ROLE OF ELECTROSTATIC & MAGNETIC TURBULENCE IN ITB FORMATION IN JET

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1. Introduction

The suppression of edge density turbulence during H-mode phases of tokamak discharges has long been associated with the formation of an edge transport barrier and a reduction in edge plasma transport. Recent results [1,2] suggest a similar correlation between core turbulence and reduced core transport during optimised or reversed central magnetic shear discharges with an Internal Transport Barrier (ITB). It is believed that ITBs may be formed through a combination of $\mathbf{E} \times \mathbf{B}$ velocity shear and magnetic shear stabilisation of plasma turbulence and instabilities [3]. In JET optimised shear discharges [4], results show that the turbulence reduction occurs in two stages. Low frequencies are suppressed throughout the plasma core by a toroidal velocity shear, then high frequencies are locally suppressed around the steep gradient region of the ITB, consistent with $\mathbf{E} \times \mathbf{B}$ poloidal shear.

2. Turbulence evolution

The plasma turbulence in a typical optimised shear discharge can be separated into three spatial regions: outside the ITB (edge), within the ITB, and inside the ITB (core). The core turbulence evolves through 4 distinct phases; (1) ohmic breakdown (2) L-mode ICRH preheat (3) main NBI and ICRH heating, and (4) the ITB phase. To illustrate the features of each phase a single B_T~3.4T, I_p~3.4MA peak discharge (#46727) is used. Fig.1 shows time traces of the main plasma parameters. Figure 2 shows spectrograms (log intensity v frequency and time) of: (top) magnetic fluctuations from a single Mirnov coil, and (bottom) electrostatic / density fluctuations (Acosϕ) from a 92GHz reflectometer channel with a cutoff layer at the ITB. Figure 3 shows a series of spectra from a 75GHz edge reflectometer channel (top row: R ~ 3.8m) and the 92GHz core reflectometer channel (bottom row: R ~ 3.2 – 3.6m), taken at various stages of the discharge. The zero frequency spike is the reflectometer carrier wave and indicates the level of reflected power.

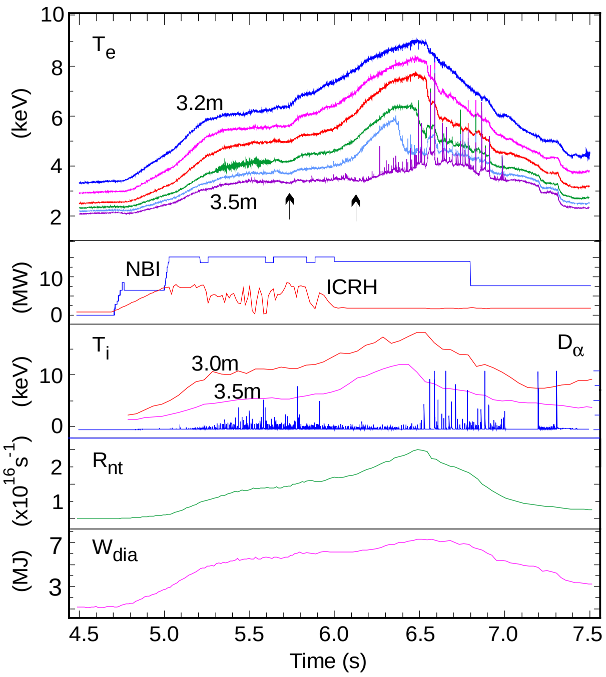

Fig.1: (a) electron temperature T_e at various radii, (b) NBI & ICRH power, (c) D_α emission & T_i , (d) neutron rate R_{nt} and (e) stored energy W_{dia} for shot #46727.

