Intermittent turbulence measurements with ultra-fast sweep reflectometry on Tore Supra

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1. Introduction

Plasma confinement in magnetic devices is mainly determined by turbulent processes. Those induce an anomalous radial transport which can strongly deteriorate plasma performances. The intermittent nature of the turbulence has long been observed in the plasma edge [1], particularly in the scrape-off layer (SOL), with the so-called “blobs” inducing a strong convective transport. These edge events are challenging on the way to understand and control the plasma-wall interactions. Temporal variations have also been observed in the plasma core with MHD tearing modes and resulting in sawtooth crashes or for acoustic modes as well as their intermittency . Interestingly, the high radial and temporal resolution provided by ultra-fast sweep reflectometry can greatly improve the understanding of these phenomena.

2. Principles of sweeping reflectometry measurements

Reflectometry has long been used to study plasma turbulence through the measurement of density fluctuations as it can provide a very good radial and temporal resolution. The recent upgrades carried out on Tore Supra X-mode FM-CW reflectometers aimed to combine both those performances by substantially improving the frequency sweep speed from 20 μs (with 5 μs between sweeps) to 2 μs (with 1 μs dead time) [2]. In order to follow the temporal evolution of the turbulence, the sweeps are repeated in a burst up to 20000 sweeps per discharge (Fig. 1)

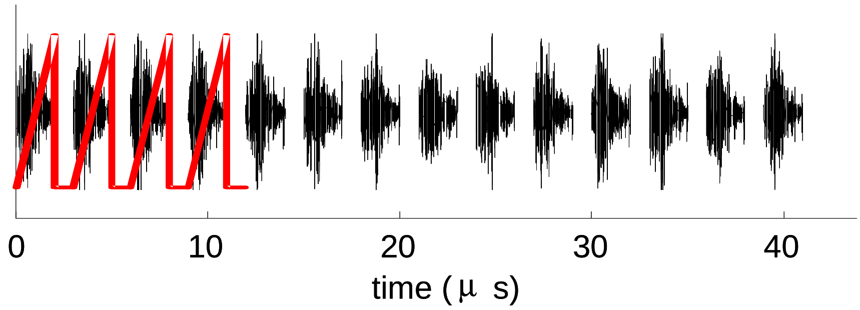

Fig. 1 : Burst mode operation for measuring fast plasma density events, consisting of successive 2 μs fast sweeps with 1 μs dead time between sweeps (red trace) superimposed to the recorded reflected signals.

The sweep reflectometry signal is commonly used to reconstruct the radial density profile from the phase delay accumulated during the wave propagation through the plasma. Any density variations are thus recorded as phase variations. Each sweep provides a phase delay which is subtracted from an average phase obtained by averaging over the sweeps of one burst (Fig. 2).

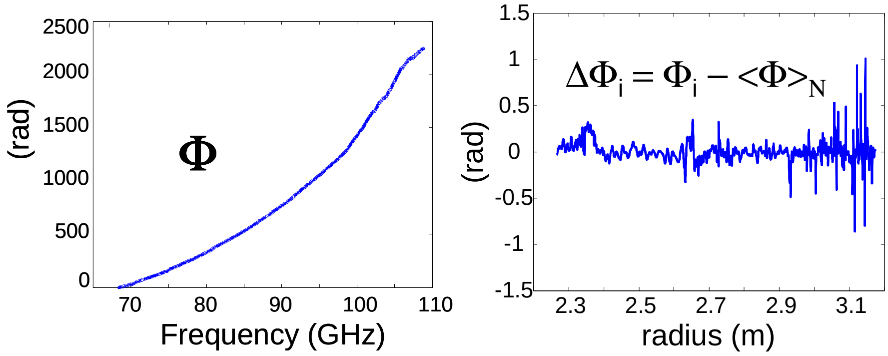

Fig. 2 : Phase delay of the reflected signal (left) and phase fluctuations (right) calculated from the difference with the phase averaged over one burst of sweeps.

