27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 12-16 June 2000 ECA Vol. **24B** *(2000) 1264 -1267*

Density and Temperature Measurements in Detached Recombining JET Divertors

A.G. Meigs[1], W. Fundamenski[1], C. Jupen[2], A. Larsen[3], S. Loch[4], M. O'Mullane[4] and H. Summers[4]

[1] UKAEA/Euratom Fusion Association, Culham Science Centre, Abingdon, Oxon. OX14 3DB UK ;
[2] Lund University, Lund, Sweden; [3] Niels Bohr Institute, University of Copenhagen, Denmark;
[4] University of Strathclyde, Glasgow, UK
(Work done partly in the framework of the JET Joint Undertaking)

1.Introduction

Diagnosis of detaching, high-density divertor plasmas is crucial to understanding them. Traditionally, Langmuir probes are used to measure the electron temperature and density at the target plates near the strike point, but the electron temperature (and thereby also the density) becomes unmeasureable below a few eV. An alternative diagnostic method applicable to these conditions has been applied on JET which involves measuring the high-n lines of hydrogen to determine the electron density. Simultaneously, measurements of the continuum near the series limit have been made where photo-recombination effects that are temperature and density dependent can be used to infer the temperature. Photo-recombination continuum modelling codes[1] have been constructed at JET using the results of Pigarov[2]. Measurements have been made in a variety of high density, detaching plasmas for two divertor geometries of increasing closure (Mark II **AP** and **GasBox**). L-mode results with inner divertor fuelling will be presented. The line-averaged electron densities and temperatures in these detached Gasbox divertor plasmas are similar to those in the AP divertor at around 1-3x10^{20} m^{-3} and about 1 eV. However, the behaviour in the approach to detachment can be much different for the more closed Gasbox divertor. In addition, simultaneous measurements of the spectra near the Balmer and the Paschen series limits have been made. Electron densities and temperatures from observations of the spatially resolved Stark/Continuum emission are compared to the results of the Advanced Onion Skin Model[3].

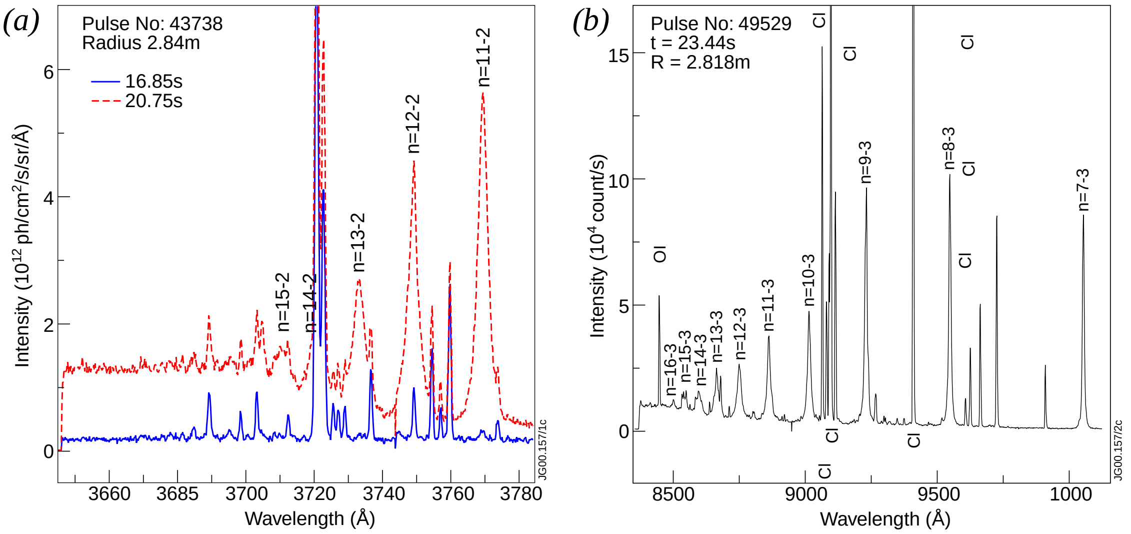

Fig.1(a) and (b): Sample Balmer and Paschen spectra in detaching divertor plasmas

Figure 1(a) shows a representative spectrum near the Balmer series limit prior to detachment and during detachment. Figure 1(b) shows the Paschen spectrum near the series limit for a detaching divertor plasma. The Paschen spectrum is not absolutely calibrated in the figure. The diagnostic used consists of 2 spectrometers viewing the divertor via a mirror link from above. The lines of sight are around 13 mm in radial width and 150 mm of the outer divertor (around 80% in Mark II Gasbox) can be imaged. See references [1,4] for a better description.

