

---

EFDA–JET–CP(01)02-54

J.Gafert, W.Fundamenski, M.Stamp, J.D.Strachan  
and JET EFDA Contributors

# Distribution of Carbon Impurity Sources Between Low and High Field Side Measured via Zeeman-Spectroscopy in JET



# Distribution of Carbon Impurity Sources Between Low and High Field Side Measured via Zeeman-Spectroscopy in JET

J.Gafert<sup>1</sup>, W.Fundamenski<sup>2</sup>, M.Stamp<sup>2</sup>, J.D.Strachan<sup>3</sup>  
and JET EFDA Contributors\*

<sup>1</sup>*Max-Planck-Institut für Plasmaphysik, IPP-EURATOM Assoziation,  
Boltzmann-Straße 2, D-85748 Garching, Germany;*

<sup>2</sup>*Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxon OX14 3DB, UK;*

<sup>3</sup>*Plasma Physics Laboratory, Princeton University, Princeton, NJ08543, USA*

*\*See appendix of the paper by J.Pamela "Overview of recent JET results",  
Proceedings of the IAEA conference on Fusion Energy, Sorrento 2000*

Preprint of Paper to be submitted for publication in Proceedings of the  
EPS Conference,  
(Madeira, Portugal 18-22 June 2001)

“This document is intended for publication in the open literature. It is made available on the understanding that it may not be further circulated and extracts or references may not be published prior to publication of the original when applicable, or without the consent of the Publications Officer, EFDA, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK.”

“Enquiries about Copyright and reproduction should be addressed to the Publications Officer, EFDA, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK.”

## INTRODUCTION

One important topic in fusion research is to identify, how the sources of impurities are distributed between divertor and main chamber, and here, between low and high field side. This distribution of impurity sources determines, together with flows in the Scrape Off Layer (SOL) [1], the spatial distribution of edge impurity radiation and global material transport as well as erosion and deposition patterns. In this paper, we show that Zeeman Spectroscopy yields valuable information on the relative strength of impurity (e.g. carbon) radiation in the inner and outer SOL; the focus here is onto the applicability and reliability of this technique. Conclusions about the corresponding sources, which can be drawn together with other results, will be discussed separately in a future paper.

As the Zeeman pattern of a spectral line is determined by the local magnetic field vector, it is possible to identify the location of emission from a highly resolved spectrum [2]. At JET, an optical line of sight near the midplane is used that views the plasma radially from the outside of the vessel. Therefore, the local Zeeman patterns from both, outer and inner SOL, contribute to the recorded spectrum. The parameters of interest are the CIII-contributions from the inner and outer SOL. They are extracted from the experimental data by a numerical fit according to:

$$\text{Function} = \text{Offset} + \text{Amplitude}_{\text{out}} \times \text{SLS}_{\text{out}} \times \text{Amplitude}_{\text{in}} \times \text{SLS}_{\text{in}}^{\rightarrow} \quad (1)$$

$\text{SLS}_{\text{out,in}}$  denote the Spectral Line Shapes determined by the local parameters ( $\vec{B}_{\text{out,in}} \rightarrow$  Zeeman patterns; ion temperatures) and the instrumental function of the spectrometer. Fig. 1 shows a calculation of the SLS for one location, using typical values of  $\vec{B}$  and the instrumental function of the KS3B high resolution spectrometer at JET.

In Fig. 2, the effect of two CIII-emissions, originating from locations with different  $\vec{B}$ , on the resulting spectrum is demonstrated. While for (2a), the contributions from low and high field were assumed to be equal, in (2b) the relative amount of the low field component was varied from 0.2 to 5.0. These differences in line shape (Fig. 2b) are the basis for the determination of the CIII-distribution between inner and outer SOL from experimental spectra.

