Modeling of the Weak Dependence of Core Plasma Carbon Content on the Wall Sputtering Rates in DIII-D using the 2D Multifluid Code UEDGE

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The 2D multifluid code UEDGE has been used to model carbon transport in the edge and divertor plasma in DIII--D under H--mode conditions. Recent analysis of spectroscopic data from DIII--D has shown that over the past several years, as boronization of the DIII--D walls has been repeated many times, the total carbon sputtering rates have decreased by over a factor of four, yet the typical core plasma carbon content has not changed. Within the UEDGE code, the carbon sputtering rate has been changed by a factor of six, while keeping the other code inputs constant. Over this range of carbon sputtering, the carbon concentration in the core plasma changed by less than 30%. Examination of the parallel forces that transport carbon ions from the divertor walls to the core plasma will be presented for the several UEDGE solutions over the range of sputtering coefficients. The implications for reducing core contamination will be discussed.

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Abstract Submitted
for the DPP99 Meeting of
The American Physical Society

Sorting Category: 5.1.1.2 (Experimental)

Modeling of the Weak Dependence of Core Plasma Carbon Content on the Wall Sputtering Rates in DIII-D using the 2D Multifluid Code UEDGE[1] W.P. WEST, T.E. EVANS, N.H. BROOKS, General Atomics, D.G. WHYTE, University of California, San Diego, R.C. ISLER, Oak Ridge National Laboratory, G.D. PORTER, N. WOLF, Lawrence Livermore National Laboratory — The 2D multifluid code UEDGE has been used to model carbon transport in the edge and divertor plasma in DIII–D under H–mode conditions. Recent analysis of spectroscopic data from DIII–D has shown that over the past several years, as boronization of the DIII–D walls has been repeated many times, the total carbon sputtering rates have decreased by over a factor of four, yet the typical core plasma carbon content has not changed. Within the UEDGE code, the carbon sputtering rate has been changed by a factor of six, while keeping the other code inputs constant. Over this range of carbon sputtering, the carbon concentration in the core plasma changed by less than 30%. Examination of the parallel forces that transport carbon ions from the divertor walls to the core plasma will be presented for the several UEDGE solutions over the range of sputtering coefficients. The implications for reducing core contamination will be discussed.

[1] Supported by U.S. DOE Contract DE-AC03-99ER54463.

☐ Prefer Oral Session
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Special instructions: DIII-D Poster Session 2, immediately following N Jalufka

Date printed: July 16, 1999

Electronic form version 1.4

Motivation

- The DIII-D Plasma Facing Wall is >90% Graphite: Carbon is the Dominant Impurity in DIII-D
- In many High Performance plasmas on DIII-D, the Core Plasma Carbon Content is sufficient to produce a $Z_{eff} > 3$.
- Understanding Carbon Sources and Transport is key to the Reduction of Core Plasma Z_{eff} and the Control of Impurity Radiation in all DIII-D Plasmas.
- Recent Analysis of Carbon Line Emission from the Divertor shows a Long Term (several year) Decrease in Carbon Source, yet No Reduction in Core Plasma Carbon Content has been noticed. (see Poster JP1.09 by Whyte et al)

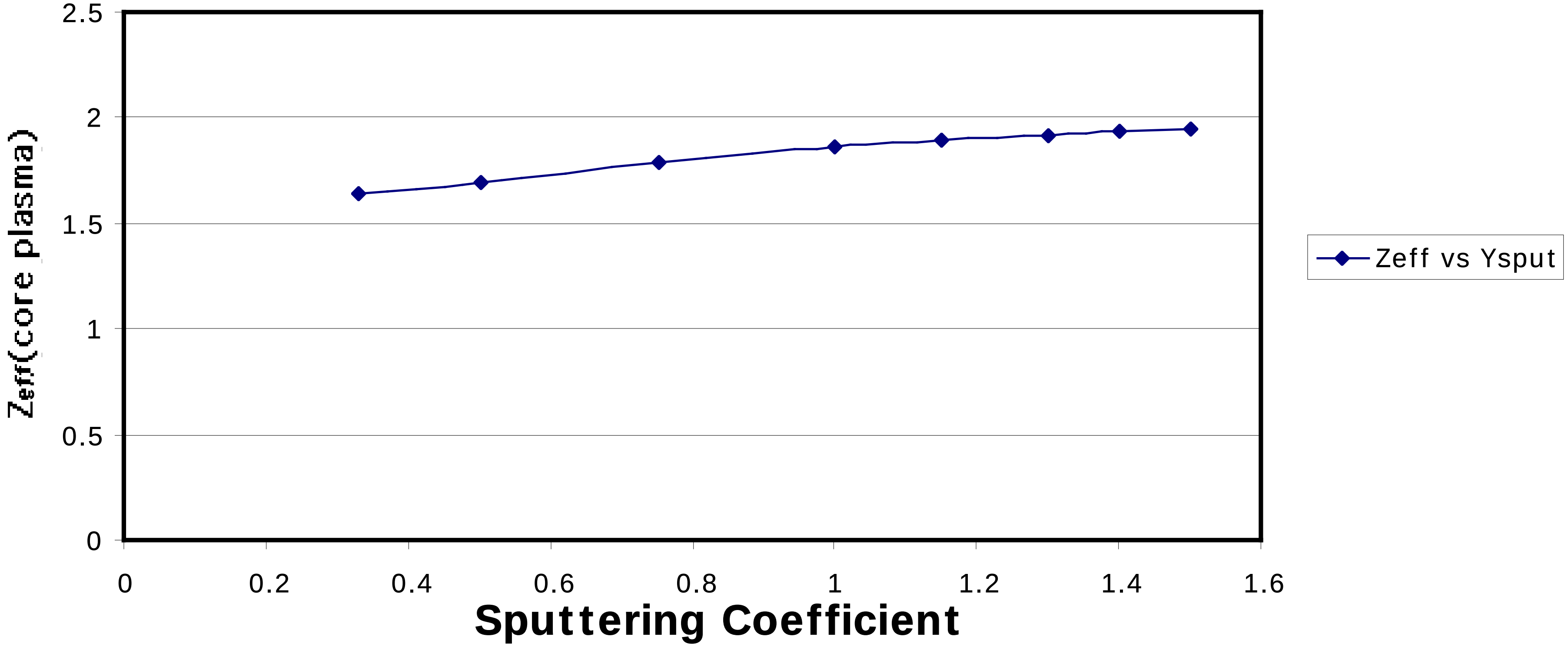
UEDGE Used to Model Reduction of Carbon Sputtering Rate

- UEDGE 2D Multifluid Modeling of H-mode Like Plasma in the DIII-D configuration shows a Significant Nonlinear behavior of Core Carbon Content with Variation in Carbon Sputtering Rate

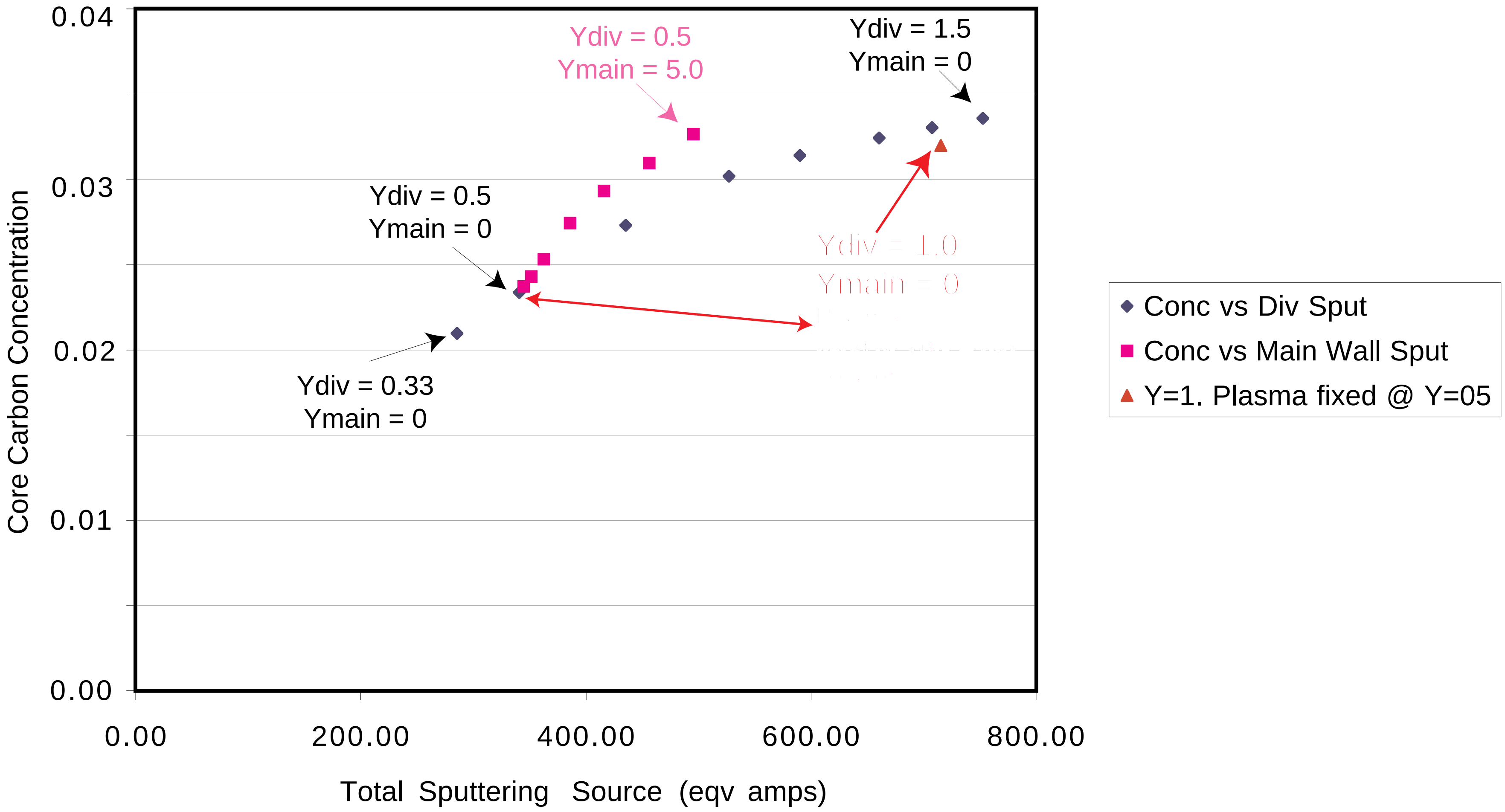
- Sputtering Coefficient Varied from 0.3 to 1.5 times typical Haazs/Davis rates while keeping all other input parameters fixed.

