Divertor Parameters in Steady State ELMy H-modes at JET

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1. INTRODUCTION

Steady state H-modes lasting up to 18s have been obtained at JET in double null magnetic configuration [1]. The ELMs were produced by heavy gas fuelling; off-axis ICRH heating prevented monster sawtooth crashes and was instrumental in maintaining the steady state conditions. Although JET long elmy H-modes had a poor energy enhancement factor, they represent a promising regime that will be further investigated in the next operational campaign.

The ELMs observed at JET are of the type 3 according to the DIII-D classification [2]. It has been shown that ELMs at JET are preceded by magnetic field and density fluctuations; a density pulse starts then propagating outwards from r=0.90-0.95 [3]. In addition, the ELM frequency has been shown to depend with an inverse square root law on the pressure gradient in the edge, the strongest dependence being on the edge electron temperature and the temperature gradient [4]

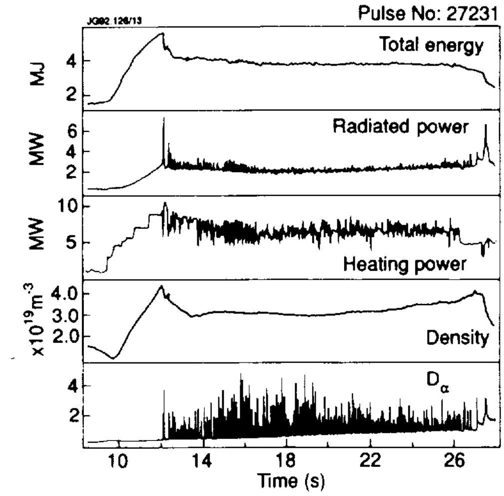

Fig.1. Main plasma parameters in shot #27231, with a 18s H-mode

In this poster we present a study of the divertor and scrape-off layer (SOL) parameters during elmy H-modes.

A comparison between Langmuir probe data and D_α measurements is presented; probe data give a much better time resolution in the case of high frequency ELMs and high densities in the divertor region.

Data taken with lower time resolution in a similar discharge show similar current spikes in two probes situated at the same radial position, one on the upper and one on the lower target plates (fig. 3).

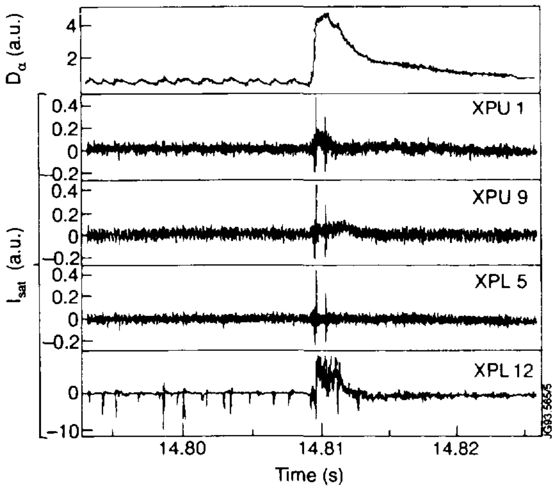

Fig.3. Fast signals in D_α and probes XPU1,XPU9,XPL5 and XPL12, shot # 26450.

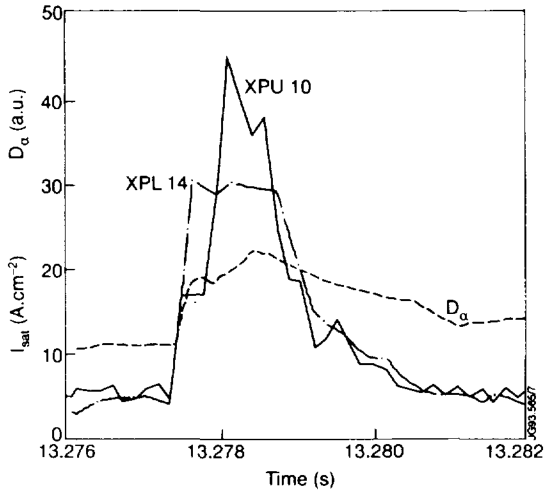

Fig. 4. D_α, and I_{sat} in XPU10 (r=270cm), and XPL14 (r=269cm), same scale for the two currents.

