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On the role of rational surfaces on ExB sheared flows and transport in fusion plasmas

presented by

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Motivation and outline

Physics of transport barriers:

- formation (role of magnetic topology)
- power threshold (role of fluctuations)
- dynamics (interplay fluctuations - electric fields)
- tokamaks versus stellarators

Transport barriers

The generation of internal and edge transport barriers is linked to plasma regions with a unique magnetic topology:

ITB are usually formed close to the location of q_{min} and in the proximity of low order rational surfaces.

Edge transport barriers are located close to the boundary between the region with open and closed magnetic field lines.

In stellarator plamas global confinement depends strongly on the value of the edge rotational transform. W7-AS has shown robust H-mode with low order resonances (n/m = 5/9) at the edge.

Barriers and ExB sheared flows

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Edge and core transport barriers are related with a large increase in the ExB sheared flows

$$E_r = -v_\theta B_\varphi + v_\varphi B_\theta + P/n Z_i e$$

$$\frac{\partial v_\theta}{\partial t} = \text{thermal stress} + \text{viscosity} + \text{electromagnetic Reynolds stress} + \text{fast ion orbit loss} + \text{Stringer spin-up} + \text{neutrals}$$

Transport barriers and rational surfaces

The operational flexibility and control of the magnetic configuration in stellarator devices make them unique laboratories to investigate the role of rational surfaces on transport

Experiments in the TJ-II stellarator

Rational surfaces and transport

Large island ($\Delta >> L_r$) would destroy confinement

Small island ($\Delta << L_r$) will not affect confinement

Medium size island ($\Delta \approx L_r$) might be beneficial for confinement

Rational surfaces in TJ-II

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ExB sheared flows near rational surfaces ?

Transport (non thermal electrons) near rational surfaces?

Probes measurements, RX spectra and fluxes

Vacuum calculations (8/5)

Experimental set-up

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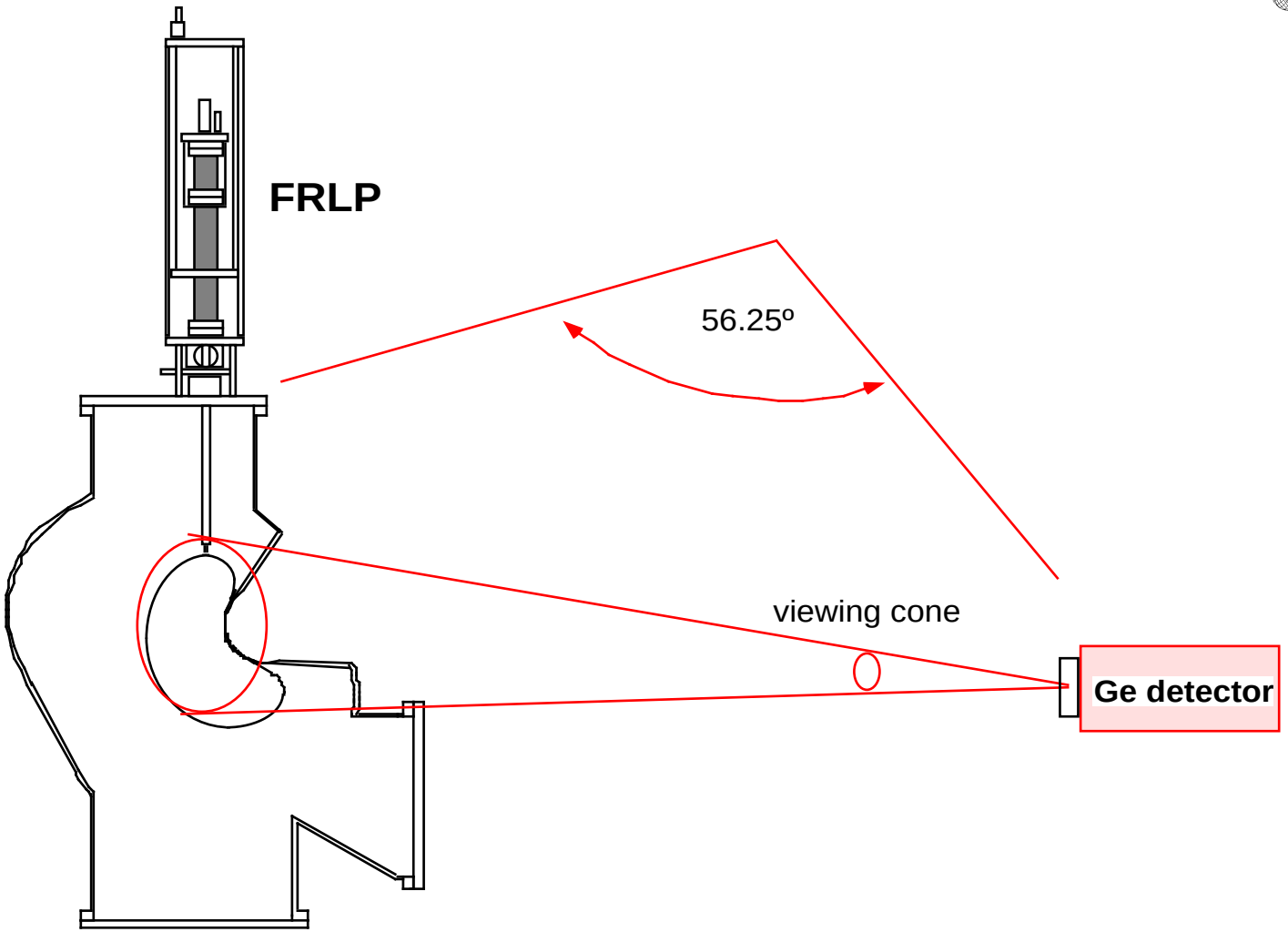

