Interpretive Modeling of DIII–D Edge Measurements Using the OEDGE Code

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1. INTRODUCTION

Interpretive code simulations play an essential role in divertor/edge physics, firstly, because the edge is intrinsically complicated: at least 3 states of matter are involved; the shape of the region is problematical: long, narrow, twisted, inaccessible; edge modeling must be at least 2D; etc. Meaningful interpretive exercises therefore require that a data set of edge measurements, which is as large as possible, be confronted simultaneously using a code. Secondly, the significance of many edge data is not directly evident and they can only contribute to a picture of the edge using an interpretive code. Thirdly, edge data sets are invariably incomplete but extrapolation is not usually adequate because variations along **B** are often non-linear. All this tends to place interpretive codes at the center of edge studies with the various lines of diagnostic information feeding into the hub as well as our ideas about what the controlling physics effects might be.

To help identify the controlling processes in the edge, an iteratively coupled code, OEDGE, is being developed and benchmarked against well-diagnosed, simple plasmas. OEDGE ('Onion-Skin Modeling + EIRENE + DIVIMP for edge analysis'). EIRENE is a neutral hydrogen Monte Carlo code developed by D Reiter, KFA Jülich [1]. DIVIMP is an impurity neutral and ion Monte Carlo code [2]. The Monte Carlo codes require a "plasma background" into which to launch particles. The Onion-Skin Modeling, OSM, code [3,4] can provide such a background by solving the 1D, along-**B**, plasma (fluid) conservation equations using across-**B** boundary conditions from experiment, e.g. I_{sat}^{+} and T_e across divertor targets from Langmuir probes [5], to produce a 2D solution for the edge plasma (toroidal symmetry assumed). The neutral hydrogen-related and impurity-related terms in the OSM's conservation equations can be provided by the Monte Carlo codes. $D_{SOL}^{\perp}$ and $\chi_{SOL}^{\perp}$ are not required as input in OSM, but instead can be extracted from OSM analysis.

Sometimes only a limited set of edge data is available, or confronted, which raises the question of what constitutes a successful exercise in interpretation of edge data. There are numerous "knobs", i.e. adjustable parameters, in edge codes. The code can therefore be under-constrained and it is not clear what a successful match of code and experiments signifies. It is necessary to confront simultaneously an entire set of complete-as-possible edge diagnostic data to make true progress in interpretive modeling, i.e. to identify the controlling processes in the edge.

2. WELL-DIAGNOSED, SIMPLE-AS-POSSIBLE-PLASMA, DIII–D DISCHARGES

The edge diagnostic set on DIII–D is perhaps the most complete of any magnetic confinement device, uniquely including a Divertor Thomson Scattering, DTS, diagnostic [6] which, with magnetic sweeping of the divertor X–point, provides 2D measurements of n_e and T_e throughout the divertor. In February 2001 a set of "Simple-as-Possible-Plasma," SAPP, (L–mode, attached), comprehensively-diagnosed discharges was run on DIII–D. First OEDGE results for these SAPP discharges are presented, specifically for the lowest density SAPP shots, $n_e = 2.5\times10^{19}\ m^{-3}$, where the plasma was attached at both inner and outer targets, making for a particularly simple edge. In total 11 identical shots were run to maximize data collection. The objective is to establish if the controlling physics processes have been included in the model, starting with the simplest case possible.