- Divertor and SOL plasma parameters change only slightly with change in carbon sputtering coefficient
  - Outer Divertor strongly attached with T_e(plate) = 44 to 47 eV, 7.9 to 5.9 × 10^{19} m^{-}3
  - Inner Divertor detached with T_e (plate) = 1.2 to 1.0 eV, n_e = 3.4 to 2.0 ×10^{20} m^{-3}
  - SOL near Seperatrix T_i = T_e= n_e =
  - Total Radiated Power 2.4 to 2.7 MW

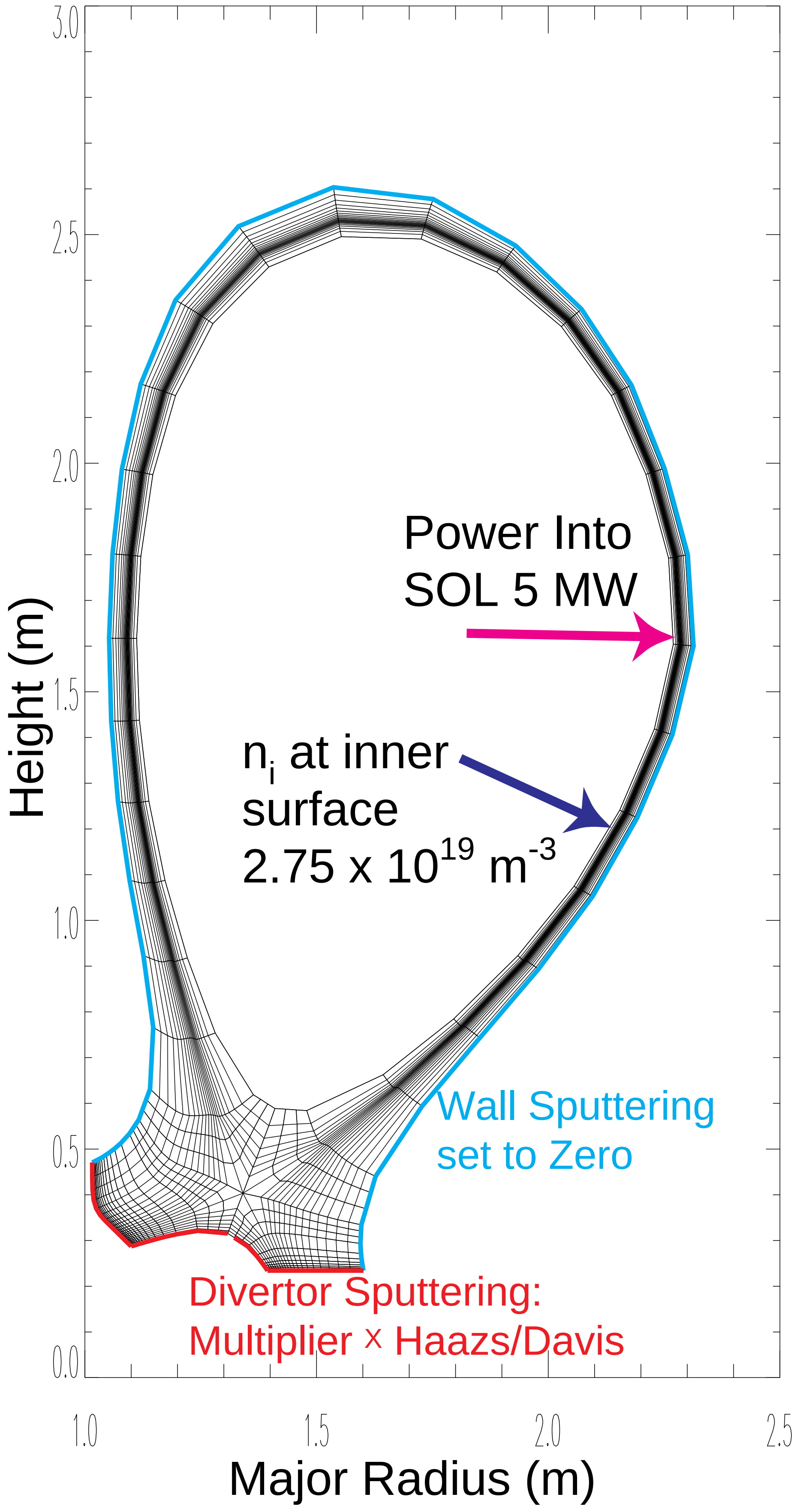
Z_{eff} Weakly Dependent on the Sputtering Yield



Core Carbon Concentration vs
Divertor & Main Chamber Sputtering Flux



UEDGE Grid and Input Parameters



Power Into
SOL 5 MW

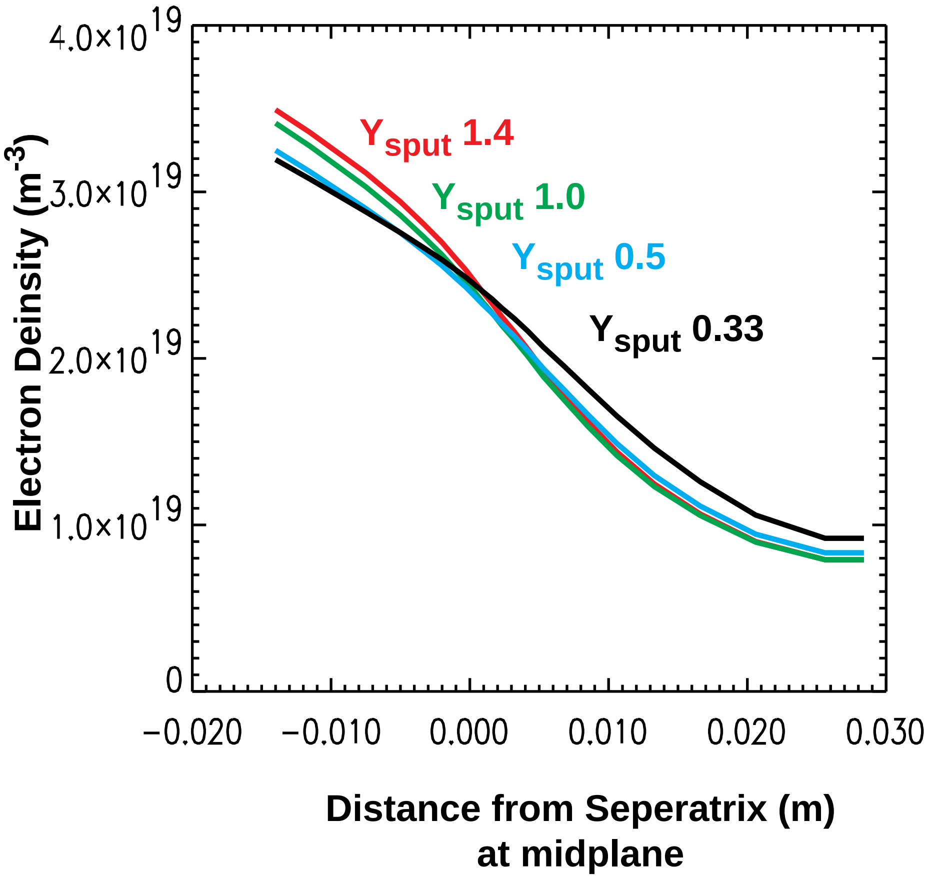
n_i at inner
surface
$2.75 \times 10^{19}\ m^{-3}$

