L-H Intermediate Phase and Type III ELMs

S. Zoletnik[1], G. H. Hu[2], B. Tál[1], G.S. Xu[2]

[1] *Wigner RCP RMI, P.O.Box 49, H1525, Budapest, Hungary*

[2] *Institute of Plasma Physics CAS, PO Box 1126, Hefei 230031, China*

An intermediate phase (I-phase) between the L and H mode is observed in several fusion experiments[1-4]. These are known under various names but share the common feature that the edge plasma undergoes quasi-periodic changes with a frequency in the few kHz range. Correlated changes have been observed in the edge turbulence amplitude, poloidal flow velocity and plasma parameters with some phase delay between them. It was suggested that these phenomena are one of two kinds of Limit Cycle Oscillation (LCO)[5] preceding the final turbulence suppression at the transition from L to the H-mode. In most cases the fluctuation amplitude change leads the flow change therefore predator-prey dynamics is suspected between the turbulence (prey) and zonal flow (predator). However, there are also observations[6] where the phase relation is reversed or even changes in time, consistently with the expectation of two different LCO types.

Although a clear m=1, n=0 magnetic signature was also detected [3,4] in some experiments it was attributed to the response of the equilibrium currents to the edge pressure changes and the I-phase is considered as a phenomenon related to the interaction of electrostatic turbulence with flows and/or profiles. However, some recent measurements on ASDEX Upgrade[6], JET[7] and COMPASSS[8] indicate that some MHD phenomena are also involved as magnetic field oscillations are measured in the 10-100 kHz range by pick-up coils outside the plasma. By Lithium-beam measurements these were localized to the pedestal or top of pedestal region[7] but their detailed properties cannot be determined due to the limited signal to noise level of the diagnostics. The aim of this paper is to present observations on the EAST tokamak mostly with a highly-efficient two/dimensional Lithium Beam Emission Spectroscopy (Li-BES) diagnostic which can measure the edge and Scrape-Off Layer (SOL) density profile evolution with high (~10 microsecond) time resolution.

Diagnostics

The Li-BES diagnostic[10] injects an accelerated Lithium atom beam (50-60 kV, 1-2 mA ion equivalent current, 2-3 cm FWHM) into the plasma at the equatorial plane at port D. In the SOL/edge region the Doppler shifted 670.8 nm line radiation of the beam is excited by plasma particle collisions therefore it is nearly proportional to the local density, it is used as a proxy for density changes. Deeper in the plasma the beam is attenuated by ionization and the whole radial beam light profile can be used for calculating the absolute plasma electron density profile. The beam light is observed by a 2D Avalanche PhotoDiode APD camera (4x32 pixels, radial x poloidal) through a high Etendue optic from a quasi-tangential direction inclined about 45 degrees both horizontally and vertically. Due to the intersection of the oblique observation line with the finite beam width the effective measurement areas in the RZ plane are inclined ellipses with 2-3 cm FWHM in both poloidal and radial direction.

The centres of these areas are separated by 0.5 cm in poloidal and 1 cm in radial direction. The signals have an excellent Signal to Noise Ratio up to 60 on 500 kHz bandwidth but contain some background from Carbon lines and possibly other sources. This latter is measured by periodically switching (chopping) the beam on/off. In the normal measurement mode the on/off time is in the range of a few ms to a few 10 ms. Most measurements presented in this paper were this way, but recently a high frequency (250 kHz) chopping mode was also tried which enable separation of the BES and background light up to 100 kHz. Additionally to Li-BES divertor D-alpha and magnetic pick-up coils were also used.

Measurements in L-mode, I-phase, H-mode and during ELMs

A series of discharges (69425-8, Ip=400 kA, $\int ne \approx 3\ 10^{19}\ m^{-2}$, USN configuration) were studied with a slow L-H transition where about 50 ms I-phase was present. An example is shown in *Fig. 1*. After ramping up the Ohmic discharge 0.3 MW ECRH and 0.3 MW LH heating was applied. 1.5 MW NBI heating was switched on at 2.1 s triggering an I-phase at about 2.2s. The D_α signal first shows negative spikes which turn into positive ones towards the end of the I-phase. Disregarding the spikes the D_α signal slowly decreases in about 60 ms when the ELM-free H-mode is reached. The Li-BES signals show that the edge density profile gradually steepens during the I-phase, the steepest profile is at the lowest D_α signal.
A similar transition was studied in Ref. [11] with Gas Puff Imaging where it was found that the positive spikes towards the end of the sequence show a ~100 kHz precursor oscillation inside the separatrix and no such precursors were found before the early oscillations. As a consequence the negative spikes were identified as dithering cycles while the later positive ones as type III ELMs. With the advanced Li-BES diagnostic we studied both cases. *Fig. 2.* shows Li-BES signals and D_α at the early and late time during the I-phase. The BES signals are plotted with a constant vertical shift, therefore larger distance between the curves

