ONION-SKIN METHOD (OSM) ANALYSIS OF DIII–D EDGE MEASUREMENTS

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ABSTRACT

- OSM analysis provides, in principle, a method for identifying the 2-D edge "fields" of n_e, T_e, T_i, etc, which is the prerequisite for analyzing the physics processes occurring in the edge, including impurity behavior

- In order to further test this method, an OSM analysis of an extensive edge database for an L–mode DIII–D discharge has been carried out, the first part of which is reported here

- Consistency of OSM results with Langmuir probe, D_α, and edge Thomson scattering measurements encourages further development of the method

OBJECTIVE

What's wanted:

The 2-D "fields" of the primary quantities n_e, T_e, T_i, $v_{||}$, V throughout the SOL and divertor

What we've got:

— Measurements here and there of some of these quantities, e.g. from probes, Thomson

— Measurements of some secondary quantities, e.g. poloidal distribution of D_α

The Task:

Piece the 2-D fields together from this limited database

One Method: Onion-Skin Method, OSM, Analysis

ORGANIZATION OF THIS POSTER

- 1st column: Abstract etc.
- 2nd column: OSM description
- 3rd column: the DIII–D shot
- 4th, 5th columns: comparisons of OSM results with measurements

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ONION-SKIN METHOD, OSM, ANALYSIS

- Solve the 1-D, along-B, plasma conservation equations using across-B boundary conditions from experiment, e.g. I_{sat}^{+} and T_e across targets from Langmuir probes to produce a 2-D solution

- The plasma solver is iterated with a 2-D neutral code, EIRENE, to provide the particle, momentum and power terms associated with hydrogen recycle

- $D_{\perp}^{SOL}$ and $\chi_{\perp}^{SOL}$: not required as input. The cross-field information is implicitly contained in the cross-field boundary conditions. In fact, they can be extracted from OSM analysis ($\Rightarrow$ "Edge TRANSP")

Comparing Standard 2–D FLUID AND OSM, First the . . .

STANDARD 2–D FLUID EQUATIONS, e.g. UEDGE

(Cylindrical geometry for illustration; use actual curvilinear, toroidal grid)

Solve for r and $s_{||}$ directions simultaneously:

1. Particles

$$\frac{\partial}{\partial s_{||}}\left(n v_{||}\right) = S_p^{neut}\left(r, s_{||}\right) + S_{p\perp}$$

where: $$S_{p\perp} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\Gamma_r\right) \quad \text{and} \quad n v_r \equiv \Gamma_r = -D_\perp \frac{\partial n}{\partial r} - n v_{pinch}$$

2. Momentum

$$\frac{\partial}{\partial s_{||}}\left(p_i + p_e + m_i n v_{||}^2 + \pi_i\right) = S_{mom}^{neut}\left(r, s_{||}\right) + S_{mom\perp}$$

where: $$S_{mom\perp} = \frac{1}{r}\frac{\partial}{\partial r} r\left[m_i v_{||}\Gamma_r\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\, \eta_\perp \frac{\partial v_{||}}{\partial r}\right]$$

3. Ion Energy

$$\frac{\partial}{\partial s_{||}}\left[\left(\frac{5}{2}p_i + \frac{1}{2} m_i n v_{||}^2 + \pi_i\right) v_{||} - \kappa_{oi} T_i^{5/2}\frac{\partial T_i}{\partial s_{||}}\right] = + e n v_{||} E_{||} + Q_{eq} + Q_{Ei}^{neut}\left(r, s_{||}\right) + S_{Ei\perp}$$

where: $$S_{Ei\perp} = \frac{1}{r}\frac{\partial}{\partial r} r\left[n\chi_\perp^i \frac{\partial (kT_i)}{\partial r} + \left(\frac{5}{2}kT_i + \frac{1}{2}m_i v_{||}^2\right)\Gamma_r\right]$$

4. Electron Energy

$$\frac{\partial}{\partial s_{||}}\left[\frac{5}{2}p_e v_{||} - \kappa_{oe} T_e^{5/2}\frac{\partial T_e}{\partial s_{||}}\right] = -e n v_{||} E_{||} - Q_{eq} + Q_R + Q_{Ee}^{neut} + S_{Ee\perp}$$

where: $$S_{Ee\perp} = \frac{1}{r}\frac{\partial}{\partial r} r\left[\frac{5}{2}kT_e\Gamma_r + n\chi_\perp^e \frac{\partial (kT_e)}{\partial r}\right]$$

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Use neutral code, e.g. EIRENE, *iterativel*y, to get S^{neut} , Q^{neut} terms

next, the . . . "ONION-SKIN" METHOD OSM EQUATIONS

PARALLEL — AND S^{neut} –TERMS are the same as in 2-D fluid models

Apply to each flux-tube individually:

1. Particles:

$$\frac{d}{ds_{\parallel}}\left(nv_{\parallel}\right) = S_p^{neut}\left(r, s_{\parallel}\right) + S_{p\perp}$$

$\int_0^L S_{p\perp}$ KNOWN from particle balance. Spatial variation of $S_{p\perp}$ to be SPECIFIED

