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Dynamics of Edge Localized Modes in the HL-2A tokamak

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Introduction: In H-mode operation, ELMs (Edge Localized Modes) expel repetitive bursts of heat and particles from the core plasma. Giant ELMs provoke detrimental effects on plasma-facing surfaces in future fusion device, such as ITER. For this reason, much effort is spent worldwide on the understanding, mitigation and control of edge localized modes, so that the largest and most destructive ELMs are avoided, while at the same time some level of particle and pressure control is maintained. In ASDEX, only type-III ELMs exist[1], and the energy loss caused by an ELM was of the order of 5%. In HL-2A, the preliminary results show that Type I and Type III ELMs were observed in the experiment, further study on the dependence of ELM frequency on heating power is in progress in future experiments.

Type I and Type III ELMs: In HL-2A divertor configuration, the ELMy H-mode operation was first achieved[2] in 2009 experiment campaign, by combining the auxiliary heating of NBI (<0.8 MW) and ECRH (<1.2 MW) with 2nd harmonic X-mode, with changes of plasma parameters such as the plasma current, plasma density, toroidal magnetic field and additional heating power. An example of shot11616 plasma parameters are given in Figure 1. From top to bottom are electron density, control signal for SMBI valve, ECRH waveform with 870 kW power from 260 ~ 900 ms, NBI waveform with 690 kW power from 300 ~ 890 ms, central

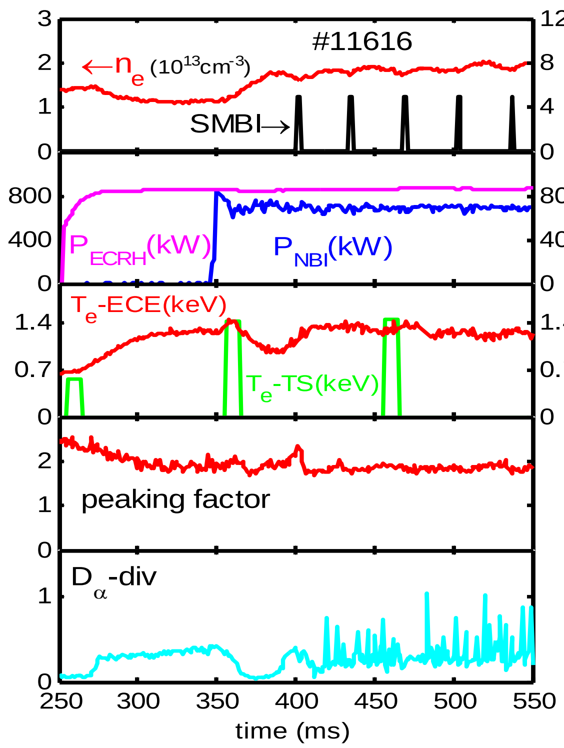

FIG.1. A typical discharge of H-mode with Type-III ELMs in HL-2A.

electron temperature Te measured by Thomson scattering diagnostic and ECE radiometer, density peaking factor, *D*α radiation from divertor. The H-mode phase is from 400 ~ 910 ms, which is ended with a time delay of ~10 ms after the auxiliary power is turned off. As shown in Fig.1, after L-H transition, the central-chord-averaged electron density increases and the density peaking factor decreases, indicating that the pedestal density increases. The core electron temperature almost keeps unchanged, and the pedestal electron temperature (by ECE