## 1. SIGNIFICANCE OF RESULTS FOR IN-/OUT-DISTRIBUTION

On the one hand the significance of the results is determined by the accuracy of the numerical fit. The related statistical errors depend mainly on the signal to noise ratio and range between  $\approx 1\%$  and  $3\%$  for typical discharges and settings of KS3B. In order to keep the scatter of the fit results low, the number of free parameters of the fit has to be reduced as far as possible. This is achieved by fixing parameters like the local magnetic fields and the ratio of the two local ion temperatures instead of extracting them from the fit. Assuming the CIII-emission to be located about 1cm outside the separatrix, the local B-fields are taken from the magnetic equilibrium data (EFIT) and used as input data. The corresponding maximum systematic error of the CIII-distribution from one side of the SOL turns out to be about  $1\%$  for the JET data, resulting mainly from inaccuracies of the separatrix position and from EFIT.

The reason for not fitting two temperatures, but only one, with the T-ratio (for inner and outer SOL)  $T_{\text{in}}/T_{\text{out}}$  being fixed, is twofold: First, an additional temperature, and thereby a further width parameter, increases the scatter of the results considerably, especially for the cases, where one component is rather weak. Second, this does not even yield more information, because several direct comparisons of one- and two temperature fitting clearly demonstrated that the quality of fit, characterized e.g. by  $\chi^2$ , remained unchanged.

In order to investigate the influence of a possible deviation of the chosen —probable—value for the T-ratio from the true one, a detailed analysis has been performed to estimate the effect on the percental CIII-contribution from one side of the SOL: It turned out that the uncertainty of the determined percentage is highest in cases of comparable contributions from both sides of the SOL, i.e. for values in the range of  $\approx (20 - 80)\%$ . However, even for a very high assumed deviation of the T-ratio of  $\approx \pm 50\%$ , the uncertainty of the CIII-percentage from one side of the SOL still lies below  $\pm 4\%$ . For a more realistic assumption ( $T_{\text{in}}/T_{\text{out}} \leq \pm 20\%$ ), the systematic error decreases to  $\approx (1 - 2)\%$ . For strong domination of one side of the SOL, the result for the CIII-contribution does, according to the expectation, not depend on the input T-ratio any longer. Considering all kinds of possible errors, the maximum overall uncertainty of the percental CIII-contribution from one side of the SOL is below 4%. This is true for the absolute value; relative changes are, of course, substantially more accurate.

## 2. SELECTED RESULTS: APPLICABILITY AND IMPORTANCE OF ZEEMAN ANALYSIS

The CIII-results shown in Fig.3 refer to a discharge with various gas puffs ( $\text{CD}_4$ ,  $\text{D}_2$ ) from valves (GIMs) at different locations (details in caption). The data for the  $\text{CD}_4$ -puff from GIM 4, a valve located in the same octant as the line of sight used, clearly support the applicability of the Zeeman analysis: As expected for this local gas puff in the outer midplane, the CIII-contribution from the outer SOL increases instantaneously and dramatically, with no impact onto the inner SOL. Similar support comes from the  $\text{CD}_4$ -puff from the toroidally symmetric divertor valves (GIM 10) into the outer SOL: While  $\text{CIII}_{\text{out}}$  increases significantly,  $\text{CIII}_{\text{in}}$  remains unaffected. The  $\text{D}_2$ -puff from GIM5 exemplifies the technique's capability of detecting CIII-changes in both, high and low B-fields:  $\text{D}_2$  from GIM5 obviously causes no increase of CIII in the outer, but only in the inner SOL.

Finally, the CIII-data (Fig. 3b, c) for the  $\text{CD}_4$ -puff from GIM6 represent the convincing argument that Zeeman analysis provides additional valuable information on the spatial distribution of radiation: The opposite changes of  $\text{CIII}_{\text{in}}$  and  $\text{CIII}_{\text{out}}$  that cancel in a pure chord integrated CIII-signal ( $\propto [\text{CIII}_{\text{in}} + \text{CIII}_{\text{out}}]$ ) would not be resolvable without Zeeman analysis.