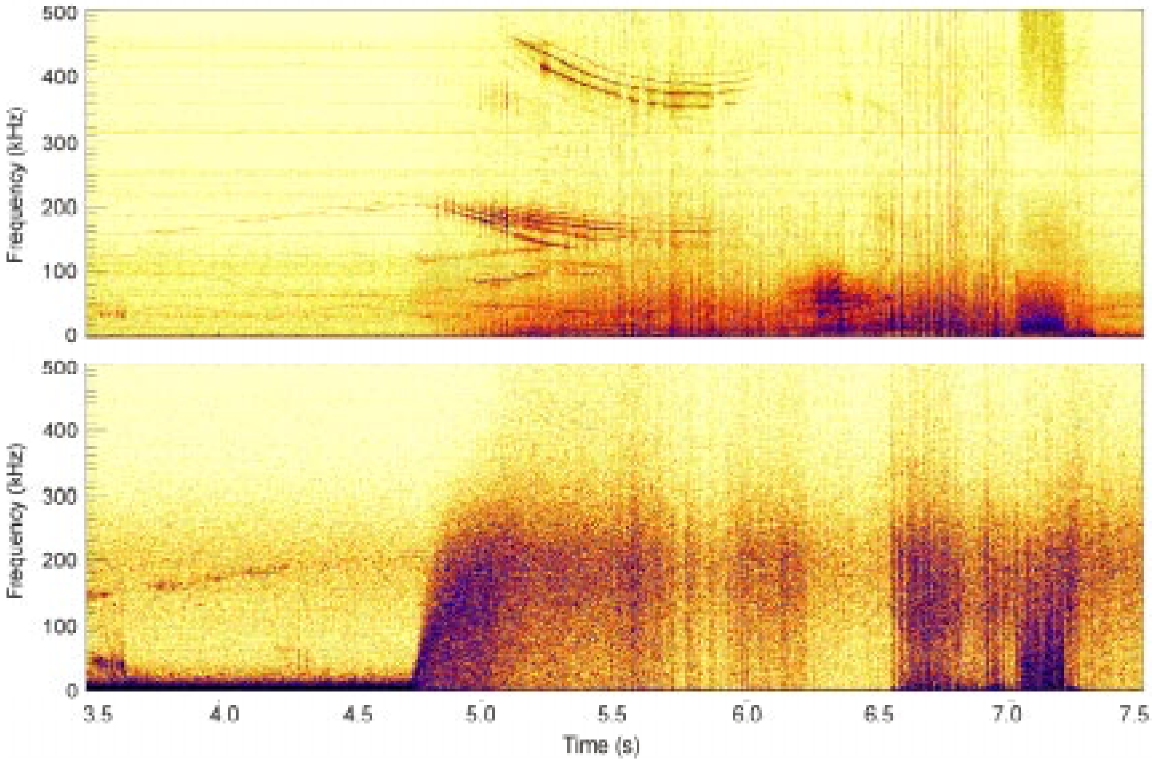

Fig.2: Spectrogram (log intensity) of magnetic fluctuations (top) and density fluctuations at ITB (bottom) from 92GHz core reflectometer channel (R ~ 3.2 - 3.6m) for shot #46727. Slight background feature around 200kHz in bottom spectrum is due to amplifier gain anomaly.

(1) **Ohmic phase**: Fig.3(a): The density spectrum is dominated by low frequency turbulence throughout the plasma, and is ballooning in character (the fluctuation amplitude is more than a factor of 10 higher at the outboard edge compared to the inboard edge).

(2) **L-mode pre-heat phase**, Fig.3(b): Applying 1 to 2MW of ICRH (to slow the current penetration and control the q profile evolution) has little effect on either core or edge turbulence (note the magnetics spectrum remains flat), but it does generate large amplitude core localised Toroidal Alfven Eigenmodes between 100 to 200kHz (evident in magnetics and core density but not in edge density), together with lower frequency modes (possibly Acoustic or Shear Alfven) around 20kHz.

(3) **Main heating phase**, Fig.3(c) & (d): Combined NBI & ICRH with P_{tot} > 15MW is applied at 4.7s. The power is stepped up in stages to delay the formation of an H-mode during the plasma current ramp. The core density spectrum shows a complete suppression of low frequency turbulence together with a rapid broadening of the spectrum with f > 300kHz. The edge density and magnetics also show a rise in high frequency turbulence.

(4) **ITB formation**, Fig.3(e): The uneven ICRH power matching (keeping the input below the threshold for triggering the ITB) delays the ITB formation until 6.2s. The ITB formation and collapse is shown in the electron temperature T_e profile in Fig.4. MHD (a q=2 snake) terminates the ITB at 6.5s. Between these times the spectrum shows a rapid reduction of high frequency turbulence. At this time the reflectometer cutoff layer is in the ITB region. There is also a similar drop in turbulence at 5.7s – which coincides with a sudden rise in core T_e and T_i and hence pressure gradient ∇P and a corresponding improvement in fusion performance. This phase however was not sustained, T_e rises at the edge reducing ∇P.