In addition to DTS, the edge diagnostics used included: (a) a tangential-view camera system, including vuv (CIV), provided intensity-calibrated 2D pictures of the divertor plasma in hydrogenic and impurity light; (b) an Infra Red TV (IRTV) system measured the heat flux to the targets; (c) power bolometry measured the complete poloidal distribution of volumetric power loss; (d) intensity-calibrated filterscope and Multi-chord Divertor Spectrometry (MDS) systems provided line-of-sight measurements of the intensities of hydrogenic and impurity line emissions in the divertor and the main chamber; (e) the DiMES (Divertor Material Evaluation Studies) material sample manipulator was used to expose a Li sample for 4 of the 11 shots; 5 different spectroscopic systems viewed the sample and LiI, II, III, IV line emissions were recorded; (f) an extensive target Langmuir probe system provided measurements of I_{sat}^{+} and T_e across the targets; (g) edge reflectometry measured profiles of n_e across the main SOL; (h) a SOL+edge Charge Exchange Recombination (CER) spectroscopy system measured spatial profiles of the ion density, ion temperature, ion toroidal velocity and ion poloidal velocity – both for the deuterons as well as for a number of charge states of carbon; (i) fast reciprocating probes measured I_{sat}^{+} and T_e at 2 poloidal locations, also Mach number; pressure gauges at various poloidal locations monitored hydrogen neutrals. Some of these diagnostics are shown in Fig. 1. In this first report, results from only a small sub-set of these diagnostics are presented and compared with OEDGE results.

3. COMPARISON OF EXPERIMENTAL AND OEDGE RESULTS

In Fig. 2 the target Langmuir probe profiles are shown across the outer target. The inner target profiles are quite similar, although they were less completely mapped. These profiles were used as the boundary conditions to OEDGE for both targets. In Fig. 3 the computational grid, based on EFIT-calculated magnetic equilibrium [7], shows the poloidal flux surfaces, i.e. the "onion-rings". In Figs. 4, 5 comparisons are made with the DTS data for 4 SOL onion-rings near the separatrix. In Figs. 6, 7 comparisons are made with the upstream Thomson profiles. In Figs. 8–10 comparisons are made with measured spectroscopic profiles across the outer target.

4. DISCUSIONS AND CONCLUSIONS

Only a small fraction of the SAPP data has been confronted in this initial report and all conclusions are therefore *necessarily tentative*. Nevertheless, the main conclusion is that the level of agreement between code and experiment is good for the most part, apparently indicating that the main controlling processes have been included in the model – at least for this lowest density, simplest of all possible conditions. A number of outstanding issues have been identified so far.

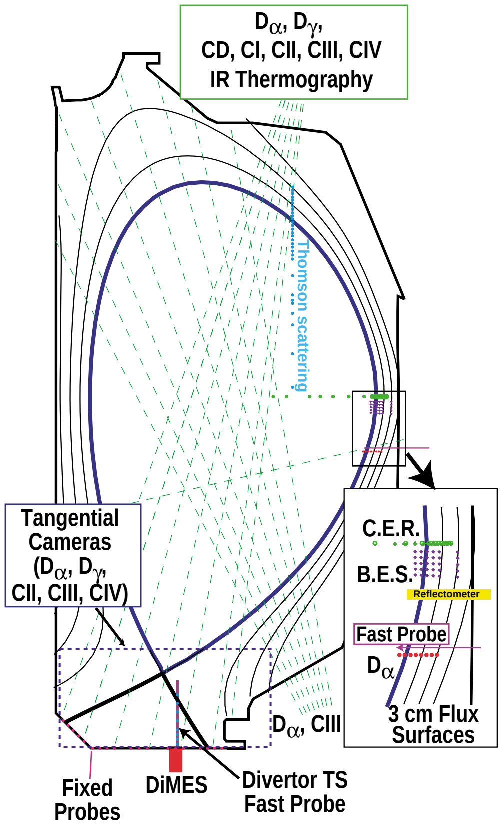

Fig. 1. Schematic of poloidal cross-section of DIII–D showing the edge diagnostics used for the SAPP discharges. See text for details.