Plasma profiles and resonances in TJ-II

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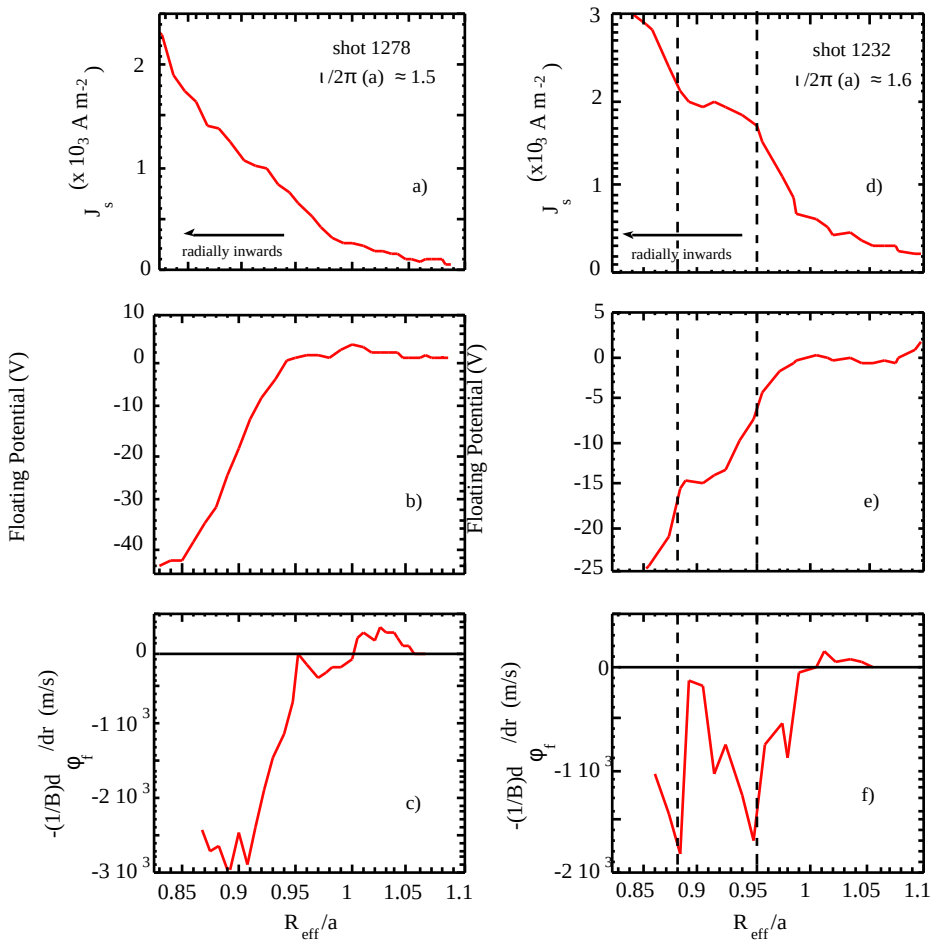

