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Edge instabilities in the high density H-mode operation of W7-AS

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The High Density H-mode (HDH) is a highly promising ELM-free H-mode regime at the Wendelstein 7-AS stellarator exhibiting no impurity accumulation [1]. This is of particular interest as future fusion-oriented devices are mainly preferred to be run at high densities, a regime often susceptible to impurity accumulation and ensuing radiation collapse. The HDH mode is also characterized by flat density profiles, edge localized radiation and improved energy confinement, twice that of the standard scaling (ISS95). The mechanism responsible for this low impurity concentration has not yet been found. It should be emphasized that the impurities are transported out of the plasma, not just blocked. Therefore our main aim is to find a possible candidate for the impurity flushing mechanism by investigating MHD modes present in the HDH phase and their relation to the impurity transport.

The investigation is based on three poloidal arrays of Mirnov coils (16 channels sampled at 350 kHz, two 8 channel arrays at 1 MHz for limited time intervals) for given time interval and a single Mirnov channel at 250 kHz available throughout the discharge. Time-frequency analysis of the magnetic perturbations indicated three types of mode activity in the HDH regime:

a, *Low Frequency Oscillations (LFO):* principle frequencies below 50 kHz with higher harmonics as well. This MHD mode is not unique for the HDH phase, it is also present in the quiescent H-mode phase (QH), an ELM-free H-mode phase prone to impurity accumulation, before the HDH transition.

b, *Quasi-Coherent Modes (QC):* narrow band oscillations in the 50-150 kHz frequency range found in the first analysis [2] named after its similarity with the QC modes of the Alcator C-Mod tokamak. The analysis indicated QC modes appearing in the HDH phase in the Mirnov signals that had good correlation with the impurity radiation making it a good candidate for the impurity flushing mechanism responsible for the low impurity concentration.

c., *High Frequency Oscillations (HFO):* in Hydrogen discharges higher frequency modes (200-350 kHz) can be found in the 1MHz Mirnov signals. As this measurement was only available for a short time window, clear relation to the impurity radiation and more information about the mode cannot be obtained.

Preliminary analysis shows that both, the low and high frequency oscillations are always accompanied by quasi-coherent modes in the HDH phase. Moreover further studies supports the remarkably good correlation of the QC modes with the impurity radiation. It should however be noted that this does not resolve the question, whether the QC modes are responsible for the impurity transport or whether they are just companying effect of the real mechanism. In the followings, properties of the QC modes will be described in detail.

The study of the QC mode included, in order to determine its properties, several magnetic configurations, global parameters and isotope plasmas. It was found that it is a bursty, frequency modulated oscillation in the plasma edge with frequencies in the 50-150 kHz regime characterized by narrow bandwidth of about 15 kHz (please note that a possible connection of the so-called high frequency oscillations to the QC modes has not yet been resolved). The QC mode is only characteristic for the HDH phase and is stable throughout this regime. Its stability and relation to the impurity radiation is shown in Figure 1. When the HDH mode is preceded by a short quiescent H-mode phase including a density ramp up, the frequency of the mode sweeps down.