1. It is evident that the fluctuation level in the edge is *very* large. The 2 Thomson systems have ~10 ns integration times and thus capture different phases of the fluctuations of n_e and T_e. As can be seen from the plots here, the fluctuation levels are of the same magnitude as the average levels, The codes used here know nothing of fluctuations and presumably give average quantities. This raises the question of whether the comparisons should be to simple (un-weighted) averages of the data – which is the sole method used here – or to some weighted average. It is easy to make the case for the latter: for example, spectroscopic intensities are likely to be non-linearly dependent on T_e, and perhaps on n_e also. Yet the

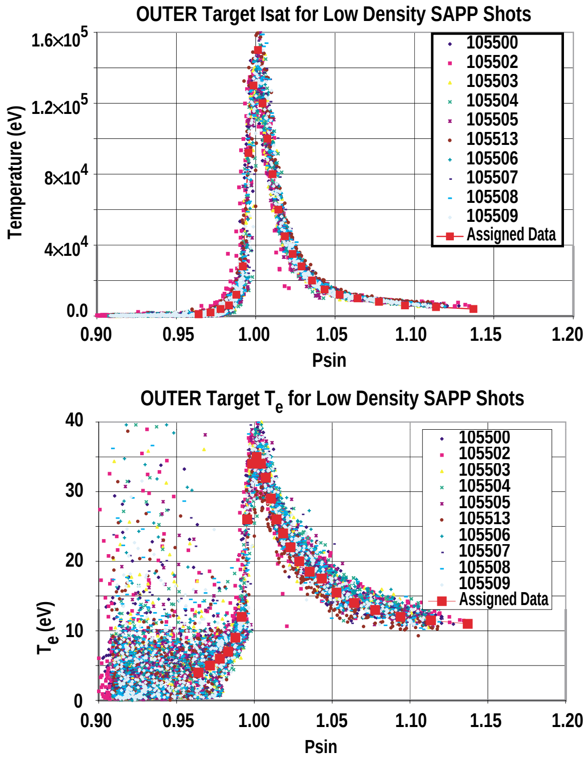

Fig. 2. Target Langmuir probe profiles measured across the outer target for all low density SAPP shots.

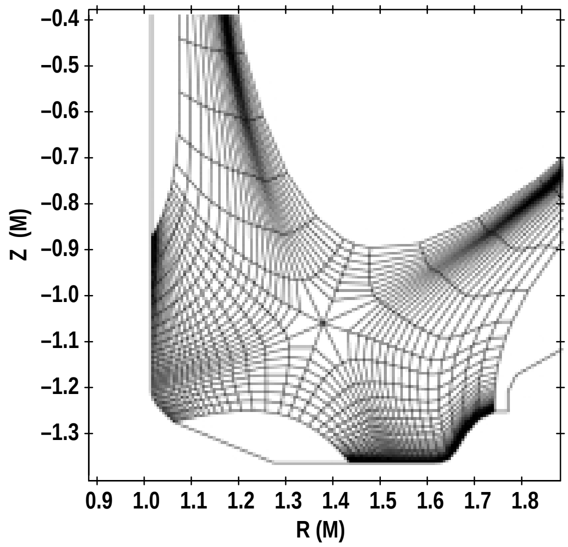

Fig. 3. Computational grid showing poloidal flux surfaces, i.e. "onion-rings". The particular rings used in Figs. 4, 5, – rings 10, 12, 14, and 16 – have normalized magnetic flux values ψ_n = 1.00148, 1.00737, 1.01431, and1.02327, respectively. Ring 10 is closest to the separatrix and the rings radially further out have larger numbers.

matches to the filterscope signals of D_α, D_β and CIII are quite good. This matter requires further investigation.

2. As known earlier, there is some major deficiency in our understanding of the private flux zone (PFZ). Here it is clear that, while the values of T_e obtained by the target Langmuir probes and the (average) DTS