The 8/5 resonance has been observed as a flattening in the density and potential profiles

Plasma profiles and resonances (8/5)

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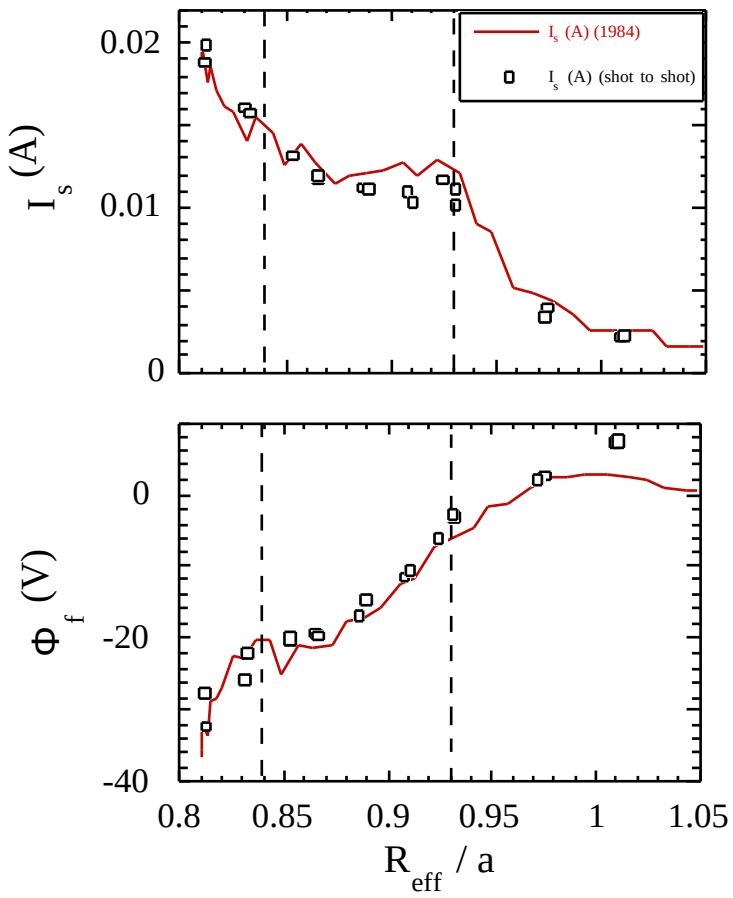

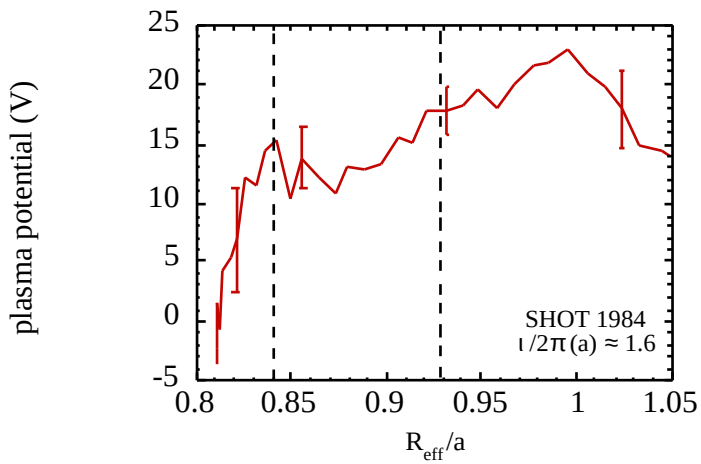

The ExB radial gradient ($B^{-1}\, dE_r/dr$) is of the order of $10^5\ s^{-1}$.

