EFDA–JET–CP(11)04/20

A. Sirinelli, B. Alper, Yu. F. Baranov, E. De La Luna, S. Devaux, D. Dodt,
and JET EFDA contributors

Details of Type-I ELM Crashes on JET Revealed Using Fast-Sweep Reflectometry

Details of Type-I ELM Crashes on JET Revealed Using Fast-Sweep Reflectometry

A. Sirinelli, B. Alper, Yu. F. Baranov, S. Devaux, D. Dodt
and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]*EURATOM-CCFE Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK*
[2]*Laboratorio Nacional de Fusion, Asociacion EURATOM-CIEMAT, 28040, Madrid, Spain*
[3]*Max-Planck-Institut für Plasmaphysik, EURATOM-Assoziation, D85748 Garching, Germany*
** See annex of F. Romanelli et al, "Overview of JET Results",*
(23rd IAEA Fusion Energy Conference, Daejon, Republic of Korea (2010)).

Preprint of Paper to be submitted for publication in Proceedings of the
38th EPS Conference on Plasma Physics
Strasbourg, France
(27th June 2011 - 1st July 2011)

1. INTRODUCTION

In H-mode plasmas, Edge Localised Modes (ELMs) are responsible for large energy losses and have been observed on all major tokamaks. They have been described in machines where fast density measurements are available (ASDEX-Upgrade [1], DIII-D [2], MAST [3], JET [4]. . .) as a fast collapse of the top of the pedestal and a rise of the Scrape-Off Layer (SOL) density occurring in less than 200μs. During the same time interval, filament structures are observed [3, 4]. The SOL density has been reported to decay in a few ms and occurs in parallel with the slower recovery of the pedestal top [4].

This paper presents new measurements, made on the JET tokamak, of the evolution of the density profile during type-I ELM crashes. The reflectometer used for this study is first described. The typical ELM crash dynamics are then presented. Finally an unexpected highdensity event observed during some ELM crashes is described.

2. JET FAST SWEEP REFLECTOMETER

A fast sweep reflectometer has recently been installed on JET [5]. It is able to measure an electron density profile every 15μs from the SOL to the plasma centre with sub-centimetre resolution. The system is composed of 6 independent reflectometers working in 4 different bands (from 42GHz to 150GHz) and 2 polarisations. Measurements are made from the lowfield-side along an horizontal line of sight close to the usual magnetic axis level. For every JET discharges, up to 100,000 density profiles are recorded and are automatically analysed. Profile absolute positioning is obtained using X-mode polarisation and rely on the total magnetic field given by the equilibrium code used at JET (EFIT).

Density profiles produced have two main uncertainties:

Position uncertainty:

Any error in the magnetic field has a direct implication in the global position of the density profiles. A typical uncertainty in B_t of 1% leads to a 4cm uncertainty in the profiles position. On JET, this error is automatically corrected by comparison of the density profiles with the line integrated density measured by the FIR interferometer at the plasma edge. The remaining global uncertainty linked to the detection of the signal rise in the SOL is believed to be around 1cm.

Gradient uncertainty:

The calibration of the reflectometer requires a known reflection position. We use the inner-wall reflection before plasma as reference. This wall being not a flat mirror but composed of tiles of different height, the reference position is known ±2cm. This uncertainty is translated into an uncertainty in the profiles gradients of $\pm 0.5 10^{19}$ m^{-3}/cm.

3. TYPE-I ELM CRASHES

JET fast sweep reflectometer has been used to measure ELM crashes at the maximum repetition rate. Figure 1 shows the evolution of the density profile for different type-I ELM crashes:

a) a typical small (150kJ) type-I ELM and b) a large (1.2MJ) compound type-I ELM. Three phenomena can be observed. The first event is the pedestal collapse which has been measured to be an almost instant event, lasting less than one sweep time (10µs). Then, the SOL and the top of the pedestal recover with different time scales. For the normal ELM, the SOL density reaches its pre-crash value in less than 5ms (as observed in [4]), while it takes more than more 15ms in the case of the compounded ELM. In both case, the pedestal takes a much longer time to fully recover.

4. HIGH-DENSITY EVENTS OBSERVED DURING ELM CRASHES

In analysing in details the onset of the ELM crashes, a phenomenon has been discovered which occurs within 100µs of a pedestal collapse. For some ELM crashes, a high density plasma is observed outside of the Last Close Flux Surface (LCFS). Figure 2 shows measurements of this dense plasma. The profiles presented are truncated: the density is so high that the limits of our X-mode polarisation systems are reached. O-mode reflectometers have higher density limits but they still cannot resolve the maximum density. This plasma has a density higher than 1.610^{20} m^{-3}, which is higher than the main plasma centre density.

This high density plasma has been observed appearing in less than 10µs and gradually disappearing after a variable amount of time. The main plasma pedestal seems not to be affected by these events as no differences have been observed in the recovery of ELM crashes in cases with the dense plasma and cases without. The high resolution Thomson scattering system has never detected such phenomenon which imply that the temperature should be much lower than 100eV. In order to be consistent with the overall conservation of particles, it is believed that this dense plasma is only present on a thin layer outside of the LCFS.