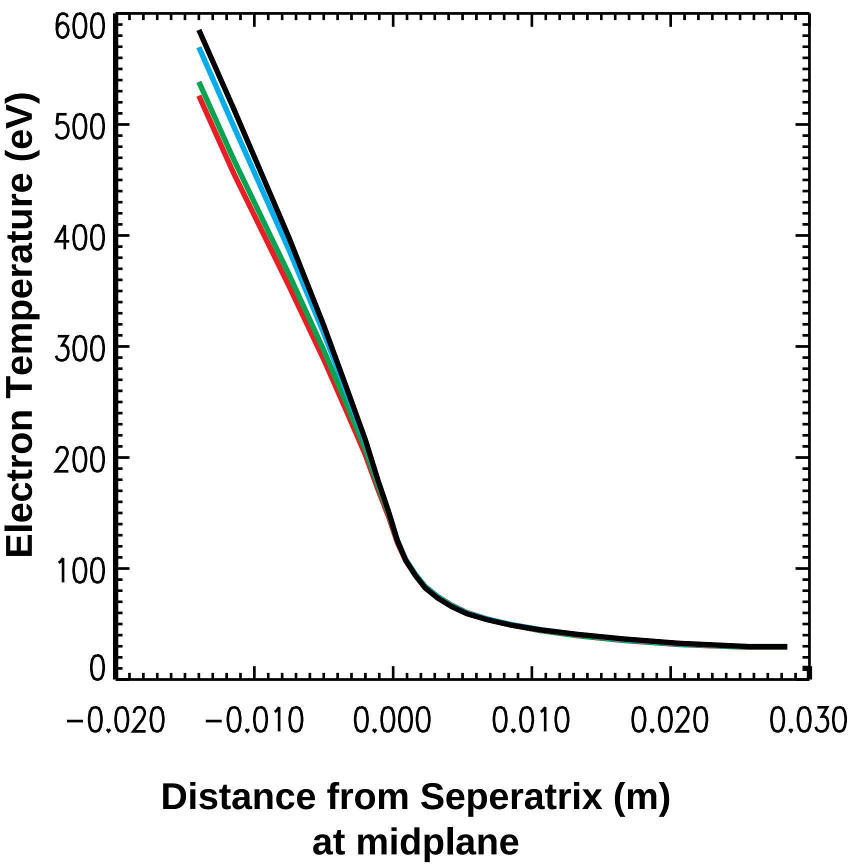
Wall Sputtering
set to Zero

Divertor Sputtering:
Multiplier × Haazs/Davis

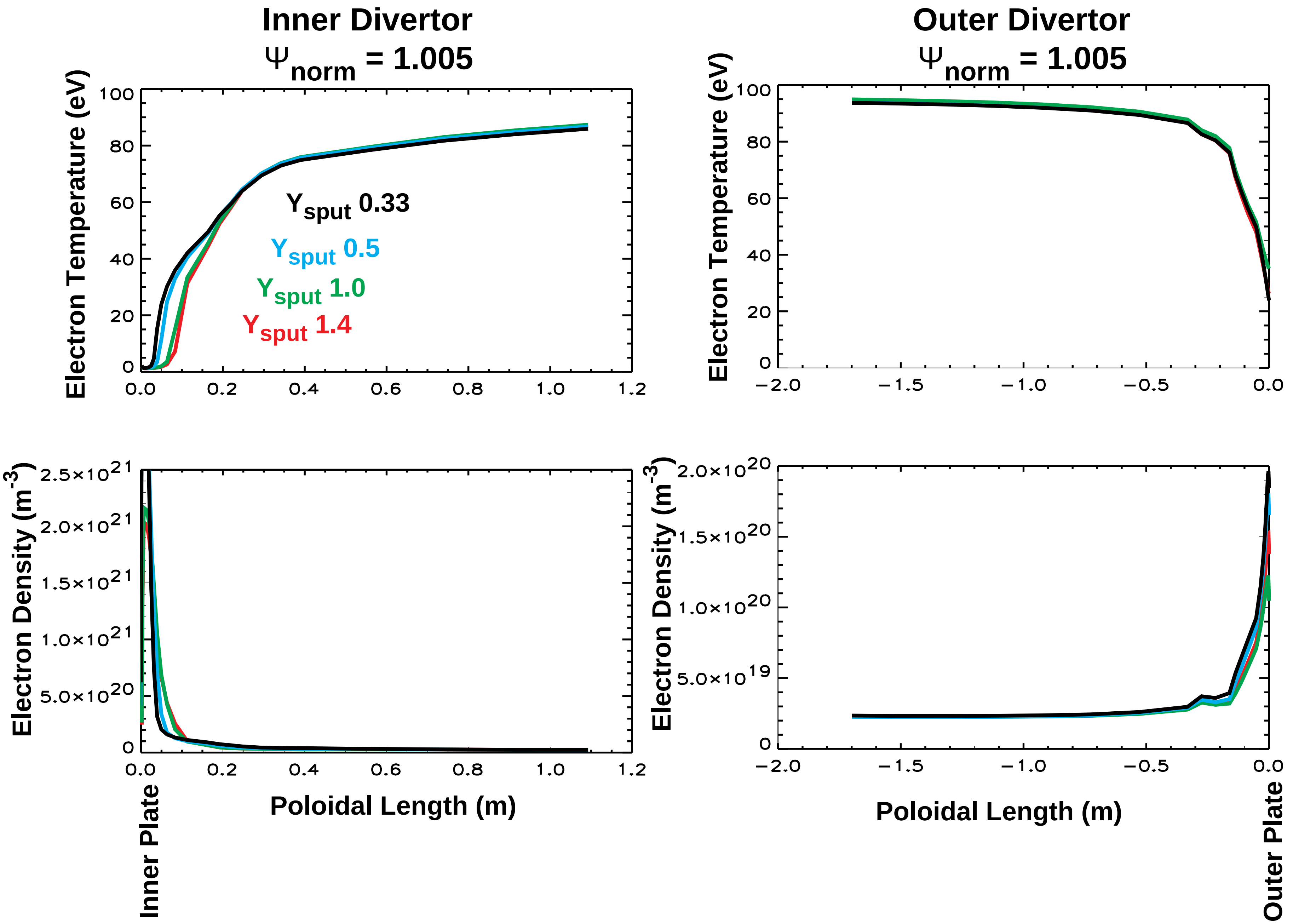
Perpendicular Transport
$k_e = k_i = 0.4\ m^2/s$
$D = 0.2\ m^2/s$

Midplane Electron Density and Temperature Radial Profiles





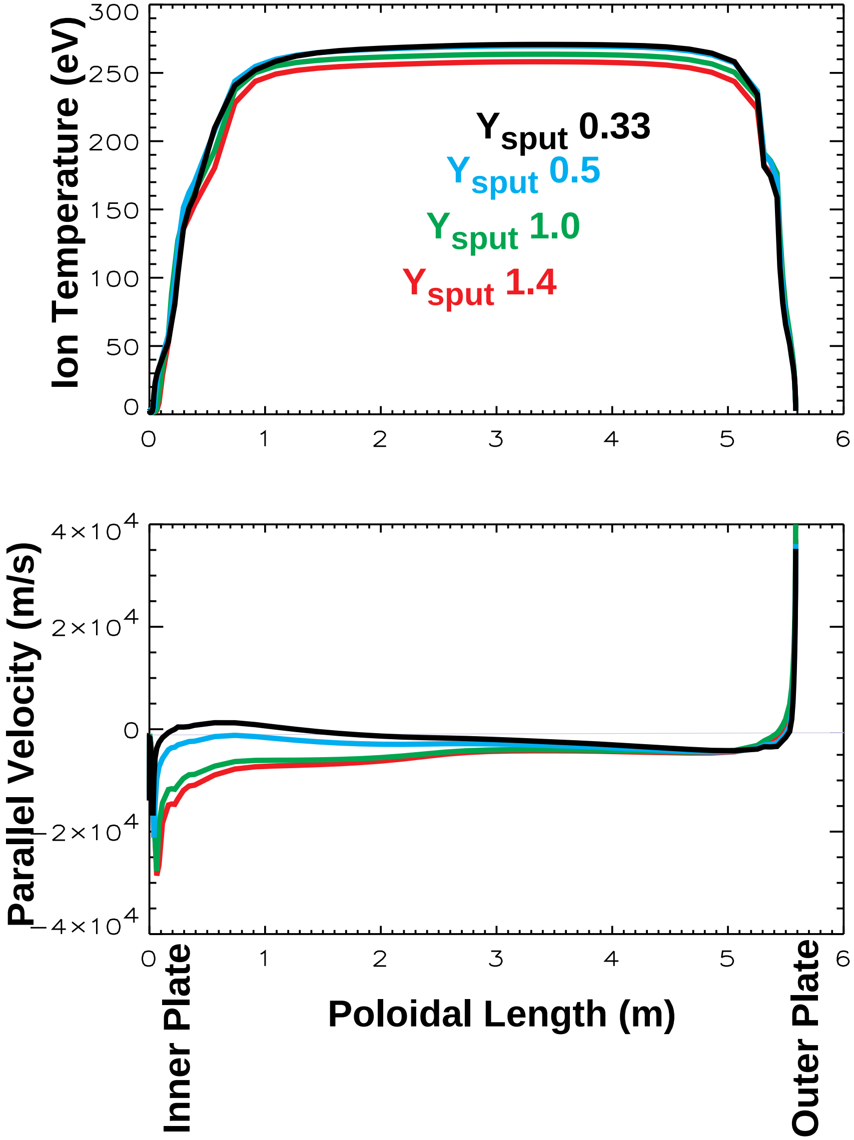
Electron Temperature vs Poloidal Length from Inner and Outer Strike Points



