The effect of nitrogen seeding on ELM filaments

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Introduction

Edge localised modes (ELMs) are strongly influenced by nitrogen seeding: in comparison to non-seeded discharges nitrogen seeded ELMs are often smaller and have a higher frequency [1]. Using the Electron Cyclotron Emission Imaging (ECEI) diagnostic the spatial - temporal evolution of the electron temperature for nitrogen seeded and normal type I ELMs has been studied in dedicated discharges on ASDEX Upgrade (AUG). The AUG ECEI system is a 2D diagnostic which consists of a linear array of 16 detectors, looking at different vertical positions in plasma. Each detector acts as a standard (1D) ECE radiometer with 8 radial channels. In total ECEI has 128 channels which cover an observational area of 10x40 cm [2]. The difference in ELM duration is connected with additional filaments being ejected in the longer ELMs during an extra phase in the crash identified before [1]. The duration of this phase is correlated with the number of filaments ejected each filament carrying away a certain of energy and particles leading to the higher pressure drop of the longer ELMs. In the following section the measurements and a possible explanation are discussed.

Evolution of ELMs during nitrogen seeding

Introducing nitrogen into the plasma gradually changes the ELM behaviour. From Fig. 1c it is seen, that the ELMs can be separated in two groups according to their duration: a 'long' ELMs group, with a duration in the range of 2-3ms (red stars) and a 'short' ELMs group (green dots), with a duration of about 1 ms [3]. In the absence of nitrogen both groups simultaneously coexist with the long ELMs prevailing. At 2.3 s the first step of the N_2 puff begins. Due

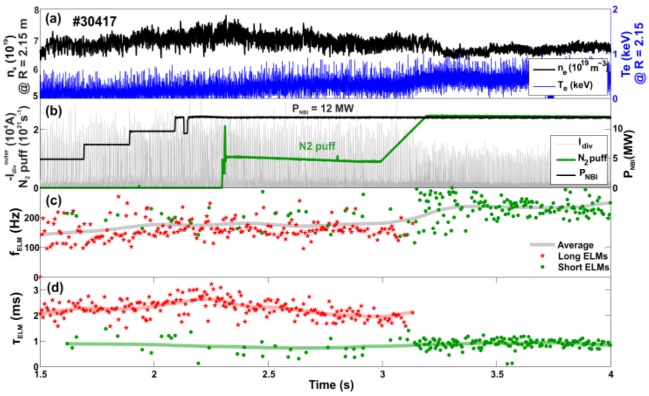

Figure 1. ELM frequency evolution related to the nitrogen seeding. a) Density and temperature time traces, b) Divertor current, NBI heating power and nitrogen puff rate, c) ELM frequency, d) ELM duration. The ELMs with a duration of more than 1.5 ms are considered to be 'long' and are marked with red stars, while the ones with a duration of less than 1.5ms are 'short' and are marked with green dots.

to the low puffing rate, it does not lead to any significant changes in the ELM behaviour. However, after the second step which starts at 3.0 s, the ELMs change: long ELMs disappear and are completely substituted by short ELMs.

ELM duration and filaments

The comparison between the short ELMs in the presence of nitrogen and the conventional type-I ELMs was performed on AUG and presented in ref. [3]. Three different phases of an ELM crash have been identified (see Fig. 2). (I) The ELM crash itself with two subphases: (Ia) the rise of the divertor thermal current signal, (Ib) the flat phase of the divertor current; (II) the decay of the divertor current, (III) the inter-ELM phase, during which the pedestal parameters begin to recover [3]. Short nitrogen seeded ELMs differ from type-I ELMs by the absence of the (Ib) phase, where the divertor current is flat. Skipping the (Ib) phase makes nitrogen seeded ELMs to be on average 1 ms shorter than type-I ELMs. The duration of phase (Ib) is correlated with the existence of additional filaments. Here by filaments we consider relatively hot and dense structures in comparison to background, which are elongated in poloidal direction. These structures, opposite to coherent and regular structure of ELM onset modes, are singular events and are only observed outside the separatrix (see Fig. 2b,c). Due to limitations of ECEI only the filaments passing the viewing window with high enough density and the size more than 2.5 cm^2 can be seen [2].

Fig. 3a shows the upper mentioned dependency: short ELMs never have more than one filament and in most cases they have no filaments at all. The ELMs which produce two or more filaments are always long. There is also a correlation between the number of filaments and both the temperature and density drop, caused by an ELM. Fig. 3b,c shows these dependencies, with the temperature and density drops taken at $\rho_{pol} = 0.95$. The ELMs with two or more filaments have a tendency to reduce the plasma kinetic profiles more than the ELMs with only one filament or with no filaments at all.

