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Intermittent Turbulence and Energy Confinement in JET

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INTRODUCTION

Recent studies of Ion Temperature Gradient (ITG) turbulence using three-dimensional fluid codes (for example [1]) suggest a link between changes in confinement scaling (i.e. Bohm or gyro-Bohm) and the proximity to some form of turbulence threshold. The simulations indicate Bohm scaling when below this threshold and gyro-Bohm scaling when above threshold. Crossing the threshold may result in particle and energy transport switching regimes. Experimentally, global scaling laws typically show elements of both Bohm scaling (in the edge plasma) and gyro-Bohm (in the core plasma). Several experiments (DIII-D [2], TFTR [3] and JET) also show that core turbulence during the H-mode phase is intermittent, or bursting in nature. This suggests that the plasma turbulence may be close to a threshold and that excursions across this threshold result in the intermittent variations in the level and structure (specifically the radial/toroidal correlation lengths) of the turbulent fluctuations. A possible implication of this is that the experimentally measured time-average global transport would appear to scale with a value between pure Bohm and pure gyro-Bohm.

RESULTS

Intermittent turbulence, or bursts of increased fluctuations, are observed in both O-mode and X-mode reflectometer signals (density fluctuations) and appear in all types of JET discharges (Hot-ion, ELMy H-modes, optimised shear) during NB or high power (>6MW) RF heating (i.e. a power threshold). Often the bursts appear, then disappear during a shot (not an instrumentation effect) but are most clear in ELM free H-modes, often starting just before the H-mode transition. Unfortunately there is no data in the ohmic phase. Fig. 1 shows time traces of the main plasma parameters for an example shot #42801 (3Telsa/5.3MW NBI 94% Tritium ELMy H-mode), while fig. 2 shows a contour plot of spectral intensity (frequency vs time) of phase fluctuations from two X-mode reflectometers with radial positions at 3.7m (inside the plasma separatrix: r/a ~ 0.8) and at 3.9m (in scrape-off layer: r/a ~ 1). The spectrum from inside the separatrix shows 4 clear bursts (40Hz repetition) which stop then restart following a sequence of type I and type III ELMs at 16.81sec. There are no bursts outside the separatrix. Note the presence of various MHD coherent mode activity throughout spectra. The bursts, seen as a dramatic increase in rms phase fig. 3, (and pdf width fig. 4) are accompanied by radial movement in cutoff layer position (from mean phase) followed by relaxation. The movement is most

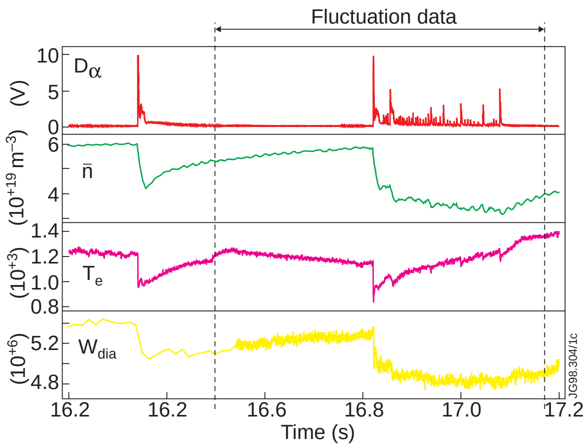

Fig.1 : Time traces for ELMy H-mode shot #42801. Bars show extent of fluctuation data.

