Ion Dynamics Observed by High Resolution Spectroscopy in the ASDEX Upgrade Divertor I and II

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1 Introduction

For the optimum control of plasma power, fuel gas, impurities, and helium ash in future fusion reactors it is necessary to study divertor physics in present-day fusion experiments carefully. These studies have to combine detailed modelling with experimental investigations of the spatial and temporal distributions of density, species composition, temperatures and flow velocities of ions. High resolution spectroscopy in the ASDEX Upgrade divertor I was demonstrated to be a suitable technique to obtain experimental information on the spatial and temporal behavior of the dynamics of atoms and ions, i. e. on their temperatures and flow velocities. Combining poloidal lines of sight ($\perp \vec{B}$) with toroidal ones directed along and opposite to the magnetic field lines the atom and ion dynamics in the area between the outer divertor tiles and the X-point as well as in parts of the inner divertor were studied using high resolution spectroscopy [1]. The highly resolved emission spectra are not only determined by the Zeeman splitting, but also by Doppler broadening and Doppler shift, from which the temperatures and flow velocities can be deduced, respectively. By this means the dependencies of ion dynamics on different discharge conditions of ASDEX Upgrade were analyzed [2].

2 Experimental Results on Ion Dynamics in the ASDEX Upgrade Divertor I

Making use of a 2D-CCD camera and a Fastie-Ebert spectrometer with Echelle grating, highly resolved emission spectra of atoms and ions emitting along up to 74 lines of sight (perpendicular, parallel and antiparallel to the magnetic field) were recorded. The characteristic features of these measurements are:

- The HeI line — as a means for probing neutrals not coupled to the magnetic field lines — does not show a significant Doppler shift in ASDEX Upgrade discharges with an attached highly recycling divertor plasma. Hence, the corresponding velocity distribution is isotropic with respect to the poloidal and toroidal lines of sight and, therefore, no preferential flow of neutral helium parallel or perpendicular to the magnetic field lines is observed.
- The emission spectra of all impurity ions show pronounced Doppler shifts due to their coupling to the magnetic field lines. The flow velocities are directed towards the target plates in the outer as well as in the inner divertor.

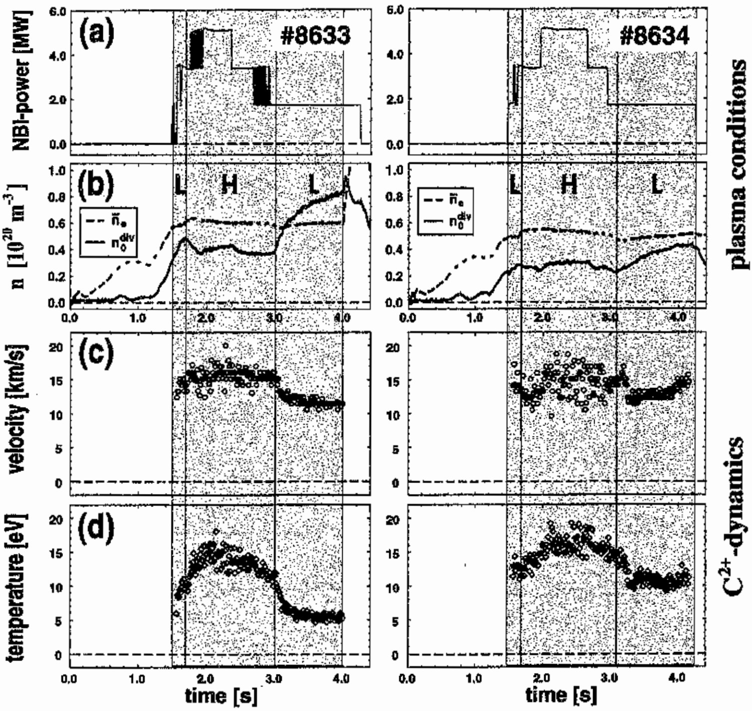

Figure 1: *Dependencies of C^{2+}-ion dynamics on L- and H-mode as deduced from highly resolved CIII-spectra ($\lambda \approx 465$ nm). Toroidal magnetic field $B_t = -2.5$ T. Plasma current $I_p = 1.0$ MA.* (a) *Neutral beam injection power, (b) neutral divertor density (full line) and line averaged midplane electron density (dashed line), (c) C^{2+}-flow velocities towards the outer divertor plates and (d) the C^{2+}-temperatures as a function of time.*

- Due to the matrix-like arrangement of the lines of sight it was possible to determine ion speeds in the outer and in the inner divertor: C^{2+}-ions flow with the same speed (≈ 11 km/s) in the inner divertor (≈ 200 mm above the plates) as in the outer divertor ($\approx$ (50–100) mm above the plates).
- Comparing L- and H-mode phases significant differences are observed in the ion dynamics that are illustrated in Fig. 1 for two ASDEX Upgrade hydrogen discharges. Using different NBI powers (Fig. 1a) and gas blow scenarios well defined L-H-transitions could be performed with the midplane electron density ($\overline{n}_e$) staying nearly constant in time and the density in the divertor (n_0^{div}, Fig. 1b) increasing in the L-mode. The parameters obtained from numerical fits to the CIII spectra ($\lambda \approx 465$ nm) are plotted in Fig. 1c and d. In both discharges the flow velocities of the C^{2+}-ions (Fig. 1c) show only small variations between 10 km/s and 13 km/s in the L-mode, while they increase up

to 20 km/s in the H-mode with the scatter being caused by the integration over ELMs. A similar behavior is seen for the temperature of the C^{2+}-ions (Fig. 1d): The values during the L-mode phases are clearly lower than in the H-mode and remain nearly constant. In the H-mode, however, the C^{2+}-ions are — most probably due to the ELMs — heated up to about 20 eV. Concerning the L-modes of the two discharges, the C^{2+}-temperature for # 8634 ($\approx$ 10 eV) is about a factor of 2 larger than that for # 8633 ($\approx$ 5 eV). The reason is the approximately doubled density in the divertor (Fig. 1b) that leads to the observed reduction of the temperature by roughly a factor of 2.

