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Inboard and outboard Type I ELM dynamics in JET measured by ECE

L.Barrera[1], E. de la Luna[1], C. Pérez von Thun[2], E. Solano[1], D. Howell [3], L. Figini[4], M.N.A. Beurskens[4], M. Brix[4], P. Lomas[3], G. Saibene[5], F. Sartori[3], F. Castejon[1] and JET-EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK
1) Laboratorio Nacional de Fusión, Asociación EURATOM-CIEMAT, Madrid, Spain
2) Max-Planck-Institut für Plasmaphysik, EURATOM Association, 85748 Garching Germany
3) Istituto di Fisica de Plasma, CNR, EURATOM-ENEA-CNR Association, Milano, Italy
4) EURATOM-UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxon OX14 3DB, UK
5) FUSION FOR ENERGY Joint Undertaking, 08019 Barcelona, Spain.
** See the Appendix of F. Romanelli et al., Fusion Energy 2008 (Proc. 22nd Int. Conf. Geneva, 2008) IAEA, (2008)*

Introduction

Reliable physics-based extrapolation of the edge localized modes (ELM) heat loads to ITER requires a better understanding of the physics mechanisms that determine the dynamics of the collapse of the plasma pedestal. Fast electron cyclotron emission (ECE) radiometry allows a space resolved study of the dynamic behaviour of the ELMs. In the present work, we extend previous studies of the ELM dynamics carried out in JET [1] by including simultaneous ECE measurements in the outboard (low-field side or LFS) and the inboard (high-field side or HFS) midplane. This is possible in JET because the existing ECE heterodyne radiometer can be set up to measure simultaneously 1st harmonic/O-mode and 2nd harmonic/X-mode radiation [2]. Access to the plasma HFS is obtained by using O-mode polarization, which is not affected by harmonic overlap, while the X-mode polarization is used to measure the LFS temperature profile. This allows comparing, for the first time, the electron temperature (T_e) crash caused by type I ELMs in both the inboard and outboard midplanes in JET. Simultaneous LFS and HFS T_e pedestal measurements can be only achieved for a subset of the available magnetic fields values at JET. Most of our measurements have been collected in experiments with B_0=2.4T and 2.7T, and I_p from 1.7MA to 2.5MA (4.9 <q_{95} <3.3). For the study presented here we have built a database of discharges with dominant Neutral Beam heating (P_{NBI}~10-22MW) and reproducible type I ELMs, covering a wide range of pedestal plasma parameters ($T_{e,ped}$= 0.5-1.8 keV and $n_{e,ped}$= 2-8·10^{19} m^{-3}). The range of average triangularity in the database goes from 0.36 to 0.42.

HFS ECE temperature measurements in JET: spatial resolution and calibration.

One of the main difficulties to analyse this new set of data has been the calibration of 1st harmonic O-mode ECE channels. In JET, the standard calibration of the ECE radiometer data is provided by a Michelson interferometer measuring 2nd harmonic X mode ECE which is absolutely calibrated. This method is not longer feasible for the O-mode radiation emitted at frequencies resonating on the HFS pedestal region (harmonic overlapping) and several calibration methods were developed. A more detailed discussion on this analysis can be found on [2]. A fully relativistic emission code, SPECE [3], has been recently used to calibrate the O-mode radiometer channels using simulated O-mode emission spectra in the L-mode phase, when uncertainties in the equilibrium reconstruction are assumed to be smaller. The calibration region is restricted to T_e> 300eV (for sufficient optical thickness) and the core region affected by sawtooth activity is also avoided in the analysis. The estimated error in the calibration is ~10%.

The effective spatial resolution in the pedestal region has been determined by performing a convolution of a step profile with the instrumental function of the ECE channels resonant in the pedestal region. The ECE instrumental function, that includes the emission line width and the antenna pattern, has a spatial width (95% of the emission) of ~3 cm for the 2nd/X-mode channels in the LFS and and ~6 cm the 1st/O-mode channels in the HFS, for the plasma parameters considered here [2]. With the spatial convolution, the resulting ECE spatial resolution is typically ~1.5 cm in the LFS and ~2.5 cm in the HFS pedestal region. The slightly better resolution for the LFS channels is due to the higher optical thickness of the 2nd/X-mode ECE. Due to the larger flux expansion in the inboard region, the spatial resolution in normalized flux co-ordinates is comparable in both regions.