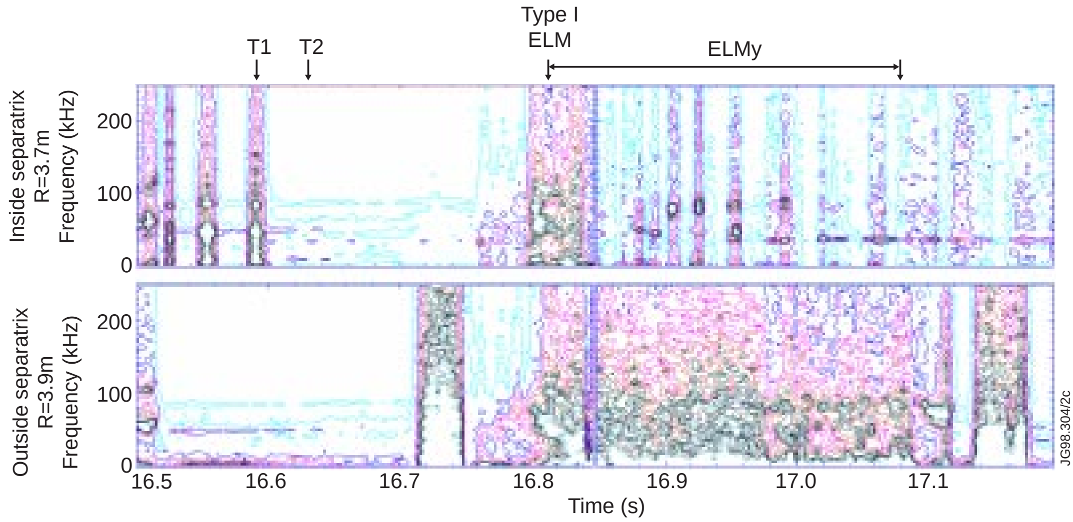

Fig.2 : Contours of log spectral intensity (freq. vs time) of reflectometer phase fluctuations at 3.7m (inside plasma separatrix) and 3.9m (outside separatrix), shot #42801. Background has been suppressed for clarity.

likely due to variations in the local density gradient. Time averaged frequency spectra of reflectometer phase and power fluctuations, during the burst fig. 4 (left) and during the quiescent period between bursts (right), show a rise in the low frequency fluctuations (change in spectral index) and the suppression of coherent MHD mode activity during the burst. At the same time there is a reduction in the spatial correlation length measured from two toroidally separated (40mm) reflectometer channels. This loss of correlation during the burst is also shown in the g^2 coherence spectrum, fig. 4, between the phase and power fluctuations.

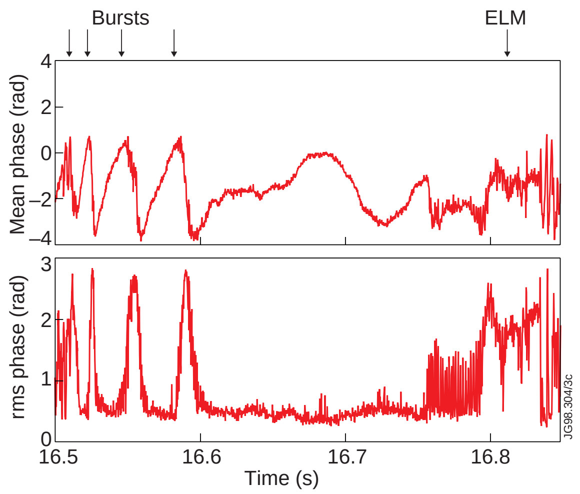

Fig.3 : Reflectometer mean and rms phase at 3.7m, inside separatrix (#42801).