Non-thermal electron confinement

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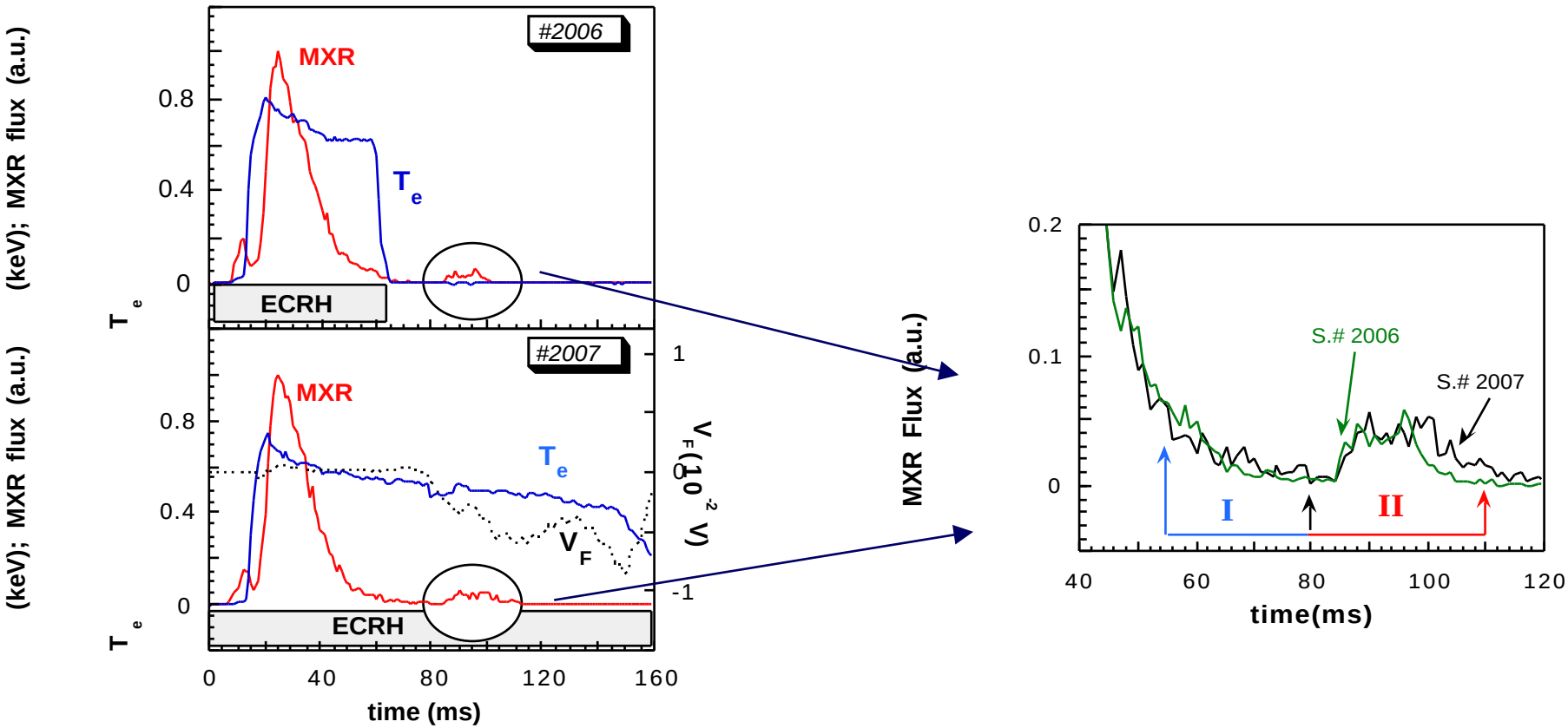