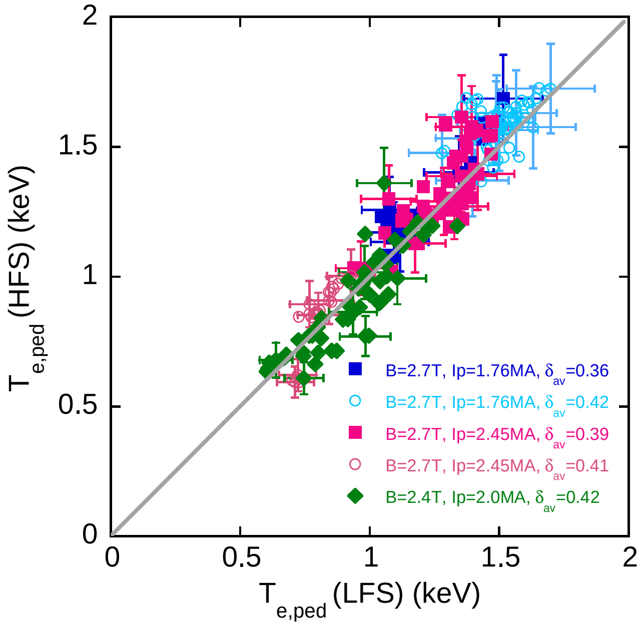

Fig 1. *Comparison of the LFS and HFS T_e pedestal top of all the pulses explained in the database analysed.*

Typically, good agreement is found between the pedestal top T_e values calculated from the HFS and LFS T_e profiles (see Fig. 1) for the different plasma scenarios used in this analysis. This is illustrated in more detail in Fig 2 where a comparison of the HFS and LFS ECE T_e profiles is shown together with the T_e profiles measured by the High Resolution Thomson scattering (HRTS) system in JET (1.5 cm spatial resolution). For this comparison, profiles are mapped to the midplane using the EFIT equilibrium reconstruction. A systematic radial shift is found between the position of the pedestal top calculated from the HFS and LFS that can be corrected applying a magnetic field correction factor (<0.8%). Interestingly this correction is also required to bring into alignment the ECE and HRTS T_e profiles. The origin of this error in the magnetic field is under investigation. It has been found that that the T_e for ρ>0.95 measured on the HFS are systematically higher that those obtained in the LFS (see Fig. 2) and the difference between both measurements increases with decreasing density. Close to the separatrix the plasma optical thickness is low and therefore the measured emission does not provide a reliable measurement of the local T_e. Because the optical thickness of the 2nd/X-mode is almost twice that of the 1st/O-mode in the

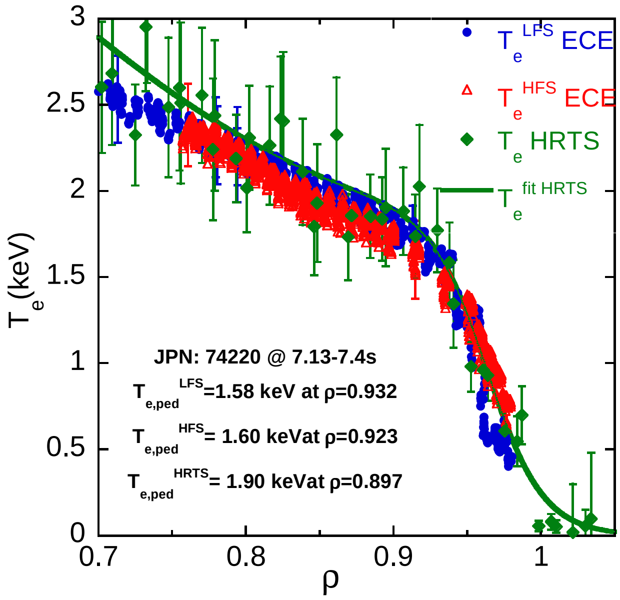

Fig 2. *T_e profiles measured with the ECE radiometer and the HRTS mapped onto flux coordinates and applying a magnetic field correction of 0.6%. Tanh fit for HRTS data is also shown.*

pedestal region, this effect has a stronger impact on the HFS T_e profiles. Estimation of the optical depth at typical radial location of the HFS pedestal gradient with $T_e \sim 0.5$ keV predicts that the density must be $n_e > 4.5 \cdot 10^{19}$ m^{-3} for the plasma to be optically thick ($\tau > 2$). Although mapping errors can not be completely ruled out in this analysis, the fact that the same trend with density is observed for different magnetic configuration supports strongly the argument.