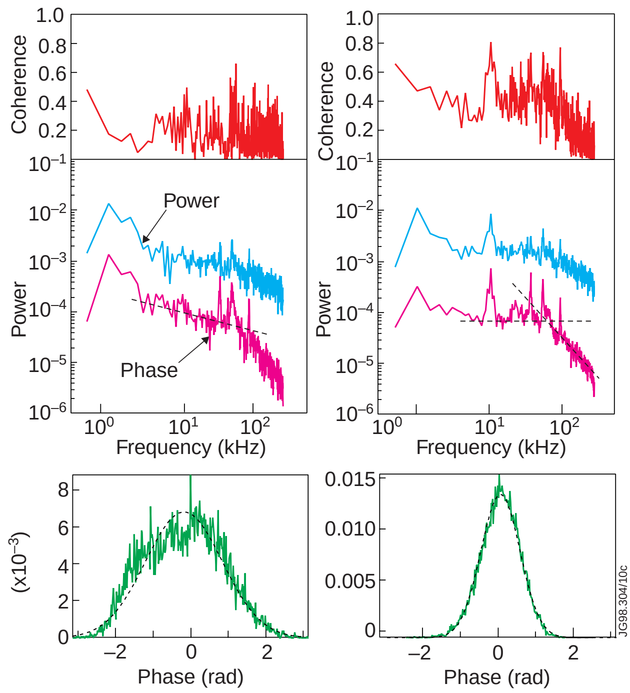

Fig.4 : Time averaged frequency spectra of reflectometer phase and power fluctuations at 3.7m during (left) a single burst: 16.58 - 16.60s and (right) quiescent period: 16.62 - 16.66s (#42801).

The plasma parameter time traces for a second example #40477, 3.4T ELM-free, D_2, Hot-ion H-mode are shown in fig. 5,. The frequency vs time contour plot of reflectometer phase signal from 3.8m, fig. 6, shows a slowing down of the burst repetition from 120Hz to around 10Hz. After the NBI power step down at 13sec the background turbulence rises and the bursts merge into a continuum. The radial position of the reflection layer remains constant at around r/a ~ 0.9 during this period, but there is a slight increase in toroidal rotation velocity (~180km/s) measured with the charge exchange spectroscopy diagnostic.

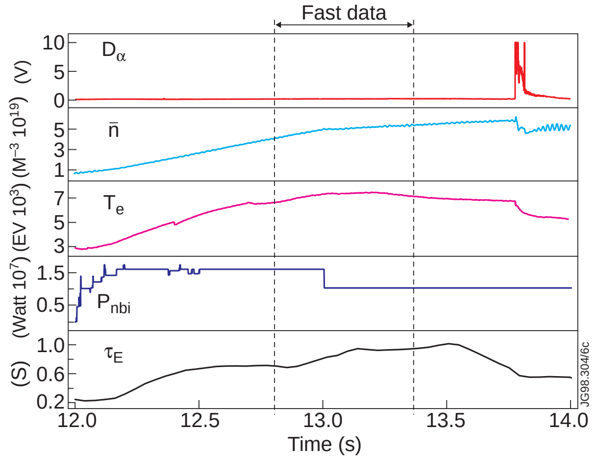

Fig.5 : Time traces for ELM free Hot-ion H-mode shot #40477. Bars show extent of fluctuation data.

