ELM-LIKE TRANSPORT EVENTS AND THEIR IMPACT ON CONFINEMENT IN W7-AS

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1. Introduction

In the stellarator W7-AS with plasma parameters close to the operational range of the quiescent H-mode, edge localized modes (ELMs) appear as bursts of turbulence associated with increased energy and particle flux across the last closed flux surface (LCFS) [1,2]. Confinement improves if the ELMs disappear and a quiescent H-phase is reached. In this phase the spectroscopically measured poloidal rotation increases together with the edge gradients for n_e, T_e and T_i.

Outside the parameter range of the quiescent H-regime for a great variety of plasma conditions relaxation phenomena are observed with characteristics similar to those of ELMs. We compare these ELM-like transport events with standard ELMs and study their qualitative dependence on the local plasma parameters and their possible influence on the quality of the confinement.

2. Characterization of ELM-like events

An example of ELM-like events in a discharge heated with 380 kW of NBI is shown in Fig. 1a. The magnetic configuration (edge rotational transform ι_a=0.350, plasma boundary defined by limiters) differs markedly from the operational range of the quiescent H-mode (ι_a=0.525±0.005, separatrix conditions). Neither an increase of heating power nor of density results in a quiescent H-mode. For comparison Fig. 1b shows typical ELM behaviour in a stationary ELMy H-mode at ι_a=0.523 with 400 kW of ECRH. The density is kept 10% below the threshold to a quiescent H-mode. A subsequent increase of the density induces the transition to the quiescent phase.

In both cases bursts of turbulence are correlated with a sudden loss of electron heat and an increase of H_α-emission. If intervals between this events are sufficiently long to be characterized (t > 200 µs) they appear like short H-phases, i.e. they show edge turbulence identical to the one in the quiescent H-mode [2]. Together with ELMs as well as together with the occurrence of ELM-like phenomena we observe periodic (10 - 30 kHz) but finite lifetime fluctuations (100 - 300 µs) with a poloidal mode number m = integer(ι_a^{-1}) in both density and magnetic field [3,4]. This type of fluctuations is not seen during the quiescent H-mode. It is localized within the first few cm inside the LCFS and extends deeper into the plasma only if