A systematic analysis of a large database of ELM crashes recorded by the reflectometry system has been carried out. High-density events have been observed for every JET pulse analysed with type-I ELMs and accessible with the fast sweep reflectometer (B_0 from 2T to 3.6T). Nevertheless, only a minority of ELMs exhibits this behaviour. The lifetime of these high-density events has also been measured as shown in figure 3. Most of the events recorded have been measured to last less than 75µs but some may have a much longer lifetime (up to 375µs) as shown in figure 2.

No comparable events have been recorded on other tokamaks. Nevertheless, on DIII-D the central vertical line of the interferometer has recorded during ELMs a sharp increase of the line integral density followed by a decay about 100µs later [6]. This was attributed to recycling in the divertor. On ASDEX-Upgrade similar behaviours have been observed with the edge high field side vertical interferometer during ELMs but also in-between ELMs [7]. On JET, this dense plasma can explain drops seen in the ECE measurements [8]. For one case, a clear correlation has been made between ECE and reflectometry measurements.

CONCLUSIONS

The new JET fast sweep reflectometer has demonstrated its capability to provide detailed density profiles covering the SOL and the plasma core during ELM crashes. SOL density dynamics after the pedestal collapse has been measured in normal and compound type-I ELMs. A new phenomenon has been observed consisting of a short living dense plasma outside of the LCFS. The physics underlying the apparition of this plasma is not yet well understood and will be the centre of further investigations.

ACKNOWLEDGEMENTS

This work, part-funded by the European Communities under the contract of Association between EURATOM/CCFE was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission. This work was also part-funded by the RCUK Energy Programme under grant EP/I501045.

REFERENCES

[1]. I. Nunes, et al. Nuclear Fusion, **44** (8):883, 2004.
[2]. L. Zeng, et al. Journal of Nuclear Materials, **337-339**: 742, 2005.
[3]. R. Scannell, et al. Plasma Physics and Controlled Fusion, **49** (9): 1431, 2007.
[4]. M. Beurskens, et al. Nuclear Fusion, **49** (12): 125006, 2009.
[5]. A. Sirinelli, et al. Review of Scientific Instruments, **81** (10): 10D939, 2010.
[6]. A. Leonard, et al. Journal of Nuclear Materials, **313-316**: 768, 2003.
[7]. K. McCormick, et al. Journal of Nuclear Materials, **390-391**: 465, 2009.
[8]. Y. F. Baranov et al. Nuclear Fusion, submitted.

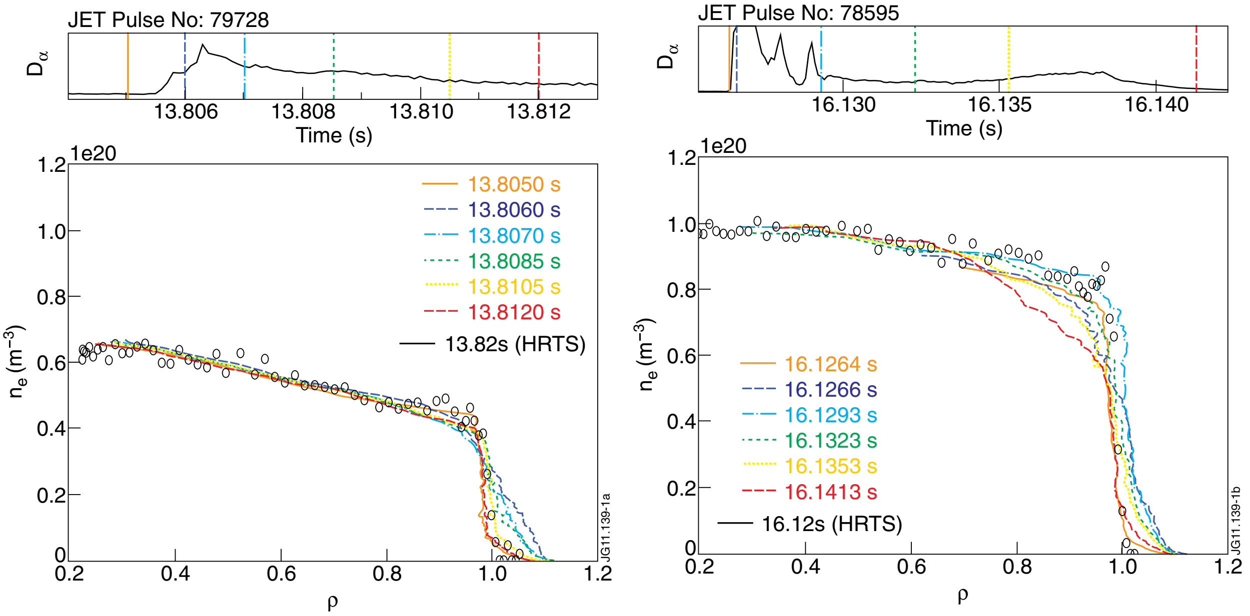

Figure 1: Type-I ELM crashes. Upper plots: time traces of the D_α plasma emission. Lower plots: evolution of the density profile during an ELM crash measured with the fast sweep reflectometer. High resolution Thomson scattering measurement is also displayed for comparison. Pulse No: 79728: $B_0 = 2.6T$, $I_p = 2.5MA$, $P_{NBI} = 15MW$, ELM energy losses: 150kJ. Pulse No: 78595: $B_0 = 3.2T$, $I_p = 3MA$, $P_{NBI} = 15MW$, ELM energy losses: 1.2MJ.