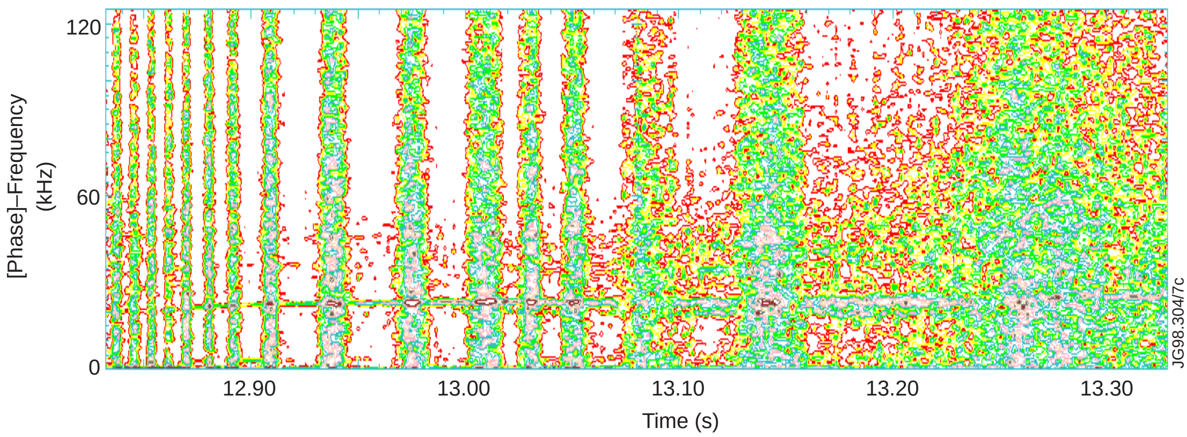

Fig.6 : Contour plot of log spectral intensity (freq. vs time) of reflectometer phase fluctuations from 3.8m (r/a ~ 0.9). Note coherent mode at 20kHz (#40477).

The phase distributions, coherence and frequency spectra of fig. 7 are during the quiescent period just after 13sec (left) and during the broad continuum period around 13.2sec (right). The spectra show a similar behaviour as in fig. 4.

SUMMARY OF CHARACTERISTICS

The intermittent turbulence occurs in short lived, 2 to 10ms wide, bursts of very broad-band incoherent fluctuations (to over 1MHz). During an individual burst the fluctuation intensity can increase by up to an order of magnitude, the spatial correlation length decreases, and the fluctuation spectral content changes. The burst duration and degree of change in fluctuation level scale proportionately with the burst repetition period, which ranges from more than 60ms to less than 5ms (continuous). The burst period also depends on the radial location and the toroidal field strength, and varies during the discharge.

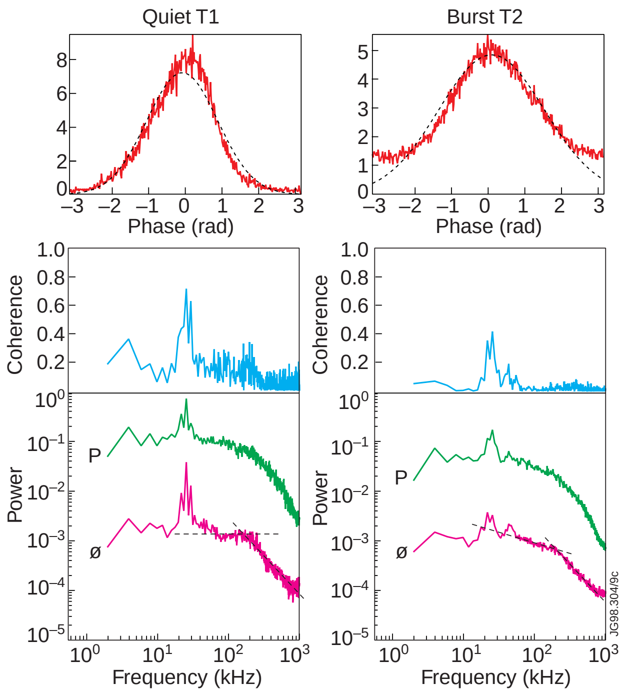

Fig.7 : Phase distributions plus frequency & coherence spectra of phase and power fluctuations during (left) quiescent: 13.0s and (right) continuum/fully developed period: 13.2s (#40477).

Spatially the bursts are observed between the core region (R ~3.0m) and the plasma separatrix (R ~3.88m). The bursts are not observed in the plasma scrape off layer. The bursts are most obvious during ELM free periods, although similar bursts are seen in the outer edge/SOL as precursors to all type I and type III ELMs. The s/n limitations (< 50:1) of the ECE measurements precludes observation of possible bursting in the electron temperature fluctuations. Since $\delta B << \delta n$ there is also no clear evidence of bursting in magnetic signals. Bursts are also frequently observed without any coherent mode activity. During periods of bursting the energy confinement time τ_E continues to rise, but ceases to rise when the bursts merge into the fully developed continuum regime.

CONCLUSIONS

The presence of intermittent turbulence indicates a proximity to some form of turbulence threshold. Variations are consistent with transition between a quasi-linear instability regime (bursting phase), and a non-linear, fully developed turbulence regime.

REFERENCES

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