## 3. FURTHER RESULTS: DEPENDENCE ON $\text{CD}_4$ -PUFF LOCATION IN THE DIVERTOR

In a campaign to investigate the effect of the septum in the JET-divertor,  $\text{CD}_4$  and  $\text{D}_2$  were puffed toroidally symmetrically from the various divertor valves. The results for  $\text{CD}_4$ -puffs into the outer

and inner Private Flux Region (PFR) for two comparable L- and H-Mode discharges are shown in Fig.4. For the puffs into the outer PFR, the behavior of CIII in the midplane SOL is similar for L- and H-Mode: While  $CIII_{in}$  remains essentially unchanged,  $CIII_{out}$  increases by about a factor of 2. This means that a considerable amount of neutral or ionized  $CD_4$  can cross the separatrix from the PFR to the outer SOL. When puffing  $CD_4$  into the inner PFR,  $CIII_{out}$  does, similar to  $CIII_{in}$  for the outer puff, not change by a reliable amount. For  $CIII_{in}$ , however, there is a pronounced difference between the L- and H-Mode discharge: In H-Mode,  $CIII_{in}$  in the midplane increases as expected due to the puff and, therefore, leads to a total CIII-intensity that evolves like the density. In L-Mode, in contrast, significantly less CIII is measured in the SOL, although the density is at the same level as for the outer puff. This leads to the conclusion that the properties of the SOL in the divertor region can have a significant impact on carbon production in the midplane.

The results presented here demonstrate that Zeeman spectroscopy provides additional valuable information on the distribution of impurity radiation between inner and outer SOL in the main chamber. In that sense, the CIII- and CII-Zeeman-data obtained for recent campaigns (e.g. septum assessment) represent an essential contribution to the respective data bases that will be used, in the near future, to acquire a better understanding of impurity sources and transport in the SOL of JET.

## REFERENCES

- [1]. Erents, K. et al., Plasma Phys. Control. Fusion, **42**, 905 – 915 (2000).
- [2]. Pugno, R. et al., J. Nucl. Mater., **290–293**, 308 – 311 (2001).

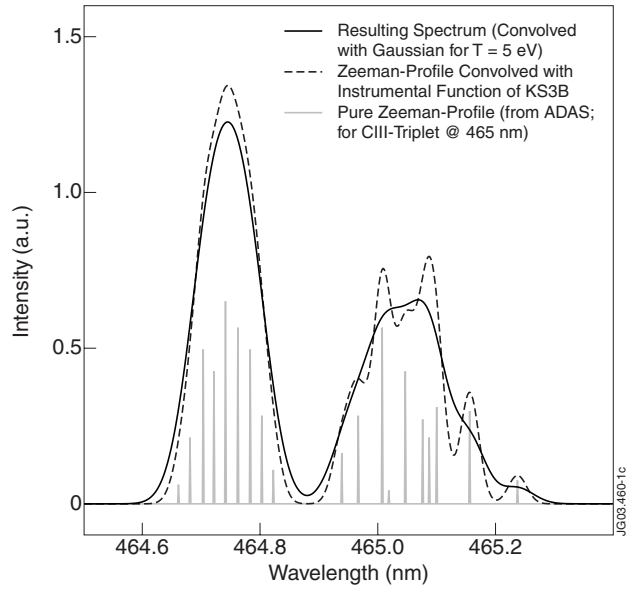


Figure 1: Calculation of Spectral Line Shape for one location:  $B = 4.0T$  (data from ADAS-database), observation angle =  $90^\circ$ , slit =  $50\mu\text{m}$  (KS3B at JET),  $T_{\text{ion}} = 5eV$ .