3. Experimental results

Thanks to the above described fast sweep reflectometer setup fast variations of the density can be continuously recorded through the whole plasma from the edge to the core. In figure 3 one can observe around ρ = 0.1 the signature of an oscillating MHD tearing mode at q=1 rational surface with a frequency of 600 Hz, followed by a crash. After the crash the mode slowly recovers and at approximately t = 3.005s one observes (Fig. 4) a fast oscillating mode radially localized around ρ = 0.11 with a frequency varying from 60 to 80 kHz, thus ranging in the acoustic range which could may be interpreted as a BAE, consistently with similar measurements in [3].

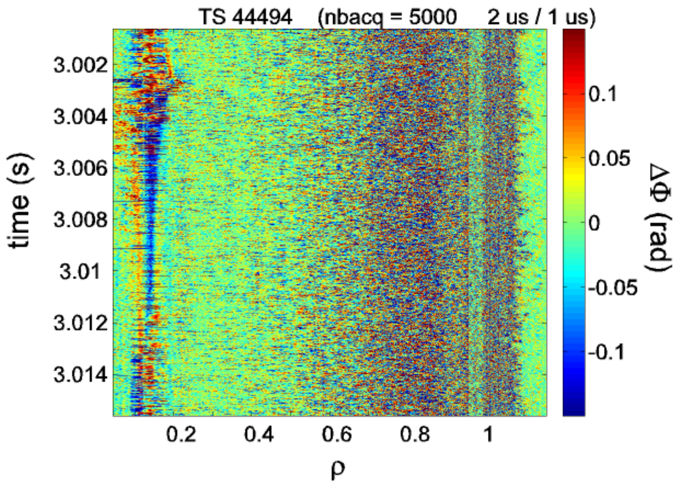

Fig. 3 : Radial evolution of the phase variation of 5000 sweeps from the edge to the plasma center in Tore Supra shot #44494.

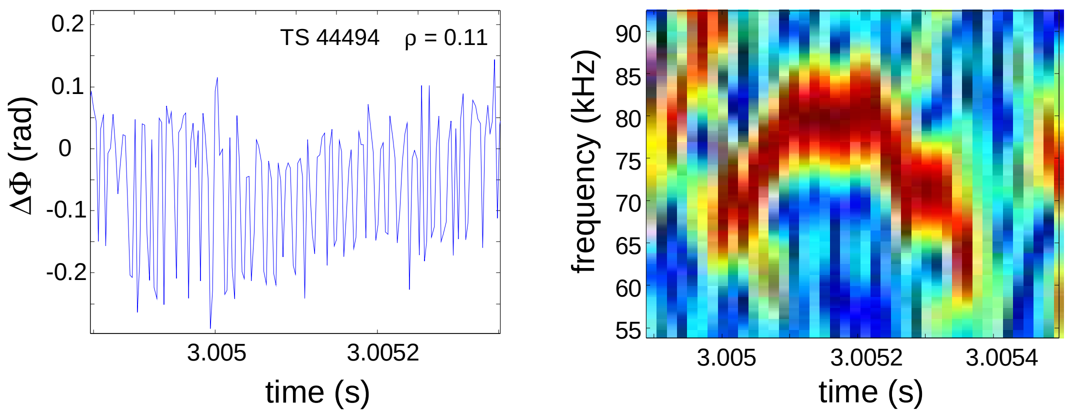

Fig. 4 : Fast oscillating mode around ρ = 0.11 measured in the acoustic frequency range after the sawtooth crash.

Interesting features are also observed in the scrape-off layer, where strong intermittent fluctuations are revealed. The origin of these coherent or “blob-like” structures is well radially determined. However, they do not appear to be connected to intermittent structures occurring in the plasma core and propagating through the separatrix. The behaviour of this observed edge turbulence appears to be nevertheless dependent on the plasma core paramaters like plasma current or density. A systematic study establishing a data base is underway in order to analyse and understand the influence of various plasma parameters..