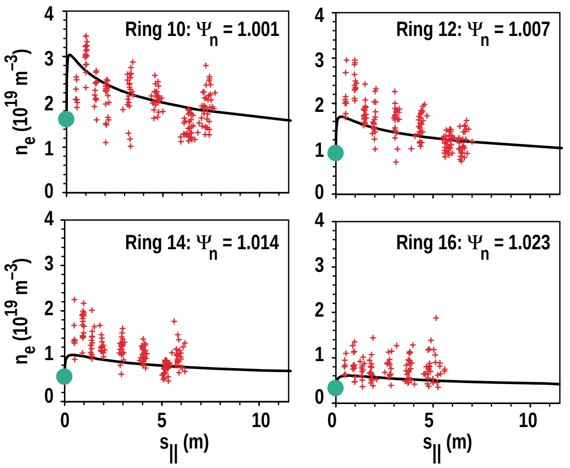

Fig.4. Comparison of Divertor Thomson, DTS, values (points) for n_e and the OEDGE result (line) for 4 outer SOL onion-rings near the separatrix. The circular points at the outer target (at $s_{||}$ = 0) are from the target probe and are the boundary conditions for the OEDGE solution. The abrupt jump in density by about 2× just in front of the target corresponds to the acceleration of the plasma flow to the sound speed that occurs just in front of the target. The DTS data are for all 11 of the low density SAPP shots. The large scatter in the experimental data is partly genuine, i.e. due to fluctuations, and is partly due to error. The error estimates for the DTS n_e values varies from 5% to 60% with an average of 15%.

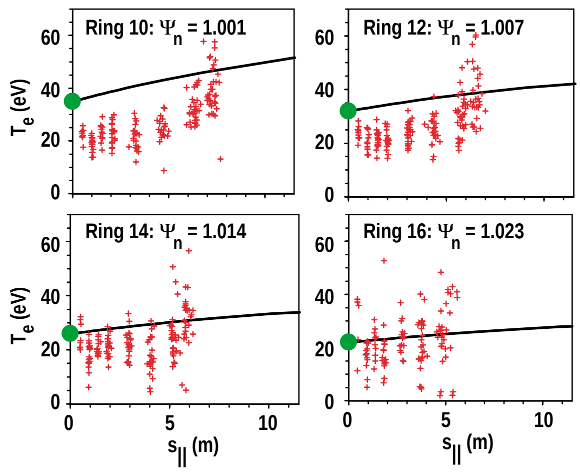

Fig. 5. As for Fig. 4 but for T_e. The error estimates for the DTS T_e values varies from 10% to 60%, with an average of 30%.

agree quite well the further one goes out into the SOL, this agreement degrades substantially as one approaches and enters the PFZ. When DTS and probe results disagree, often the probe interpretation has been questioned; however, the agreement between code (thus probe) and filterscopes at the outside target, *including in the PFZ*, seems to confirm the probe profiles. This matter requires further investigation.

3. The matches to the upstream Thomson are largely excellent, however, the code is

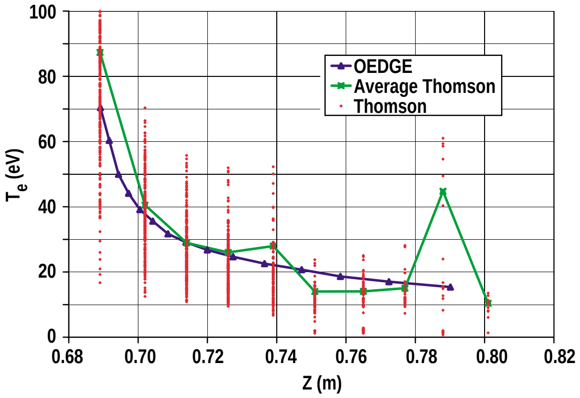

Fig. 6. Comparison of T_e profile along the vertical line of the upstream Thomson system, see Fig. 1. The points are the Thomson values for 5 of the low density SAPP shots. Also shown is the average value of the Thomson data as well as the OEDGE result. The contributions of the individual onion-rings to the OEDGE solution are evident. The error estimates for the T_e values varies from 10% to 80%, with an average of 35%.