2. Method

Electron density and temperature can be inferred from various features of the Balmer and Paschen spectrum. Stark broadening of the high-n transition lines give the electron density weighted by the emissivity along the line of sight. The electron temperature can be inferred from one of three methods: the photo-recombination continuum, the ratio of intensities of the high-n hydrogen lines, or from the ratio of the intensity of the high-n hydrogen lines to the continuum away from the series limit. The first two methods have been used.

For the electron density profiles from the Stark broadening the spectrum is fit using Voigt profiles to the Stark broadened lines with the Gaussian component fixed to the instrumental width. It is assumed that the Lorentzian FWHM of the Voigt profile is same as the Quasi-Static Stark Effect profile width to derive n_e. Also, the fit includes only the transitions up to 13-2 and 10-3 respectively to avoid the photo-recombination baseline. Initial analysis of density profiles from the same pulse for the Balmer 11-2 line and the Paschen 8-3 and 7-3 lines shows reasonable agreement between the 8-3 and the 11-2, but the 7-3 deviates.

For photo-recombination continuum modelling, a single shell for the emission has been assumed. Also, the model is fixed to the experimental data at the long wavelength end (to ~3815Å) 'calibrate' the model. As the model is sensitive to Z_{eff} and the neutral density both of these values are fixed to reasonable plasma values in order to get initial estimates (Z_{eff} ~2.5 and n_n/n_e ~ 0.01). Although there is not room in this paper to present the results graphically, they do yield electron temperatures in the range of 1 eV or lower during detachment.

The other method used to estimate the electron temperature is the Balmer emissivity ratio of the 11-2 to the 10-2 transition. The emissivity as a function of n_e and T_e is taken from ADAS[5] for recombination only. The n_e dependence is negligible over the range T_e 0.2-5.0eV and ne (0.3- 5)x10^{20} m^{-3}. The ratio is insensitive outside of 0.5 to 1.5 eV, but is a clear indicator for T_e going through 1eV.

3. Divertor Closure's effect on the Density Profile Behaviour (Mark II AP and Gasbox)

Four L-modes discharges are considered with nominally I_p=2MA, B_T=2.4T, P_{NBI}=1.9MW and inner divertor fuelling. Figure 2 shows the global behaviour of the pulses. The central line-averaged densities are nearly the same at the time of disruption. The Gasbox requires much more fuelling to detach in the outer divertor than the AP divertor. This may just a measure of how the septum separates the inboard divertor chamber from the outboard. Figure 3 shows the electron density (from 11-2) and temperature (ratio of 11-2/10-2) profiles for the pulses. From this figure the following observations can be made: Outer divertor electron density detachment occurs on a slower time scale in the Gasbox than the AP divertor. The Gasbox pulses show three distinct behaviours in the electron density profile: 'quick' (44816), 'slow' (47486) and 'reluctant' (49529) to detach. And finally, electron temperatures from line ratios are around 1eV with the coldest spots around the vertical plate moving inwards for the 'quick' detachment case (44816). However,

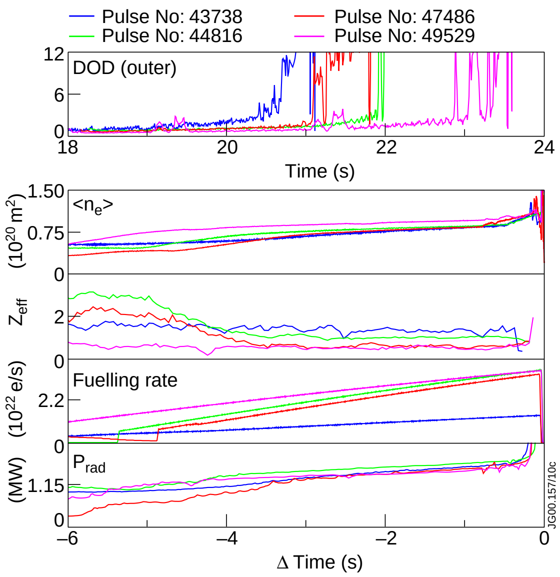

Figure 2. Global behaviour of the 4 pulses. 43738 is AP-geometry and the rest are Gasbox. Note absolute time shown in the top figure and the rest show time relative to disruption. DOD is the degree of detachment traditionally determined via the two point model for the ion saturation current normalized prior to detachment (DOD = $C_{attached}$ $<n_e>^2/I_{sat}$).

hotspots above 1.5eV are seen which may actually indicate regions where excitation is strong (shown as white regions) or bad statistics. The low spots (< 0.5 eV) should possibly be de-emphasized due to sensitivity of the line ratio.