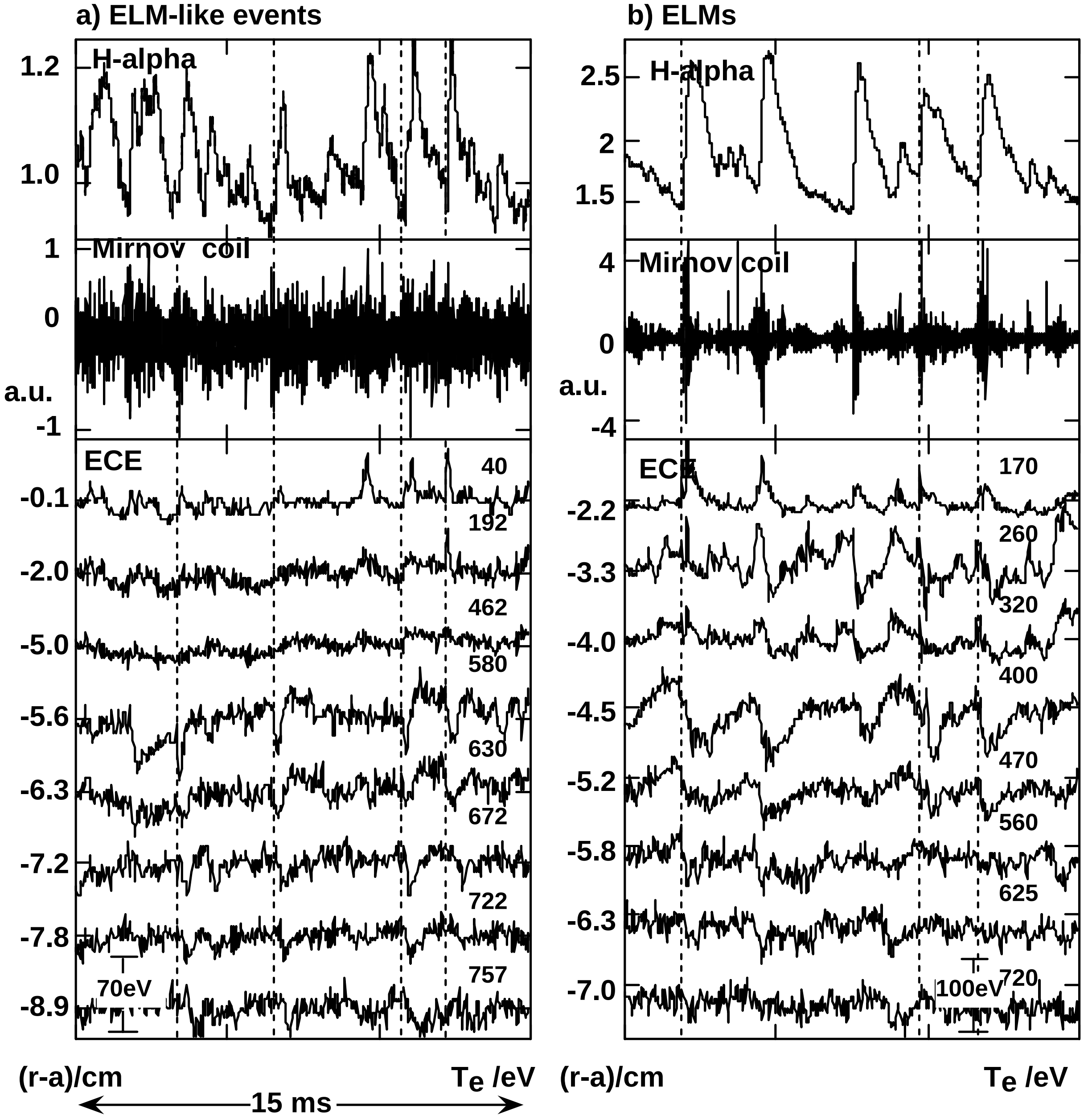

Fig. 1. Signals from Hα-emission, Mirnov coil (dominant coherent mode activity subtracted) and the outermost channels of the ECE radiometer measured a) during 15 ms of a stationary NBI-heated plasma (ι_a=0.350, limiter configuration) and b) during a stationary ELMy H-mode (ι_a=0.523, separatrix configuration). Some ELMs and ELM-like events are indicated by dashed lines.

the pressure gradient is weak and confinement is poor. The temporal correlation of these instabilities with the short increase of transport related to each ELM or ELM-like event is a subject of further analysis. The magnetic precursor activity (f ≈ 400kHz) which has been observed for ELMs [1] has not yet been investigated for ELM-like phenomena.

ELM-like phenomena and ELMs appear as transport events with increased electron heat and particle flux across the LCFS. The flattening of the edge density gradient is observed with beam emission spectroscopy and reflectometry. The immediate loss of electron heat is characterized by a pivot point as shown by the ECE traces in Fig. 1. Whereas for ELMs this immediate energy loss affects less than the outermost 4 to 5 cm of the main plasma in case of the ELM-like events this region can extend up to 8 cm. In any cases, as a consequence of the fast edge cooling, a cold pulse propagates towards the plasma center on a diffusive time scale. This suggests that the inward propagating component of electron temperature fluctuations as measured at W7-AS [5] results from ELM-like events of differing size.

3. Dependence on plasma parameters

ELM-like phenomena are observed for a wide variety of discharge parameters (edge rotational transform, line averaged density) and different heating scenario with ECRH and NBI. Temperature and density profiles for the discharges used as an example in Fig. 1 are given in Fig. 2. At $\iota_a \approx 0.35$, with parameters clearly different from the quiescent H-mode operational range, the position of the pivot point of the ELM-like events varies within a few cm during the discharge and in general tends to be more than 3 cm inside the LCFS (3 to 5 cm inside LCFS for discharge in Figs. 1a and 2). The layer where the pivot point is observed is situated deeper inside the LCFS in configurations where the pressure gradient is shifted correspondingly. Single ELM-like events are more pronounced and more clearly separated from each other if pressure gradients are steep. If the pressure gradient is generally low events tend to merge in time and are less pronounced than in Fig. 1a.

This situation is clearly different for ELMs i.e. with operation parameters close to those of the quiescent H-mode operational window: Pronounced ELM-activity occurs with a pivot point that is mostly situated in a narrow layer approximately 3±0.5 cm inside the LCFS. However, no pronounced maximum of the pressure gradient exists at this position (Fig. 2). A steep pressure gradient develops right at this layer only after a quiescent phase is reached.