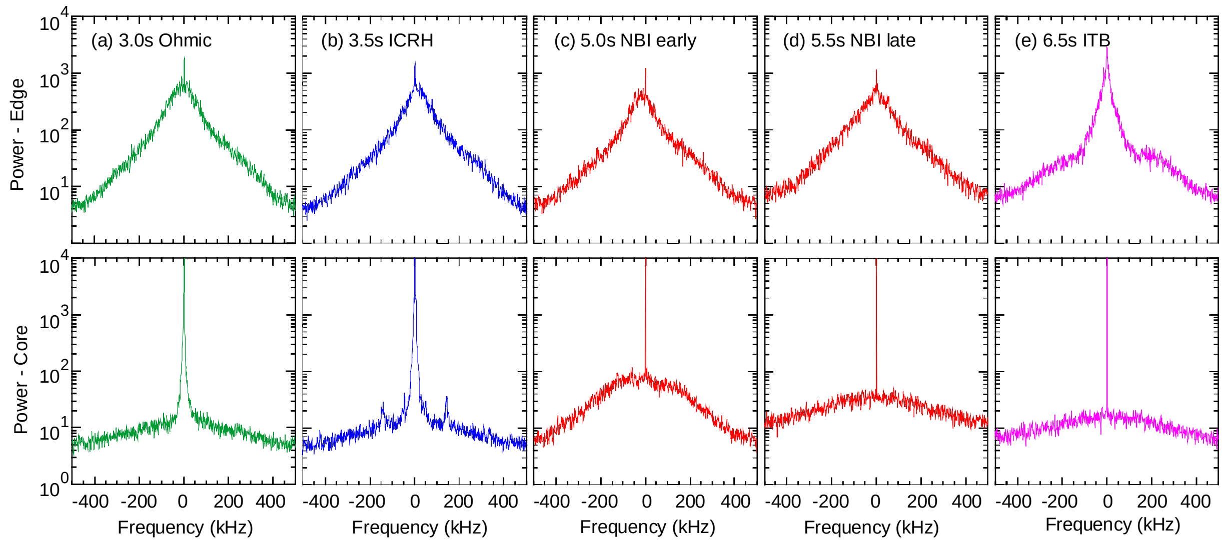

Fig.3: Fourier spectra from 75GHz edge (top row) and 92GHz core reflectometer channel for 3.4T shot #46727; (a) ohmic (b) ICRH (c) early NBI (d) late NBI and (e) ITB.

3. Edge turbulence

Figure 3 shows the edge turbulence remaining high throughout the discharge. The shape of turbulence spectrum however depends on whether the discharge maintains an L-mode like edge, in which case the spectrum is narrow with an exponential shape, or develops an ELMy H-mode pedestal with a broader bell shaped spectrum, often with strong MHD. Note there is no suppression of edge turbulence with an ELMy pedestal.

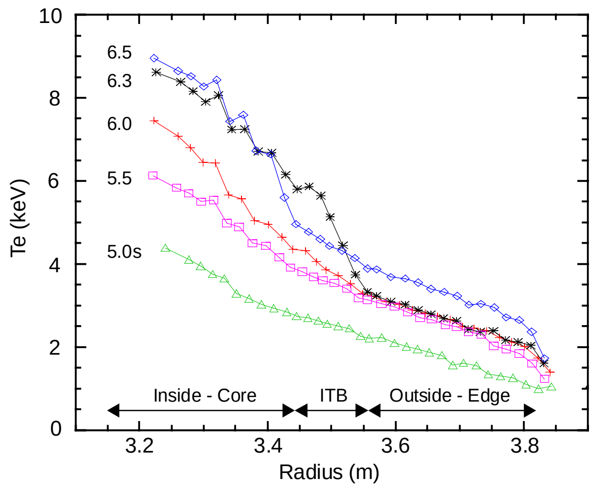

Fig.4: Radial electron temperature profiles measured with a 48 channel heterodyne ECE radiometer showing evolution of ITB during shot

