# Comparison of External and Internal Transport Barriers in Drift Wave Predictive Simulations


J. Weiland[1], K. Crombe[2], P. Mantica[3], T. Tala[4], V. Naulin[5] and the JET-EFDA Contributors*

1. Chalmers University of Technology and EURATOM-VR Association, Gothenburg, Sweden
2. Association EURATOM-Belgian State Department of Applied Physics, Ghent University , Belgium
3. Istituto di Fisica del Plasma-P Caldirola, Association EURATOM-ENEA-CNR, Milano, Italy
4. Association EURATOM-Tekes VTT P.O. Box 1000 FIN-02044 VTT Finland
5. Association EURATOM-Risö DTU DK 4000 Risö Denmark



**Joint US-EU Transport Task Force Workshop, San Diego April 6-9 2011**

# Poloidal spinup due to Reynolds stress

- The radial flux of poloidal momentum

$$\Gamma_p = < \mathrm{v}_{\mathrm{Er}} \mathrm{v}_\theta > = -D_B{}^2 k_r k_\theta \frac{1}{2} \hat{\phi}^* \left[ \hat{\phi} + \frac{1}{\tau} \hat{P}_i \right] + c.c \qquad (1)$$

We have obtained a spinup of poloidal momentum both at an internal and at an edge transport barrier. In both cases the bifurcation seems to be closely related to this spinup.

- Electromagnetic toroidal (parallel) momentum equation including curvature effects from the stress tensor (coriolis pinch)

$$m_i n_i \left( \frac{\partial}{\partial t} + 2\vec{U}_{Di} \cdot \vec{\nabla} \right) \delta u_\parallel = -m_i n_i \vec{\mathrm{u}}_E \cdot \nabla U_{\parallel 0} - \left[ \hat{e}_\parallel \cdot \nabla + U_{\parallel 0} \frac{m_i \vec{U}_{D_i}}{T_i} \cdot \nabla \right] \left( \delta p_i + e n_i \phi - \frac{\omega + \omega_{*e}(1+\eta_e)/\tau}{k_\parallel c} A_\parallel \right) \qquad (2)$$

# Internal transport barrier

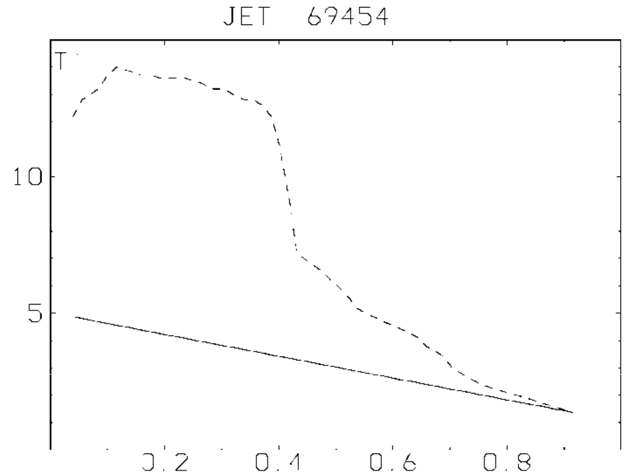
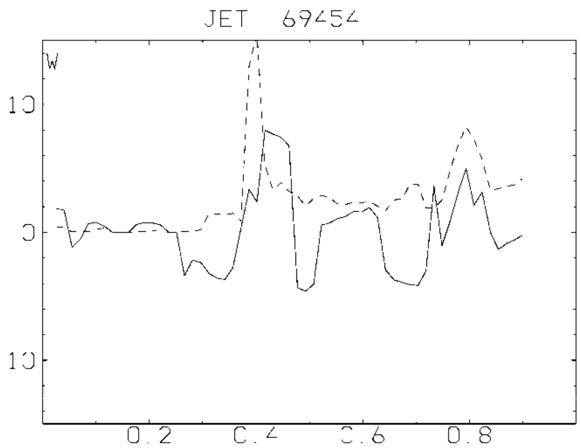



Fig 1

- Internal transport barrier in $T_i$ (dotted) in JET69454 as simulated in the code selfconsistently including also $T_{e,}$ $V_{pol}$ and $V_{tor}$. The location and approximate magnitude are in agreement with the experiment.

