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Density and Magnetic Fluctuation Studies on the W7-AS Stellarator

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Anomalous transport responsible for enhanced cross-field diffusion of magnetically confined plasmas has been studied extensively over the past years. Turbulence in the edge and core plasma is judged to be responsible, thus strongly motivating the study of fluctuations of relevant plasma parameters. This contribution documents fluctuations and transient profile changes in electron density at the plasma edge (Li-BES) and magnetic field (Mirnov coils) as a function of global plasma parameter on the Wendelstein 7-AS (W7-AS) stellarator, relating these to the electron temperature profile (ECE) as well.

The analysis is performed using a combination of time-frequency analysis techniques [1,2] and a newly developed algorithm based on correlation techniques that separates and characterizes the three basic phenomena present in fluctuations; ELM-like events, MHD waves and ambient SOL turbulence. The method was originally developed for the fast (1MHz) Lithium Beam Emission Spectroscopy (Li-BES) measurement based on the fact that these phenomena show up as markedly different shapes in the auto-correlation functions. It was found that due to their long auto-correlation time (~400 μs), ELM-like transients can even be detected in the "standard" slow Li-BES measurements (5kHz) by extrapolating the auto-correlation function from τ=200,400 μs to τ=0 μs. Profile flattening of the electron temperature profile (measured by ECE) caused by the ELM-like transients appears as a well recognizable pattern in the cross-correlation function as shown in Figure 1, that can be detected by simple techniques. The strength of this pattern characterizes the relative amplitude of the ELM-like transients.

On the W7-AS stellarator ELM-like transient phenomena were observed in various plasma parameters in L-mode as well as in H-mode discharges. These transients with characteristic lifetimes of some hundred microseconds have been shown to contribute at least to some extent to the anomalous heat and particle transport in discharges where iota was close to 1/2 or 1/3 [3]. Both the transients and the anomalous transport exhibit strong sensitivity to the magnetic configuration [4], an attribute that can be excellently studied on W7-AS due to its flat and externally controllable iota profiles. In order to systematically examine the appearance of these phenomena, a series of 147 low density ($\int n_e dl \sim 4\cdot10^{18}$ m^{-2}), ECRH heated (~170 kHz) discharges have been selected, covering a wide iota range ($\iota = 0.29 - 0.64$). Figure 2 shows the magnetic configuration dependence, i.e. the rotational transform dependence of the strength of ELM-like transients appearing in the electron density and electron temperature profiles as discussed above. The appearance of these transients is in good agreement with the narrow regions of optimum confinement near and slightly above iota=1/3, 2/5 and 1/2 [4].

At higher densities, the limited number of distinct rotational values enabled only partial analysis of the appearance of these phenomena. Thus only an indication could be obtained that the two otherwise ELM-free H-modes, the Quiescent H-mode and the High Density H-mode (HDH) may also exhibit micro-ELM activity at specific iota values as shown in Figure 3. Thus it can be concluded that ELM-like activity can be observed in all operational regimes of W7-AS, but the appearance strongly depends on the magnetic configuration. Furthermore ELM like phenomena do not appear to be responsible for substantial changes in transport, especially regarding the reduced impurity confinement time of the HDH mode.

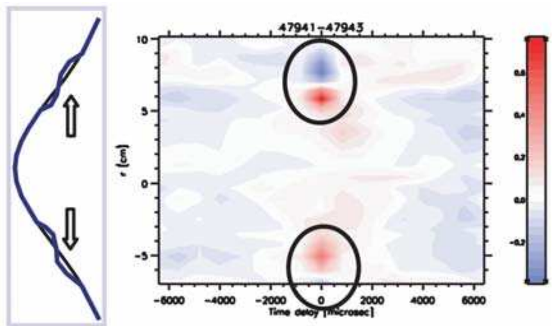

Figure 1. Appearance of ELM-like transients in the cross-correlation function of the ECE diagnostic. With pattern-recognition technique the profile flattening is detected and shown in Figure 2.