2. Momentum:

$$\frac{d}{ds_{\parallel}}\left(p_i + p_e + m_i n v_{\parallel}^2 + \pi_i\right) = S_{mom}^{neut}\left(r, s_{\parallel}\right) + S_{mom\perp}$$

$\int_0^L S_{mom\perp}$ KNOWN from particle balance. Spatial variation of $S_{mom\perp}$ to be SPECIFIED

3. Ion Energy:

$$\frac{d}{ds_{\parallel}}\left[\left(\frac{5}{2}p_i + \frac{1}{2}m_i n v_{\parallel}^2 + \pi_i\right)v_{\parallel} - \kappa_{oi} T_i^{5/2}\frac{dT_i}{ds_{\parallel}}\right] = +env_{\parallel}E_{\parallel} + Q_{eq} + Q_{Ei}^{neut}\left(r, s_{\parallel}\right) + S_{Ei\perp}$$

$\int_0^L S_{Ei\perp}$ KNOWN from particle balance. Spatial variation of $S_{Ei\perp}$ to be SPECIFIED

4. Electron Energy:

$$\frac{d}{ds_{\parallel}}\left[\frac{5}{2}p_e v_{\parallel} - \kappa_{oe} T_e^{5/2}\frac{dT_e}{ds_{\parallel}}\right] = -env_{\parallel}E_{\parallel} - Q_{eq} + Q_R + Q_{Ee}^{neut} + S_{Ee\perp}$$

$\int_0^L S_{Ee\perp}$ KNOWN from particle balance. Spatial variation of $S_{Ee\perp}$ to be SPECIFIED

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Use neutral code, e.g. EIRENE, *iterately*, to get S^{neut}, Q^{neut} terms

OSM OPTIONS FOR SPECIFYING $S_{p\perp}$, $S_{mom\perp}$, $Q_{Ei\perp}$, $Q_{Ee\perp}$

- To mimic the standard diffusive assumption use:

$$S_{p\perp} = \text{constant x } (\partial^2 n/\partial r^2) \quad \text{etc.}$$

where $\partial^2 n/\partial r^2$ is known from iteration, thus one can extract the constant, i.e. extract

$$D_\perp^{SOL}, \ \chi_\perp^{SOL}$$

- Or simply use $S_{p\perp}$ = constant, or $\propto$ n, or $\propto \partial n/\partial r$,

after all, we don't actually know if cross-field transport is diffusive, and if diffusive, we don't know if $D_\perp^{SOL}$, $\chi_\perp^{SOL}$ are spatially constant, etc.

GOOD NEWS:

The solutions are often insensitive to the *spatial distribution* of $S_{p\perp}$, $S_{mom\perp}$, $Q_{Ei\perp}$, $Q_{Ee\perp}$, particularly when the boundary conditions are imposed at the downstream, *target* end

OSM ANALYSIS OF A DIII–D L–MODE DISCHARGE

- DIII–D shot no. 86575: lower single null, L–mode, P_{NB} = 0.85 MW, $n_{eo} = 2.1 \times 10^{19}$ m^{-3}

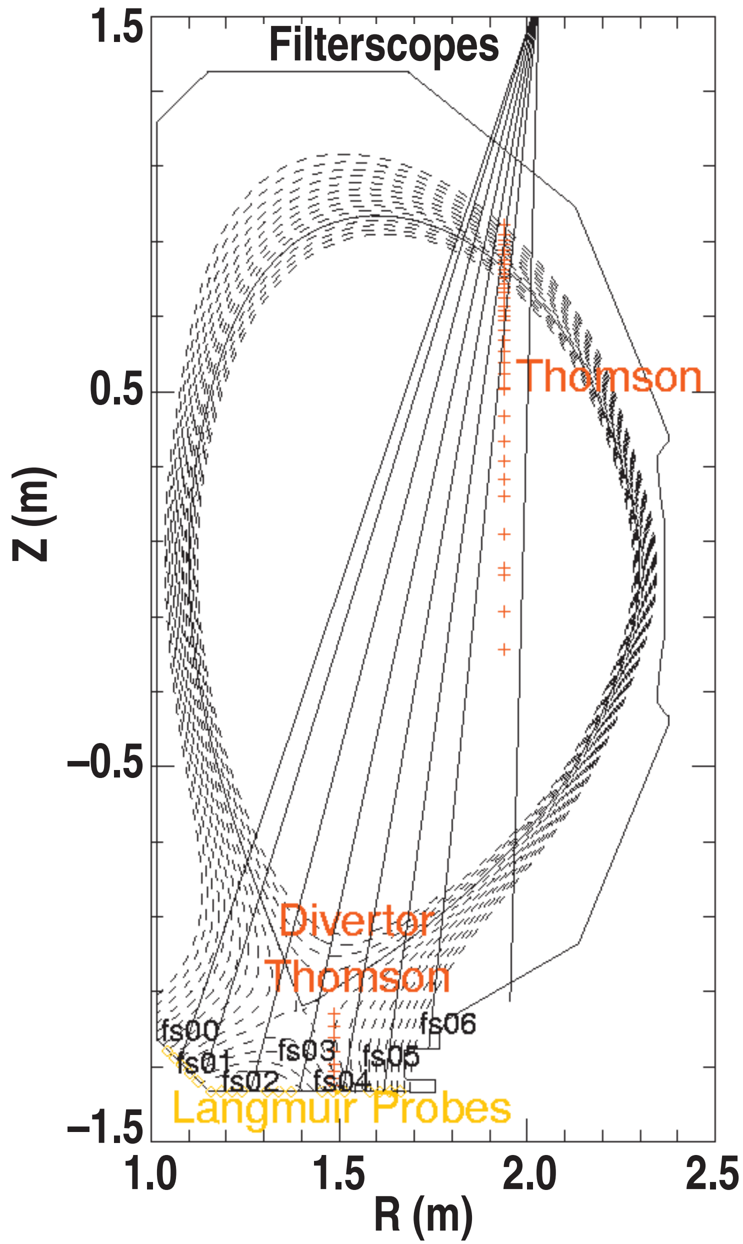
- Divertor Thomson Scattering, DTS, measured n_e and T_e along R = 1.49 m X–point was swept to map out the divertor plasma