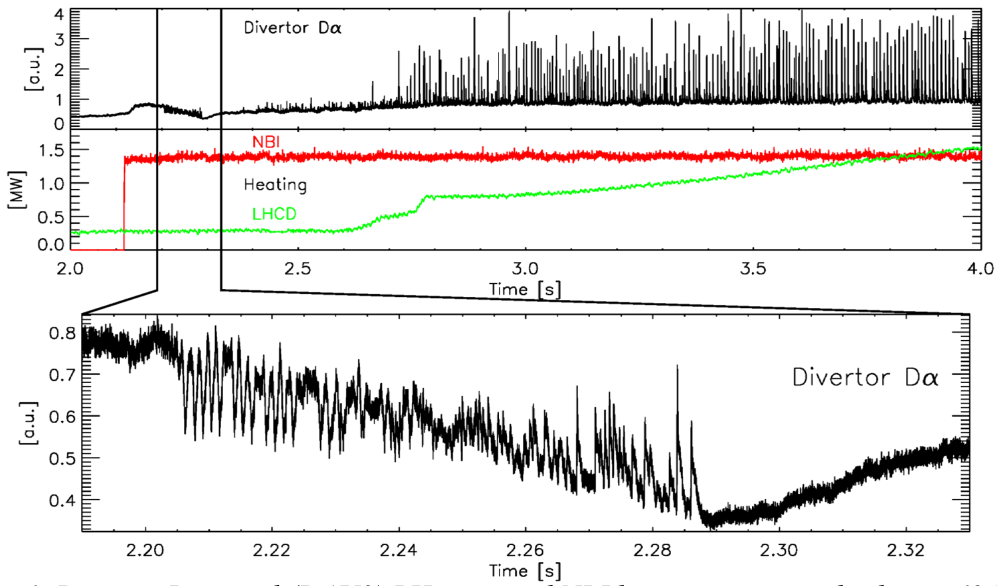

Fig. 1. Divertor D_α signal (DAU2) LH wave and NBI heating power in discharge 69426. The insert below shows the D_α signal during the I-phase.

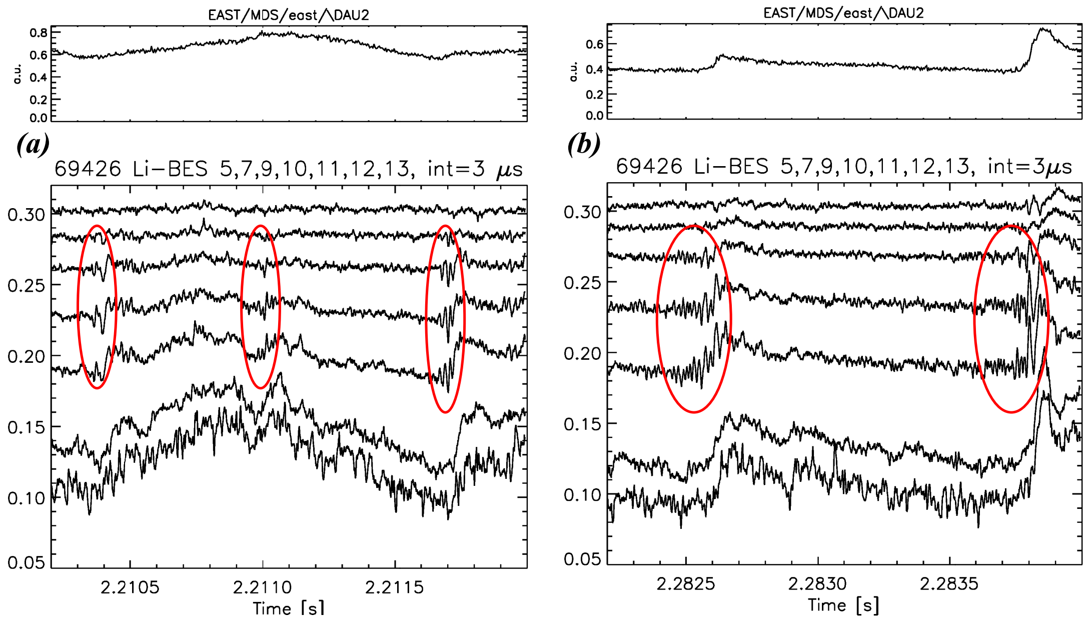

Fig. 2. Divertor D_α signal and some Li-BES signals in the SOL-edge region plotted with constant vertical shift. The lowermost signal is in the SOL, the uppermost is at about the top of the pedestal. (a) Early time in the I-phase (b) Towards the end of the I-phase.

indicates steeper part of the profiles. At the steepest gradient a growing oscillation (red marks) appears just before the D_α signal and the SOL Li-BES signals start to increase. The most obvious difference between the early and the later I-phase is the growth rate of the mode. In the early phase only a few periods are seen while in the later phase the mode is present for about 10 periods. Most probably this is the reason why it was not identified by the GPI diagnostic in Ref [11].