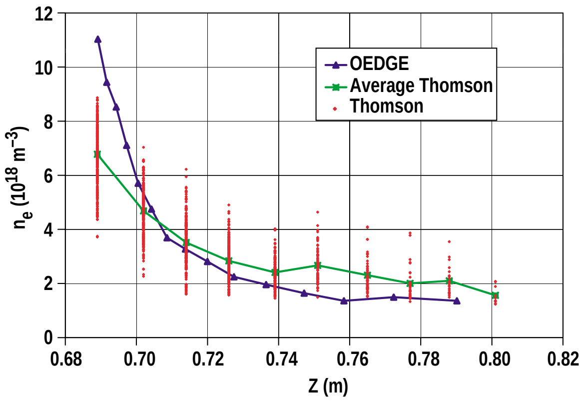

Fig. 7. As for Fig. 6. but for n_e. The error estimates for the n_e values varies from 5% to 50%, with an average of 20%.

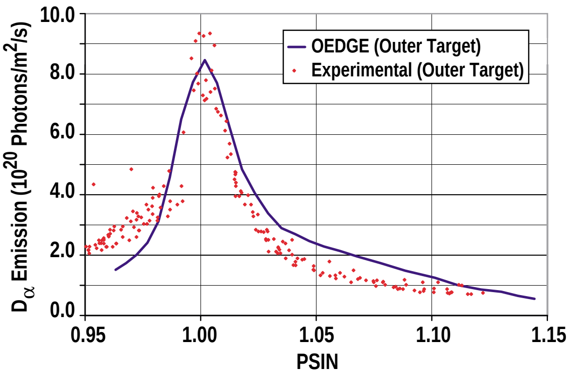

Fig. 8. Comparison of the filterscope D_α profile across the outer target (obtained with sweeping of the X-point, and by combining data from several filterscope channels) with the OEDGE (EIRENE) result.

clearly too high for n_e near the separatrix, perhaps, indicating again some missing physics in/near the PFZ. Alternatively, this may be related to uncertainties in the separatrix location. (In this report the separatrix location, and generally the location of all flux surfaces, have been taken as being correctly given by EFIT).

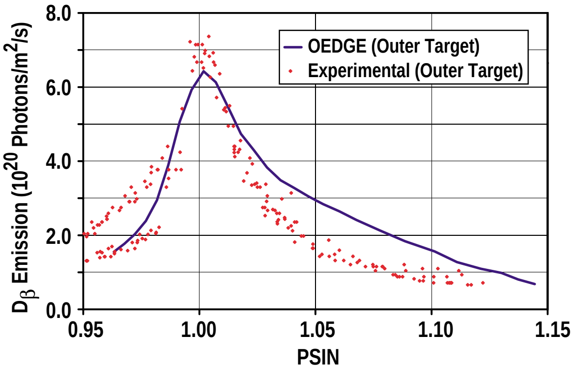

Fig. 9. As Fig. 8. for for D_β.

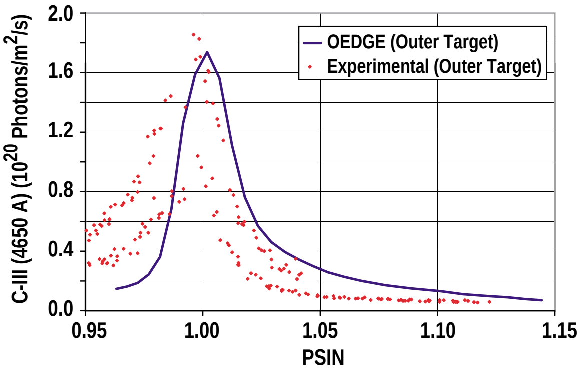

Fig. 10. As Fig. 8 but for CIII (4650A). Code result from DIVIMP with ADAS database.

SUMMARY

OEDGE, an interpretive edge code, has been applied to a set of extensively diagnosed, simple-as-possible-plasma DIII-D discharges, with the aim of identifying the physics processes controlling the tokamak edge. To date only a partial data set, for the lowest density and simplest of all conditions, has been confronted by the code. The generally good agreement between the code and experiment indicates that many of the controlling processes have probably been included in the model, at least for this simplest case.

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