The dependence of ELM-like behaviour on the local temperature gradients has not yet been systematically analyzed. In ELMy H-mode discharges the ELMs become more pronounced with increasing heating power and thus increasing temperature gradients. Below a critical threshold power no ELMs are observed.

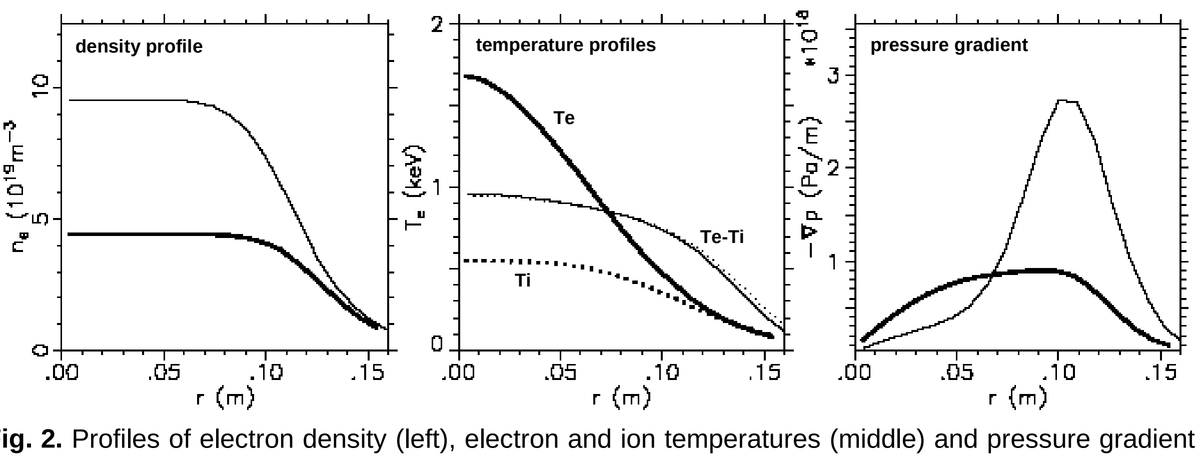

Fig. 2. Profiles of electron density (left), electron and ion temperatures (middle) and pressure gradient for the discharges in Fig. 1. Thin lines correspond to the NBI heated discharge in 1a (#43715). For similar conditions optimum energy confinement in W7-AS is observed [6,7]. Thick lines correspond to the ELMy H-mode in Fig. 1b (#43536).

In order to identify the underlying instabilities, a stability analysis with respect to resistive and ideal interchange modes has been carried out for limiter dominated discharges ($\iota_a \approx 0.35$) which show ELM-like phenomena. In a radial range of the strong pressure gradients the NBI heated discharge in Figs. 1a and 2 is stable with respect to ideal interchange but marginally unstable with respect to the resistive interchange criteria. However, ELM-like phenomena are also observed in an ECR heated discharge with the same magnetic configuration which is expected to be linearly stable.

4. Impact on confinement

In the ELMy H-mode at a heating power of 400 kW the typical energy loss per ELM is estimated from the profile changes to be <4% of the total stored energy at a typical ELM repetition frequency of about 1 kHz. As the energy confinement time is 25 ms a substantial fraction of the energy flux across the LCFS should be due to ELMs. Diamagnetic energy increases by up to 30% if an ELM free state is established. If ELM-like events disappear while other discharge parameters remain unchanged, an increase of the diamagnetic energy content of more than 20% has been observed. These observations indicate that a significant amount of energy flux is carried across the LCFS by ELMs or ELM-like events, respectively.

5. Conclusion

Both ELMs and ELM-like phenomena were found to be indistinguable with respect to their appearance as a burst in turbulence together with a transport event. For limiter dominated discharges at $\iota_a \approx 0.35$ the width and the localization of the layer where during an ELM-like event transport is transiently increased is correlated with width and maximum of the pressure gradient. However, for the ELMs observed close to the H-mode window the increase of transport occurs in a narrow layer where during the ELMy phase the pressure gradient shows no distinct maximum. Strong gradients occur only if ELMs disappear and a quiescent H-mode develops. Such the characteristics of both phenomena cannot be understood from the pressure gradient as the only driving force. In addition, also the stability of the transport barrier which is perturbed by the events will affect the behaviour of ELMs or ELM-like phenomena. These stabilizing elements are expected to be different for ELMs, i.e. under the separatrix conditions in the H-mode operational window and the configurations where ELM-like events occur.

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