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# Re-construction of detached divertor plasma conditions in DIII-D using spectroscopic and probe data

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**Abstract**

For some divertor aspects, such as detached plasmas or the private flux zone, it is not clear that the controlling physics has been fully identified. This is a particular concern when the details of the plasma are likely to be important in modeling the problem – for example, modeling co-deposition in detached inner divertors. An empirical method of 'reconstructing' the plasma based on direct experimental measurements may be useful in such situations. It is shown that a detached plasma in the outer divertor leg of DIII-D can be reconstructed reasonably well using spectroscopic and probe data as input to a simple onion-skin model and the Monte Carlo hydrogenic code, EIRENE. The calculated 2D distributions of $n_e$ and $T_e$ in the detached divertor were compared with direct measurements from the divertor Thomson scattering system, a diagnostic capability unique to DIII-D.


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## 1. Introduction

Interpretive codes such as TRANSP provide a useful method for analyzing the plasma inside the separatrix by taking experimental radial profiles of electron density, $n_e$, electron and ion temperatures, $T_{e,i}$, etc. as input, and extracting information such as the cross-field heat diffusivity, $\chi_\perp(r)$, through evaluation of radial particle, momentum and energy balances. It would be valuable to have an equivalent interpretive analysis method for the region outside the separatrix. Such an empirical 're-construction' of the edge plasma could be used to extract cross-field transport information, as for the

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main plasma. It could also be used to help unravel the complicated atomic physics processes that are always important in the edge: the 'background plasma' could be employed as input to the powerful Monte Carlo (MC) neutral hydrogen codes, such as EIRENE, and MC impurity codes such as DIVIMP.

Unfortunately, it will probably be a long time before the exact analogue of TRANSP will be achievable for the edge: (a) the edge region is 2–3D instead of 1–1.5D, and (b) the spatial coverage of edge diagnostics is typically rather limited. In the meantime, however, a mixed approach can be used to achieve an empirical re-construction of the background plasma, where simple 1D 'onion-skin' models/prescriptions are used along with the direct specification of the plasma from experimental data (as much as possible) in order to generate 2D 'fields' of the edge plasma quantities, $n_e$, $T_{e,i}$, parallel plasma velocity, $v_\parallel$, etc. The versatile MC codes are then applied to this background plasma to produce comparisons with additional edge experimental data, such as spectroscopic line emissivities and line shapes, neutral pressure gauge readings, etc. – and these further constraints are used to improve the plasma re-construction iteratively.

DIII-D's divertor Thomson scattering (DTS) system [1] provides a unique opportunity to directly measure $n_e$ and $T_e$ in a divertor plasma, even for strongly detached plasma conditions. When combined with magnetic sweeping of the X-point, 2D fields of $n_e$ and $T_e$ are produced over substantial regions of the divertor. DTS data are particularly valuable for empirical plasma re-construction. Unfortunately, on most tokamaks DTS is not available and even on DIII-D, DTS access to the (generally detached) inner leg is very limited. Since the inner leg is the key region for some of the most critical edge processes – for example, the co-deposition trapping of tritium [2] – there is a strong incentive to develop a method for empirically re-constructing detached divertor plasmas in the absence of DTS. In contrast with DTS, Langmuir probe (measuring $I^+_{sat}$) and spectroscopic measurements are usually available.

The objective of this paper is to establish the basic methodology of empirically re-constructing a detached *outer* leg in DIII-D *using only Langmuir probe and spectroscopic data* (*no DTS*). The measure of success is the level of agreement between the reconstructed plasma and the DTS data.

Low power L-mode [Simple-as-possible plasma (SAPP)] conditions were used with $\bar{n}_e = 4.4 \times 10^{19}\ \mathrm{m}^{-3}$ where the outer divertor leg was weakly detached (shots 105516–9). These SAPP shots are from the same set of experiments as the low density (attached) shots (105 500–9), where $\bar{n}_e = 2.5 \times 10^{19}\ \mathrm{m}^{-3}$, that were analyzed in Ref. [3]. Please see that paper for further details of these shots and of the DIII-D edge diagnostic set that was available.

## 2. Empirical reconstructive modeling of the detached plasma

Two different versions of the onion-skin method Eirene Divimp edge (OEDGE) code [3,4] were used in these studies. In the earlier attached-plasma SAPP study of simple (L-mode) attached divertor plasmas, an OSM model that solves the standard fluid conservation equations (particles, momentum, energy) was successfully applied. However, for other divertor operational modes and regions – such as detached plasmas or the private flux zone (PFZ) – it appears that the controlling physics has only been partly identified. This is a particular concern when the details of the plasma are likely to be important in modeling a problem – as appears, for example, to be the situation when trying to model co-deposition in detached inner divertors [2]. In this case, it is appropriate to use a more empirical OSM version that attempts to reconstruct the plasma from the available experimental data. An example of the application of this approach to the C-Mod PFZ can be found in Ref. [5]. We undertake the same type of analysis here,

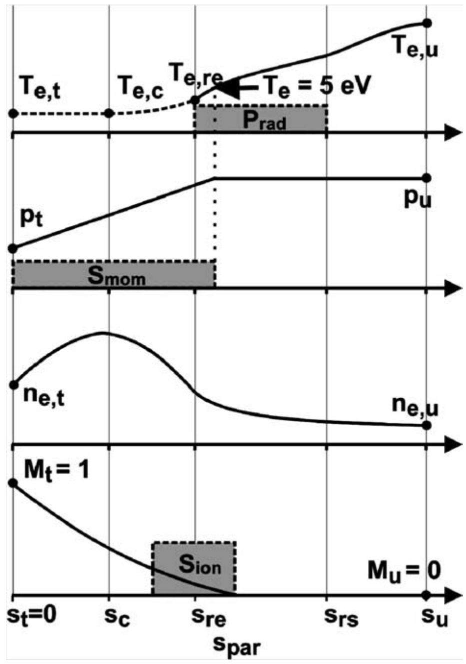


Fig. 1. Schematic of the empirical modeling method used here to reconstruct the plasma in the detached outer divertor of DIII-D. '*s*' denotes the distance along the field line, with $s = 0$ at the target.