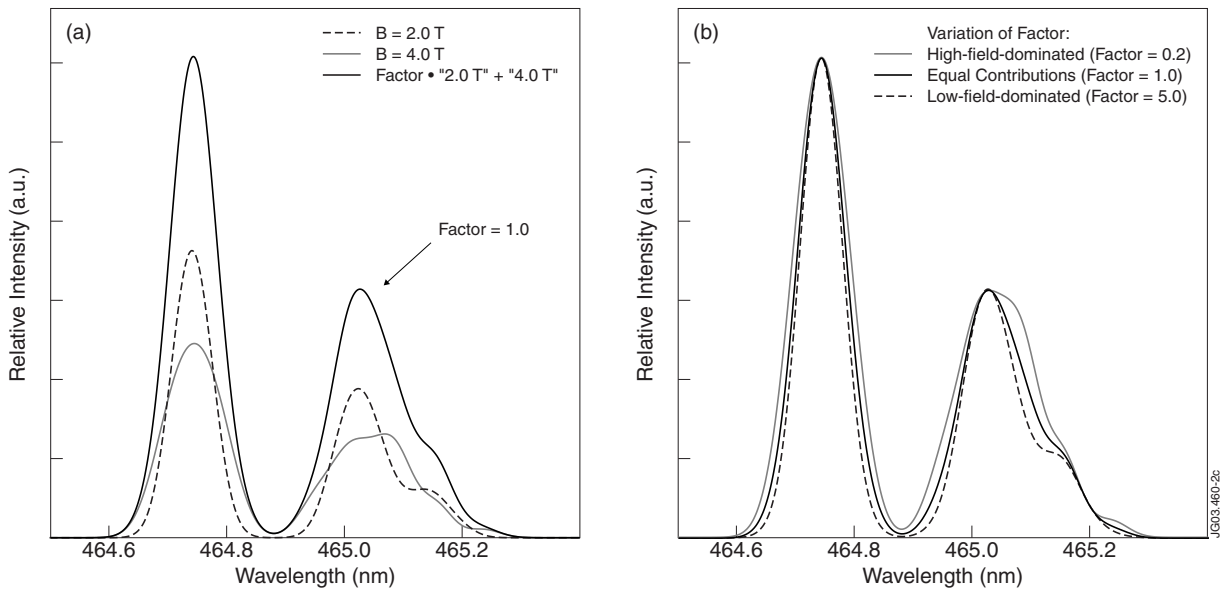


Figure 2: (a) Spectral Line Shapes for  $B = 2.0T$  (dotted grey line) and  $B = 4.0T$  (thin dark grey line) and resulting spectrum for equal contributions (factor = 1.0, thick black line) (b) Resulting spectra for varying contributions (factor = 0.2, 1.0, 5.0) from low field ( $B = 2.0T$ ); normalized to maximum of each spectrum ( $T = 5eV$  and KS3B-values for (a) and (b)).