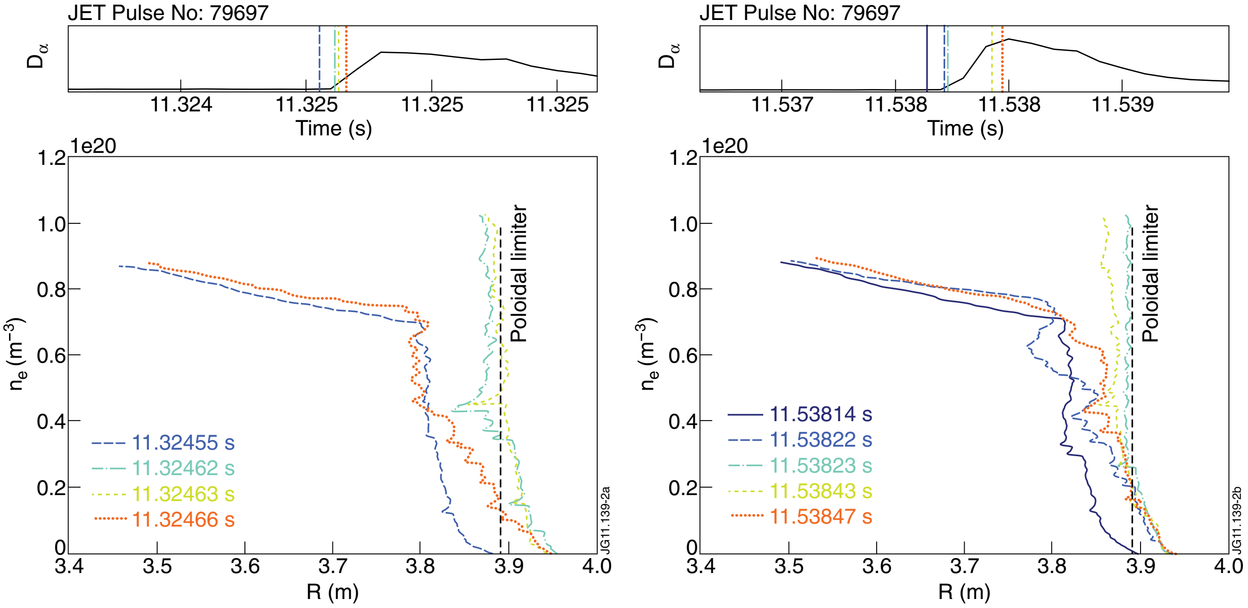

Figure 2: Example of high-density events measured using X-mode reflectometers. The high density profiles are not complete because they reach the limit of the diagnostic. The density is even higher than $1.610^{20} m^{-3}$*. In the first case, the event lasts about 30µs while in the second, the dense plasma is seen during 210µs. Pulse No: 79697:* $B_0 = 3.6T$*,* $I_p = 4MA$*,* $P_{NBI} = 22MW$*, ELM energy losses: Section 1550kJ.*

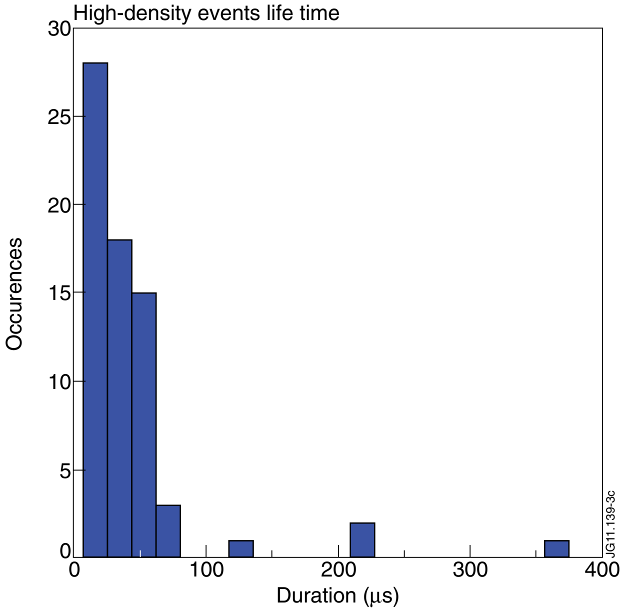

Figure 3: Statistic of the high-density events lifetime observed.