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Orbit-Following Monte Carlo Study of Differences in Divertor Target Ion Load Profiles Between Helium and Deuterium Plasmas in JET

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Abstract. In H-mode deuterium discharges in JET, a sharp load peak on the divertor targets has been observed [1]. The load profiles and mechanisms behind the observed target load asymmetry have recently been studied by orbit-following Monte Carlo methods using the ASCOT code [2]. However, in similar helium discharges where only type III ELMs are present, no sharp feature in the deposition profile has been experimentally observed [3]. The observations from helium plasmas in JET could be interpreted as evidence that type I ELMs might be responsible for the narrow features. To propose another explanation for the observations, ASCOT [4] has been applied to study the differences in the divertor target ion load distributions arising directly from the differences in the thermal velocity and the collisionality of various ion species.

Introduction. Besides the absence of type I ELMs, there are other differences between the deuterium and helium plasmas: in a helium plasma, with plasma parameters similar to those of a corresponding deuterium plasma, direct orbit losses should be efficiently quenched due to the smaller thermal velocity ($v_{th,He} \approx 0.71 v_{th,D}$) and the higher ion-ion collisionality. In the present work, target particle fluxes obtained by Langmuir probe measurements in deuterium and helium plasmas are compared to ASCOT orbit-following Monte Carlo simulation results keeping in mind that ASCOT only models the orbit loss flux and omits fluid-like transport. To see the effect of the mass and charge of plasma ions on the ion component of the divertor loads, a parameter scan of mass number A and charge number Z was made using ASCOT.

Monte Carlo Simulations. The Monte Carlo code ASCOT follows guiding centre orbits of test ions in realistic geometry using the EFIT magnetic equilibrium data and measured core temperature and density profiles of a (JET) discharge. The scrape-off layer (SOL) density and temperature for ions and neutrals are imported from OSM2/EIRENE. The effect of ion-ion collisions on test particle pitch ($v_{\parallel}/v$) and energy are taken into account by using a Monte Carlo model derived from the corresponding Fokker-Planck terms for a Maxwellian background plasma. A simple model for charge exchange (CX) collisions in the SOL is also applied. As the radial electric field E_r inside the separatrix is of consequence to the orbit losses, it is calculated self-consistently during the simulation. A constant prescribed E_r can be applied in the SOL, and has been set to zero in the present work.

To obtain the divertor target load profiles using ASCOT, 420 000 test particles representing the bulk plasma were initially launched between $\rho = 0.96$ and $\rho = 1.0$ and followed