Ion Temperature and Parallel Velocity vs Poloidal Length in the Near and Far SOL

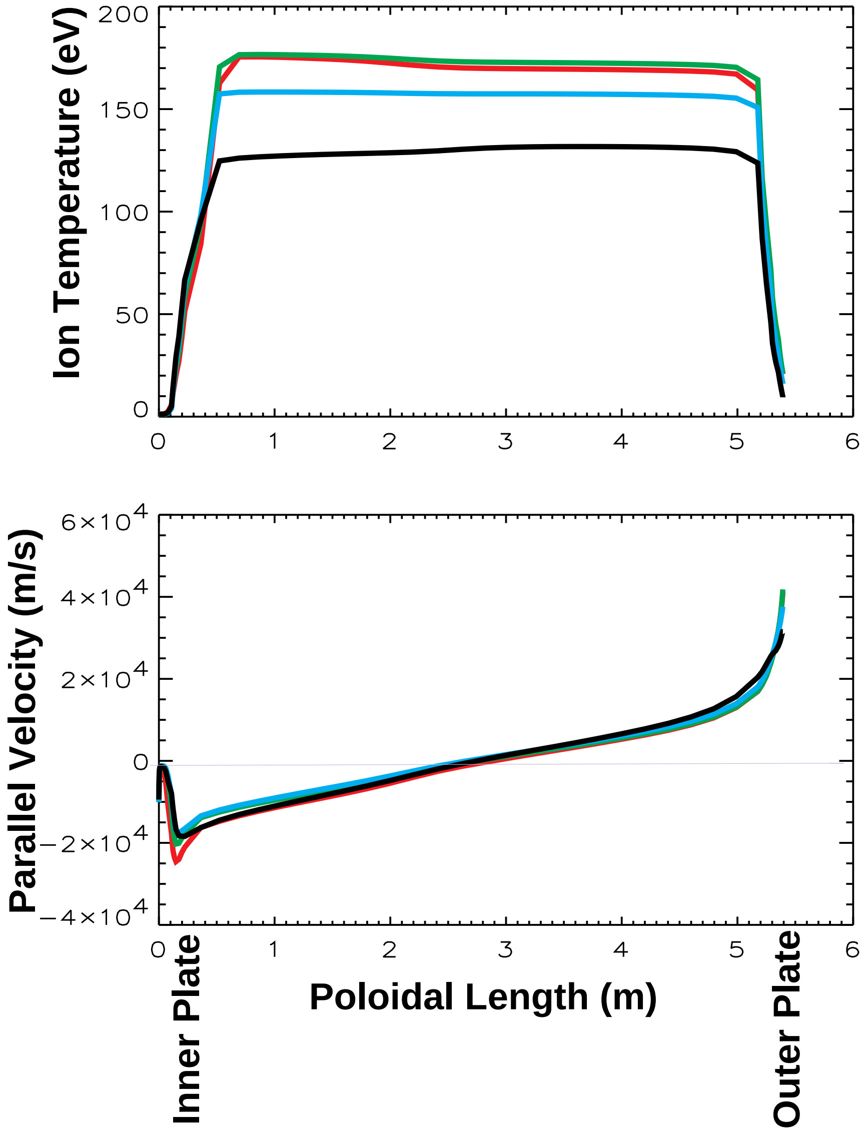
Near SOL

$\Psi_{norm} = 1.005$

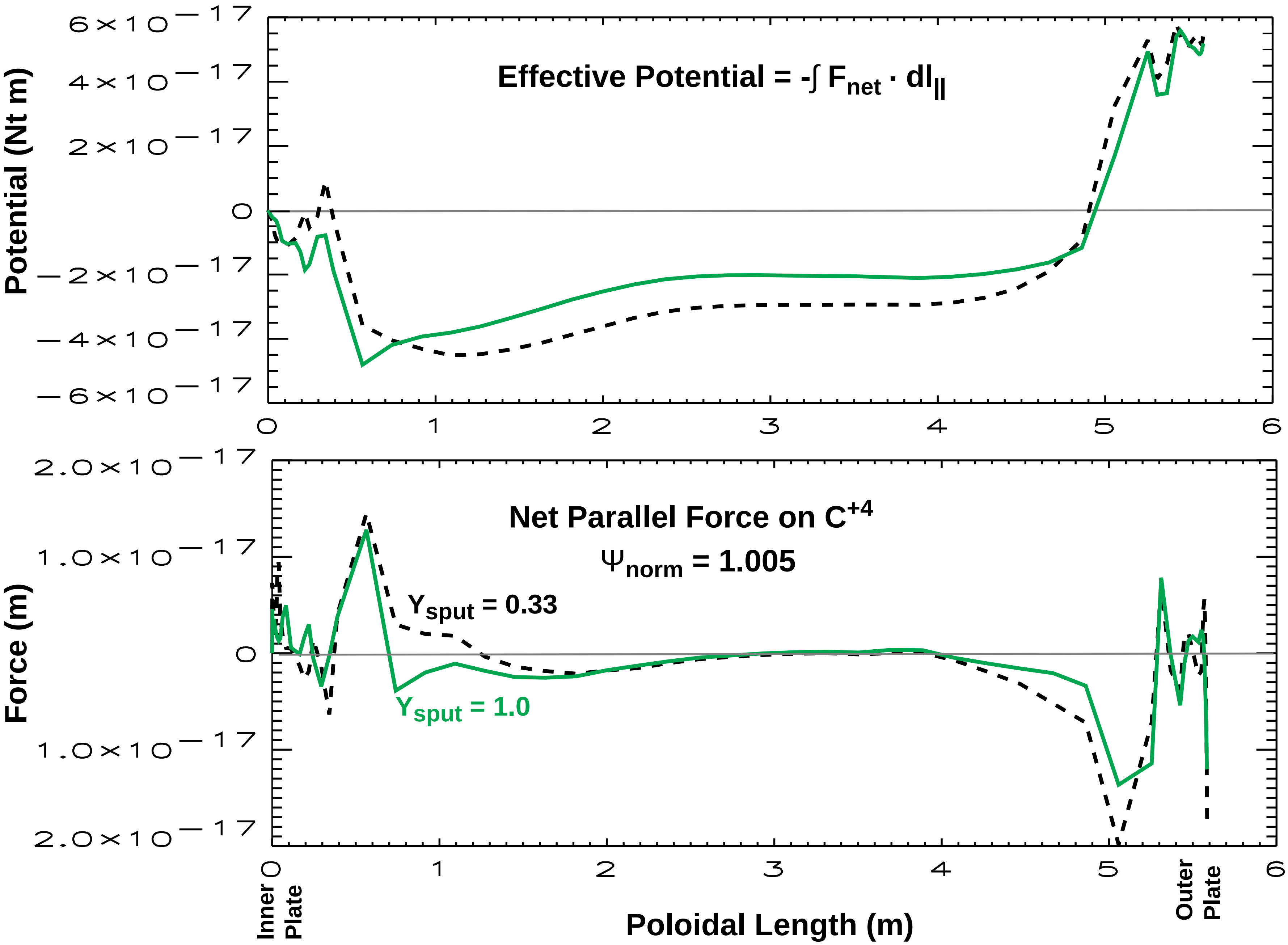


Far SOL

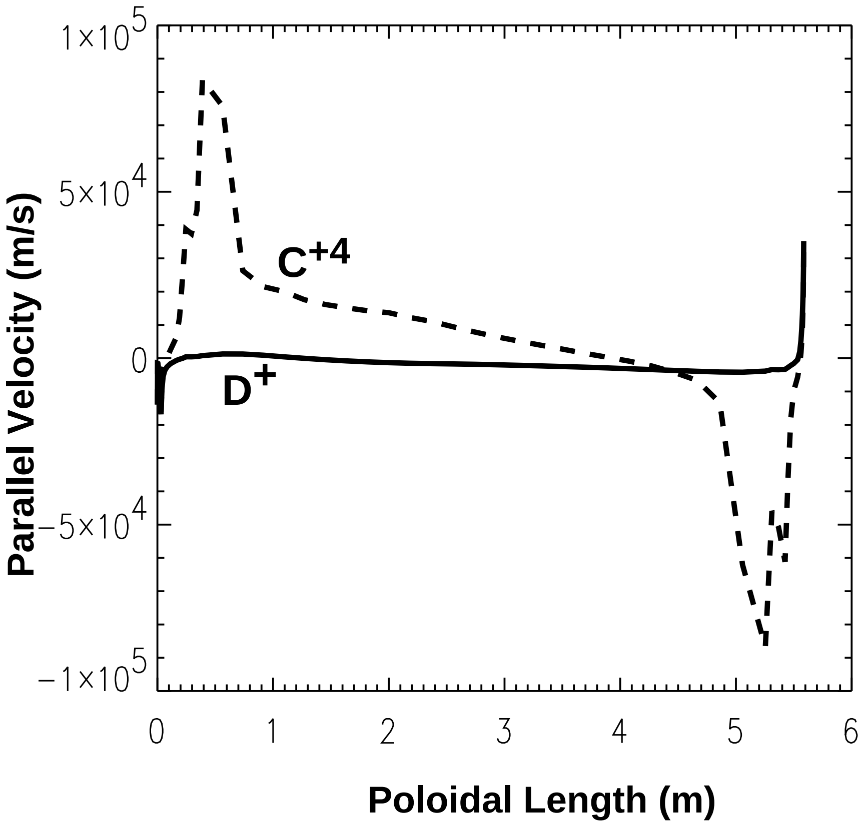
$\Psi_{norm} = 1.07$



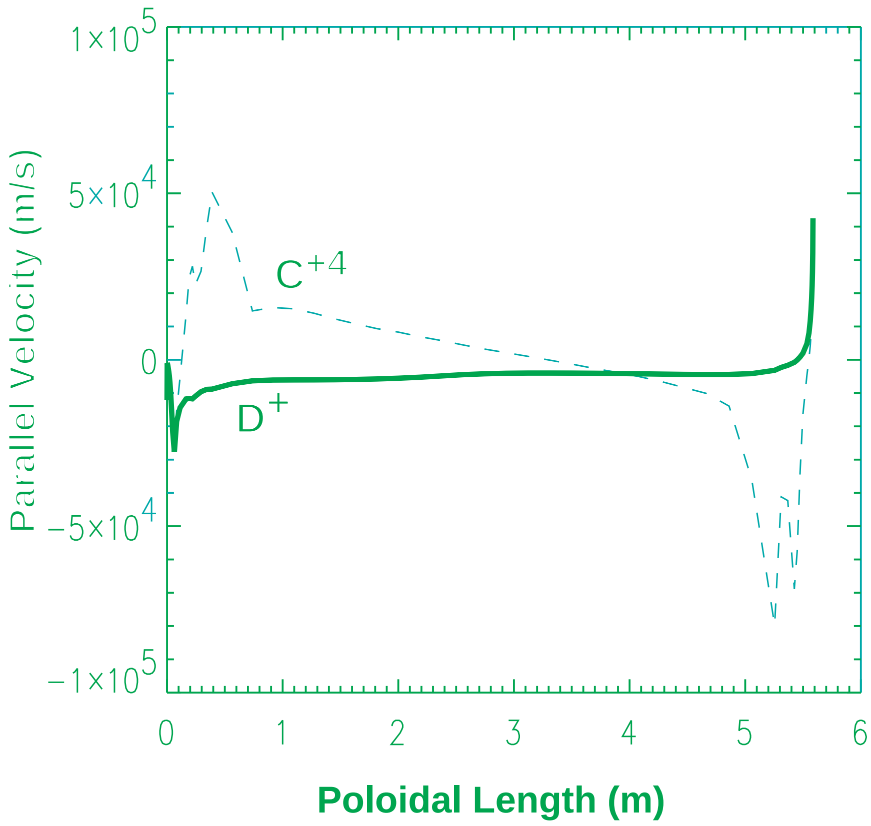