- The fast fluctuations are even observed in probes that are in a shadowed position, such as XPL5, hence these are probably caused by fluctuations in the plasma potential.

- Negative current spikes are more frequent in the probes situated in the inner strike region, and have been ascribed to electron currents [6].

- There is no evidence from these data that a heat pulse precedes the particle pulse causing the D_α emission, as reported in ASDEX-U [5]. Ascribing all the rise in I_{sat} to a change in the electron temperature would give an unreasonably high T_e (hundreds of eV).

- Probes situated on the toroidal limiters and on the antenna protection tiles also measure current during ELMs in some discharges; when this occurs, the wide angle view camera shows that interaction of the plasma with the walls takes place.

5. COMPARISON OF PROBE AND CLOSE VIEW CCD CAMERA DATA

- In long steady state H-modes, with every ELM observed in the vertical D_α, an interaction with the upper target is observed in the close up view CCD camera. In D_α light, it appears as a toroidal band of radiation situated some 10 cm inwards of the inner separatrix. No similar interaction is observed in the outer side. The field of view of the camera is more reduced in the outer than in the inner side; however if interaction occurred within the next 10cm of the outer separatrix it would be observed.

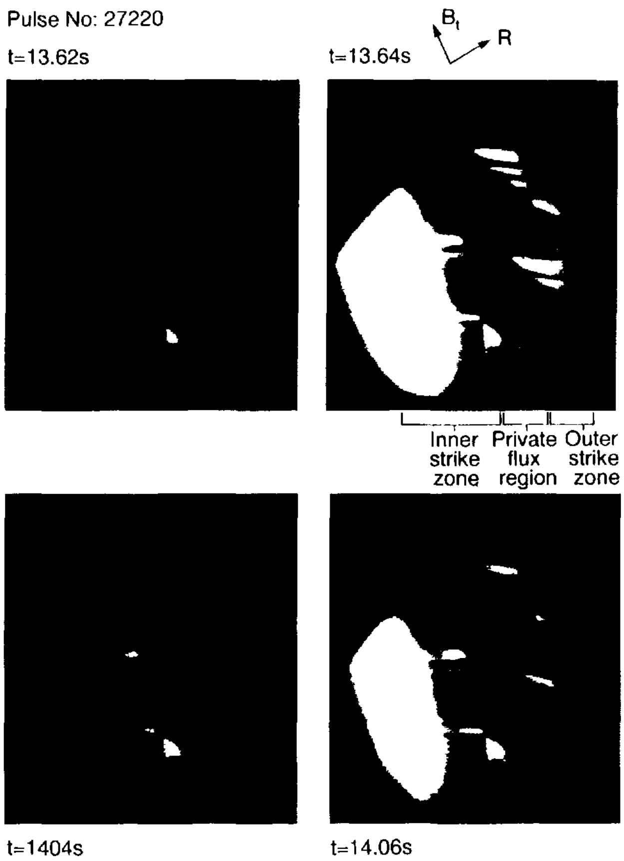

Fig.5. CCD camera close up view of the upper target before the ELM

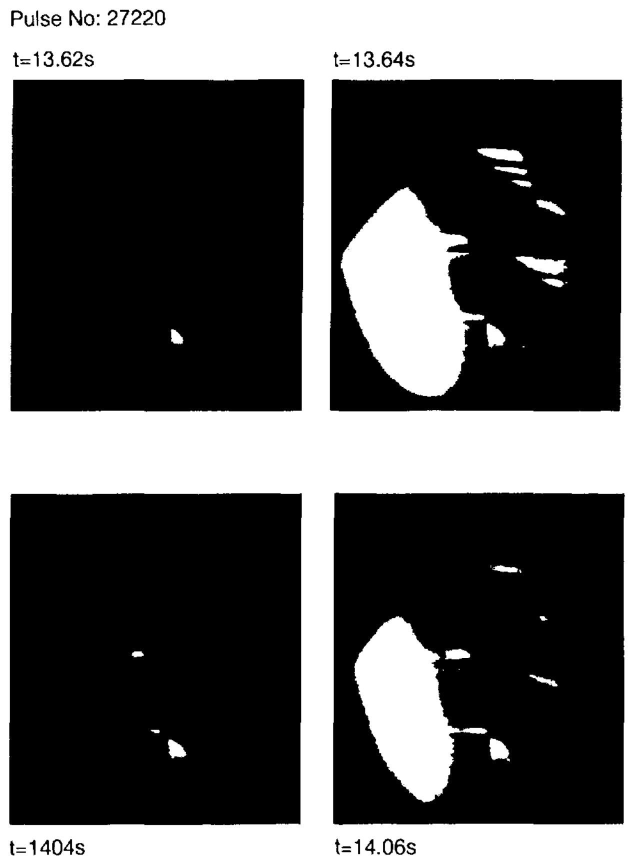

Fig.6. CCD camera close up view of the upper target during the ELM