- The large range of the data in the H-mode is a consequence of the ELMs that can not be resolved completely due to the integration time (1 ms) of the 2D-CCD camera. Nevertheless, by a more detailed correlation analysis of states of constant plasma conditions, a reduction of the C^{2+}-velocity with increasing CIII-intensity is found. If an ELM causes the amount of carbon to rise, then the reduced velocity — averaged along a toroidal line of sight — can be considered as experimental evidence for the backflow of ions from the divertor plates.
- the experimental results referring to the L-mode phases of these and other discharges were compared to the results of B2-EIRENE code calculations [3] for similar conditions in the L-mode. Although these simulations were not especially adapted to the corresponding ASDEX Upgrade discharges, the C^{2+}-velocity from B2-EIRENE is only 50 % too high, and the ranges for the ion temperature overlap nearly completely.

3 ASDEX Upgrade Divertor II: Changes, Improvements and Goals

As described before, the lines of sight in divertor I were arranged in a way to cover both the outer and a part of the inner divertor area. Although this setup was advantageous in many respects, it has a disadvantage resulting from the chord integration that complicates the interpretation of the measured data. For the toroidal lines of sight, the intensity contributing to a spectrum is collected from two regions (in the outer divertor) with different distances from the target plates. This leads to a limitation of the spatial resolution and is probably the main reason why the expected differences during and between ELMs did not yet show up as clearly as desired. Therefore, for the changed geometry of the ASDEX Upgrade Divertor II, the toroidal lines of sight were designed on the basis of B2-EIRENE calculations and optimized to run mainly through one emission region only. The projections of 12 of these new chords into a poloidal plane are plotted in Fig. 2 together with the calculated magnetic flux surfaces. The lines of sight — especially those in the outer divertor — are to yield flow velocities and temperatures of several ions with a sufficient spatial resolution now. As in divertor I, there are again some lines of sight viewing — through the X-point — into the inner divertor, from which information should be obtainable on the velocities there.

In addition, 105 new poloidal lines of sight were installed which are illustrated in Fig. 3. In the outer and in the inner divertor area, there are mainly two observation systems,

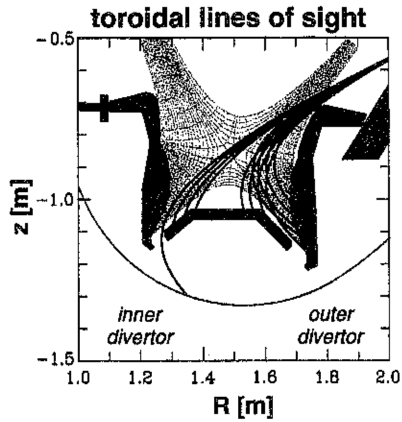

Figure 2: *A subset of 12 toroidal lines of sight in the ASDEX Upgrade Divertor II projected into a poloidal plane; the outer and inner divertor area are covered to allow for spatially resolved velocity measurements*

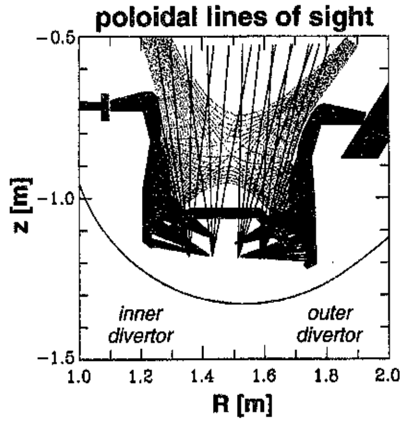

Figure 3: *Poloidal lines of sight in the ASDEX Upgrade Divertor II. The area in front of the target plates can be probed with high spatial resolution; the X-point region is covered by chords viewing in z-direction.*

each consisting of about 20 lines of sight. One set of chords points directly onto the strike-point tiles, while the other one is oriented upwards (in z-direction) and probes the region between the baffle and the core plasma. There are several improvements in connection with this new setup: First, spatial emission profiles can be obtained in the outer and inner divertor range, thereby determining the location of atom- and ion-emission experimentally with high accuracy. Second, the ion temperatures can now be measured separately in front of the outer and the inner target plates. Third, 5 valves have been installed in this area to blow several diagnostic gases into the divertor. By comparing the spectra of poloidally identical lines of sight in sectors with and without valves, the topic of chemical erosion can be addressed.

Finally, we note that not only all the lines of sight in the divertor, but also chords viewing the main plasma can be combined with the spectrometers of different resolution available. Using this enhanced set of spectroscopic diagnostics, important subjects of divertor physics will be investigated in more detail. These are, e. g., the ion dynamics on the timescale of the ELMs, the question of flow reversal, the in-out asymmetry of the ion temperatures or the nature of impurity production.

References

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