- As seen in the initial profiles there was no initial trace of a barrier. The density was kept fixed and did not show any sign of barrier.

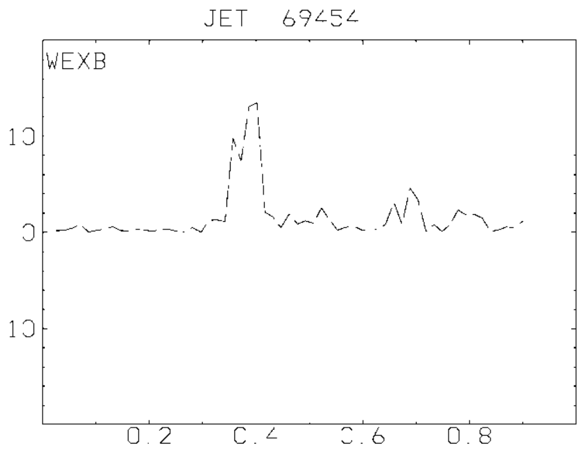
# A TE mode is still unstable at the centre of the internal barrier




Real eigenfrequency

Growthrate

The fastest growing mode is an electron mode in the barrier. (top figure)




The shearing rate is not sufficient for stabilization at the centre of the barrier.

(note that the scales are the same!)

# Simulation of JET69454 -Poloidal spinup

- The ITG mode was stable in the barrier but provided a flux of poloidal rotation towards the barrier

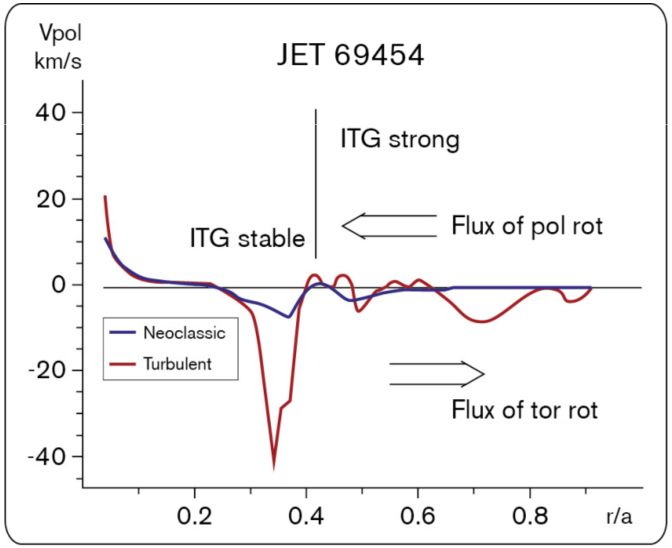



Fig 2

- The TE mode was marginal at the barrier. The location and magnitude of the poloidal spinup was in agreement with the experiment