- However, the Langmuir probes situated in the outer strike region measure a flux of particles with the ELM just as the probes in the inner region do!

- In hot ion mode single null discharges that develop giant ELMs, a similar interaction is observed, only now in the outer strike region; no interaction occurs in the inner strike zone.
  In this case as well, probes measure ELMs in the two strike regions.

- These results are not well understood, but are consistent with the findings in JT-60 [7], where higher heat fluxes are measured in the inner than the outer strike region in elmy high density discharges. Their flux becomes higher in the outer strike region as wall conditioning improves, as in our case in the hot ion mode.

DIAGNOSTICS

Two arrays of single Langmuir probes (labelled XPU and XPL respectively), situated on the upper and lower divertor targets, have been used, as well as other probes located at different toroidal and poloidal positions. Measurements from CCD cameras looking at the divertor plates in D_α light are also presented. An extensive use of a wide angle view CCD camera has been made to identify the zones of interaction of the ELMs with the walls.

The vertical D_α signal is normally used as a reference for ELM events by all the other diagnostics.

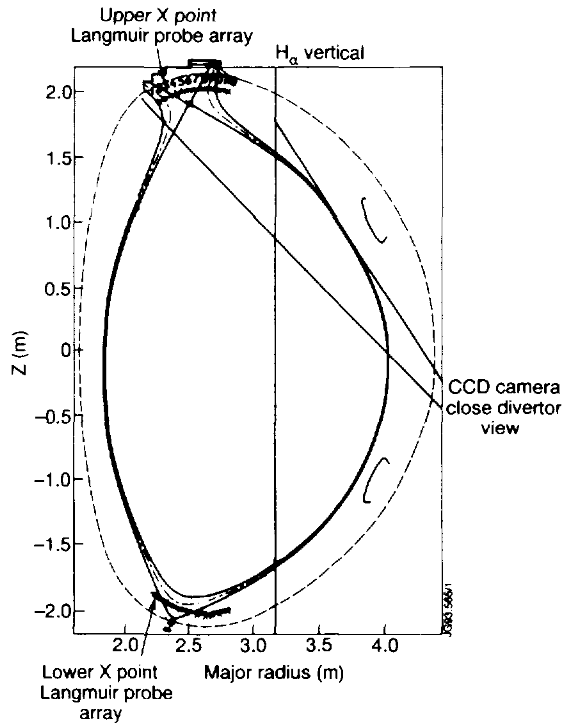

Fig.2. Divertor and SOL diagnostics: Langmuir probes, D_α, CCD cameras.

BIASED PROBES

- The Langmuir probes have been biased in high frequency ELM discharges. —> only ion saturation current measurements.
- In a restricted number of discharges, the current measurements from a few probes on the upper and lower targets have been digitised, together with the vertical D_α, with a 250KHz ADC.

