

## Analysis of inter-ELM bursts in the JET scrape-off layer

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Heat loads caused by edge localized modes (ELMs) are typically considered as major concerns for the main chamber wall. However, other smaller but more frequent events, so called inter-ELM bursts [1], which appear between type-I ELMs, could also harm the plasma-facing components in future fusion reactors. Although they only occasionally appear in the JET scrape-off layer in the majority of the discharges, they became frequent [2] in a discharge series, where the effect of fuelling on plasma parameters was studied. These plasmas were in the middle of the JET operation space ( $B_t=2.2$  T,  $I_p=2.2$  MA,  $P_{NBI}=13.5$  MW,  $P_{ICRH}\approx 1-2$  MW), had high triangularity and the strike points were placed close to the pumping duct in the corner of the divertor. The study of these inter-ELM bursts was carried out mainly based on the signals measured with the Lithium Beam Emission Spectroscopy diagnostic (KY6 Li-BES [2]) at JET. This system is responsible

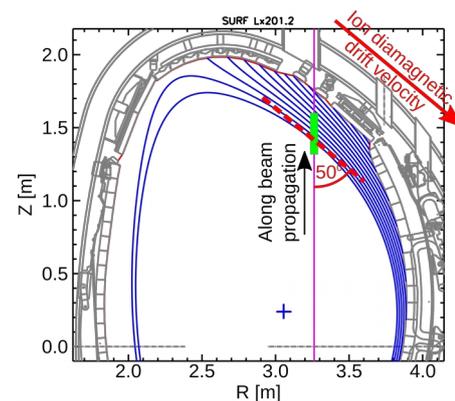


Figure 1: Plasma shape and observation geometry of the KY6 Li-BES in JPN89341. Light emission in the green area is observed and investigated below.

for the plasma edge density profile measurements of the JET Scrape-Off Layer (SOL). It is sketched in Figure 1: accelerated Lithium atoms are injected into the plasma from the top (magenta vertical line), where they collide with particles. Due to the interaction they emit light and become ionized. The photon flux is recorded in the entire region where these processes take place, i.e. in the edge and SOL, depicted with a vertical green line in Figure 1. Density profiles are calculated from the measured light profiles with a deterministic code, which solves the rate equations for the fast (45 kV) Lithium atoms along their trajectory [3]. The beam crosses the separatrix at an angle of around 50 degrees. Although the coordinate along the beam can be simply labelled by the vertical coordinate  $Z$ , as it is done in Figure 2 and Figure 3, this direction is neither radial nor poloidal.

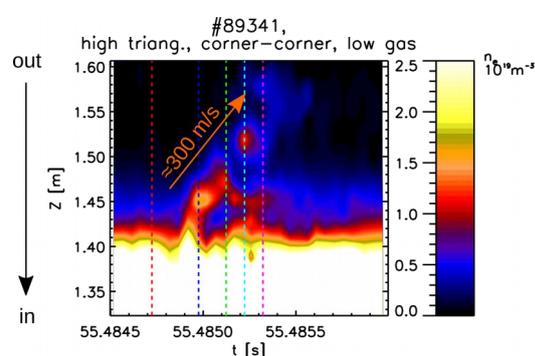


Figure 2: Example of inter-ELM burst in electron density from KY6 Li-BES as a function of time ( $x$  axis) and vertical – along beam coordinate ( $y$  axis)

(blue line). It disappeared and appeared again (green line), and again (cyan line) and again (magenta line). Although this was not a continuous movement the process had an apparent outward propagation velocity of  $v_z \approx 300$  m/s. The profiles at the denoted time slices are shown in Figure 3 with corresponding colors. The amplitude of the burst was  $n_e \approx 1.5 \times 10^{19} \text{ m}^{-3}$  at the closest point to the separatrix ( $\approx 0.04$  m away along the beam in this case), its amplitude did not decrease up to 0.12 m far and it was still observable at a distance of 0.2 m from the separatrix along the beam. (The real peak amplitude values might have differed from these

An example of an inter-ELM burst is shown in Figure 2. The beam is injected from the top and crosses the separatrix at  $Z_{\text{sep}} \approx 1.41$  m. The plasma was quiescent at the beginning of the time interval, e.g. at the time slice denoted by a vertical red line. A disturbance might have occurred around the separatrix at  $t = 55.4849$  s. This did not move directly along the beam but a filament appeared at an outer region later

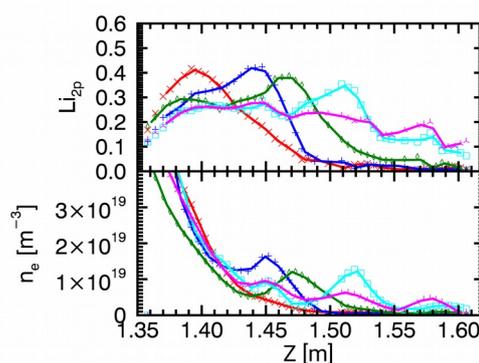


Figure 3: Profiles during an inter-ELM burst as a function of vertical - along beam coordinate in  $Z$ . Top: KY6 Li-BES light, bottom: KY6 Li-BES reconstructed density. Time slices are denoted with corresponding colors in Figure 2.

estimations in the far SOL if the plasma was below 5 eV in the filaments.) In the profiles denoted by magenta and cyan lines not only one filament peak but several events were observed.