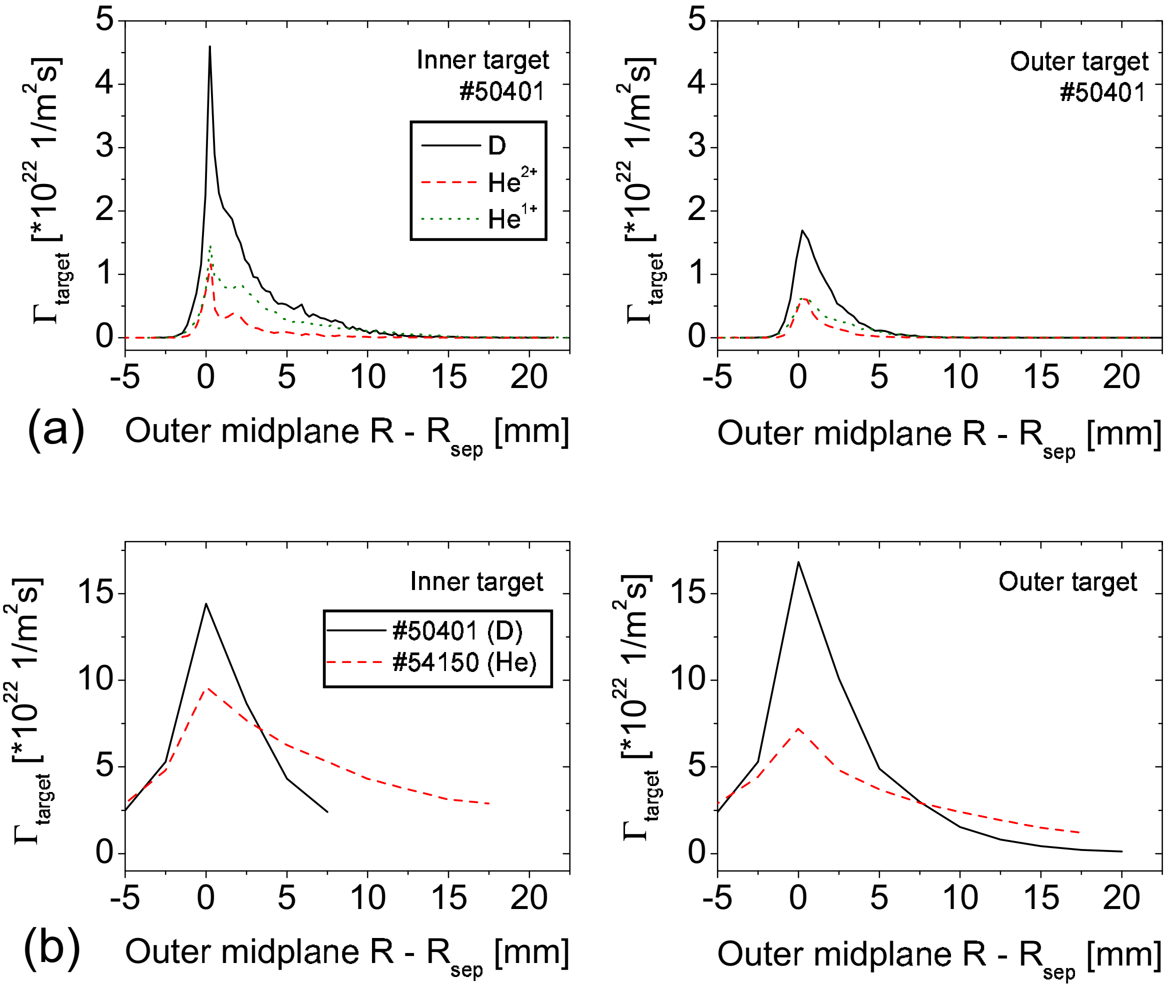

Figure 1: (a) ASCOT simulation of ion flux on the targets for deuterium (solid line) and two charge states of helium (dashed and dotted lines). The magnetic equilibrium and edge plasma temperature of discharge 50401 was used for both simulations. (b) Langmuir probe measurements of particle flux on the inner target and the outer target for deuterium discharge 50401 (solid line) and similar helium discharge 51450 (dashed line). The horizontal axis coordinate is the distance of the magnetic surface at the target from the separatrix, measured along the equator.

for 1 ms. Particles hitting the first wall or the divertor targets were re-initialized in the core in such a way that the test particle distribution inside the separatrix remained constant. By recording the energy and location of the particles hitting the targets, profiles of incident power and particle flux were obtained.

Comparing the results of ASCOT simulations (Fig. 1a) to plasma fluxes observed by the Langmuir probes embedded in the targets (Fig. 1b), a satisfactory qualitative agreement is seen. When switching from deuterium to helium plasma, the peak fluxes are strongly reduced on both targets. On the outer target, a satisfactory agreement of a reduction by a factor of 3 is seen between simulations and measurements. The simulations and measurements both suggest that the peaking of the flux is less pronounced in a helium discharge, and the shapes of the simulated and measured flux profiles are in satisfactory agreement. To explain the difference in the magnitude of the simulation results and the probe measurements, it must be noted that radial and parallel diffusion and convection play an important role in the total particle flux to the targets, and the energetic orbit loss ions modelled by ASCOT in reality contribute only a part of the particle flux, although they can be of more relevance to the target *power* fluxes. Comparison of ASCOT simulations to thermocouple measurements of total power hitting the targets are typically in much better agreement.

The difference in the load asymmetry between the inner and outer target is caused by the assumption of zero SOL radial electric field E_r in the ASCOT simulations. In a real tokamak, a large positive E_r may arise because of e.g. the sheath potential, and has been shown to strongly affect the in-out load asymmetry [2].

The more general effect of plasma ion mass number A and charge Z is demonstrated in Fig. 2. ASCOT simulations were made by changing the bulk ion species A and Z. Increasing the mass and charge of the ions has a clear effect on the target fluxes. When the mass and charge of the ion species are increased, the target power fluxes diminish consistently with the decreasing thermal velocity and the increasing collisionality, which