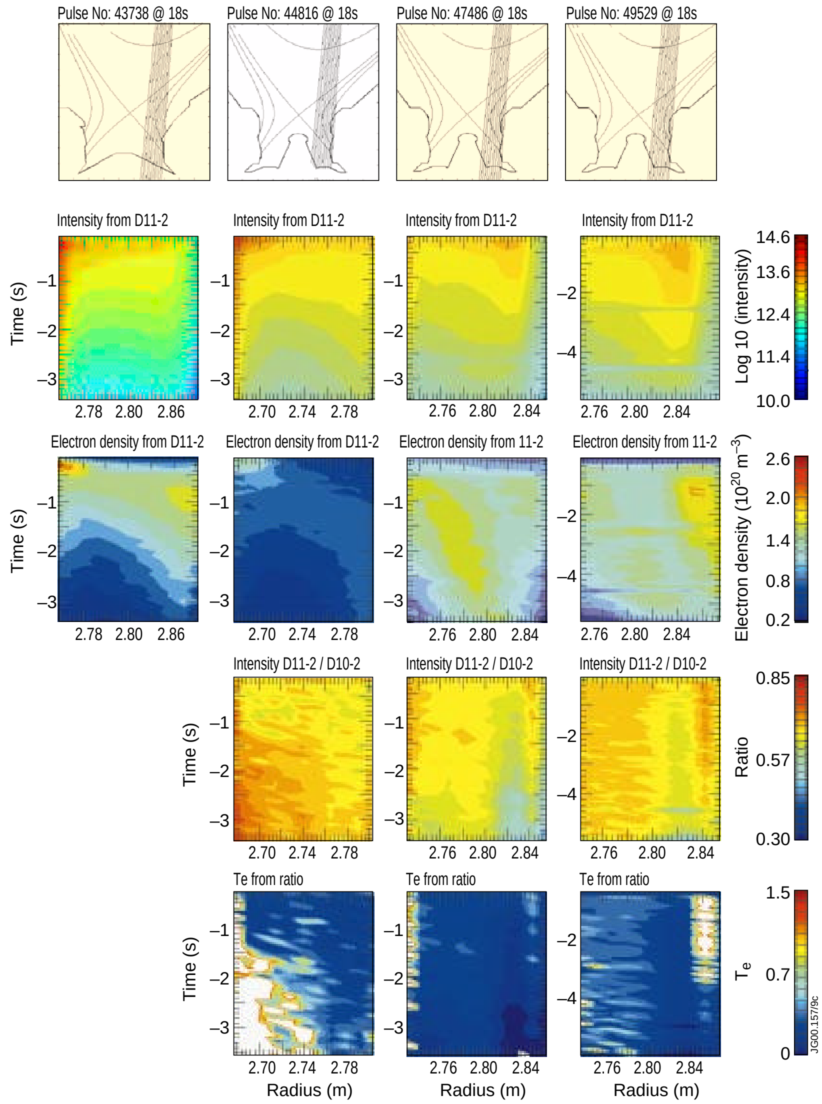

Figure 3. $D_{11\text{-}2}$ profiles with pulse geometry shown in the first row followed by intensity of the line, electron density from Stark broadening, the intensity ratio of $D_{11\text{-}2}$ to $D_{10\text{-}2}$ and finally the electron temperature derived from the ratio. The AP pulse (43738) does not have T_e from the ratio as the 10-2 line was not in the spectral range.

4. Divertor Onion Skin Model Results for an L-mode Density Limit (Pulse 47486) with comparison to Inferred Electron Density and Temperature

OSM2/NIMBUS reconstructs the 2-D plasma distribution based on target Langmuir probe n_e and T_e measurements, D_α, and plasma conservation equations. Three times are modelled (t=19,20,21 s) corresponding to gradual outer target detachment (DOD rises from 1 to 2). Figure 4(a) shows the global behaviour for the pulse including inner and outer divertor parameters. The input to the onion skin model are: Target Langmuir probe profiles (I_{sat}, T_e). In the absence of information on T_e or I_{sat} in the private flux region, a sharp radial decay is assumed; and D_α profile is taken from the line-of-sight view of the divertor. probe Te's is adjusted (lowered) to match the outer peakin D_α. The output from the model is a 2-D solution of plasma (n_e,T_e,T_i,....), neutrals, and line emission.