Experimental evidence of non-thermal electron confinement near rational surfaces

Non-thermal electron confinement

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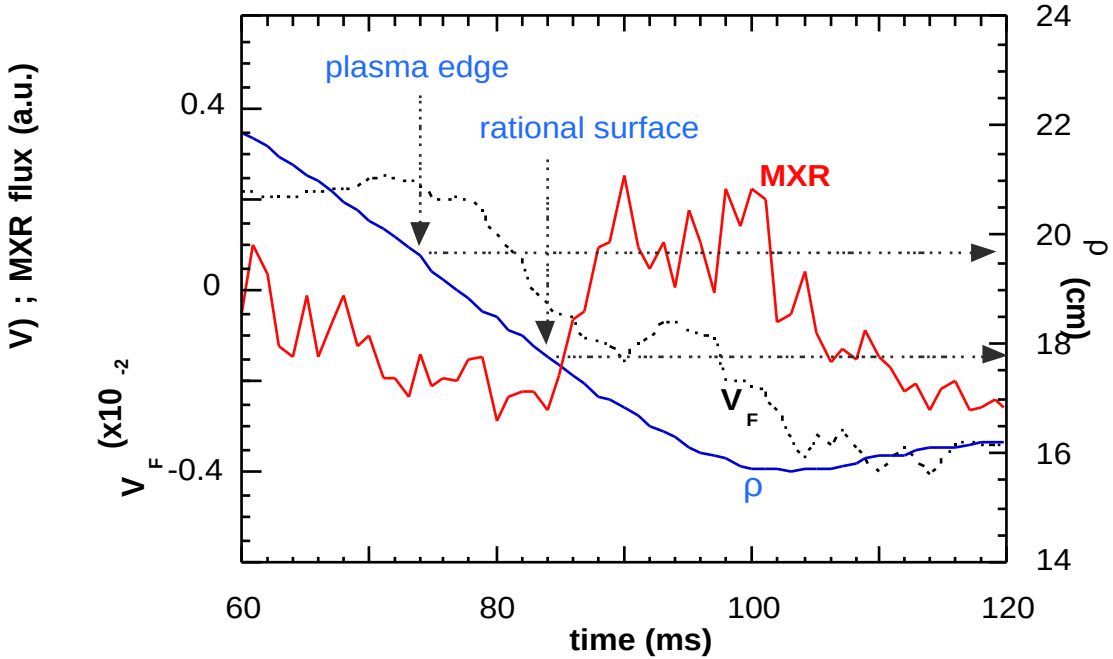

Why sheared ExB flows at the resonances?

Instabilities (Reynolds stress) ?

Ion - electron fluxes ?

Non-thermal electrons ?

Which mechanisms provide a power thresholds?

ExB flows driven via Reynolds stress

When the groth rate of fluctuations is large enough to drive a critical sheared flows (power threshold) the transition to improved confinement regimes takes place.

ExB flows driven by (Γ_i - Γ_e) fluxes

Non-termal electrons

ExB sheared flows via Reynolds stress at rational surfaces

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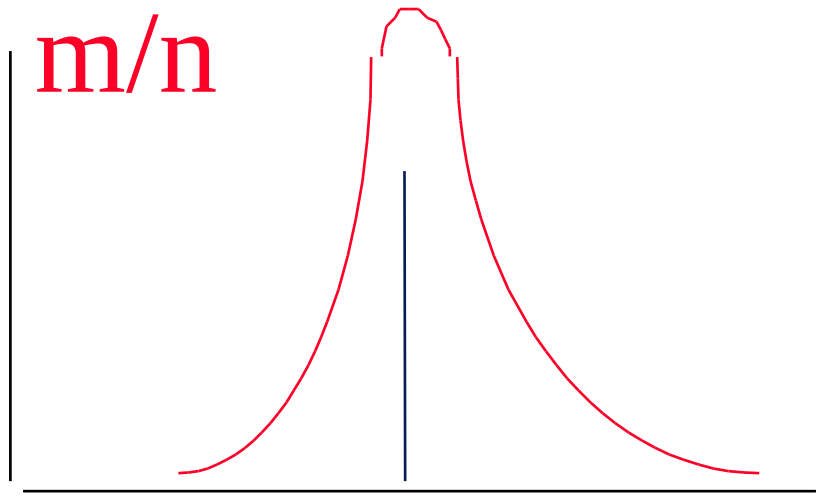
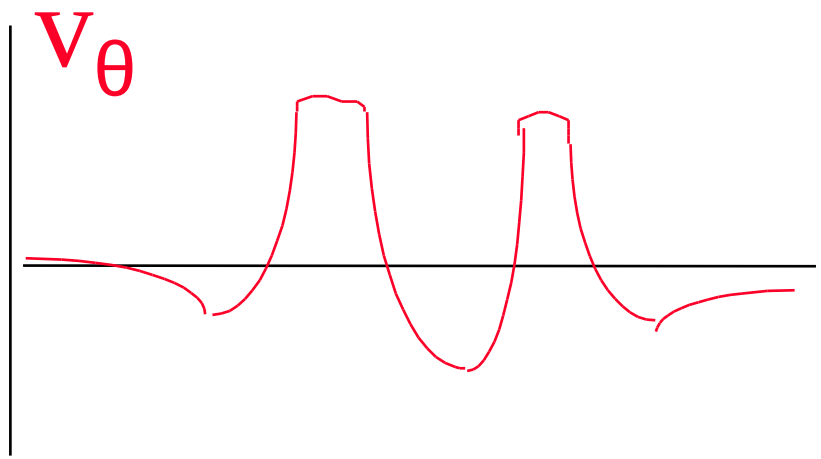


Δ Fluctuations are expected to show a maximum amplitude at the rational surface.