# Edge barrier with basic data from JET69454

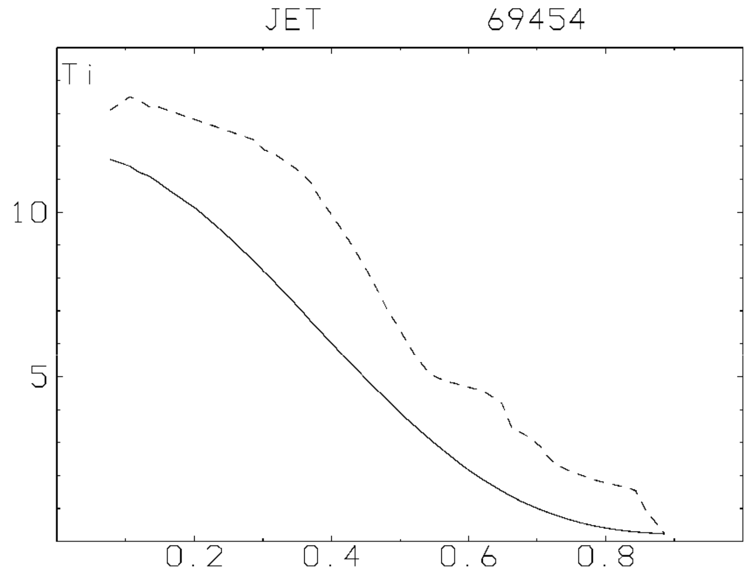



Fig 3

**Start profile**

**Simulation**

**Experimental $T_i$ at r/a = 0.9 was around 1.5 KeV. $B_p$ =0.2T**

# Increased $B_p$

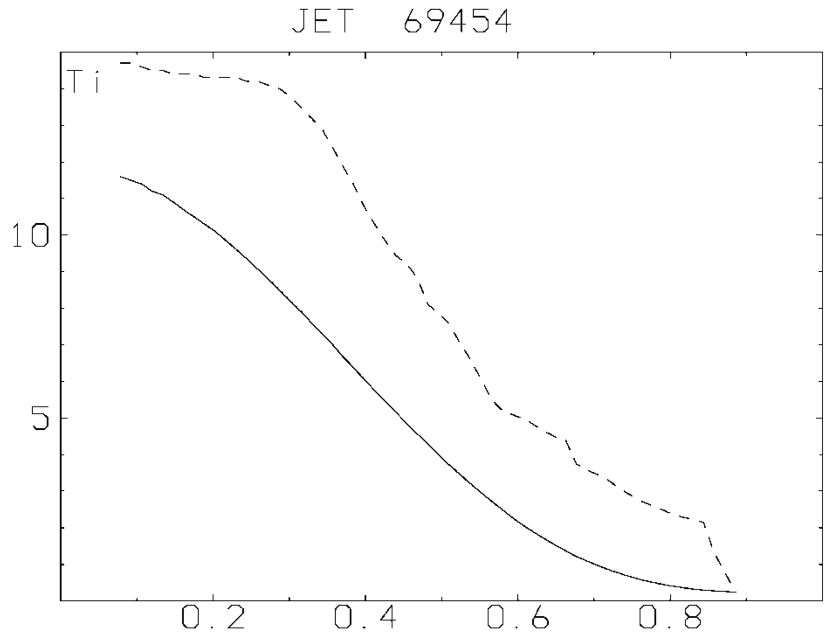



Fig 4

**Same case as in Fig 3 but with $B_p$ increased by 50%. The height of the pedestal has increased but no further increase is seen for higher $B_p$ .**

# Bifurcation due to flows

We use the radial forcebalance for ions:

$$E_r = B_\theta V_\phi - B_\phi V_\theta + \frac{1}{eZn_i}\frac{\partial P_i}{\partial r} \qquad (3)$$

The energy flow can be written: (Compare Hinton and Staebler, Phys. Fluids B**5**, 1282 (1993))

$$Q = -\left[\chi_0 + \frac{\chi_1}{\alpha(du_E/dr)^\gamma}\right]\frac{\partial P_i}{\partial r} \qquad (4)$$

# Bifurcation due to flow

Here $U_E$ is the ExB drift due to the radial electric field from force balance (3), $\chi_0$ is the diffusivity due to short wavelength modes that are not stabilized by flowshear and $\chi_1$ is the diffusivity due to long wavelength modes. $\alpha$ and $\gamma$ are parameters of the model.

Hinton and Staebler assumed neoclassical poloidal rotation. In this case the pressure gradient would usually dominate in (3). However, as is seen from (1), the pressure perturbation, which is due to background pressure gradients, will enter also for the poloidal spinup.