Parallel Force and Effective Potential Seen by C^{+4} ions Not Strongly Dependent on Y_{sput}



Parallel Flows in near SOL Not a Strong Function of Y_{sput}

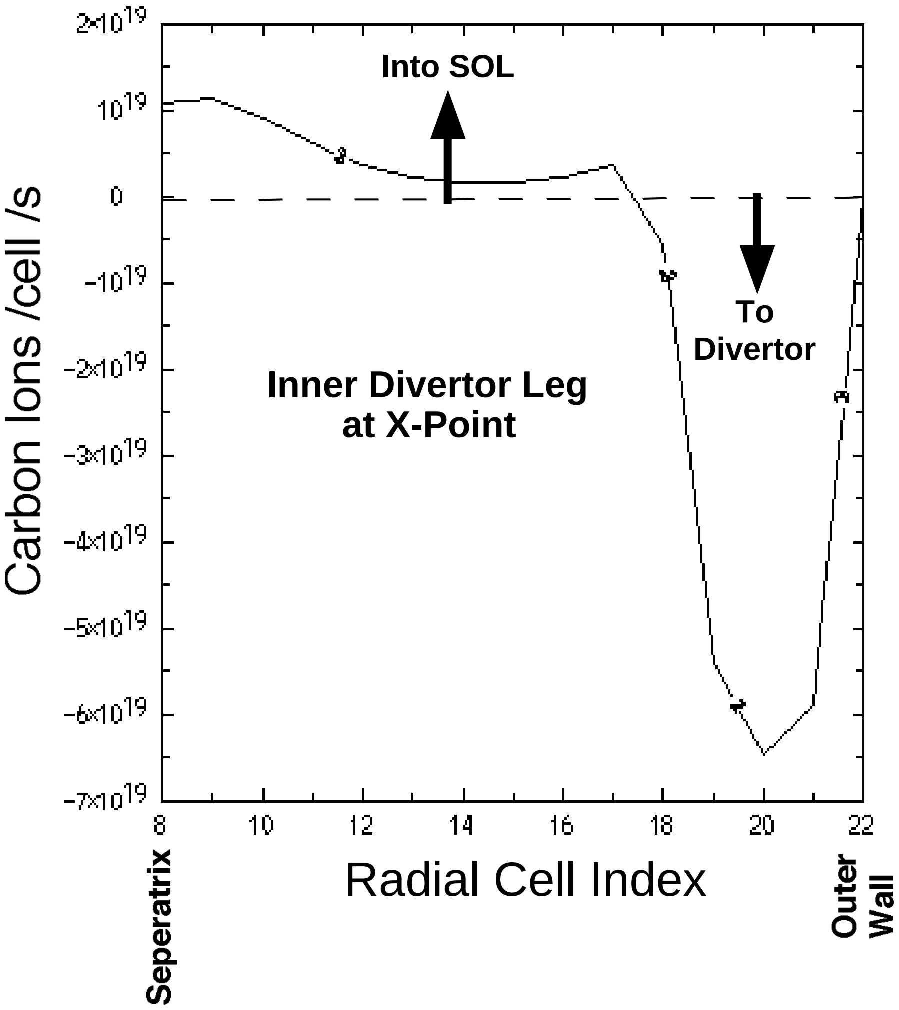


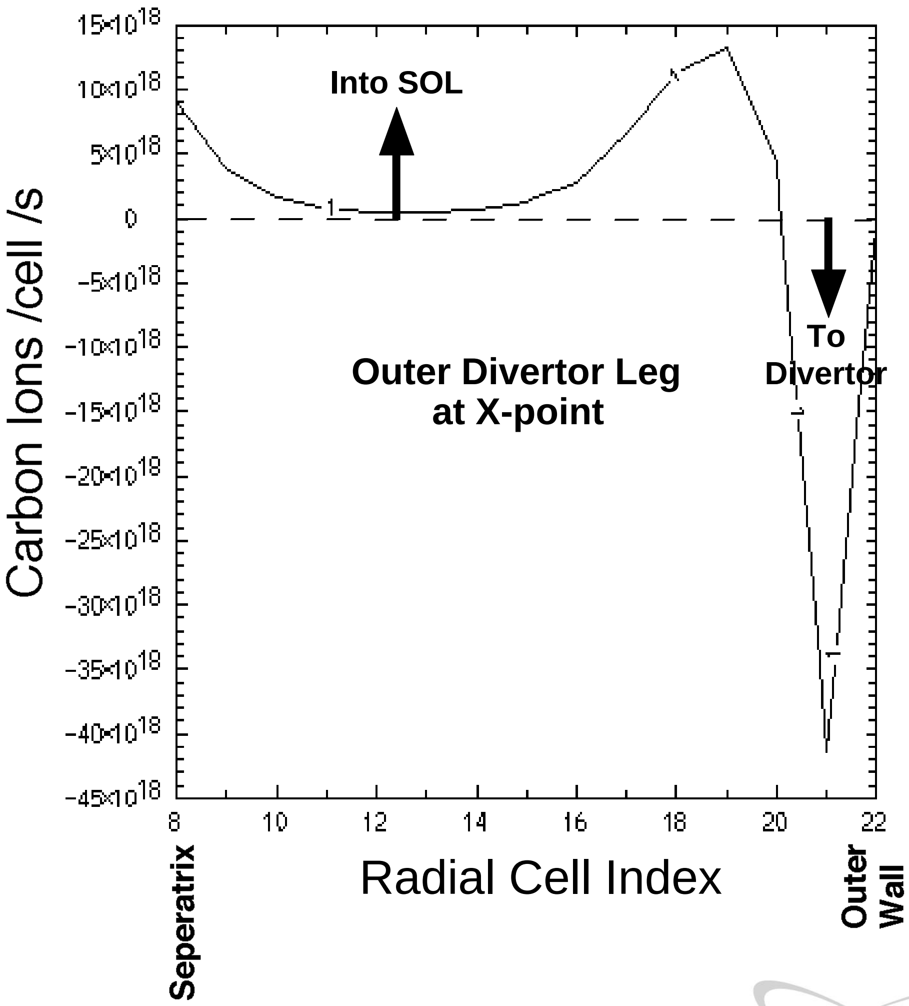
Y_{sput} = 0.33



Y_{sput} = 1.0

Carbon Flux From Divertor Into SOL near Seperatrix
From SOL to Divertor near Outer Wall