3. FAST BIASED PROBE RESULTS

In the fast measurements, probes XPU1, XPU9 (upper X-point, inner and outer strike regions), XPL5, XPL12 (lower X-point, inner and outer strike regions, 5 in a shadowed position) were used, with a time resolution of 4 μs.

The magnetic configuration was double null, with ΔX_U=1cm and ΔX_L=3cm.

Two effects are observed (fig 2):

1. A fast perturbation in all the probes: this occurs simultaneously in all four probes, within the 4μs resolution of the ADC
2. Underlying these fast fluctuations, a rise in the ion saturation current is observed. The delay between the D_α signal and the current signal is less than 50μs.

6. DIVERTOR PARAMETERS DURING LONG ELMY H-MODES

In shot 26779, a two second steady state H-mode was achieved with 12 MW of total input power (fig. 7). The upper Langmuir probes collected data in bias mode for about 1s, with 0.16 ms time resolution (fig.8).

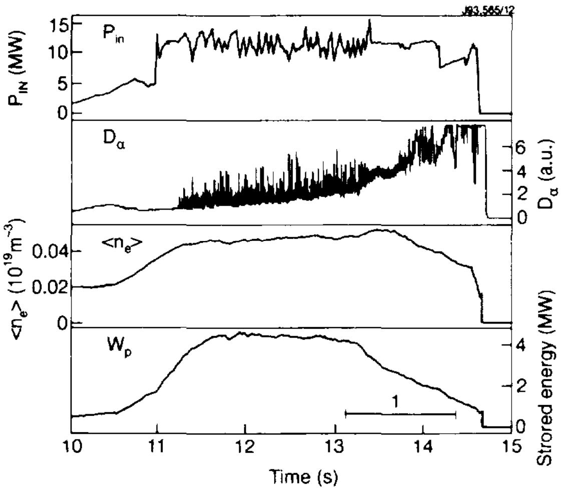

Fig. 7. Total input power, D_α vertical, volume averaged density and plasma stored energy for shot #26679.

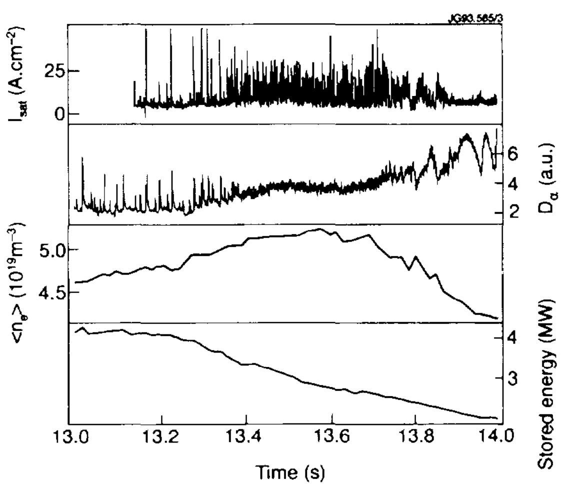

Fig. 8. I_{sat} in XPU10, D_α vertical, volume averaged density and plasma stored energy for shot #26679.

- Around 53.2s, the ELMs increase in frequency. This is observed both in the D_α signal and in I_{sat} in XPU10, situated in the outer strike region at 12cm of the separatrix.

- When the ELMs become more frequent, around the 53.4s, they are no longer resolved by the D_α signal, but are seen in probe XPU10.

- The decay time of an ELM signal is, assuming an exponential decay,

  I_{sat} signal: 0.25-0.6 ms
  D_α signal: 2.5-3.4 ms

  In figure 9 the two signals corresponding to one ELM are plotted with a logarithmic vertical scale. The signal in I_{sat} decays approximately 7 times faster the signal in D_α, so the probe can discriminate higher ELM frequencies.

- The connection length L is around 20m in the case of a double null discharge. The characteristic residence time for ions in the scrape-off layer, τ=L/c_s, is

	L=5 m	L=20 m	L=50 m
T_e=5 eV	0.23 ms	0.9 ms	2.3 ms
T_e=50 eV	0.07 ms	0.3 ms	0.7 ms

- The measured decay time of the ELM in the I_{sat} is of the order of the expected τ value in the case of a SOL temperature of 50eV, whereas the decay time of the D_α signal is too long to reflect only the relaxation time of a pulse of particles.