- An array of Langmuir Probes built into the divertor targets measured T_e and I^{+}_{sat} across the targets

- The poloidal distribution of D_{α} light across the divertor measured by a calibrated "filterscope"

- An Upsteam Thomson Scattering System measured n_e and T_e across the SOL and main plasma

MAGNETIC EQUILIBRIUM FOR SHOT 86575 AT 1650 ms SHOWING LOCATION OF EDGE DIAGNOSTICS



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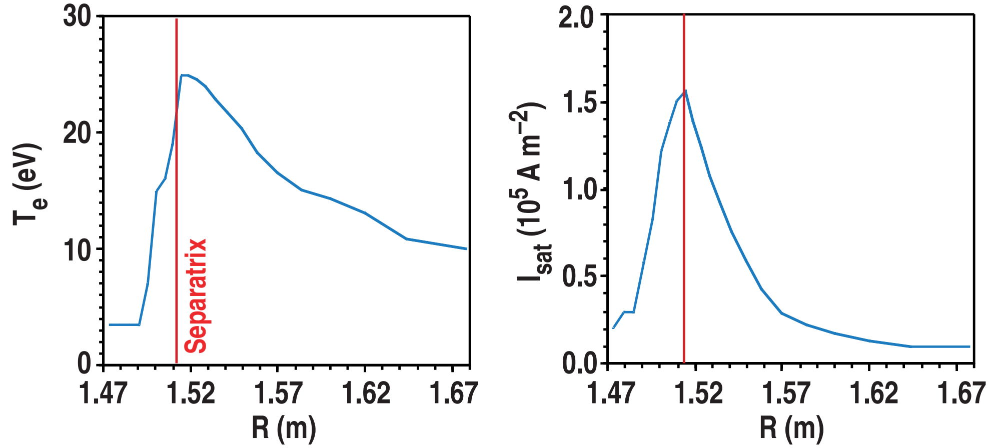
EFIT

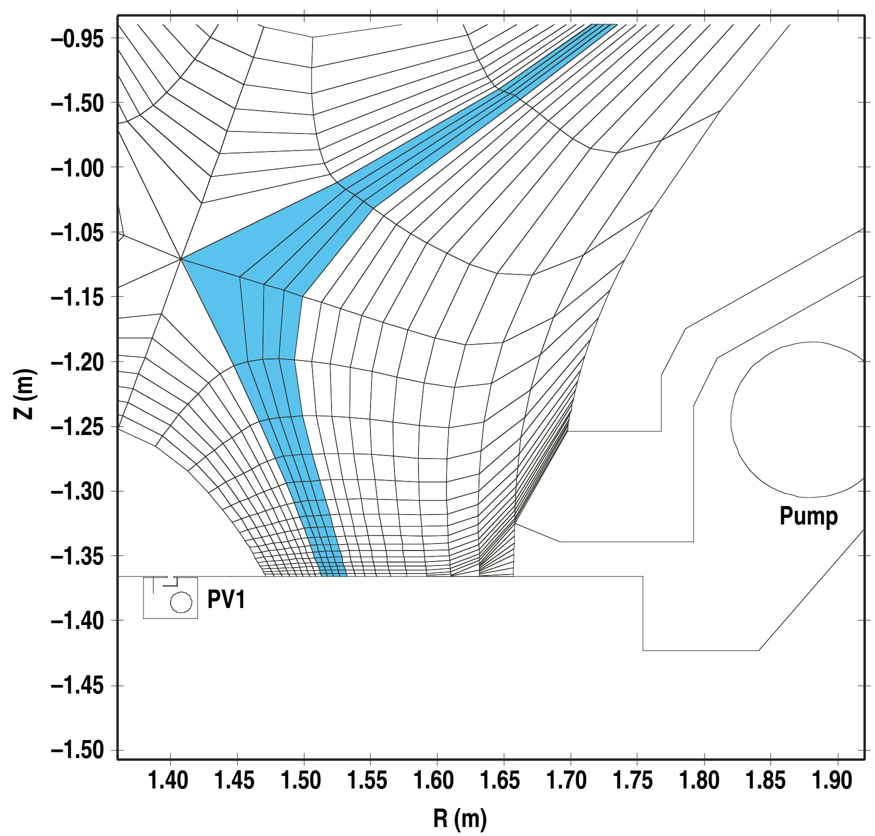
- OSM analysis depends centrally on the validity of the computational grid
- Grid is generated from EFIT analysis, e.g. of magnetic pickup coil data
- EFIT uncertainties are ~ 1 cm, e.g. in locating separatrix
- This is same order as SOL radial scale lengths
- Experimental data were therefore shifted relative to the computational grid by up to ~1 cm, to see if this would give a match between the OSM-calculated and measured values of n_e, T_e, etc. e.g. from Divertor and Upstream Thomson