The effect of additional ICRH has been studied by comparing two bursts of sweeps before and during the heating phase. A density increase is generally observed, along with a broadening of the SOL, when the additional heating is applied. While the Ohmic phase exhibits a quite intermittent turbulence activity in the SOL, fast convective events are clearly seen, with radial velocities up to 800 ms^{-1}, propagating outwards

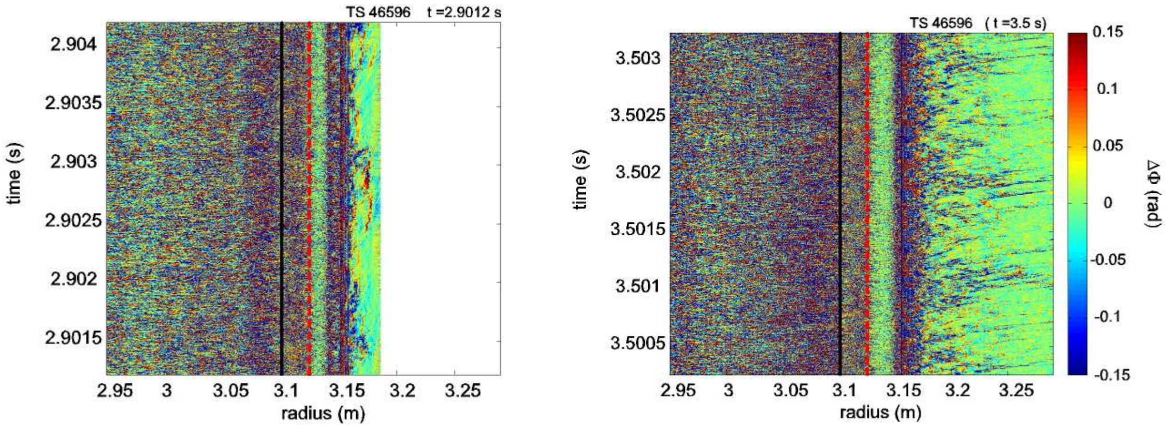

Fig. 4 : Comparison of the turbulence intermittent behaviour between ohmic (left) and ICRH (right) heated plasma in Tore Supra shot #46596. The black solid line represents the separatrix and the red dashed line the ICRH antenna position.

The reconstructed density profiles exhibit a slowly evolving intermittent structure during the ohmic phase with no clear radial convective transport, while stair-step like density escapes the plasma during the ICRH phase.

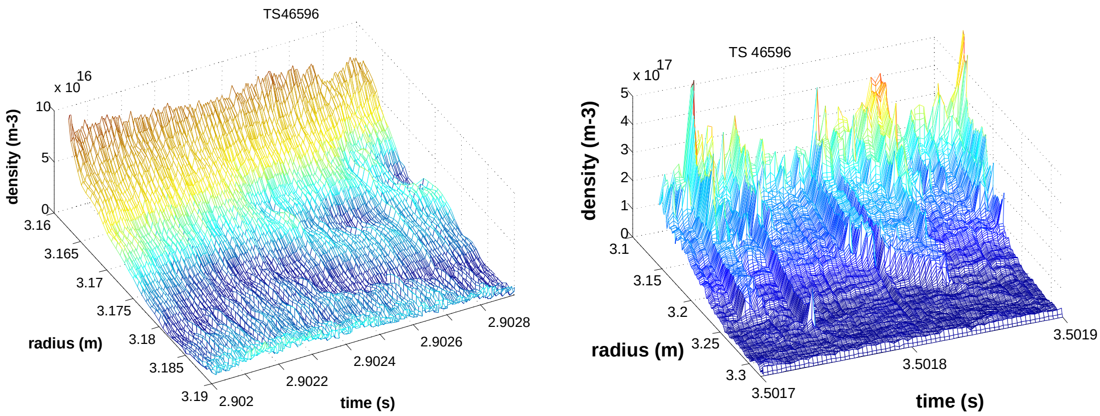

Fig. 4 : Comparison of the reconstructed edge density profiles between ohmic (left) and ICRH (right) plasma phase discharges.

4. Conclusions

The unique performance of fast sweeping reflectometry on Tore Supra proved to allow detection and radial localization of fast intermittent coherent turbulent structures ("blob-like") in the plasma SOL. The ongoing characterization of those in terms of core plasma parameters and heating opens the way to a better understanding of edge turbulence transport.

References

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