Δ Modification in the degree of anisotropy in the radial-poloidal structure of fluctuations



$$\frac{\partial}{\partial r} < \tilde{v}_r \, \tilde{v}_\theta > \neq 0$$

Δ Momentum re-distribution:

$$\omega_{ExB}$$

The modeling (L. García, B.A. Carreras, V. Lynch)

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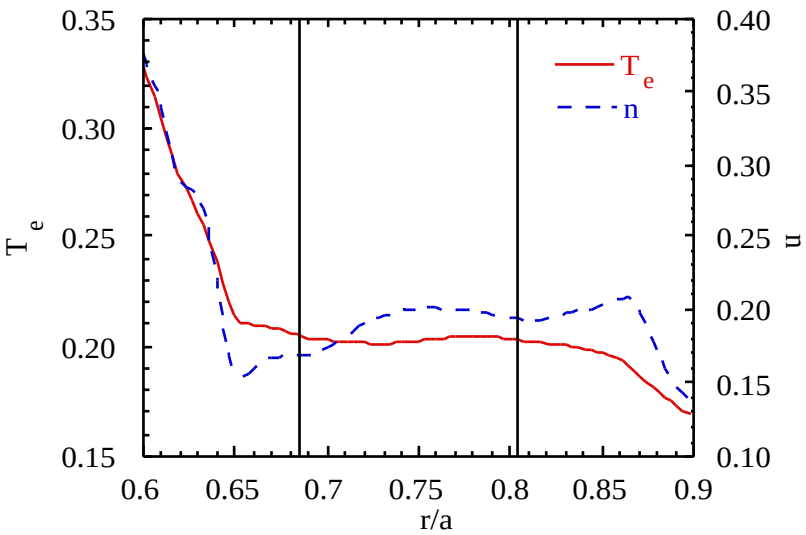

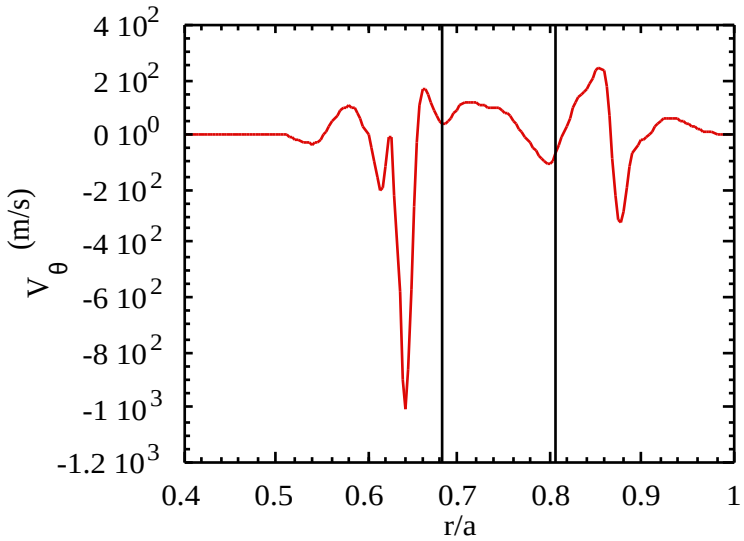

The effect of a magnetic island induced by resistive interchange modes on the radial structure of sheared flows driven by fluctuations via Reynolds stress have been investigated.

The radial structure of the flow v_θ shows two sharp spikes just outside the island region.

Transport barriers in tokamaks vs stellarators

Tokamaks:

Active control of plasma current profile

MHD stability and transport barriers

Stellarators:

Absence of free energy sources due to the plasma current

High beta stability (grad_p free energy source)

MHD stability in the presence of transport barrier and rational surfaces

ExB sheared flows linked to rational surfaces should overcome damping flow (viscosity)

Conclusions

Experimental evidence of ExB sheared flows linked to rational surfaces in the plasma edge of the TJ-II stellarator

Confinement of fast electrons near rational surfaces.

These results suggest radially inhomogeneous transport diffusivities in fusion plasmas and may explain the formation of transport barriers near rational surfaces.

These results open a research area to induce transport barriers in fusion plasmas (particularly in stellarators).