ELM triggering and dynamics

The analysis of the HFS and LFS ECE data has been focussed on the study of the radial extent and structure of the ELM crash. By avoiding high density pulses, that can be affected by refraction, and excluding channels for $\rho > 0.95$, we get a reasonable agreement on both pedestal regions, allowing us to compare the behaviour of the ELM crash in both plasma sides, with the benefit of the high spatial and temporal resolution of the ECE measurements. The analysis of the fast ECE data (~250 kHz bandwidth) has shown no delay between the pedestal temperature drop caused by the ELM crash in both HFS and LFS pedestal channels. This is not unexpected due to the fast time scales (~1 µs) involved in the energy transport along the field lines. To calculate the volume of the plasma affected by the ELM we calculate the T_e profiles before an ELM and immediately after it (typically ~300 µs after the ELM crash) for 2 or 3 consecutives ELMs. Figure 3 shows the result of this analysis for both the HFS and LFS profiles for two pulses with different collisionality. In line with results obtained in previous analysis [1] (where only the LFS ECE data was available), the size of the T_e drop after the ELM crash decreases with increasing pedestal collisionality, and the area affected by the ELM collapse is weakly dependant of the pedestal density. The maximum T_e drop is slightly larger in the LFS but the size of the area affected by the crash on flux coordinates is very similar on both pedestal regions. We have found a correlation between the size of the ELM and the difference between the T_e drop caused by the ELM in the HFS and the LFS region. For bigger ELMs ($\Delta W_{ELM} > 0.25$ MJ, $\Delta Te > 500$eV), this discrepancy can not be explained without taking into account fast changes in the equilibrium and local changes on the magnetic field. More detailed analysis using equilibrium reconstruction with faster temporal resolution will be carried out in future work.

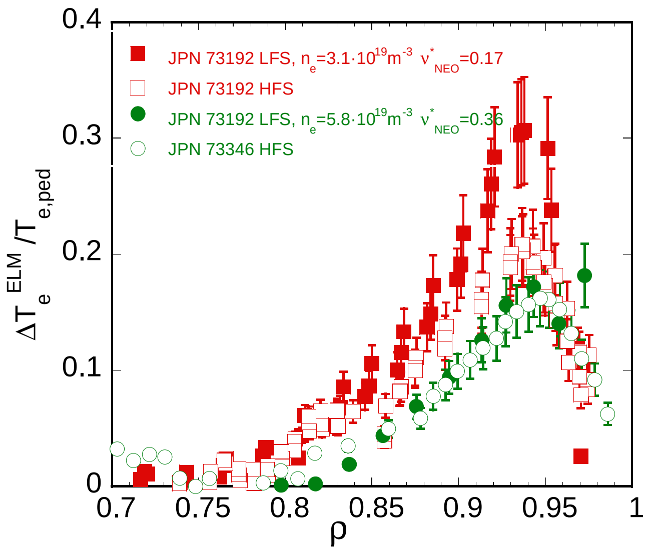

Fig 3. *ELM affected area calculated from the HFS and LFS T_e profiles measured by ECE for two pulses with different collisionality:*
red) $n_e = 3.1 \cdot 10^{19} m^{-3}$ and $\nu^*_{NEO} = 0.17$;
green) $n_e = 5.8 \cdot 10^{19} m^{-3}$ and $\nu^*_{NEO} = 0.36$.