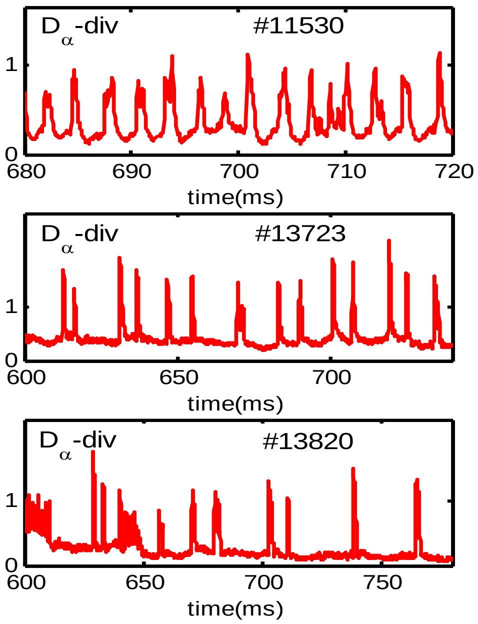

Fig.2, time intervals for different ELMs

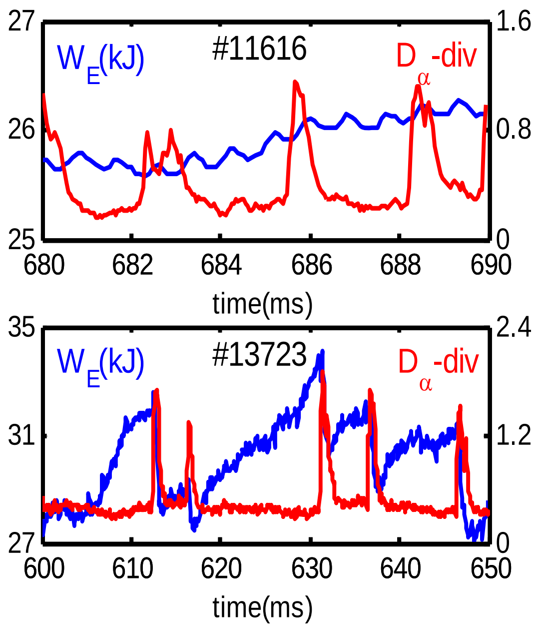

Fig.3, energy loss for an ELM

radiometer) changes a little. With the useful method to categorize ELMs by comparing the pedestal temperatures and densities of discharges[3], the ELM of present HL-2A H-mode operation may be recognized as Type III, with typical frequency about 400~600 Hz. In 2010 Spring campaign, new features of ELMs were observed. As shown in Fig.2, two periods of ELMs were observed in shot13723, the time interval was longer than 10 ms and even more than 30 ms in shot13820. Fig.3 presents the energy loss by an ELM. For a typical type III ELM as in shot11616, the energy change is less by 3%; the ELM loss is more than 10% in

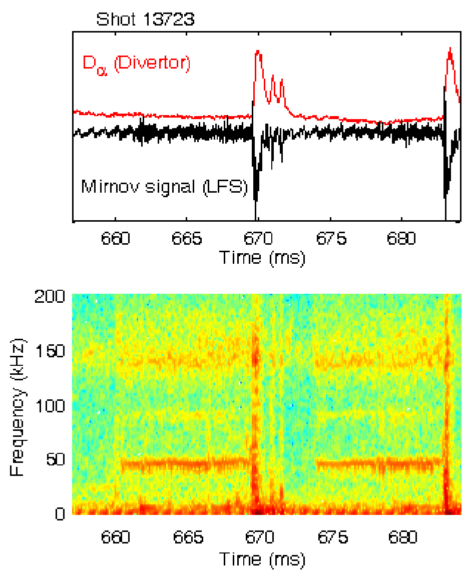

Fig.4, magnetic fluctuations during an ELM

shot13723, indicating the signature of a typical Type I ELM[4]. The ELM manifests itself on the magnetic fluctuation signal as a broadband turbulent phenomenon with frequencies reaching up to 180 kHz. Figure 4 shows a contour plot of the temporal evolution of the frequency spectrum of the magnetic fluctuations for a Type-I like ELM. The precursor is seen as a narrow line at about 50 kHz. Contrary to the experimental results in ASDEX, any magnetic precursor is hardly observed for a typical Type III ELM. These preliminary results show that Type I and Type III ELMs were observed in the experiment, further study on the dependence of ELM frequency on heating power is in progress in future experiments.