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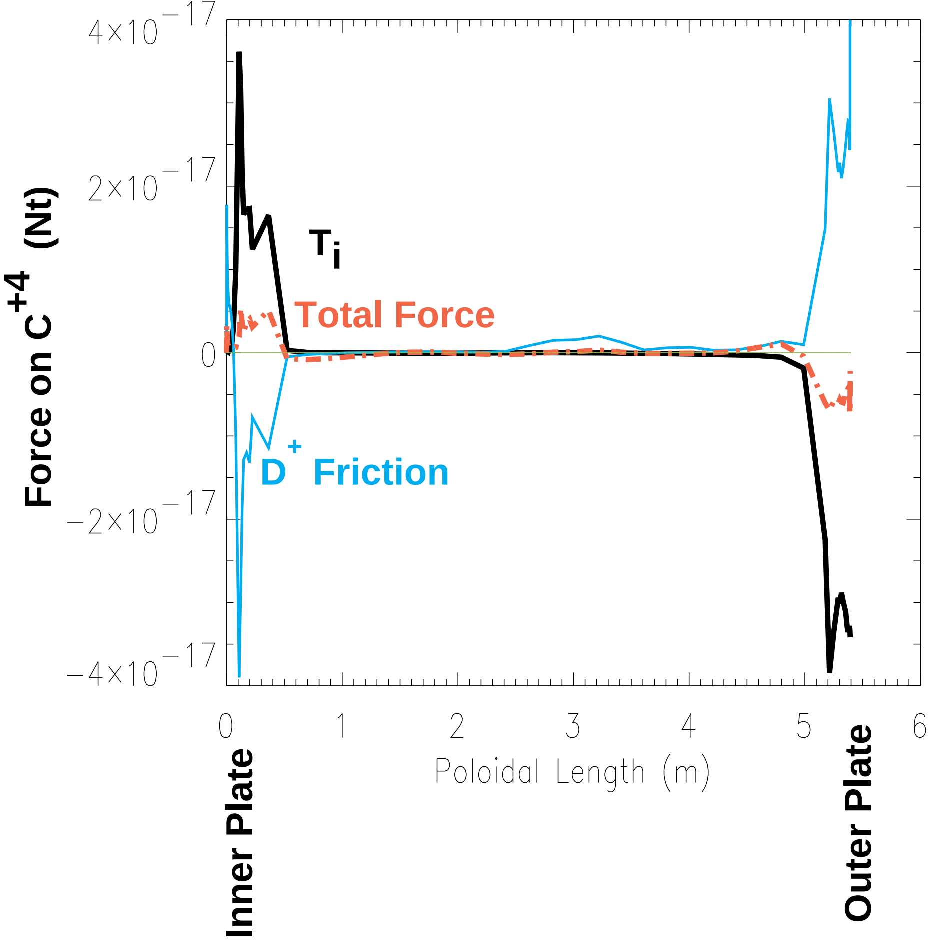
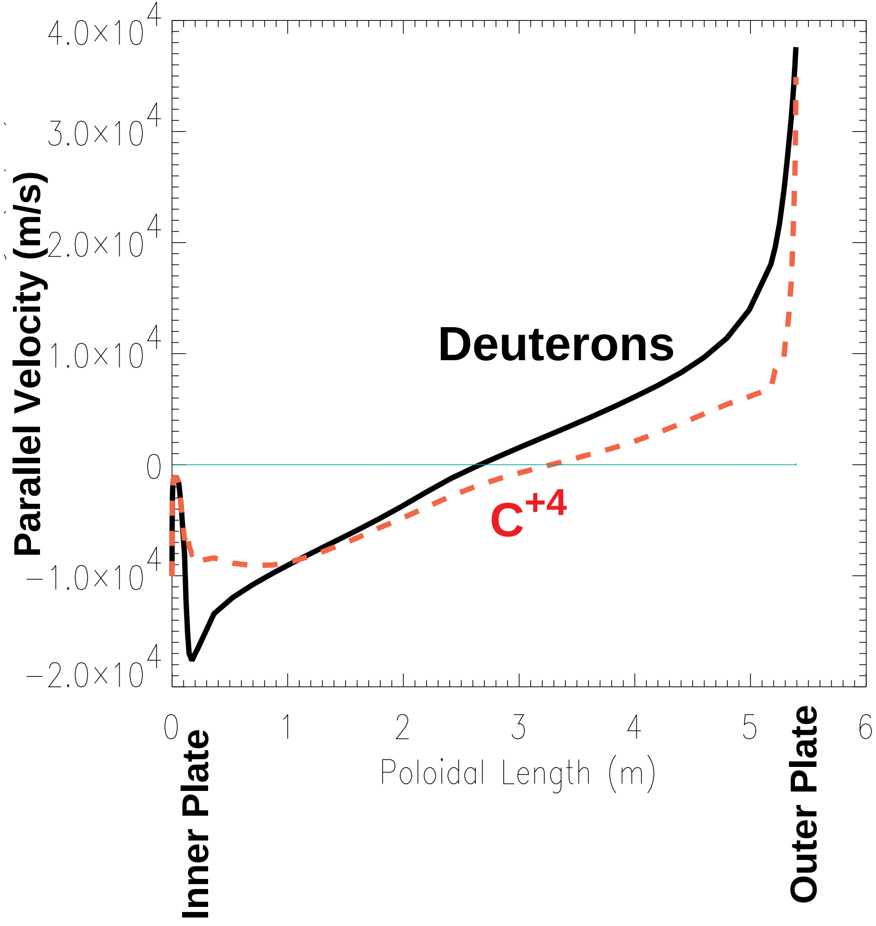
Forces and Flow of C^{+4} in the far SOL
Carbon Ions flow to divertor plate