MHD activity

Using the HFS and LFS fast ECE signals (~250 kHz bandwidth) it is possible to further study the poloidal variation of some of the MHD modes observed in Type I-ELMy H-mode plasmas in JET. Figure 4 shows the temporal evolution of the spectrogram for two ECE channels resonating close to the temperature pedestal top together with the D_α signal. A long-lived (from 14 to 15.4 sec) coherent oscillation at 6 kHz (and its harmonics), with n=1 for the fundamental frequency, is clearly observed in both the HFS and LFS channels resonant in the pedestal region (with ρ>0.95). Only the first harmonic is observed in the HFS channels due to their lower S/N. This is the so called 'Outer Mode' observed sometimes in Hot-ion mode plasmas [4]. Due to the higher magnetic field gradient in the HFS region, the separation between the radiometer channels is smaller and, as a consequence, the coherent oscillation can be seen in at least 5 channels while the oscillation is only seen in two of the LFS channels. Therefore it has been possible to establish the non tearing character of the mode, as the oscillations on the HFS show no radial phase inversion. Interestingly, later in the pulse, short lived type I-ELM bursty precursors with a high n-number (n>10) and frequency 10-12kHz can also be seen prior to some ELMs in both the LFS and HFS. Unfortunately, in this case, the mode in the HFS is observed in channels resonating in a much wider region (ρ < 0.6) than that observed in the LFS (ρ <0.92). It is important to notice that in this pulse the plasma density changes abruptly after the first ELM from $n_e=5\cdot10^{19}$ m^{-3} to $7\cdot10^{19}$ m^{-3} which is much closer to the cut-off density (80% of the $n_{e,cut-off}$) at the resonant location and therefore the emission can be strongly affected by the refraction. Ray tracing calculation remains to be done to investigate the origin of this discrepancy.

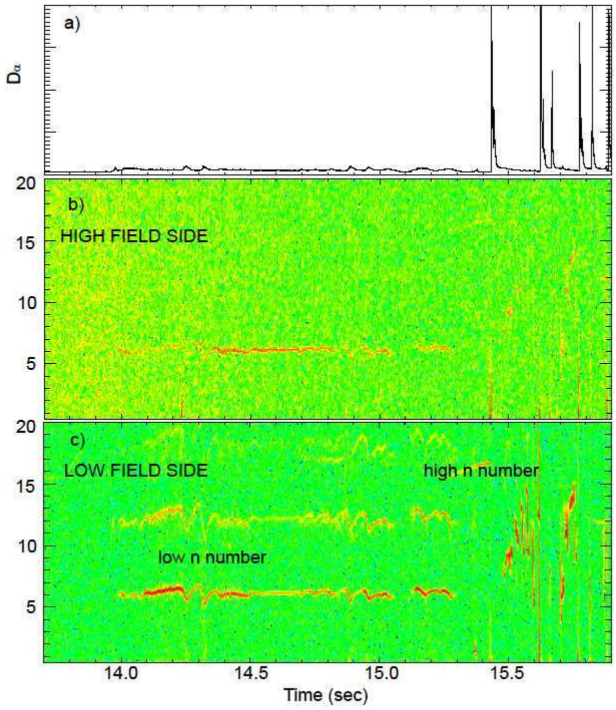

Fig 4. *a) D_α signal and spectrogram of a HFS (b) and LFS (c) ECE channels located in the pedestal top. Both signals have a similar power spectra peaked at 6 kHz in the time interval where the Outer Mode is present [4]. Both spectra show also a mode at 10-12 kHz (ELM precursor, high n) before the 2nd ELM.*

Conclusions

The inboard/outboard pedestal temperature profiles on JET have been measured in a variety of plasma conditions using the ECE radiometer. In low density plasmas, where refraction effects can be excluded ($n_e<7\cdot10^{19}$ m^{-3} for B=2.7 T), a good agreement has been found between the pedestal T_e profile measured at ρ<0.95 in the inboard and outboard plasma region. The possibility of having simultaneous LFS/HFS T_e measurements allows comparing the ELM affected area caused by the ELM crash. In the different plasma conditions studied here, the volume affected by the ELM crash in flux coordinates is similar on both pedestal regions, although the maximum T_e crash is systematically higher in the LFS region (the discrepancy increases with ELM size). The analysis of the fast ECE signals also allows the comparison of MHD activity in the different poloidal regions. The investigation of the type I ELM precursors is ongoing. The analysis of ELM precursor in more favourable plasma conditions (higher magnetic field and/or lower density) remains to be carried out before making any definitive conclusion about the ballooning character of the ELM precursor modes.

References

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