In the studied measurements the beam was switched on for 8 ms and off for 2 ms therefore we have the chance to compare pulses both in beam-on and beam-off phase. This shows that the SOL pulses are a mixture of beam and background light but the precursor oscillations in the steep part of the profile are a clean beam signal, they originate from local density modulation. These modes were not found in magnetic pick-up coil signals.

In the L-mode just before the I-phase this mode is also found in beam light fluctuation spectra (*Fig. 3a.*) with low amplitude and broad spectrum. In some cases SOL signal increase is observed when the mode amplitude increases. In the H-mode (*Fig. 3b.*) the mode appears with quasi-stationary amplitude gradually increasing as the D_α signal slowly increases. From correlation analysis in the poloidal direction 15 cm poloidal wavelength was found in both L and H mode.

At small ELMs before 2.6s this quasi-stationary mode might play a role. In some cases its amplitude grows in others for 1-2 periods the mode disappears when the SOL signals increase, examples are shown in *Fig. 3*c. From the few available fast beam chopping measurements, when the saturated mode was not present, a similar fast growing mode is observed before small ELMs. At higher heating power larger ELMs appear with different character. The quasi-stationary mode may still be present but the ELM is related to a much

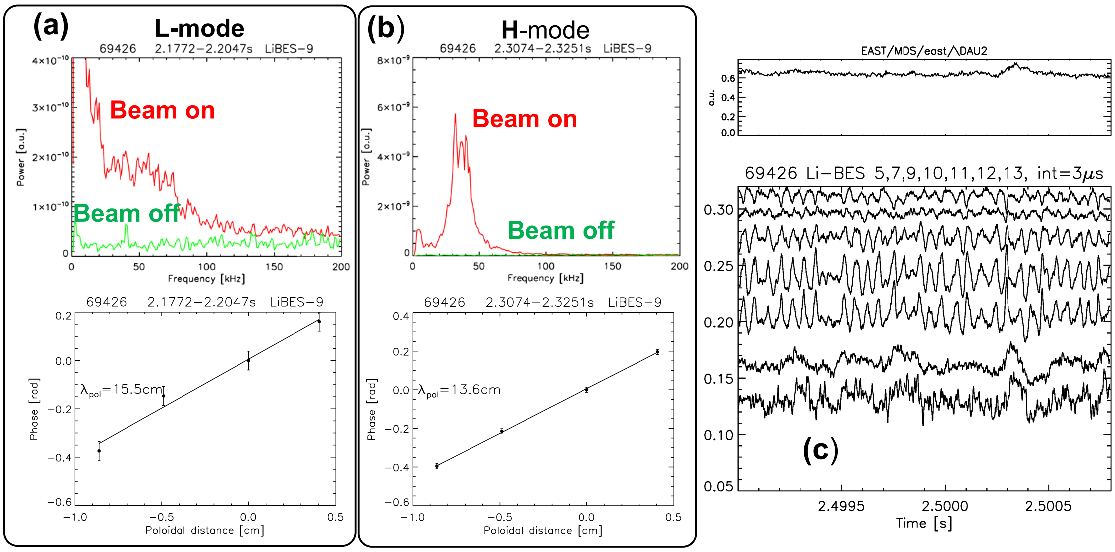

***Fig. 3**. Power spectra and phase shift as a function of poloidal distance for L-mode (a) and H-mode (b). The phase is averaged for the 30-70 and 35-60 kHz bands in L and H-mode, respectively. (c) Shows the same Li-BES signals as in Fig. 2 during the small-ELM regime.*

faster change in the pedestal density profile, most probably an MHD instability which grows faster than its oscillation period at one measurement location.

Conclusions

Our measurements show that a mode with about 15 cm poloidal wavelength is present in the edge plasma in L-mode before the I-phase. During the I-phase the mode disappears but suddenly reappears with few times 10^{-4} s^{-1} growth rate just before the transient L-phases. This observation makes us suspect that the transport enhancements in the I-phase are actually triggered by a single long-wavelength mode rather than by turbulence alone.

As the plasma develops towards stationary H-mode the mode growth rate appears to decrease and finally it may appear with steady state amplitude during the H-mode. A mode amplitude change is related to small ELMs while in other discharges without quasi-stationary mode it also appears less than 100 microseconds before ELMs. The above observations might indicate that the I-phase and small ELM regimes are related on EAST.

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