The inter-ELM bursts are distinguished from the ELM events based on their behaviour in the divertor: the latter ones are typically identified at JET based on spikes in the divertor Be II (527 nm) line radiation. However, this type of inter-ELM bursts do not enhance the radiation of this line. This might suggest that they deposit their energy on the main chamber wall. Their traces were also revealed on the limiter Langmuir probe signals but the quality of those signals was too low for detailed analysis. Considering the discharge with the lowest gas fuelling level (JPN89341),  $f_{\text{ELM}} \approx 35$  Hz, typically 2-6 bursts were present between the ELMs. With increasing gas injection level both the ELM frequency and the number of bursts between ELMs increased.

The filament that has been introduced in Figure 2 and in Figure 3 appeared and disappeared with a frequency of  $f_{\text{filament}} \approx 10$  kHz. If it had been a single filament rotating toroidally around it would have needed a toroidal rotation speed of  $v_{\text{tor}} \approx 200$  km/s, which is much higher than the typically few km/s  $v_{\vec{E}_r \times \vec{B}}$ . Hence, the burst may have consisted of several filaments ejected simultaneously. A possible method how the plasma generates such structures is sketched in Figure 4: a magnetic mode with high poloidal and toroidal mode number is excited. Due to this instability blobs arise at a localized toroidal position. Although their birth place is around the midplane they spread to the top of the plasma along the magnetic field lines. When they become disconnected from the bulk plasma they start rotating perpendicularly to the magnetic field in the ion diamagnetic drift direction due to the SOL  $E_r$  field. At the same time they move in the direction of the major radius due to charge separation. These blobs are sketched with different colors in Figure 4, where the vertical red line indicates the KY6 Li-BES observation volume. This manner the observed apparent outward propagating behaviour along the beam can be explained.

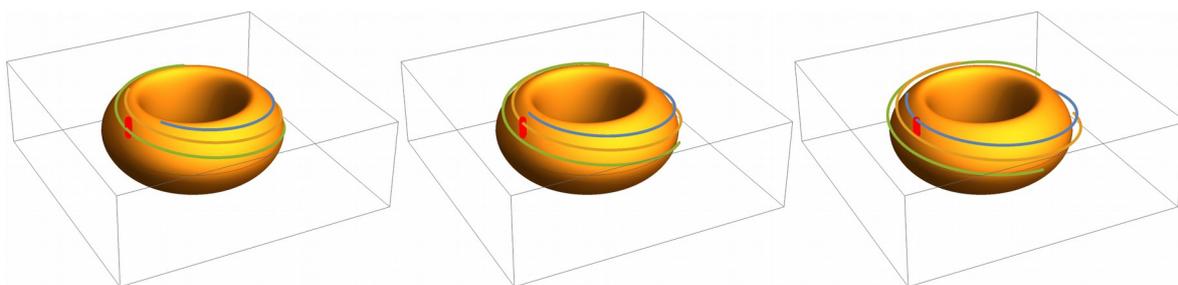


Figure 4: Multiple filament model of inter-ELM bursts. Thick red vertical line: Li-BES observation volume

Another sketch about the possible burst structure in the vertical-poloidal plane is depicted in Figure 5. Due to the high tilt of the magnetic field lines in the toroidal direction the problem is considered in 2 dimensions as a first approximation. Here the black ellipses denote the entire burst, which may have an inner structure consisting of filaments. The thick blue line is the separatrix, and the red dots indicate the observation volumes. In JPN89341 two channels separated perpendicularly to the beam was also available (see the red dots at the upper end of the observation volume). With the time delay estimation technique and the assumption of plane wave structure  $v_{\text{plane}} \approx 120$  m/s at an angle of  $\approx 30$  degrees upward relative to the horizontal plane was

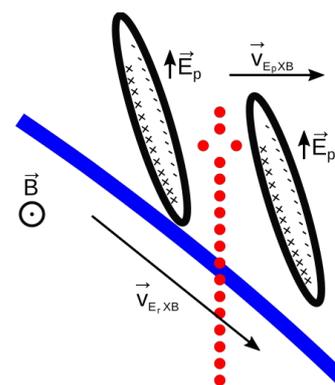


Figure 5: Sketch about possible burst movement across the observation area. Blue: separatrix, red: observation channels, black: outer contour of the entire burst

obtained for the particular filament introduced in Figure 2. The plane wave assumption is done based on the assumption of a highly elongated structure. Note that this way only the velocity perpendicular to the major axis of the structure is received and the direction refers to the tilt of the structure and not to the direction of the velocity. Projecting this propagation along the beam  $v_z \approx 250$  m/s has been calculated, as expected in Figure 2. The statistical corroboration of this statement is ongoing and will be reported later.

**Summary** High amplitude inter-ELM bursts have been observed in the JET far SOL with the Li-BES diagnostic, which have no traces in the divertor. They have a fine filamentary structure. They may originate from toroidally localized high  $m$ ,  $n$  modes in the midplane. When these modes arise several filaments become disconnected, which start rotating perpendicularly to the magnetic field due to the SOL  $E_r$  and additionally drift outward due to charge separation.

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 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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