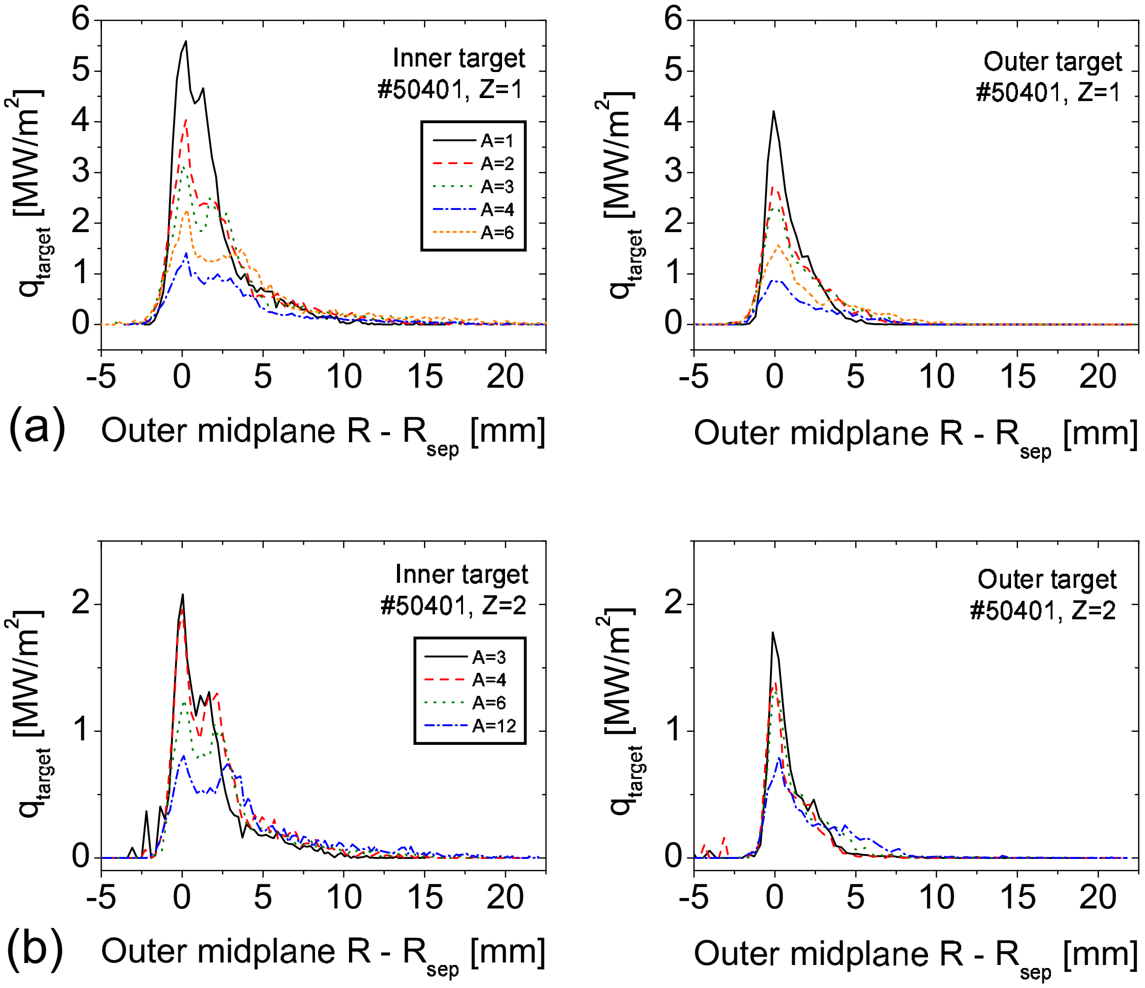

Figure 2: ASCOT simulation of divertor power loads as a function of mass number A (a) for $Z = 1$ and (b) for $Z = 2$ bulk ions.

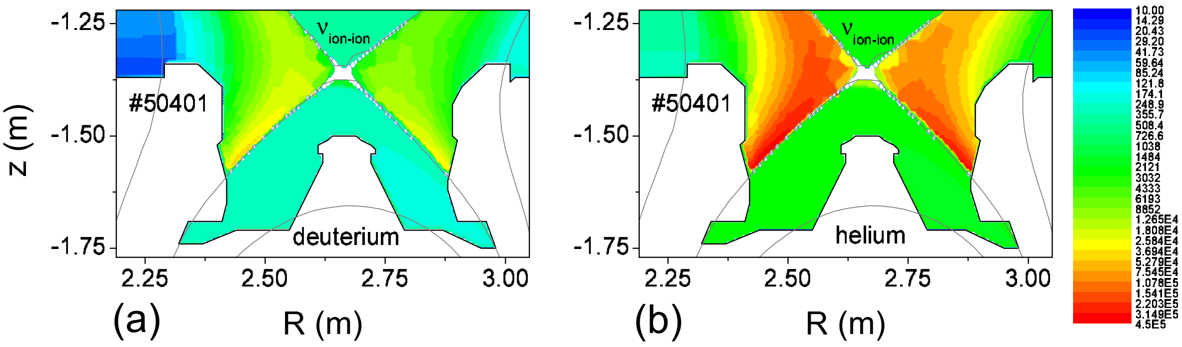

Figure 3: The ion-ion collisionality experienced by a 100 eV ion in the divertor region for (a) deuterium and (b) helium. The test ion is of the same species as the background plasma.

thermalizes the escaping ions more efficiently and spreads the flux on the target more uniformly. The SOL collisionality in the divertor region for a deuterium plasma and a helium plasma is shown in Fig. 3 for a 100 eV ion. It is evident from the simulations that the higher collisionality of heavier multiply-charged ions causes the flux of escaping energetic ions to dissipate in the SOL.

Conclusions. From comparisons of target load simulations made using the ASCOT code, it is evident that the flux distributions on the targets are strongly affected by the differences between various ion species in thermal velocity and in SOL collisionality. Heavier ions escaping from the core plasma have a smaller thermal velocity at a given temperature than lighter ions, and the flux of escaping heavy ions is dissipated in the SOL more efficiently by collisions. This is in agreement with experimental observations of significantly lower target load profiles in a helium plasma with an edge temperature comparable to a reference deuterium plasma.

Especially in the SOL, the ion component of a helium plasma is a mixture of singly and doubly charged ions. In future work, it would be of interest to improve the applied simple CX model to properly take into account the different charge states of multiply-charged ions.

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