UEDGE CODE ANALYSIS

- A first-cut, multifluid UEDGE analysis (Gary Porter) was also carried out for this shot/time
- Input: $\chi_{\perp e}^{SOL} = \chi_{\perp i}^{SOL} = 2.5\ m^2/s$, $D_{\perp}^{SOL} = 0.625\ m^2/s$
- Input: recycling coefficient at the walls and targets of unity
- Input: carbon physical and chemical sputtering from the Toronto database (Davis and Haasz, 1996 PSI)
- Input: plasma density was set to match the experimental value upstream near the separatrix



I_{sat}^{+} and T_e from Target Langmuir Probes



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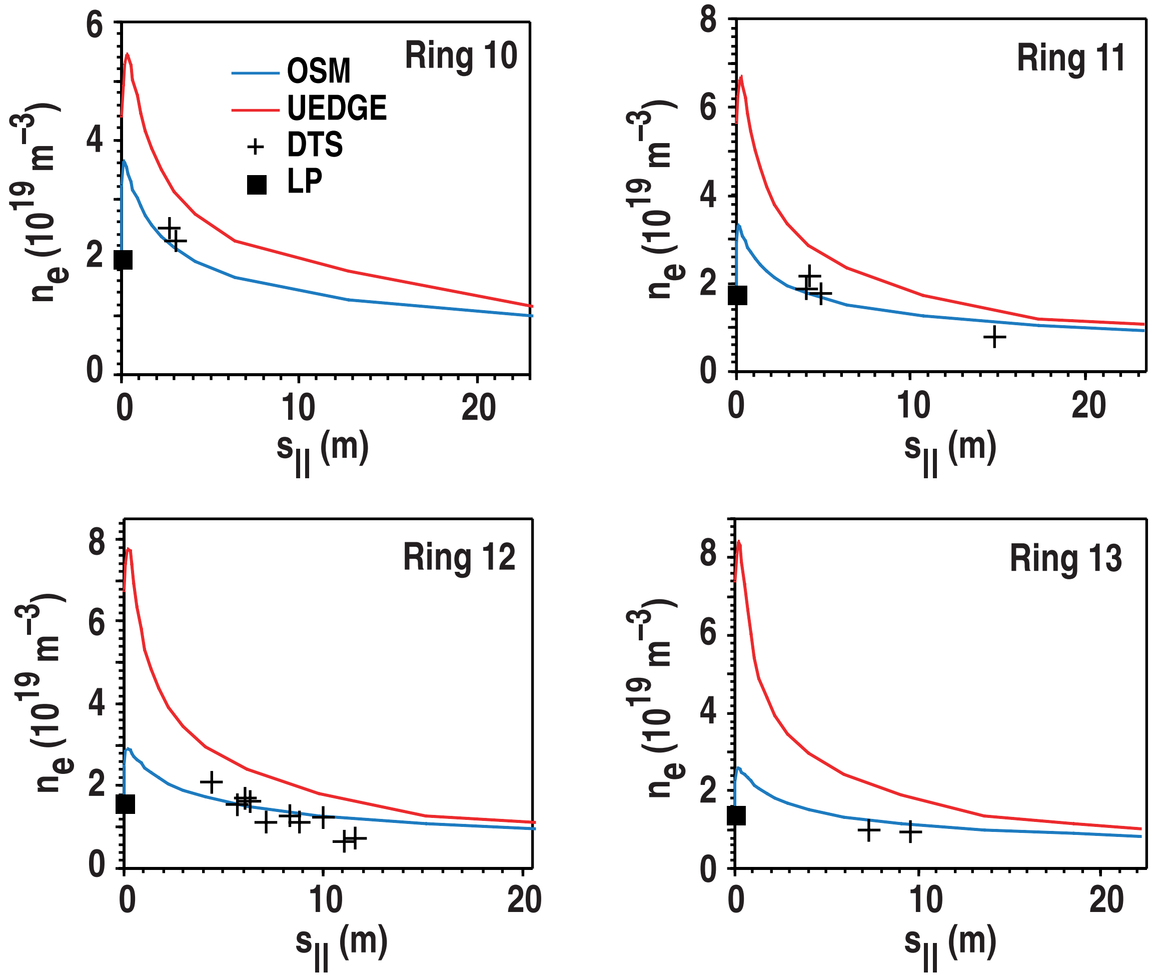
Computational Grid