Figure 4(b) shows the contours shown in the vicinity of the outer strike point. The model shows some signatures of detachment: The ionization front moves away from the target (D_α peak) and the total pressure (static + kinetic) ratio upstream rises; however, a strong recombination front is seen in the simulation only when T_e(target) < 0.3eV [6] which may support the low temperatures seen in the line ration measurements (see Fig.3). In comparing the onion skin model with the vertical line-of-sight n_e from D_{11-2} (Fig.3 third column), the following observations can be made: $n_{e,OSM}$ peak appears closer to target than<n_e,$_{D11-2}$> and the $n_{e,OSM}$ peak is stationary, although the D_α peak moves away from the target. Further work in the recombination dominated regime (lowering T_e to below 0.3eV) is expected to better reproduce the experimentally seen behaviour; this work will be pursued in the near future. So far the following conclusions on the simulation can be made: Recombination appears to be necessary to explain the movement of the front away from the target; 'sub-eV' target temperatures are required for onset of recombination dominated detachment.

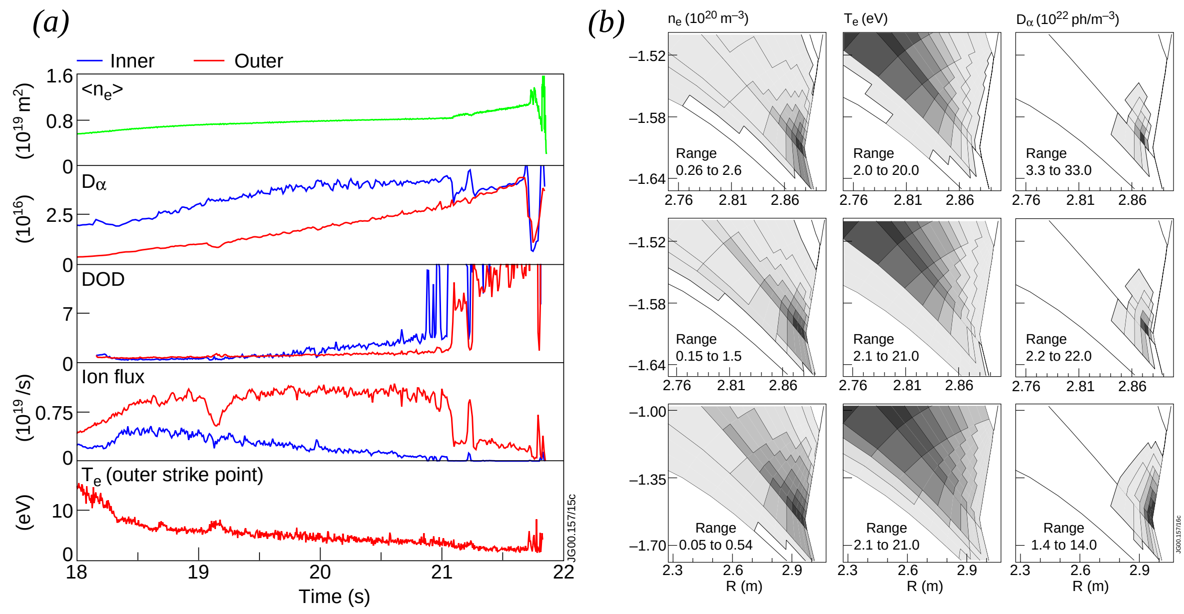

Figure 4(a) The behaviour of 47486 for both inner and outer divertor. Figure 4(b) Output from the onion skin model for n_e, T_e and D_α. Time increases going upwards from 19, 20, and 21 s.

Further Work

Work is necessary to: refine the fitting program to the include continuum model(s) as part of the least squares fit, include simple model(s) for line-of-sight integrals to obtain more local estimates of density and temperature, and finally, continue work in comparing the experimental results to divertor plasma models.

Acknowledgements

This work was supported by EURATOM and the UK Department of Trade and Industry.

References

[1] A. Larsen, Master's Thesis, Niels Bohr Institute, University of Copenhagen, 2000.
[2] A.Y Pigarov, J.L Terry, B.Lipschultz,, MIT report PFC/JA-97-26, 1999
[3] W. Fundamenski, U. Toronto, Ph.D. Thesis, 1999 and Plasma Surface Interactions-14, 2000
[4] A.G. Meigs et al, Proceedings of 1998 ICPP & 25th EPS CCFPP, Prague Czech Republic
[5] H. Summers et al, JET Report IR(94) 06, JET Joint Undertaking
[6] W. Fundamenski, Plasma Surface Interactions-13, 1998