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EFFECT OF DIVERTOR GEOMETRY ON FUELING PROFILE OF THE CORE PLASMA IN LOW-DENSITY, OHMIC PLASMAS IN ASDEX UPGRADE AND DIII-D

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Effect of Divertor Geometry on Fueling Profile of the Core Plasma in Low-Density, Ohmic Plasmas in ASDEX Upgrade and DIII-D

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Detailed measurements in, and modeling of ASDEX Upgrade and DIII-D Ohmic plasmas were carried out in an attempt to elucidate the effect of divertor geometry on the core plasma fueling profile. Nearly identical upstream plasma parameters were obtained in both devices for a low-density, Ohmic plasma. Weak dependence of the divertor plasmas on the divertor closure was observed: in both devices the outer divertor plasma is attached to the target plate, while the inner divertor plasma is partially detached at the strike point. The experimental and simulation data are stored in MDSplus-based databases to ease the comparison of the two devices. UEDGE simulations validated against the experimental data predict more neutral leakage out of the inner divertor plasma for DIII-D causing a broader neutral fueling profile above the high-field X-point. For both devices the simulations indicate strong ion fueling at the top of the plasma due to classical ion $\mathbf{B}\times\nabla B$ drifts.

I. Goals and Methodology

With the overarching goal of determining the poloidal profile of core plasma fueling as a function of divertor geometry, similarity experiments were carried out in the ASDEX Upgrade (AUG) and DIII-D tokamaks emphasizing detailed measurements of the plasma parameters for benchmarking of scrape-off layer (SOL) models. Validation of computer codes simulating the processes in the plasma edge region (to the extent that they are known) against experimental data is of great importance since these codes are used to aid the design of the next-step magnetic fusion device, ITER. Given sufficient confidence in the obtained numerical solution, the code can be exercised to calculate the poloidal fueling profiles across the separatrix and pedestal.

Similar in size (e.g., AUG and DIII-D major radius ~1.7 m), the lower divertor target plates in AUG are aligned vertically representing a closed divertor geometry (with respect to neutrals), whereas the geometry of the lower DIII-D divertor is open with the outer plates being horizontal and the inner plate tilted by 45 degrees against the horizontal plane. Closed divertor geometries can more readily access divertor detachment [1]. In this study, the AUG and DIII-D target tiles were made of graphite, and graphite is also used as the plasma-facing components (PFCs) in the DIII-D main chamber. In contrast, the PFCs in the AUG main chamber are made of tungsten. The comprehensive sets of diagnostics installed in the lower divertor of the two devices were exploited by running lower single null (LSN) discharges with target strike point sweeps. The toroidal magnetic field was in the "forward" direction, with the ion **B**x∇B drift pointing toward the lower divertors. To ease the analysis, plasmas with low, dominant-Ohmic heating were performed. The plasma density was varied in separate plasma discharges, covering a range of 25% to 50% of the Greenwald density (n_{GW}).

The presented comparison of cross-device measurements and simulations takes advantage of two profile databases for the edge region, built and populated with experimental and modeling results from this study. The experimental database for the SOL is part of the pedestal database previously established under the auspices of the International Tokamak Physics Activity (ITPA) [2], and uses, as its parent, a MDSplus data structure. Data specific to the SOL encompass the profiles of ion saturation current and heat flux to the divertor plates, divertor electron density and temperature, total radiation, and line emission from the main plasma constituents. Other data may be added as they become available. Similarly, MDSplus-based data structures were developed for the outputs of 2-D fluid codes [3], including synthetic diagnostics, to facilitate the comparison of code results and experimental data.

II. Experimental Results

Our initial analysis concentrated on the Ohmic plasma at the lowest density: $\langle n_e \rangle$ = 2.6x10^{19} m^{-3} (25% of n_{GW}). Additional operational parameters are given in Table I. Between the two devices the profiles of upstream electron density and temperature as measured by Thomson scattering near the outer midplane region are nearly identical in the SOL and near-separatrix core region [Fig. 1(a,b)]: $n_{e,sep}$ ~ 7x10^{18} m^{-3} and $T_{e,sep}$ ~ 50 eV. The ion temperatures at the separatrix as measured by lithium beam (AUG) and charge exchange recombination spectroscopy on the neutral deuterium beam (DIII-D) are also similar for the two devices, and they are significantly higher than those of the electrons: $T_{i,sep}$ ~ 150 eV [Fig. 1(c)].