COMPARISON OF OSM AND DIVERTOR THOMSON n_e



- n_e ($s_{||}$) profiles for the first 4 computational "rings" (onion skins) in the SOL, see earlier figure
- Thomson: crosses
- OSM: blue line
- UEDGE code: red line
- The OSP starts from the Langmuir probe values at the target (squares)
- All data have been shifted by $\Delta R = -10$ mm relative to the EFIT-based computational grid

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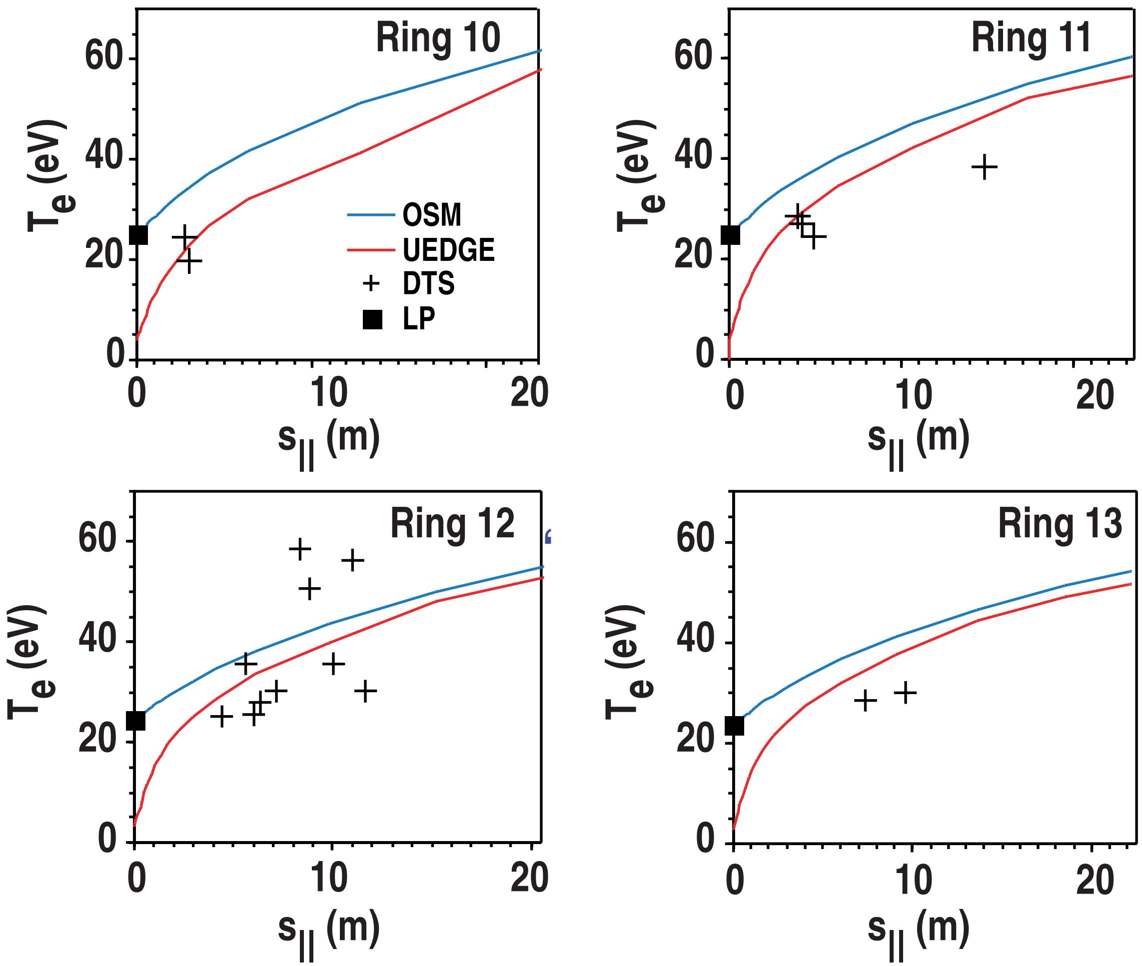
COMPARISON OF OSM AND DIVERTOR THOMSON T_e



- T_e ($s_{||}$) profiles for the first 4 computational "rings" (onion skins) in the SOL, see earlier figure
- Thomson: crosses
- OSM: blue line
- UEDGE code: red line
- The OSP starts from the Langmuir probe values at the target (squares)
- All data have been shifted by ΔR = –10 mm relative to the EFIT-based computational grid