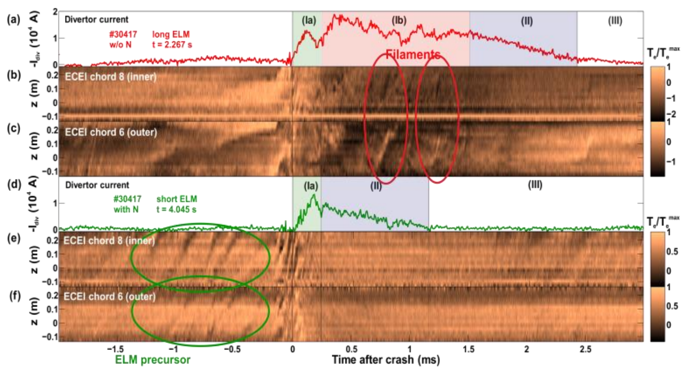

Figure 2: Long (in red) and short (N2 seeded, in green) ELMs as seen by the divertor current (a,d) and ECE Imaging (b,c;e,f). a) Divertor current for an ELM without nitrogen. b) ECEI inner vertical chord. c) ECEI outer vertical chord, two filaments are marked by the red circles d) Divertor current for a nitrogen seeded ELM. e) ECEI inner vertical chord for the ELM without nitrogen, ELM precursor is marked. f) ECEI outer vertical chord.

The less filaments are expelled by an ELM, the shorter the ELM is in terms of divertor current signal. As nitrogen seeded ELMs are usually short, a hypothesis is that nitrogen reduces the number of filaments expelled by ELMs. As it is shown in ref. [4], nitrogen seeding enhances the radiation around the X-point, which reduces the temperature in the SOL relative to non-seeded discharges. This likely increases the resistivity as well as the viscosity in the SOL. According to JOREK simulations for JET, lower SOL temperatures lead to a lower number of filament sets ejected [5]. Assuming that nitrogen seeding has a similar effect on the SOL as modeled in ref. [4] in our plasmas, the reduction of filaments due to higher SOL resistivity and viscosity may well explain the differences we observe. The study of the SOL changes and possible JOREK modeling of the AUG experiments is subject to future work.

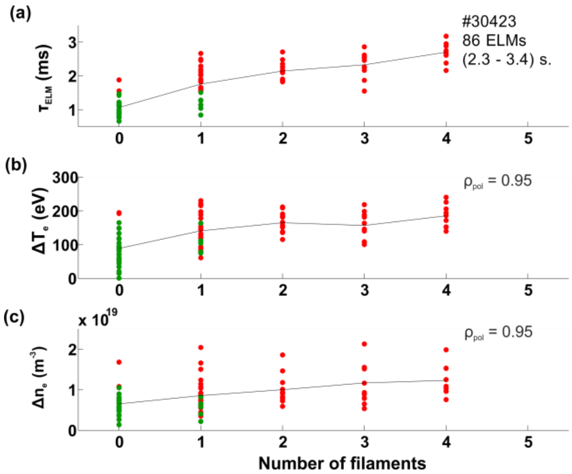

Figure 3: The effect of filaments seen by ECEI on: a) ELM duration b) Electron temperature drop c) Density drop. Long ELMs are marked with the red stars, short ELMs are marked with the green dots. The lines indicating the mean of the groups.

Filaments related temperature and density drop

Fig. 4 shows the averaged density and temperature drops, caused by the ELMs with different number of filaments. The data is obtained from the profiles, delivered by Integrated Data Analysis (IDA) [6]. There is a trend seen, which shows, that the crashes with a higher number of filaments lead to higher drops in both the density and the temperature profiles. Each filament causes, on average, 5 kJ of energy loss, compared to 30 kJ for an averaged loss caused by a type-I ELM in the considered discharge.

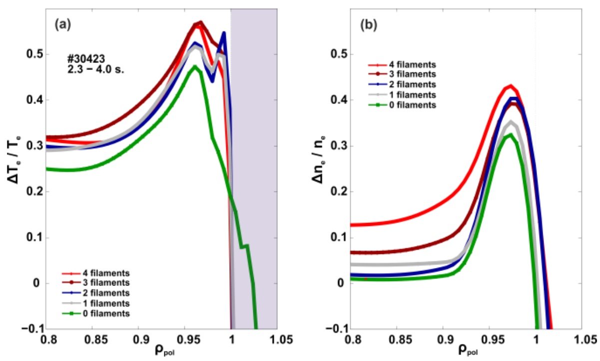

Figure 4: Relative temperature and density drops averaged by the different number of filaments, expelled by the ELMs. The data in the shaded area on the temperature plot is outside of the separatrix and is not reliable.

Discussion

In the experiments conducted on AUG both long and short ELMs take place simultaneously, with the domination of long type-I ELMs, before nitrogen seeding is applied. When the nitrogen puff is high enough (~80% of the D_2 gas puff rate), the long type-I ELMs completely disappear. The ELM size is usually determined by the ELM duration and/or the pressure drop caused by it. As is shown, both the duration and the temperature and density drop are correlated to the number of filaments expelled by an ELM. With some assumptions a possible mechanism, explaining this ELM behaviour is the following. Nitrogen changes SOL parameters, also reducing the temperature in the divertor and SOL regions [1][4][7] which can lead to reduction of the number of expelled filaments [5]. As soon as there is enough nitrogen in the plasma, the number of filaments expelled by each ELM reduces and subsequently ELMs become shorter. The mechanism of the additional losses in the absence of nitrogen had not been identified for a long time, however, filaments were one of the likely candidates [3]. With the help of ECEI on AUG it became possible to prove, that filaments are a determining factor for these losses.

Acknowledgment

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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