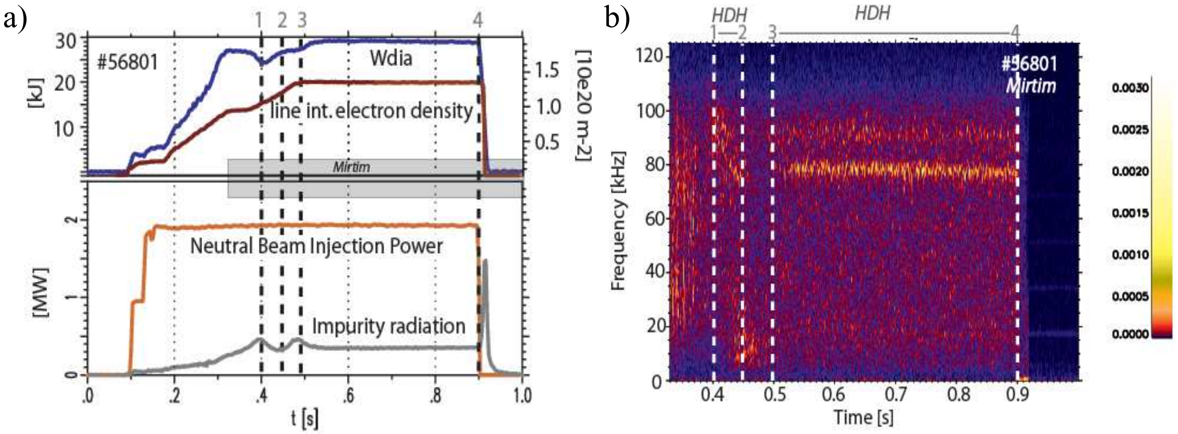

Figure 1 – (a) Overview plot of the plasma parameters for a HDH discharge including the impurity radiation. (b) Spectrogram of the low resolution Mirnov coil signal .Time intervals: 1: QH – HDH transition 1--2: HDH phase, the QC mode sweeps down from 100 kHz to 78 kHz. 2: back-transition. 2-3: impurity radiation increases, the QC mode is not present. 3-4: the plasma enters the HDH regime again, impurity radiation decreases then stabilizes, stable QC modes at 78, 90 kHz until the end of the discharge

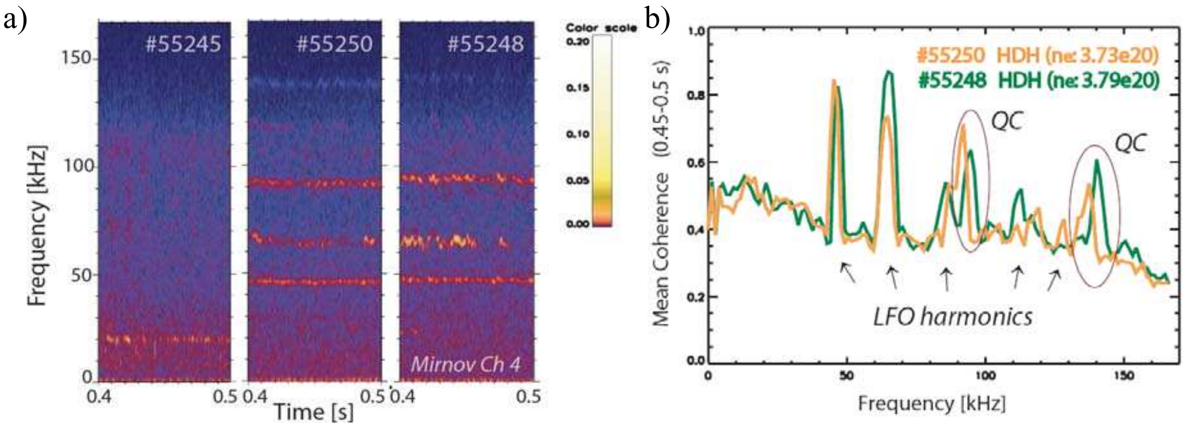

Figure 2 – Dedicated density scan at 2 MW NBI heated in Deuterium plasmas. Three stable discharges as of: (a) QH, $n_e \sim 2.99\cdot10^{20}m^{-2}$ (b) HDH phase, $n_e \sim 3.73\cdot10^{20}m^{-2}$ (c) HDH phase, $n_e \sim 3.79\cdot10^{20}m^{-2}$.

The universality of the QC mode in the HDH phases is tested by analysing specific density scans for given heating power, magnetic configurations and isotope plasmas (Hydrogen or Deuterium plasmas). An example is shown in Figure 2., where the increase of the QC amplitude with density can be clearly seen as well.

The analysis of the transition from attached to detached plasma operation shows the disappearance of the LFOs and the strengthening and attenuation of the different QC modes as shown in Figure 3.

