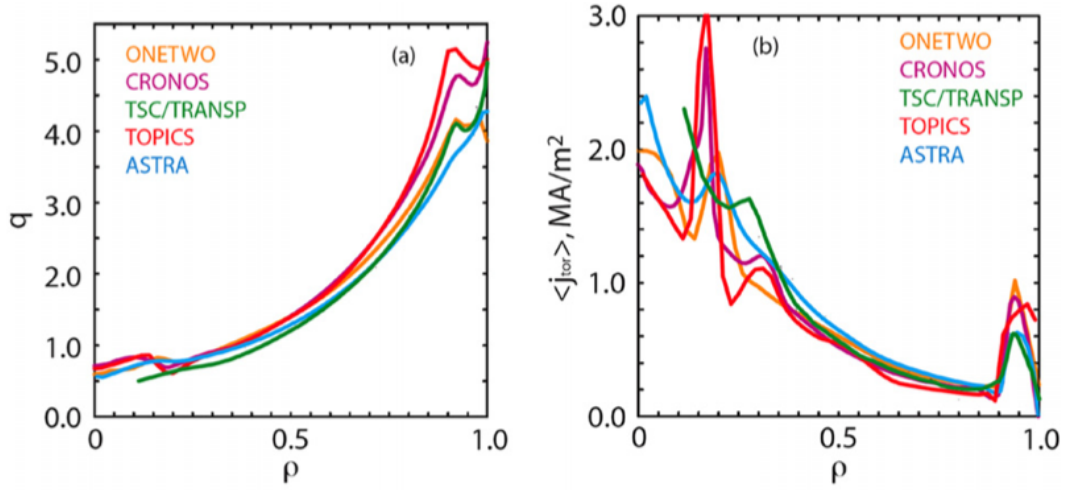
Magnetic-surface-preserving RMPs



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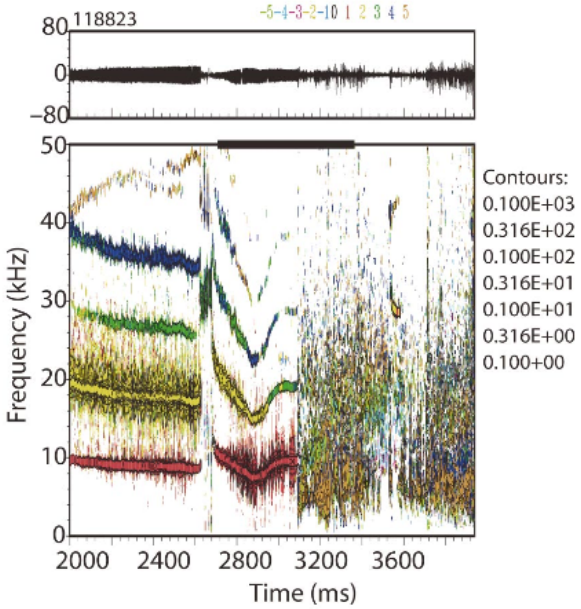

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Proposal: to apply RMPs which resonate with $q_{max,}$ (or q with low magnetic shear) to pump out energy without causing the coupling to SOL modes

Summary

I. We find that there is possible correlation of infernal modes at q_{max} or low magnetic shear modes with EHOs/OMs observed experimentally.

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