Parallel Forces

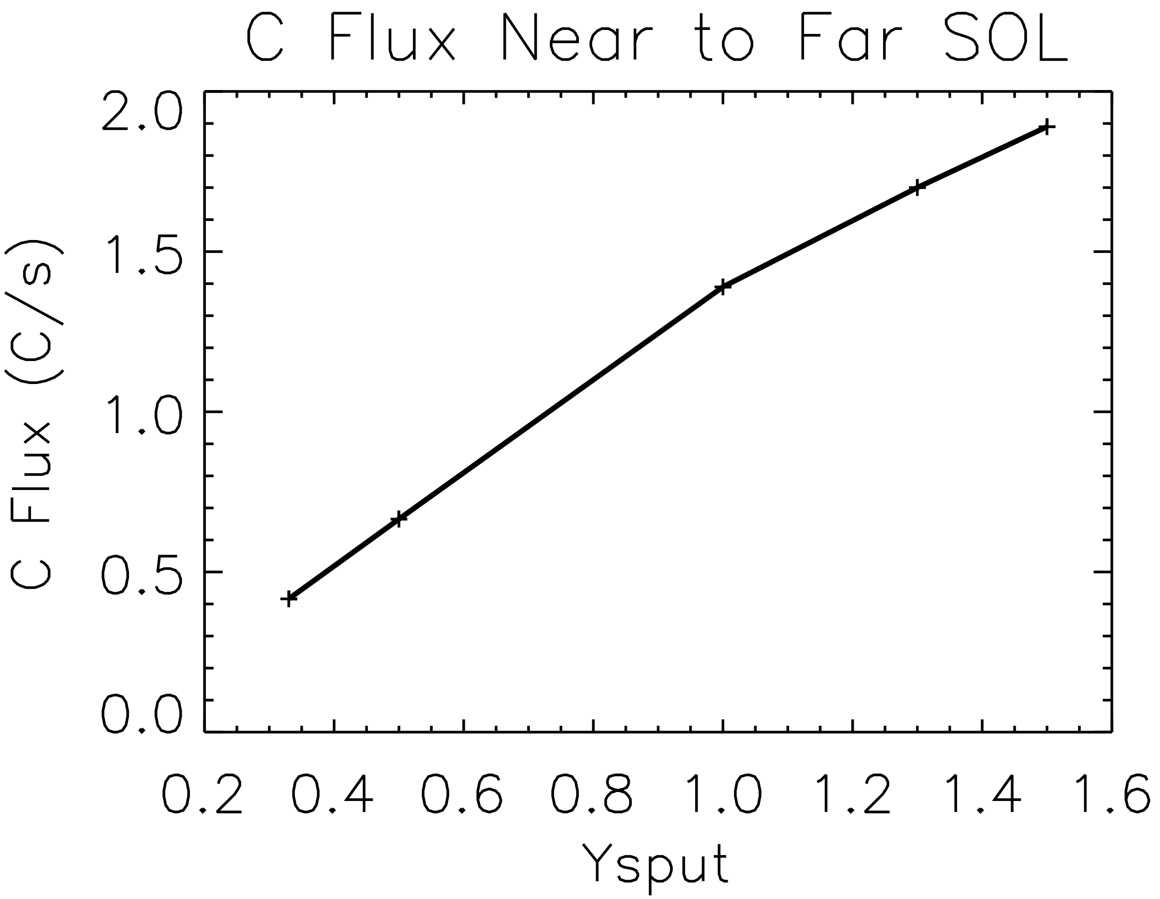


Parallel Velocity

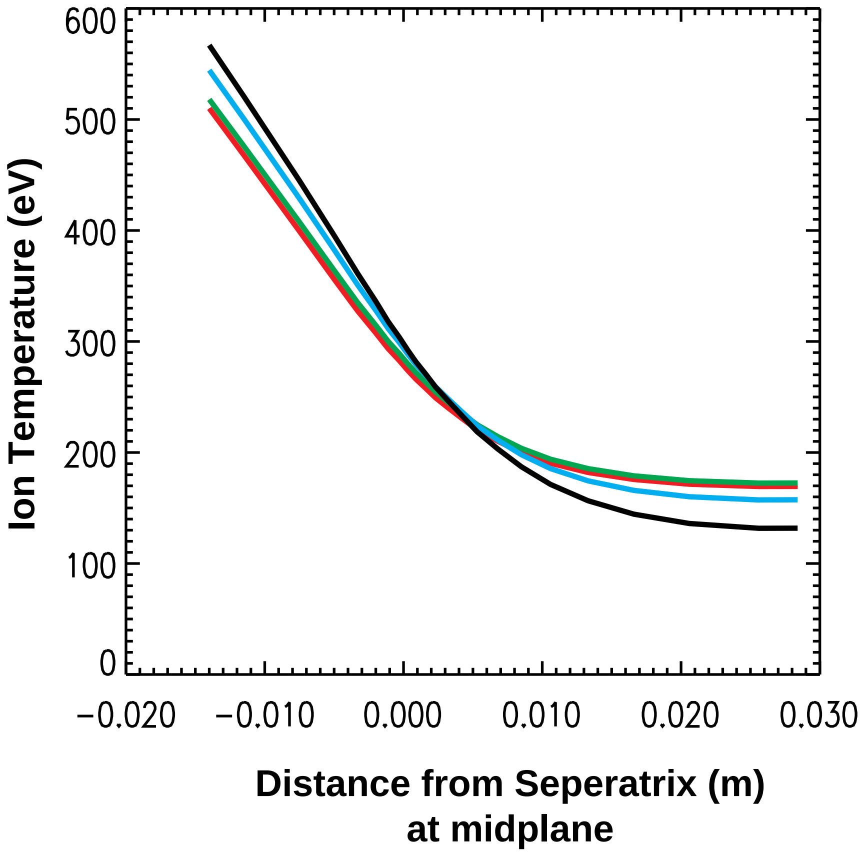
Positive toward outer plate

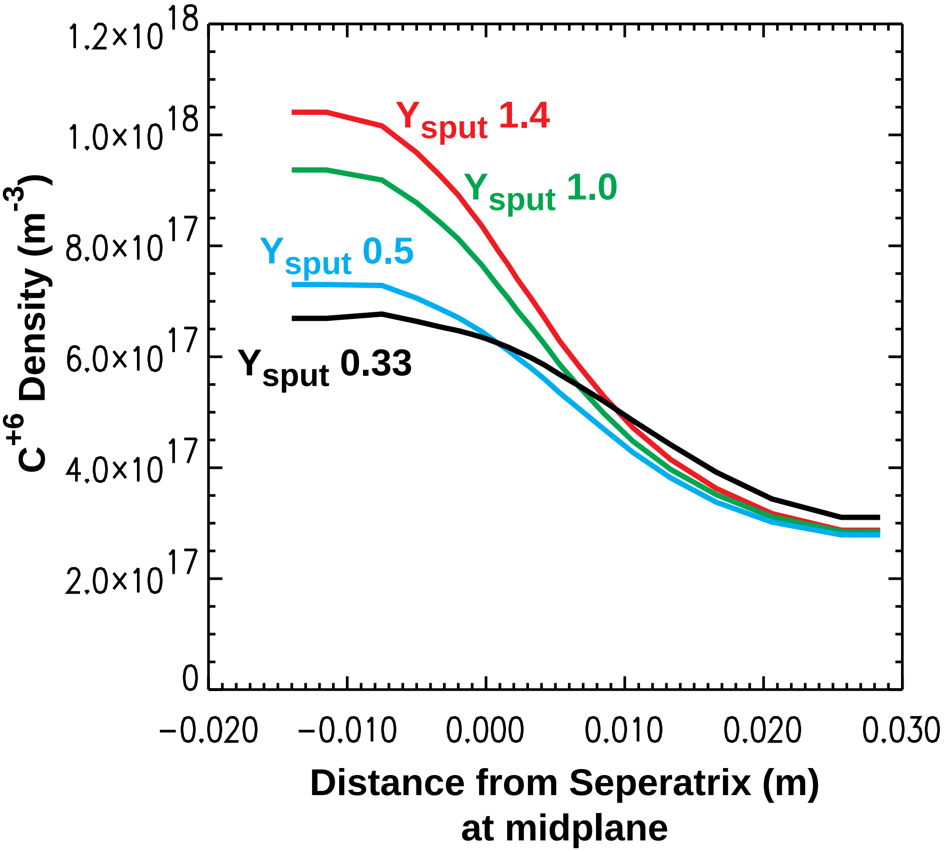


Radial Flux of Carbon Ions From Near to Far SOL Proportional to Sputtering Coefficient



Midplane SOL C^{+6} Density Radial Gradient Scale Length Drops as the Sputtering Rate Drops





Qualitative Picture of Divertor/SOL Impurity Flow In these H-mode Like Plasmas

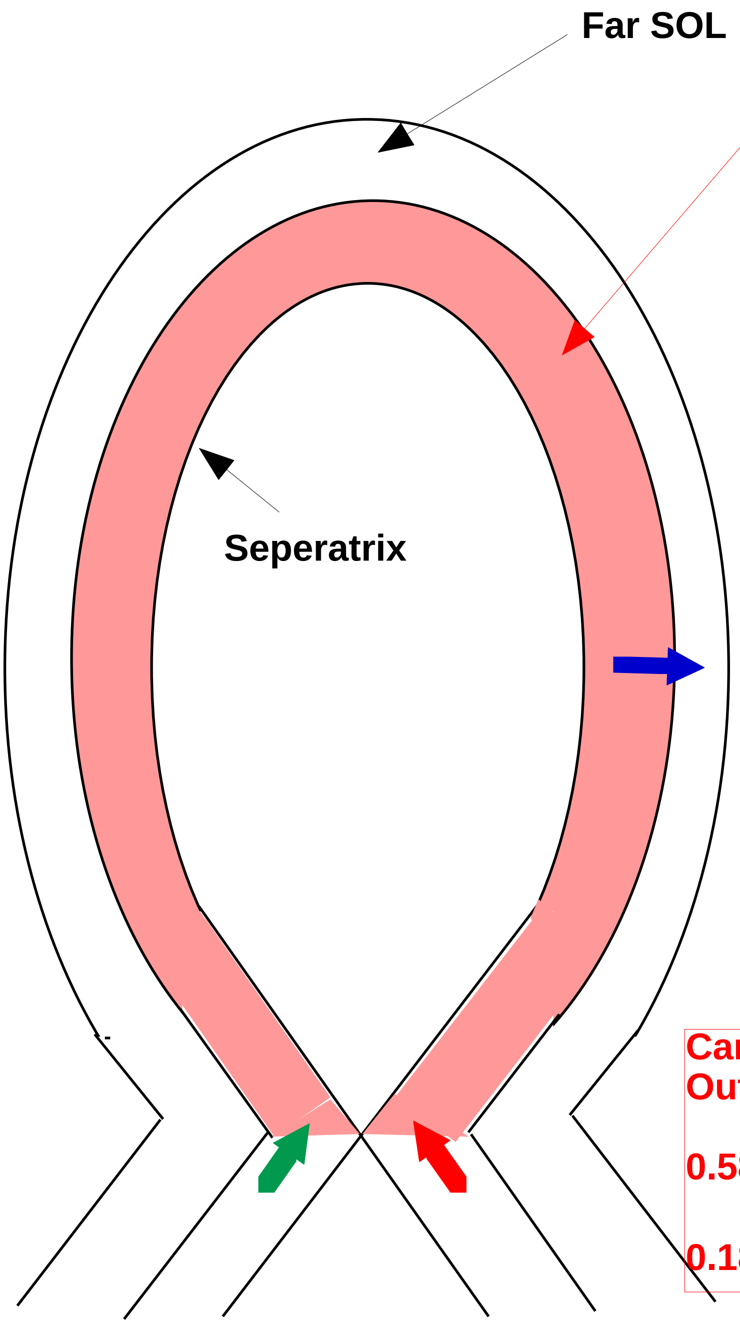
- Near the seperatrix, the T_i force is strong and “pulls” the carbon ions upstream to the midplane SOL

- Once near the midplane, carbon ions flow radially outward to the far SOL. In a steady state UEDGE solution, the impurity ions must return to the divertor plates due to the zero flux boundary condition at the main chamber wall

- In the far SOL, the impurity ion pressure builds until the ions are able to overcome the smaller T_i force in this region and flow back to the divertor plate.

- It’s then plausible that the parallel transport in the far SOL is controlling the midplane impurity density near the seperatrix.