Chaotic feature of the observed ELMs: During an ELM, electrons are ejected from the core plasma and then rapidly travel along the scrape-off layer towards the target plates where they interact with neutral particles. Thus Dα light is emitted, and the ELMs are detected by distinctive spikes in the Dα radiation from divertor chamber. From the divertor Dα signal, the inter-ELM period and the corresponding ELM amplitude can be obtained by a threshold

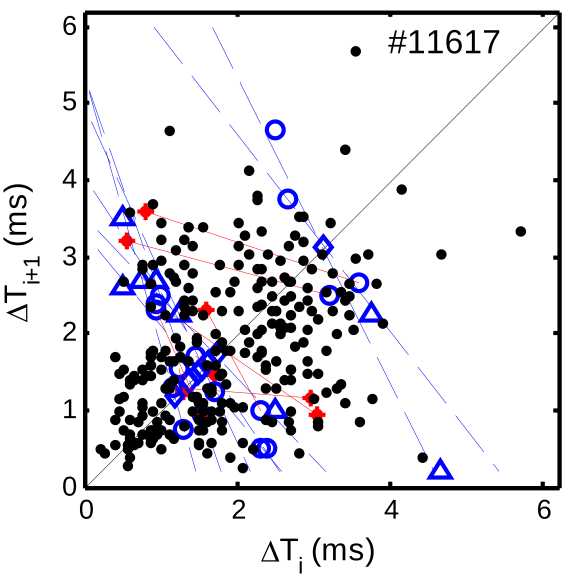

Fig.5, The first return map of the inter-ELM periods ΔT_i versus ΔT_{i+1} for shot11617

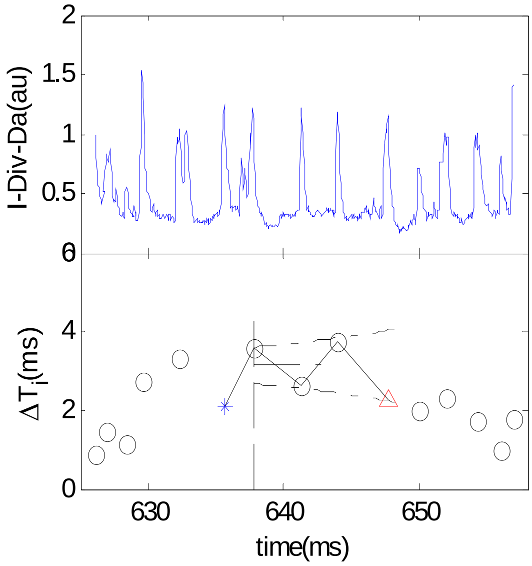

Fig.6, top plot is the *Dα* signal of the ELMs and the bottom is a candidate UPO in Figure 5.

detection technique for determining the occurrence time of an ELM. If the ELM with amplitude A_i occurs at the time t_i, then the ELM interval ΔT_i is defined by the time variance from this ELM to the next ELM: $\Delta T_i = t_{i+1} - t_i$. It is shown obviously that ELM events exhibit irregular behavior. There are two extreme considerations: (1) the underlying dynamical system is subject to a noisy environment; (2) the system is in a chaotic state. The chaotic feature of the observed ELMs is analyzed with unstable periodic orbits (UPOs) [5]. The recurrence method [6] detects chaos in discrete time series by searching for UPOs. The method simply fits some consecutive points to a straight line on the first return map and if the absolute value of the linear regression coefficient is more than 0.98, a UPO is found. The specific criteria are: (i) Departure phase: The occurrence of at least three consecutive collinear points (($\Delta T_i, \Delta T_{i+1}$), ($\Delta T_{i+1}, \Delta T_{i+2}$), ($\Delta T_{i+2}, \Delta T_{i+3}$)) with linear regression coefficient > 0.98 and a slope $s_+ < -1$. The location of the fixed point ΔT^* is obtained as the intersection point of the best fitted line from these points with the diagonal. (ii) Approach phase: The slope of the line connecting the fixed point ($\Delta T^*, \Delta T^*$) with the point ($\Delta T_{i-1}, \Delta T_i$) has a slope s_- between 0 and -1. The point ($\Delta T_{i-1}, \Delta T_i$) also is on the other side of the diagonal to the point ($\Delta T_i, \Delta T_{i+1}$), where ΔT_i is the time interval between i-th and (i+1)-th ELMs. The UPOs in the ELM time series have been observed, indicating that a deterministic, chaotic process governs the apparently random distribution of the time delay between ELMs in HL-2A tokamak. For a chaotic system, UPOs can be stabilized with small perturbations of available control parameters, thus it is a possible technique to mitigate ELMs by controlling UPOs, thereby increasing the ELM frequency and decreasing the ELM energy loss.

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