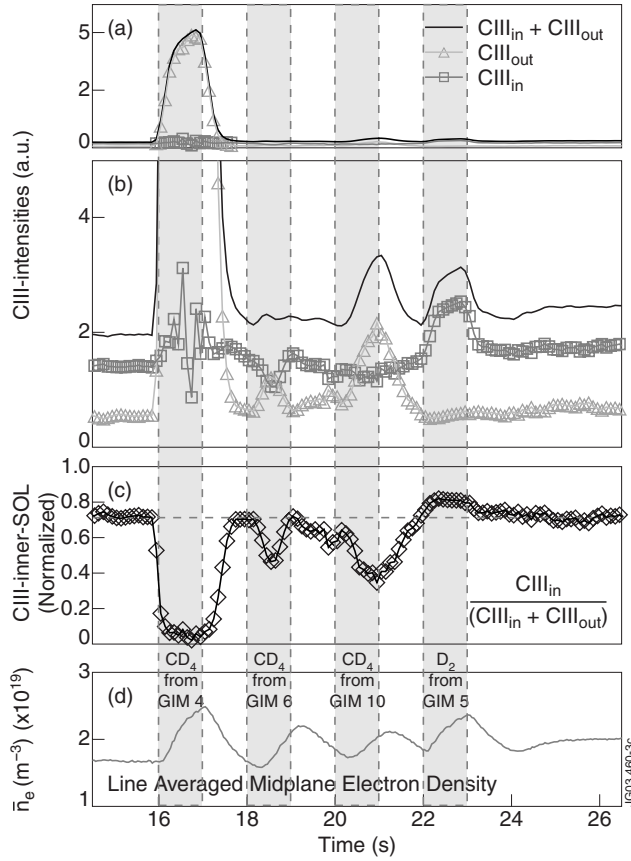


Figure 3: CIII-emission in midplane SOL for L-Mode-Pulse (No: 52393) with 1-sec-gas-puffs ( $CD_4$ ,  $D_2$ ; grey bands) from GIM4 (outer midplane, close to line of sight), GIM6 (top of vessel), GIM10 (outer divertor; toroidally symmetric), GIM5 (top of vessel). Response times of the signals are different due to valve time constants. (a, b) CIII-contributions from Zeeman analysis; note the change of scale from (a) to (b); (c) normalized CIII-contribution from inner SOL (dashed line: average with-out puffs); (d) line averaged midplane electron density. CIII in the outer SOL clearly dominates during the GIM-4- $CD_4$ -puff. The GIM-6- $CD_4$ -puff demonstrates the importance of Zeeman analysis: The changes of  $CIII_{in}$  and  $CIII_{out}$  cancel in the line-integrated CIII-signal.

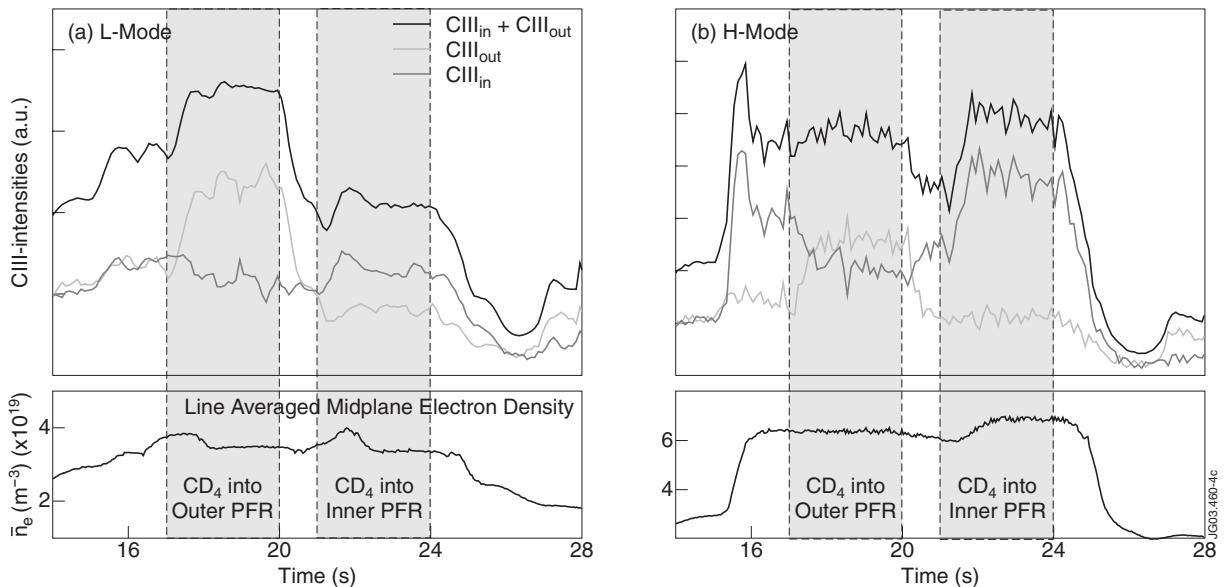


Figure 4:  $CD_4$ -puffs into outer and inner Private Flux Region (PFR) for closed divertor (strike points in corners). (a) L-Mode (Pulse No: 53068), (b) H-Mode (Pulse No: 53069); different CIII-scales for L- and H-Mode.