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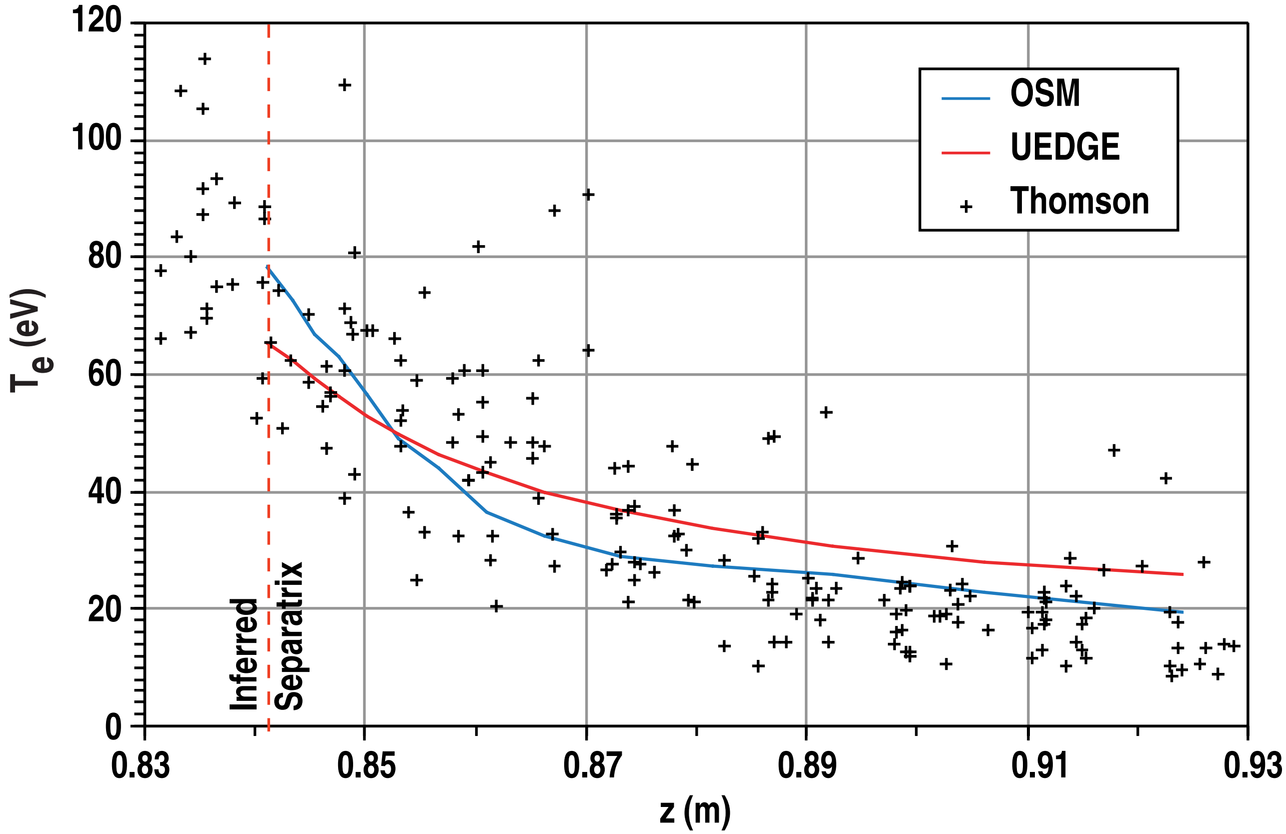
COMPARISON OF OSM AND UPSTREAM THOMSON T_e



- T_e(Z) profiles along the line of the Upstream Thomson
- Thomson: crosses
- OSM: blue line
- UEDGE code: red line
- Thomson data have been shifted by ΔZ = +15 mm relative to the EFIT-based grid

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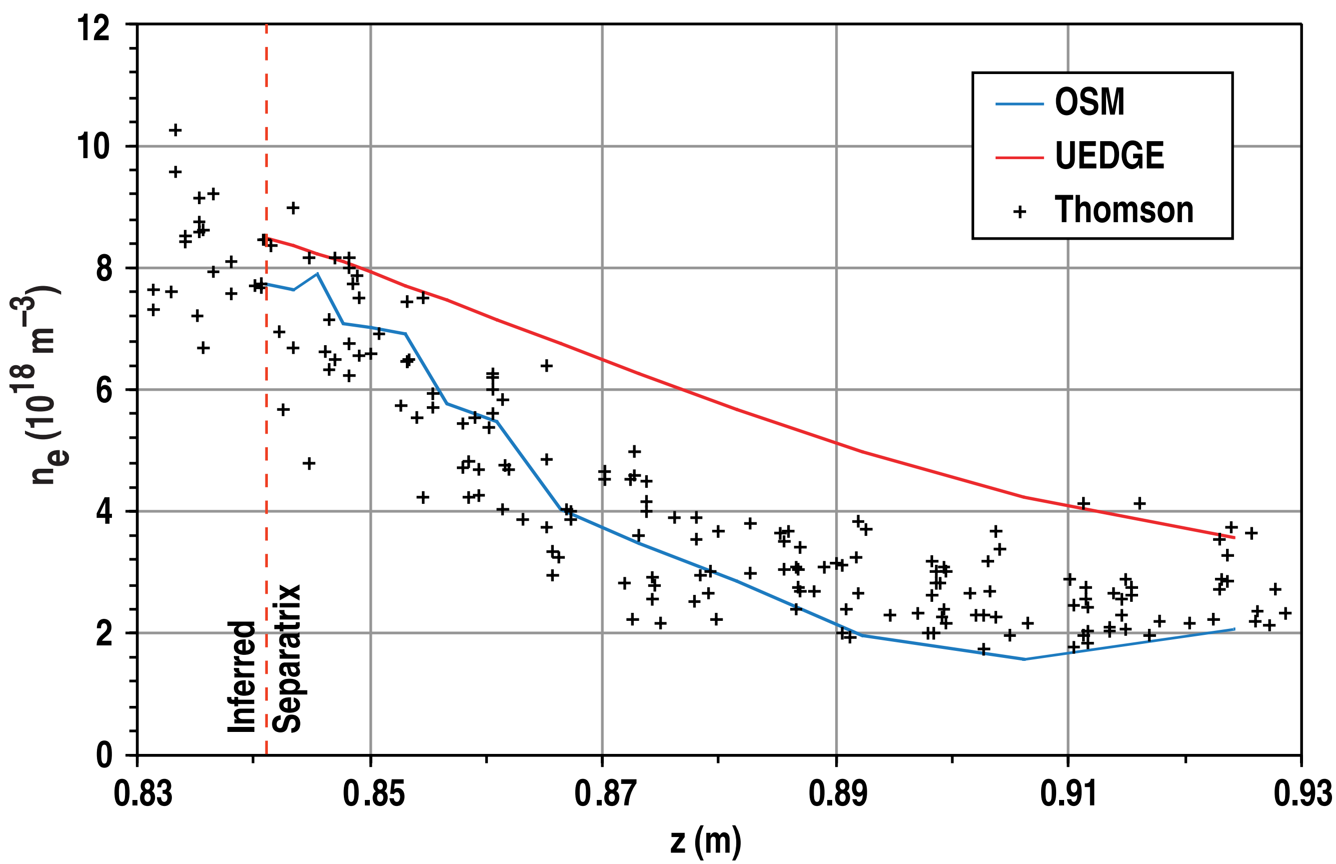
COMPARISON OF OSM AND UPSTREAM THOMSON n_e