- In the long steady state elmy discharges an increase in the central electron density is often observed towards the end of the H-mode phase (see also fig. 1). This is probably an effect of saturation of the target. In fig. 8 this increase is observed when the frequency of the ELMs increases from around 200 to>600 Hz. (In conditions of non saturation of the walls, e.g. the L to H transition in hot ion modes, small ELMs of frequencies up to 1-2KHz can be resolved in the D_α signal).

- An ion flux enhancement factor over the baseline can be estimated by integrating the flux due to the ELMs. At high frequencies it is found to be just above 2, in agreement with the increase in the D_α particle flux.

- If the dependence of the edge temperature on the ELM frequency found in reference 4 is assumed, this change in the fluxes would correspond to a factor of 3 increase in the divertor density.

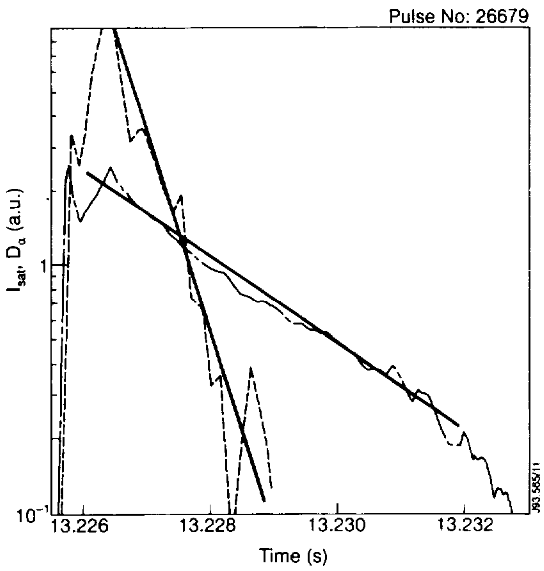

Fig. 9. ELM signal in I_{sat} and D_α

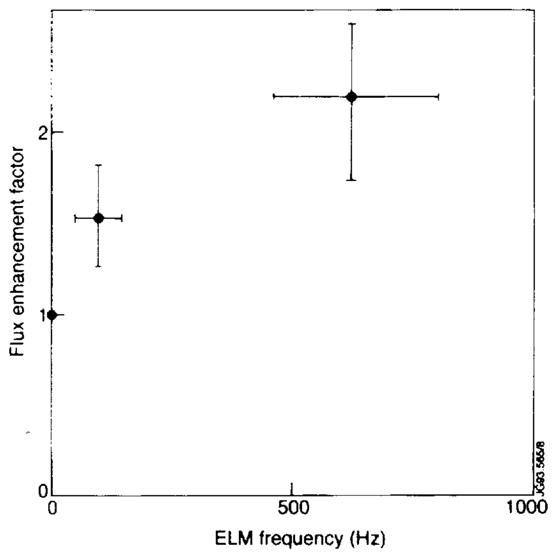

Fig. 10. Flux enhancement factor versus ELM frequency

RAMPED PROBE DATA

All the Langmuir probes installed at JET during the campaign 90-91 were single probes. If the probes are ramped (to obtain electron temperatures and densities), ELMs distort too much the probe characteristics for the fitting procedure to work. In a few cases however, where the ELM frequency was < 30-40 Hz, T_e and n_e measurements have been obtained.

→ the electron densities and temperatures obtained are representative of the baseline between (low frequency) ELMs.

In figures 11 and 12 , the values of T_e and n_e at the outer separatrix in the divertor region have been obtained with probes XPU9 and XPU10, for elmy and quiescent H-modes with a similar total input power.