# Bifurcation cont

This will lead to the same type of bifurcation as found by *Hinton* and *Staebler* both for the edge and internal barriers.
Of course the present model applies to quasistationary situations where a broad spectrum is involved. In our simulations the excitation of zonal flows has been essential both for ETB's and ITB's. Several authors have studied this analytically with low dimensional systems (Chen, Lin and White, Phys. Plasmas **7**, 3129 (2000), Guzdar, Kleva, Das and Kaw, PRL **87**, 015001 (2001), Singh, Tangri, Kaw and Guzdar, Physics of Plasmas **12**, 092307 (2005)). While such systems will eventually develop into turbulent systems, they may well describe an initial onset of a transition. For phase mixed situations we may use the inverse modenumber of the fastest growing mode as correlation length (Weiland, Nordman Proc Varenna-Lausanne Joint Workshop, Chexbres 1988 p 451, Nordman, Weiland Nuclear Fusion **29**, 251 (1989)).

# What determines the slope of the Edge barrier?

In the edge pedestal electromagnetic effects become important. In this case we need a somewhat longer correlation length. This is actually accomplished by our parameter dependent correlation length according to Weiland and Holod (Phys Plasmas **12**, 012505 (2005)) leading to $k_\theta\ \rho \sim 0.1$ (rather than 0.3 in the core). The main destabilizing mechanism in the model for strong pressure gradients is the *kinetic ballooning mode*.

The height of the barrier increases with $B_p$. However, this is due to increased slope. Thus $\beta_p$ is almost unchanged! It appears that a stronger B allows a steeper temperature gradient as expected from a $\beta$ limit. However the *width* of the barrier is unchanged.

The poloidal spinup is due to nonlocal effects (pileup) both for the internal and edge barriers

For stabilization of the relevant instabilities  it is the temperature length scale that is important for bifurcation.

At the edge the outer temperature is kept low by the boundary condition and increased heating diectly leads to a reduced temperature lengthscale

In the core the temperature and temperature gradient can increase together keeping the same length scale.  Thus we need something more, like small magnetic shear to cause the initial local reduction of transport.

# Similarities between Transport barriers in Core and Edge

## Electromagnetic – Nonlocal simulations

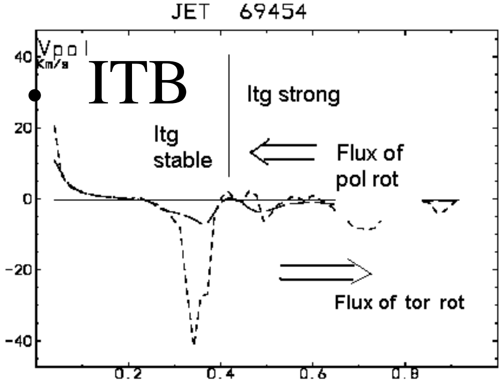



Fig 5

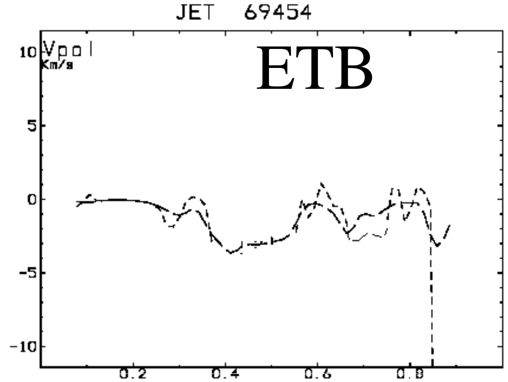



Fig 6

**J. Weiland et. al EPS Dublin 2010**

**J. Weiland TTG Cordoba 2010**

Strong poloidal spinup both in internal barrier (ITB) and in edge barrier (ETB). Both electromagnetic and nonlocal effects needed for the internal barrier. For the edge barrier we also need nonlocal effects but electromagnetic effects reduce the barrier.