- n_e(Z) profiles along the line of the Upstream Thomson
- Thomson: crosses
- OSM: blue line
- UEDGE code: red line
- Thomson data have been shifted by ΔZ = +15 mm relative to the EFIT-based grid

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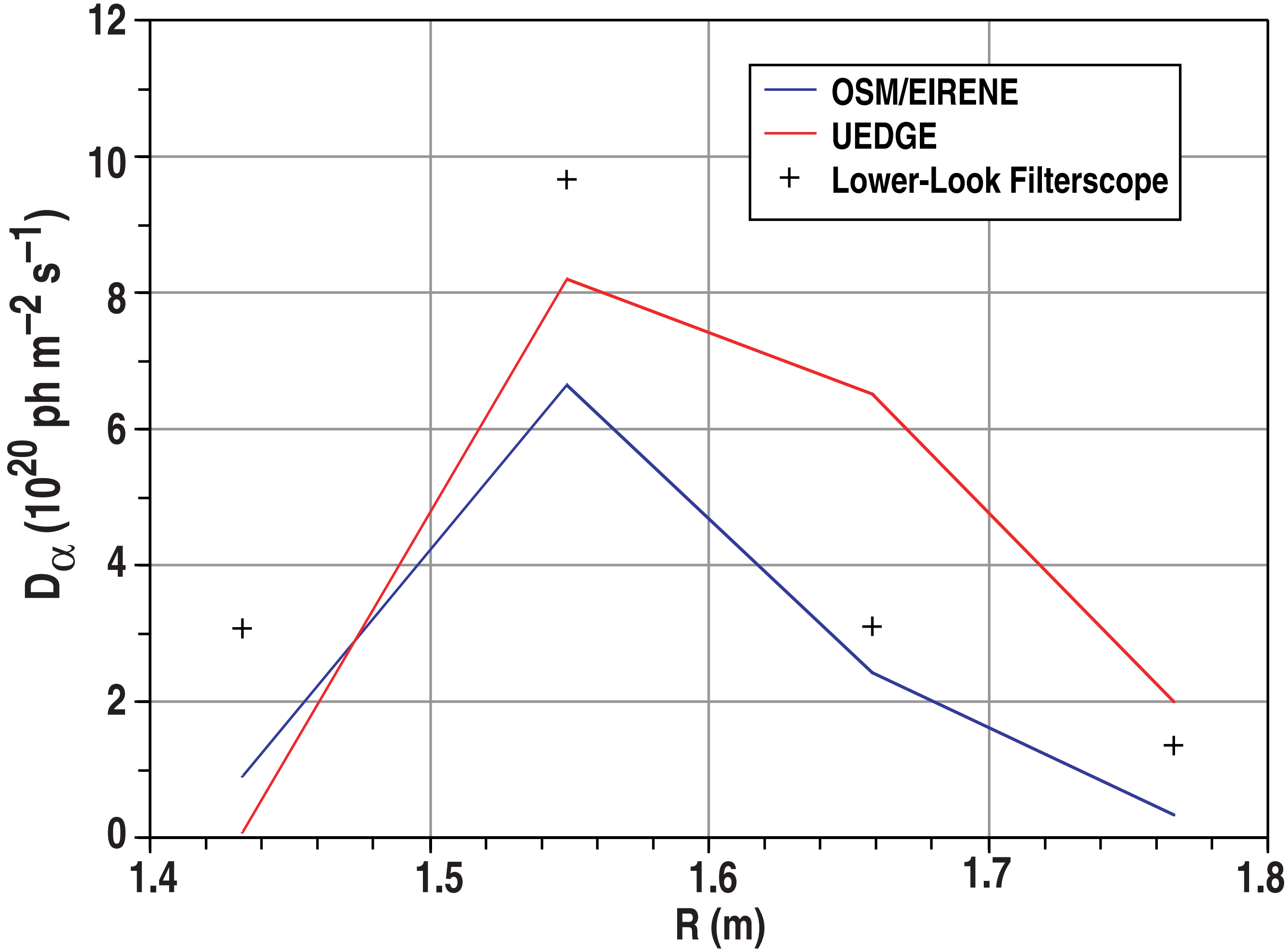
COMPARISON OF OSM AND MEASURED D_α POLOIDAL DISTRIBUTION