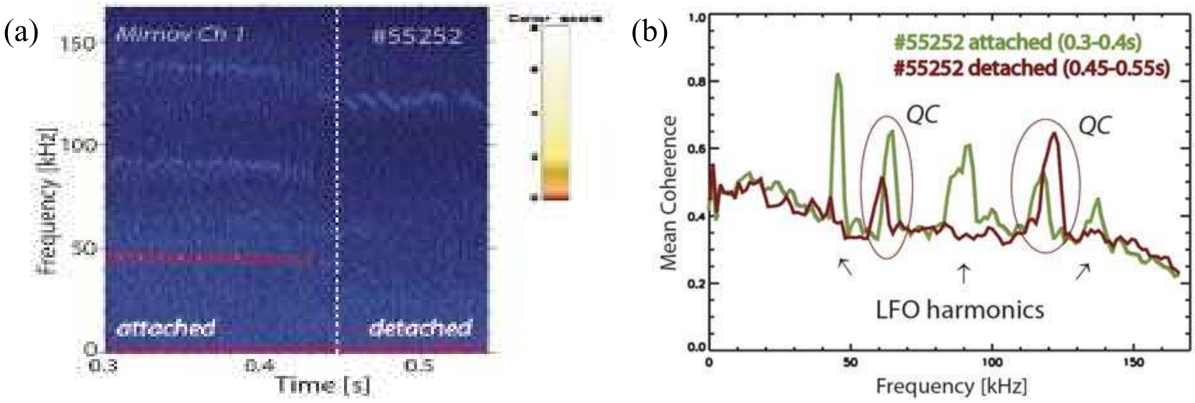

Figure 3 – Spectrogram (a) and coherence (b) of the magnetic fluctuations for the attached – detached transition.

Determination of the mode number from the poloidal Mirnov array has been attempted, however no mode number (m<6) could be resolved. A reciprocating probe housing two poloidal field pick-up coils (MRCP), based on the concept of Snipes et al [3], has been inserted into the plasma that measuring the radial decay of the magnetic field perturbations along the distance to the separatrix as shown in Figure 2.

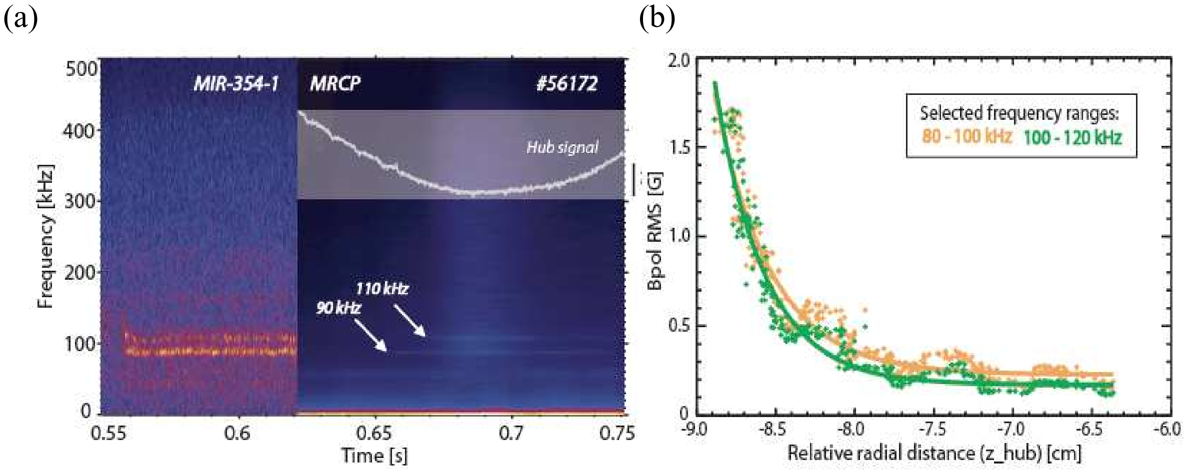

Figure 4 – (a) Spectrogram of the magnetic fluctuation measured by the high resolution Mirnov coil array and the MRCP coil including the Hub signal showing the relative distance of the MRCP coil to the separatrix. (b) Radial decay of the magnetic fluctuations measured by the MRCP probe in the frequency range of the QC modes respectively.

The amplitude of the mode falls off rapidly, in about 2 cm-s, with the distance from the separatrix with an exponential decay length of k_r~2.82 (±0.78) cm^{-1} and k_r~ 3.18 (±0.79) cm^{-1} respectively corresponding to the 90 kHz and 110 kHz QC modes. We then used this rapid radial decay of the amplitude to estimate the poloidal wave number of the QC mode. By assuming a field aligned perturbation and using the Laplace equation outside the fluctuating current layer (method described in [3]) as it is the case for the MRCP probe, we get $k_t \sim k_{pol} \cdot 0.037$ and thus $k_r \approx k_{pol}$. This way the rough estimate of the poloidal mode number is around $m \sim 40$.

In order to gain more insight into dynamics of the QC mode and define the driving force behind it, the closing phase of the discharge has been studied in detail as shown in Fig 5. The NBI heating is shut down at 0.9s, and after 5ms the plasma leaves the HDH regime and the impurities start to accumulate anew. At 0.911s the back transition to L-mode can be clearly observed. Fig. 5b shows the QC mode on the Mirnov signal spectrogram, disappearing quite rapidly about 2-5 ms after the switch off of the NBI heating apparently when the HDH ends.