# Mechanism of poloidal spinup

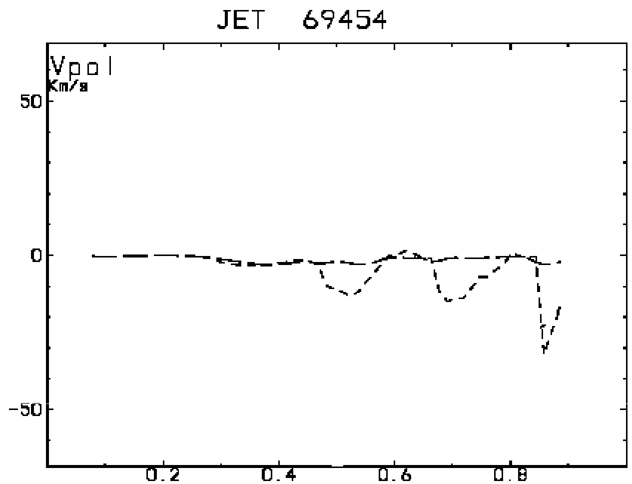



Fig 7

Poloidal rotation

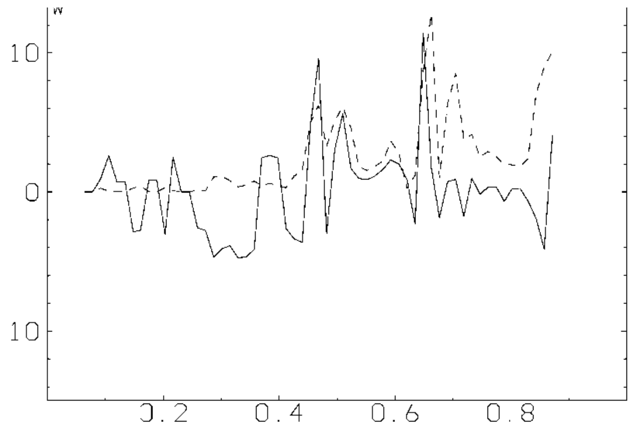



Fig 8

Eigenvalue most unstable mode

# Flowshear

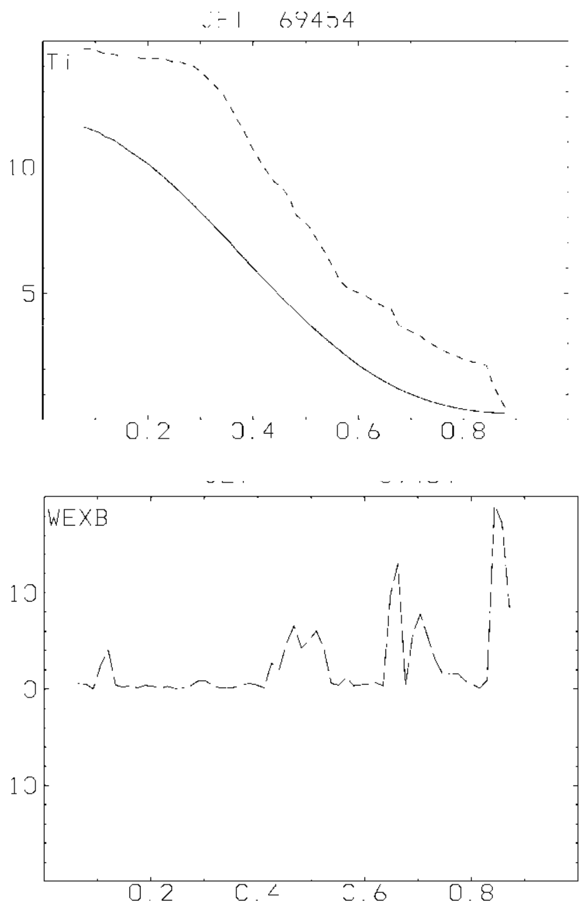



Fig 9a,b

Ion temperature and Flowshear profiles showing why we get stabilization at the edge. Note that this was obtained self-consistently in a global simulation The flowshear is driven primarily by the poloidal nonlinear spinup of rotation. Careful study of simulation data shows that a mode propagating in the electron drift direction is unstable at the edge point and at the first point inside the edge.