- D_α emissivity (photons/m^2/s) across the outer target
- Experiment (filterscope): crosses
- OSM: blue line
- UEDGE code: red line

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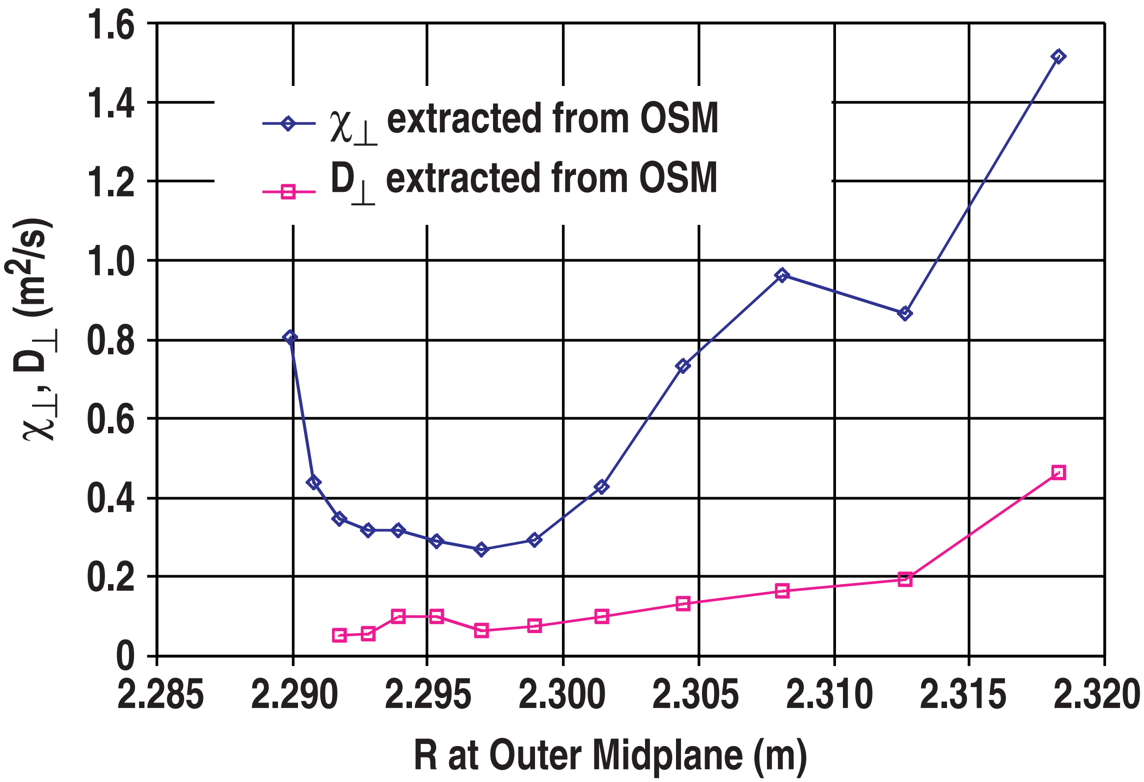
VALUES OF $D_\perp^{SOL}$ AND $\chi_\perp^{SOL}$ EXTRACTED FROM THE OSM ANALYSIS



- Cross-field ion and electron power flows were added, so the $\chi_\perp^{SOL}$ value is an average of $\chi_{\perp e}^{SOL}$ and $\chi_{\perp i}^{SOL}$
- The trend for $\chi_\perp^{SOL}$ (r) to increase with distance into the SOL has also been reported for JET

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CONCLUSIONS

- OSM analysis has been tested against a larger edge data set than before
- OSM results are within error/scatter of Langmuir probe, D_{α}, and edge Thomson measurements, encouraging further testing and development of the method
- A number of issues remain to be addressed:
  - — EFIT uncertainties license data shifting, but may “sweep under the carpet” real discrepancies, missing physics, etc.; analysis of other discharge types, direction of B, and yet larger edge sets, are required
  - — Thomson data are particularly valuable, but have substantial scatter (Thomson samples the fluctuations). Un-swept, averaged data required
  - — Detachment, PFZ, and impurity modeling are still to be tackled
  - — Coupling to UEDGE code