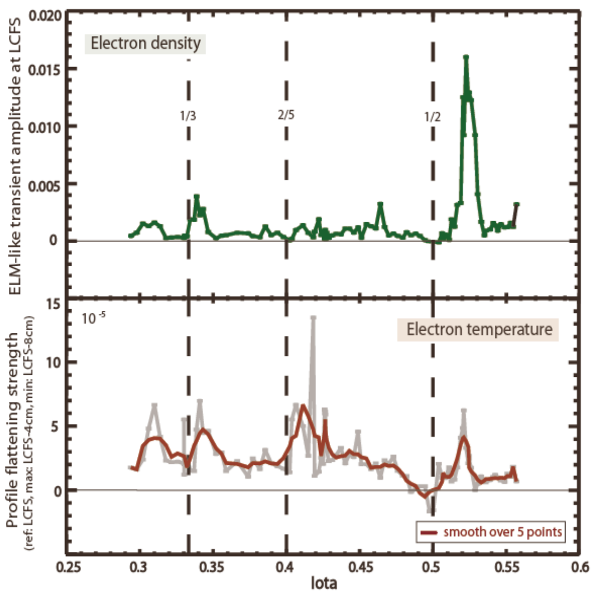

Figure 2. Rotational transform dependence of ELM-like transients in the electron density at the LCFS and electron temperature profile (reference at the LCFS).

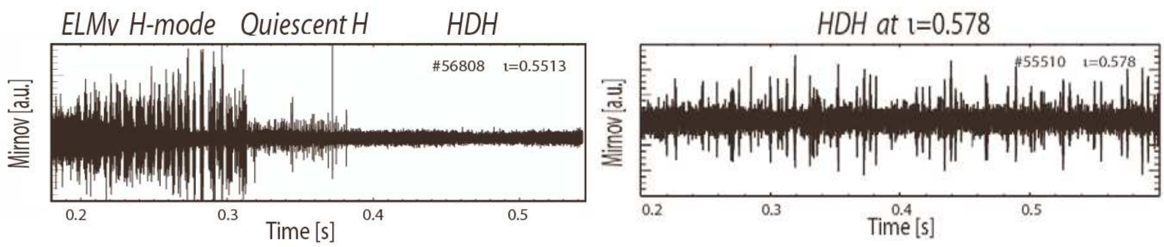

Figure 3. Micro-ELM activity in the two usually ELM-free H-modes of W7-AS in the raw Mirnov signals.

The HDH mode [5], being a highly promising ELM-free mode exhibiting no impurity accumulation, is of particular interest as the mechanism responsible for the reduced impurity concentration is yet undetected. It is believed to reside near the plasma edge, effectively driving impurities across the transport barrier and shifting the radiation to the outside [5]. The analysis of high resolution Li-BES data (time resolution: 0.4 μs, spatial resolution: cm) revealed no additional mechanism appearing at the transition to HDH mode in the SOL and a 1-2 cm beyond the separatrix showing only the disappearance of ELMs and the significantly reduced amplitude of the typical SOL turbulence.

In the course of the hunt for the impurity flushing mechanism, the Mirnov signals (time resolution: 3μs) were studied in detail comparing HDH with the Quiescent H-mode (the standard ELM-free H-mode showing extensive impurity accumulation) and ELMy H-modes. Although the study is still under way, first time-frequency analysis results show a Quasi-Coherent (QC) mode appearing in the HDH phase of many discharges and having a strong correlation with the impurity radiation as illustrated by Figure 4. A series of 20 discharges were performed incorporating all three H-modes to compare their properties in the best possible way. In Figure 4 a typical spectrogram of the Mirnov coil magnetic diagnostics and the time evolution of the impurity radiation are presented.