Despite the AUG divertor being more closed than the DIII-D divertor, the plasma conditions in front of the inner and outer target plate are rather similar. Langmuir probes [LP; Fig. 2(a,b)] and infrared cameras (IRTV) measurements suggest that in both devices the outer divertor plasma is well attached to the plate, while the inner divertor plasma was partially detached at the inner strike point. For DIII-D, both the LP and IRTV profiles at the inner plate show the ion and heat flux peaking ~5-10 cm radially inboard of the inner strike point. This observation has yet to be explained. Noteworthy is also the agreement of the measured ion saturation current profiles in AUG and DIII-D, despite different probe designs being used in AUG the LPs are flush-mounted, while in DIII-D a protruding (domed) design is adapted. Partial detachment of the inner divertor plasma is also supported by measurement of the 2-D distribution profiles of emission from deuterium neutrals (AUG), and singly and doubly ionized carbon (DIII-D).

Table I. Main plasma parameters of AUG and DIII-D Ohmic plasmas at line-averaged density $\langle n_e \rangle = 2.6 \times 10^{19}$ m^{-3}. The toroidal magnetic field, B_T, is in the "normal" direction.

	AUG	DIII-D
Discharge #	21303	119919
I_p (MA)	1.0	1.1
B_T (T)	-2.0	-2.0
q_{95}	3.4	3.9
δ_{low}	0.3	0.5
P_{input} (MW)	0.7	0.9
P_{rad} (MW)	0.4	0.4

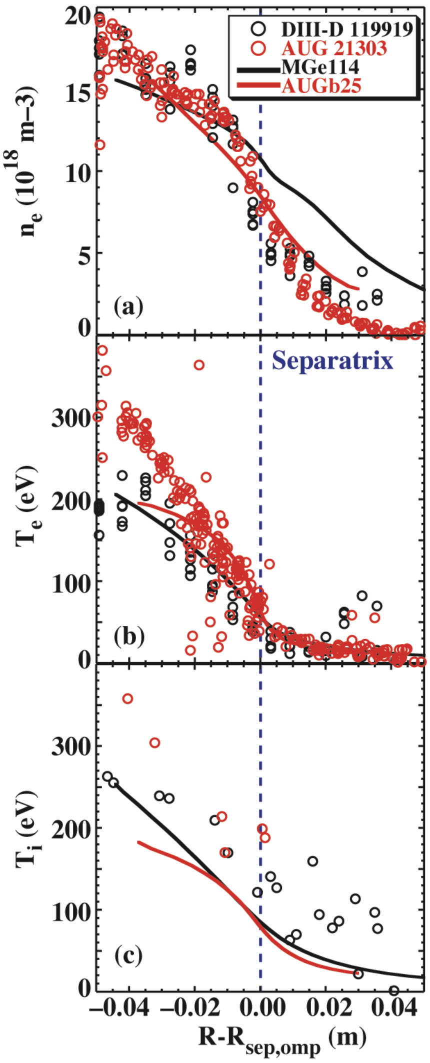

Fig. 1. Measured electron density (a), electron temperature (b), and ion temperature (c) mapped to the outer equatorial plane in AUG (red) and DIII-D (black) Ohmic plasmas at line-averaged density $\langle n_e \rangle = 2.6 \times 10^{19}$ m^{-3}. The data is compared to UEDGE runs MGe114 for DIII-D and AUGb25 for AUG.

III. UEDGE Modeling

Detailed modeling and validation against the experimental data presented here was carried out with the UEDGE code [4]. UEDGE uses the fluid approach and solves, in the parallel magnetic field direction, the Braginskii equations, including the ion **B**x∇B and **E**x**B** terms [5], while a prescribed diffusive model is assumed in the direction perpendicular to the field. Hydrogenic neutrals are treated as an additional fluid species, including parallel inertia and neutral-neutral collisions. Physical and chemical sputtering/erosion of carbon due to deuterium ions and neutrals are assumed at the plates, and chemical erosion is included at the main chamber wall for DIII-D, using published yields [6,7]. Carbon transport is modeled by using a force balance equation in the parallel field direction, and imposed diffusion in the direction perpendicular to the field. The modeling domain encompasses regions of the core, SOL, and private flux: $0.9 \le \Psi_N \le 1.08$ (AUG)/1.15 (DIII-D), where Ψ_N is the normalized poloidal flux. The particle and heat fluxes across the outermost grid boundary are constrained by reciprocating Langmuir probe measurements in the outer midplane SOL.