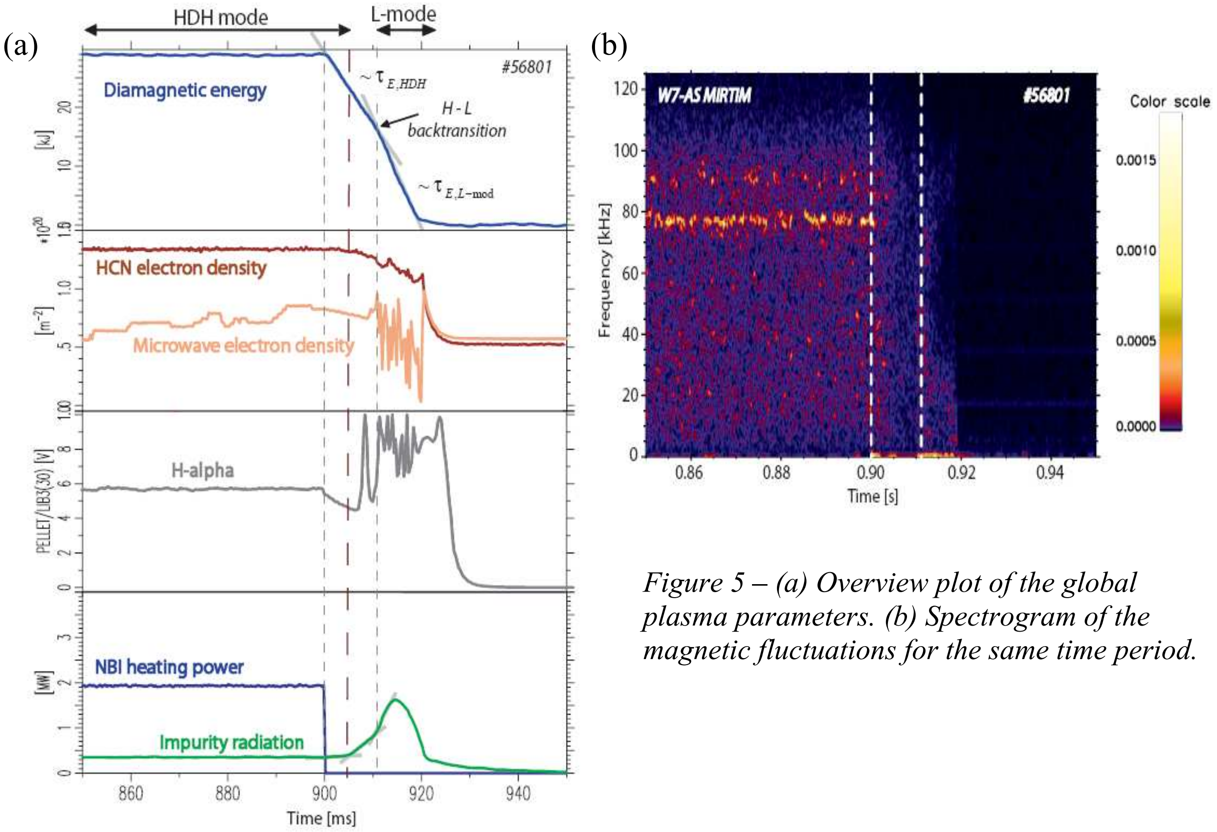

Figure 5 – (a) Overview plot of the global plasma parameters. (b) Spectrogram of the magnetic fluctuations for the same time period.

Other fluctuation diagnostics such as Lithium Beam Emission Spectroscopy, reflectometry, ECE, H-alpha, SXR have been checked as well. Unfortunately mainly due to high electron densities, none of them sees the pedestal area and/or the resolution cannot resolve the frequency regime in question.

At this time, no definite answer can be given whether the QC mode is the mechanism responsible for the enhanced impurity transport in the HDH regime or it is a by-product of the real mechanism. Further work is under way to deepen the physical understanding of this mode. At the Alcator C-Mod tokamak, similar QC modes are known to be responsible the impurity transport in the ELM-free, stable high density H-mode regime, i.e. the Enhanced D-alpha (EDA) H-mode [4]. This prompts a careful comparison of the QC modes in the two regimes to gain more insight into the nature of these modes.

References

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