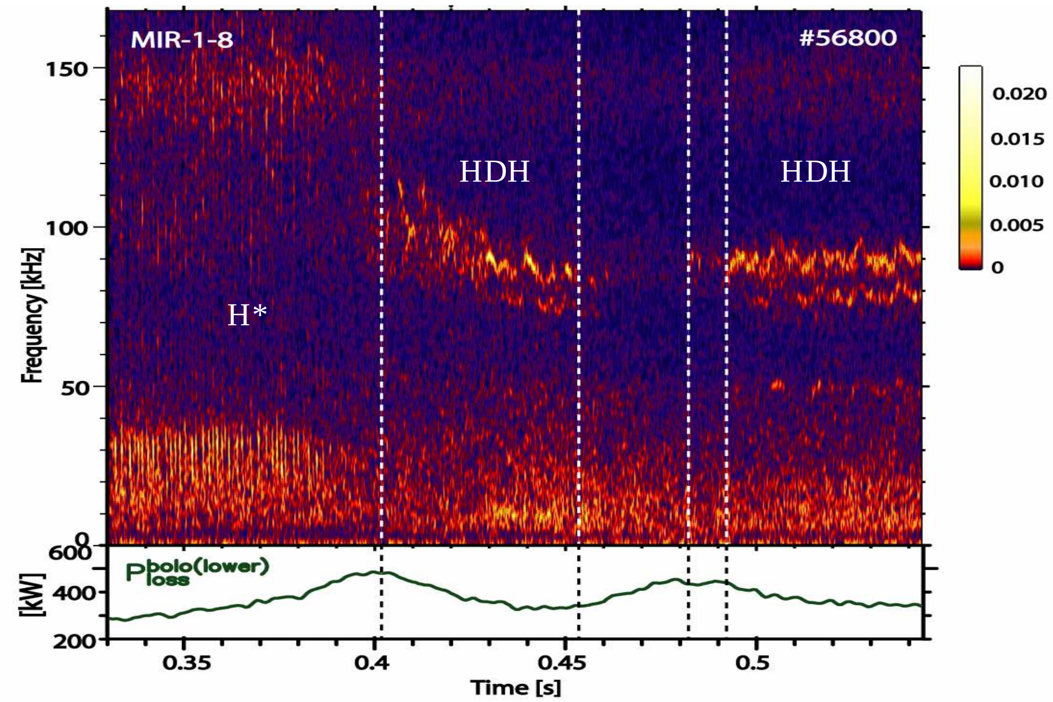

Figure 4. Spectogram of the Mirnov diagnostics and time evolution of the impurity radiation for the Quiescent H mode and two HDH mode phases.

In the quiescent phase (0.33-0.4s) with increasing impurity radiation, only micro-ELM activity can be observed, dominated by low frequency components. At the entrance to the HDH mode (0.4 s), the QC mode(s) appear in the high frequency regime first sweeping down in frequency from 110 kHz, than stabilizing in three stable, but frequency modulated modes at 90, 78 and 50 kHz. The QC modes disappear for the time period of 0.47-0.49s where the impurity radiation increases again and the plasma is brought out of the HDH mode. Although this behaviour is clear, this mode is not universal for all HDH discharges. Thus it may not be the key to the understanding the nature of the HDH mode.

Nonetheless, comparing the W7-AS QC mode with that of Alcator C-Mod [6], which is believed to be responsible for the reduced impurity accumulation of their ELM-free high energy – low impurity confinement mode called the Enhanced D_α Mode (EDA) mode, several similarities can be observed. When present on W7-AS, the QC mode is a continuous high frequency, narrow band oscillation typically strongly modulated in frequency showing strong correlation with the impurity radiation. The modulation frequency and the QC mode frequency dependence on global plasma parameters is yet inconclusive, although the amplitude seems to increase with density. In the case of W7-AS, the mode strongly depends on whether the plasma is detached or attached state. The frequency of the mode may sweep down from around 110 kHz when preceded by a short quiescent H phase. Determination of the poloidal mode number from Mirnov coil signals was attempted, but no m<6 mode number could be identified as shown in Figure 5. This finding agrees with the large mode numbers found in Alcator C-Mod.

On Alcator C-mod, the QC mode accompanying the EDA regime is universally detected only with the Phase Contrast Imaging (PCI) diagnostics. For W7-AS the mode was found only in Mirnov diagnostics so far and the sensitivity range of the Mirnov diagnostics may play a role in the detection of the W7-AS QC mode.

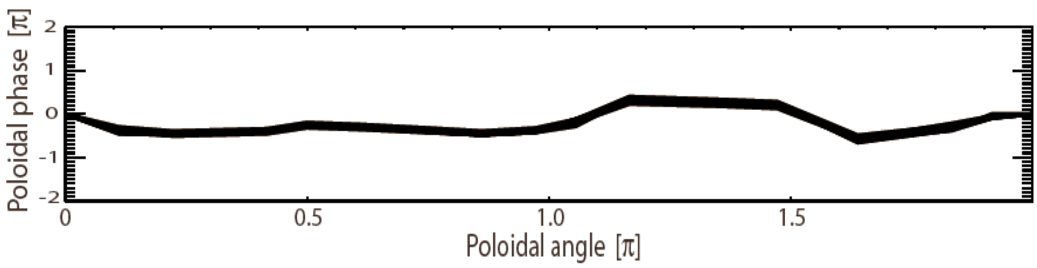

Figure 5. Poloidal phase of the stable QC mode of the HDH mode at 90 kHz for 0.5-055s from Figure 4.

References:

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