Similar, spatially constant diffusion coefficients ($D_{\perp,AUG,DIII\text{-}D} = 0.8$ m^2/s) and ion thermal diffusivities ($\chi_{i,AUG} = 0.6$ m^2/s, $\chi_{i,DIII\text{-}D} = 0.8$ m^2/s), but significantly higher electron thermal diffusivities for DIII-D ($\chi_{e,DIII\text{-}D} = 2 \times \chi_{e,AUG} = 1.6$) were used to obtain a reasonable match of the numerical solutions to the measured upstream parameters (Fig. 1). To accommodate cryopumping for AUG 10% of the neutral flux across the private flux (PF) boundary is removed from the computational domain. In DIII-D the lower divertor was not pumped in the experiment, however, 2% pumping at the PF wall is needed in the simulations to prevent detachment of the inner and outer divertor plasma. The upstream SOL density is a factor 2 higher in the DIII-D simulation than what was measured, and remains high even if pumping at the PF wall is increased to 10%. Both simulations underestimate the measured ion temperatures [Fig. 1(c)]. At the inner plate, the simulations overestimate the ion flux at the separatrix by a factor 2-3 [Fig. 2(a)], while at the outer plate the agreement between the measurements and simulations is slightly better [Fig. 2(a)]. The predicted electron temperatures at the inner strike point are 3.5 eV and 1.5 eV for AUG and DIII-D, respectively, indicative of a high-recycling divertor plasma. The calculated emission from doubly ionized carbon in the simulation is off the inner target plate as observed in DIII-D.

While the simulations do not reproduce the experimental data completely, some conclusions can be drawn about core plasma fueling. For both devices, UEDGE modeling suggests that the fueling profile is dominated by ion flow across the separatrix into the core at the top of the plasma due to **B**x∇B drift, and ion outflow at the outer plasma region due to diffusion and **B**x∇B drift (Fig. 3). Neutrals fuel the core plasma via the high- and low-field X-point regions. For DIII-D, a broader neutral fueling profile is predicted near the X-point, possibly due to the more open divertor geometry. Ion fueling above the high-field X-point is seen in DIII-D simulations due to the large density in the inner divertor SOL.

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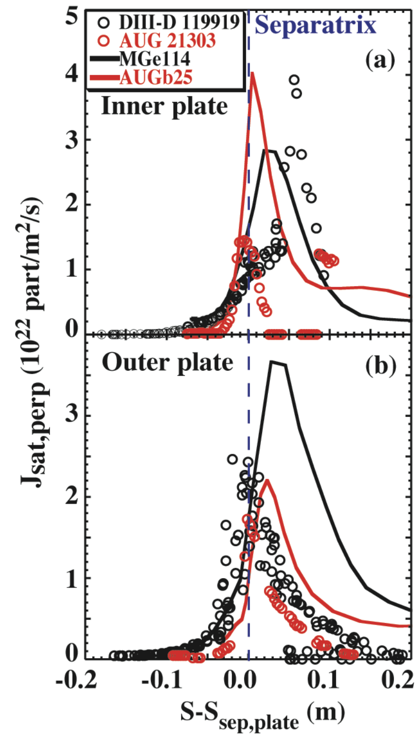

Fig. 2. Perpendicular ion saturation current to inner (a) and outer (b) target plates for experimental and modeling cases as shown in Fig. 1. Negative values on the abscissa denote the private flux region.

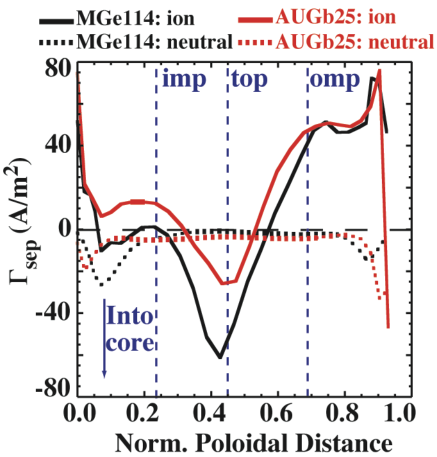

Fig. 3 UEDGE ion and neutral fluxes across separatrix as a function of poloidal distance from the high-field to the low-field magnetic X-point [DIII-D (black), AUG (red)]. A negative particle flux represents transport into the core domain. The labels imp, top, and omp denote the inner midplane, top of the plasma, and outer midplane, respectively.

References

[1] G.C. Vlases, *et al.*, J. Nucl. Mater. **266-269**, 160 (1999).
[2] http://itpa.ipp.mpg.de/pedestal_edge/ profile_database/
[3] D.P. Coster, Proc. of 30th EPS Conf., St. Petersburg, Russia, 2003, P1.169.
[4] T.D. Rognlien, *et al.*, J. Nucl. Mater. **196-198**, 347 (1992).
[5] T.D. Rognlien *et al.*, Phys. Plasmas **6**, 1851 (1999).
[6] W. Eckstein, *et al.*, Max Planck Institute für Plasmaphysik Report **9/82** (1993).
[7] J.W. Davis, *et al.*, J. Nucl. Mater. **241-243**, 37 (1997).