# Peeling

Preliminary simulations have also been made with the inclusion of a kink term (peeling)

$$\frac{\partial n_{ef}}{\partial t} + \nabla \cdot \left[ n_{ef} \left( \mathbf{v}_{\mathbf{E}} + \mathbf{v}_{*\mathbf{e}} + \mathrm{v}_{\|} \frac{\delta \mathbf{B}_{\perp}}{\mathrm{B}} + \mathrm{v}_{\|} \hat{\mathbf{e}}_{\|} \right) \right] = 0$$

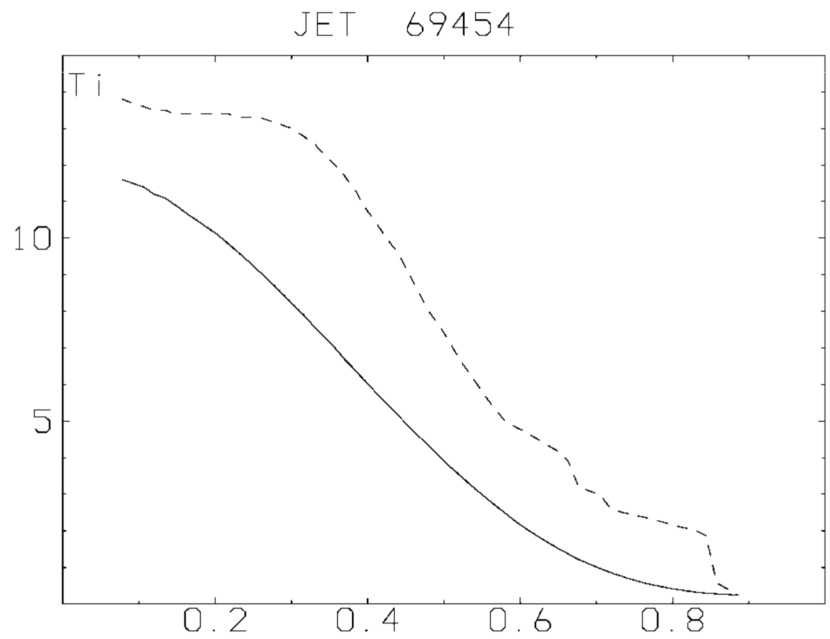



Fig 10. This case corresponds to Fig 4, i.e. 50% increase in $B_p$ . As seen also without peeling, a mode rotating in the electron drift direction gets unstable at the outer end of the barrier. This trend gets stronger when peeling is included.

# Discussion

We have here applied a transport code for both ITB’s and ETB’s. The principle justifying this is the same as for core transport, i.e. in a phase mixed situation we can use the correlation length corresponding to the inverse mode number of the fastest growing mode. This means that in a phase mixed situation with a broad spectrum, the sidebands studied in low dimensional nonlinear systems will be part of the broadband turbulence giving the correlation length as the inverse modenumber of the fastest growing mode. As it turns out, nonlocal and electromagnetic effects are important for both ITB and ETB just as in turbulence simulations. In the broadband, phase mixed situation we can use the model of Hinton and Staebler (Phys. Fluids B**5**, 1281 (1993)) modified to dominating poloidal flow, to describe the bifurcation.

# Summary

Previous results on the formation of an internal transport barrier have been extended to include also the edge barrier. Electromagnetic and nonlocal effects play dominant roles in both cases.

The turbulent spinup of poloidal rotation is instrumental for both transitions.

Our parameter dependent correlation length gives a realistic description of turbulence also in the edge barrier.

The peeling mechanism leads to further excitation on an electron mode close to the outer boundary.