Net Carbon Flow Into and Out of Near SOL Proportional to Sputtering Coefficient



Carbon Flux from Near to Far SOL

1.39 C/s for $Y_{sput}=1.0$

0.665 C/s for $Y_{sput}=0.5$

Carbon flux from Outer Div to Near SOL

0.587 C/s for $Y_{sput}=1.0$

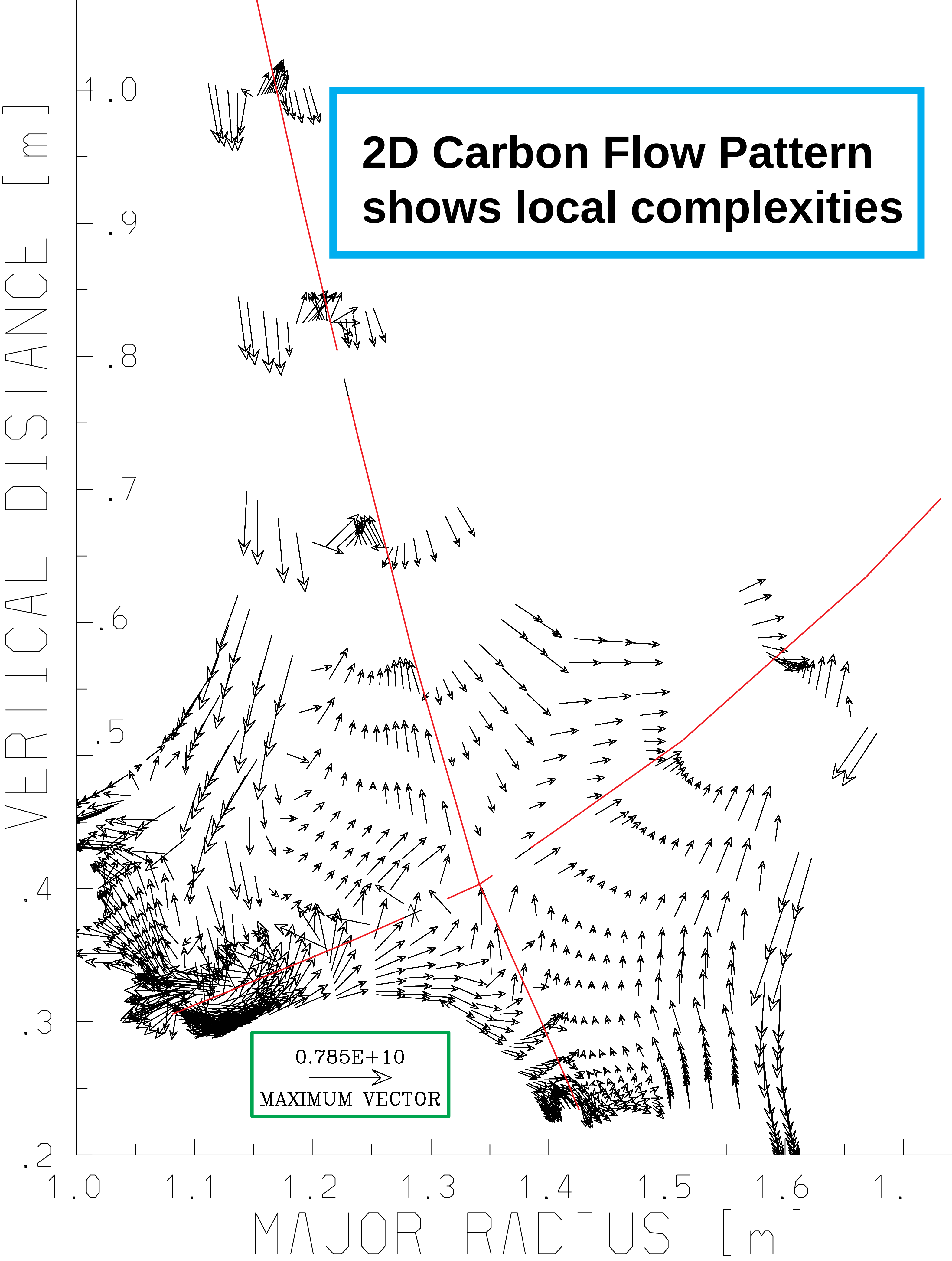
0.185 for $Y_{sput}=0.5$

Carbon flux from Inner Div to Near SOL

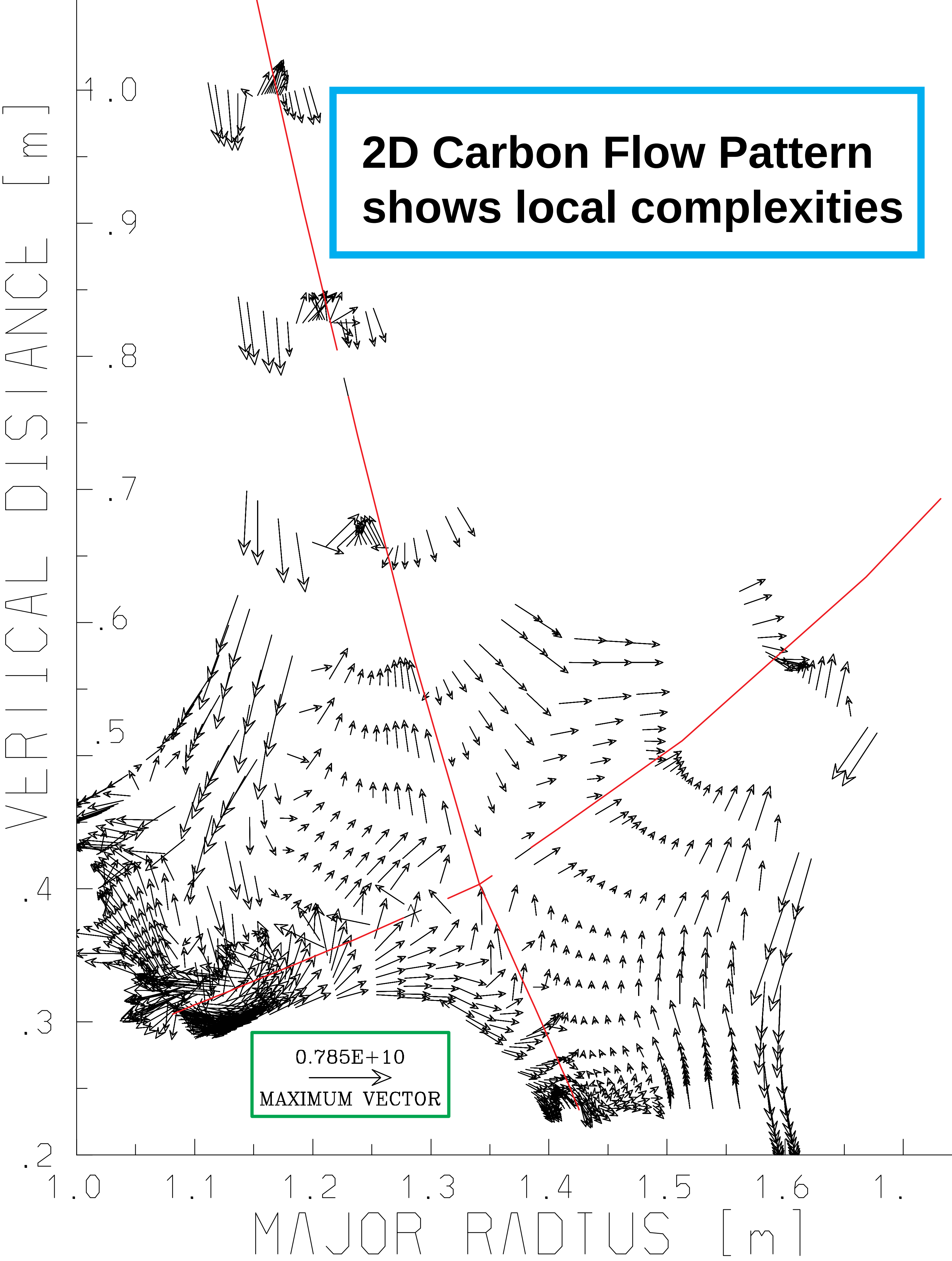
0.689 C/s for $Y_{sput}=1.0$

0.465 for $Y_{sput}=0.5$

2D Carbon Flow Pattern shows local complexities



2D Carbon Flow Pattern shows local complexities



Summary

For these 5MW H-mode like UEDGE solutions using the open DIII-D LSN geometry with a detached inner divertor and an attached outer divertor:

- Core carbon content drops, but less than linearly, with divertor sputtering rate
- Carbon flux into the near SOL varies more closely with sputtering rate
- The radial gradient scale length of the C^{+6} density in the SOL drops as the sputtering coefficient is dropped, dropping the cross field radial flux from the near seperatrix region into the far SOL. The impurity density near the seperatrix is therefore maintained.
- The validity of the zero ion flux main chamber boundary condition used in this study is called in question. Also, the validity of a fluid model in the low collisionallity region of the outer SOL is called into question.
- The main chamber wall source is not modeled well by UEDGE and has been set to zero in this study. It is clear that a divertor carbon source is sufficient to provide significant carbon to the core plasma