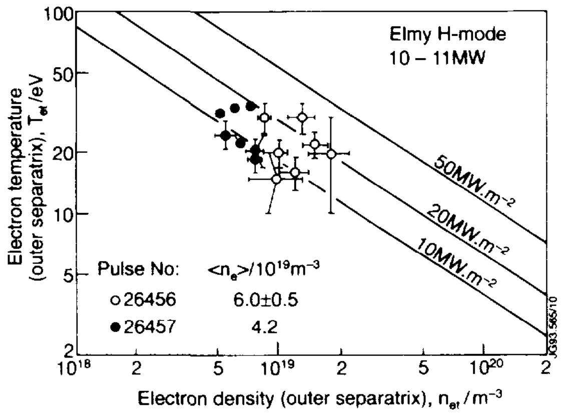

Fig. 11. T_e versus n_e in the divertor outer sol in low frequency elmy H-modes.

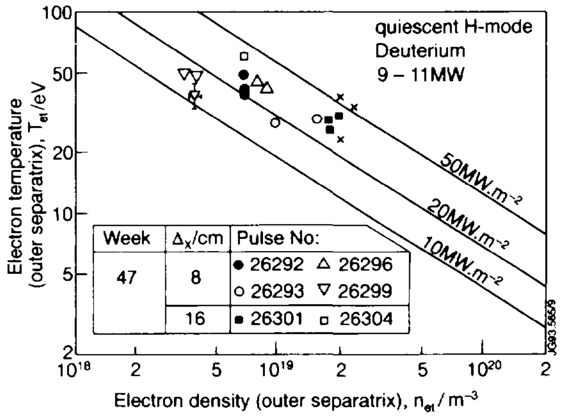

Fig. 12. T_e versus n_e in the divertor outer sol in quiescent H-modes.

- It is observed that we obtain, between ELMs, lower electron temperatures in the divertor than in quiescent H-modes for the same range of divertor densities, in single null discharges.

- Using the calculated enhancement factors we estimate that densities in the order of 6×10^{19} m^{-3} have been obtained in the outer divertor region.

7. DISCUSSION

- Ion fluxes are measured with Langmuir probes and are simultaneous with the D_α spikes during ELMs (≤50μs). We have no evidence of a large heat pulse preceding the particle pulse, which was reported in ASDEX-U.

- In long elmy H-modes there is an inconsistency between the detection of ELMs with the vertical D_α

measurements (outer strike region) and with the CCD camera, which shows most of the interaction at the inner strike zone. Probes measure ion fluxes in both strike regions. In the hot ion mode discharges the D_α pattern at the target is reversed, with most of the interaction at the outer strike region. Similar patterns have been observed for heat deposition in JT60 [7], for discharges where the recycling is high as opposed to discharges where the wall pumping is good. Their results are consistent with ours, as other measurements at JET show that during ELMs D_α emission and heat deposition occur in the same zone. This is consistent with a strong pressure imbalance between the two strike regions due to the transient nature of the ELM and the short timescale involved.

- The decay time of the I_{sat} pulse is consistent with the typical residence time of the ions entering the SOL. The longer times observed in the D_α decay are probably related to the fact that the vertical chord is far from the divertor target (0.7m) where the plasma wall interaction occurs, and recycling taking place further out than the position of the probes is contributing to the D_α emission. Other atomic physics processes (ionization of D_2 molecules) can also contribute.

- Although no probe measurement of T_e during ELMs exist, the indications are that very low temperatures are obtained in the divertor region during elmy H-modes: lower T_e are measured between ELMs in (low frequency) elmy H-modes than in quiescent H-modes; and ECE data [3] show that T_e decreases with the ELM frequency in the edge region within the separatrix.

8. IMPROVEMENTS FOR THE NEXT EXPERIMENTAL CAMPAIGN

The new JET divertor will have a more closed structure, a high pumping capability, and the divertor coils will allow different magnetic flux expansions in the divertor region for a given configuration. In addition, the diagnostics in the divertor region will be improved.

- A poloidal array of triple probes will be installed in the divertor target plates.

- A fast infrared linear array will be used to obtain poloidal power deposition profiles.

- Fast CCD cameras will be used to determine impurity fluxes with high time resolution.

9. REFERENCES

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