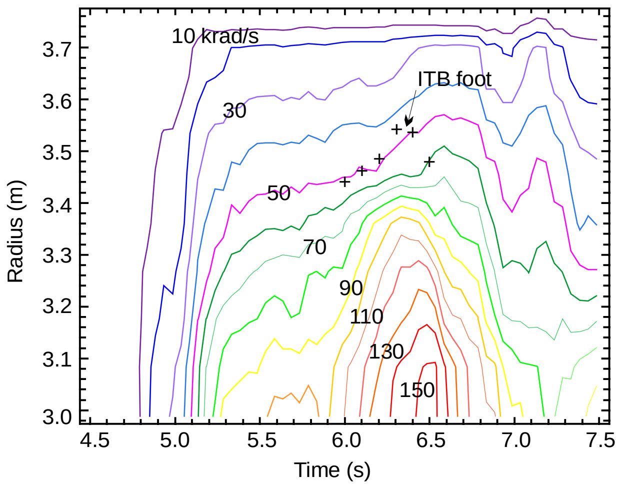

Fig.5: Contours of ω_{rot} toroidal angular rotation frequency from CXS v radius & time for shot #46727. Crosses mark position of ITB 'foot' from T_e.

4. Toroidal velocity shear & long wavelengths

Both the T_e and T_i profiles show steep gradients with foot points that coincide and track each other as the ITB expands and contracts. The foot points also track a boundary between regions of low and high shear in the toroidal rotation. Figure 5 is a contour plot of the toroidal rotation frequency ω_{rot} (from charge exchange spectroscopy) v major radius and time for shot #46727. The plasma core spins up toroidally (driven by pressure gradient and/or momentum injection) while the edge remains virtually stationary. The boundary (indicated by the change in contour spacing) expands with the ITB foot (crosses). The central toroidal velocity shear region encloses half the plasma area or more so it could primarily affect fluctuations of similar scale lengths, i.e. long wavelengths. Reflectometer correlation measurements and mode analysis of magnetic signals confirm that the ohmic/L-mode phase contains only long wavelength fluctuations, while the NBI/ICRH phase contains only short wavelengths. Doppler rotational shift may account for some of the spectral broadening [1], but it can not explain the change in wavelengths; nor the rise in high frequency turbulence in the stationary edge, or the fact that the spectrum spreads faster than the toroidal spin-up. One possible explanation is that the velocity shear breaks up the long wavelength turbulence into shorter wavelengths. This hypothesis is supported by observations of edge turbulence suppression during ELM-free Hot ion H-modes when a strong velocity shear forms at the H-mode pedestal; and of no turbulence suppression during ELMy H-modes when this velocity shear is destroyed.

5. $\mathbf{E} \times \mathbf{B}$ poloidal shear & short wavelengths

The two periods of reduced high frequency turbulence at the ITB coincide with periods of localised increase in the electron and ion pressure gradients ∇P_e and ∇P_i. Together with the fast transitions in turbulence level, this suggests a positive feedback-loop mechanism [3]. An increase in pressure gradient enhances the local $\mathbf{E} \times \mathbf{B}$ poloidal shear, which leads to localised suppression of turbulence (with scale lengths comparable to the ∇P width, i.e. short wavelengths) which in turn leads to improved confinement and hence a further increase in ∇P.

6. Conclusions

The results indicate that the formation of a core region of high toroidal velocity shear in JET suppresses long wavelength fluctuations. The subsequent formation of an internal transport barrier is correlated with the localised suppression of short wavelength turbulence within the ITB gradient region. The short wavelength suppression is consistent with a positive feedback loop involving a localised enhancement in $\mathbf{E} \times \mathbf{B}$ poloidal shear, driven by plasma pressure gradient.

Acknowledgements

A.Fasoli, R.C.Felton, D.Testa and R.F.Heeter for assistance with data acquisition, A.Thyagaraja for useful discussions, and members of Task Force B and JET Team for the operation of the JET tokamak.

References

[1] C.L.Rettig *et al*., Plasma Phys. Control. Fusion **40**, 811 (1998).
[2] M.G.Bell *et al*., Plasma Phys. Control. Fusion **41**, A719 (1999).
[3] K.H.Burrell, Phys. Plasmas **4**, 1499 (1997).
[4] C.Gormezano *et al*., Phys. Rev. Lett. **80**, 5544 (1998).
[5] X.Litaudon *et al*., Plasma Phys. Control. Fusion **41**, A733 (1999).
[6] K.L.Wong *et al*., Phys. Lett. A **236**, 339 (1997).