MEASUREMENT OF RADIAL H_α AND H DENSITY PROFILES NEAR THE SEPARATRIX AND IMPLICATIONS ON ION TEMPERATURE DETERMINATION

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1. Introduction

The knowledge of particle densities of neutral deuterium and hydrogen in the scrape off layer and near the separatrix is crucial for the understanding of the physical processes in this plasma region. The neutral particle decay length inside the separatrix is especially supposed to be connected to the H mode confinement of a divertor plasma [2, 3, 4]. There are three methods for measuring neutral particle profiles. The most general one uses laser induced fluorescence to determine the ground state density of hydrogen. This method has been successfully applied e.g. by Mertens [7] at the TEXTOR Tokamak, but it suffers from the difficulty to produce laser radiation in the vacuum ultraviolet region. The second possibility is to use electron density and charge exchange diagnostics in connection with a sophisticated modeling code like B2-EIRENE to calculate neutral particle density profiles [1, 2].

Finally the radiation of the H_α transition is directly related to the neutral particle density and can be spectroscopically measured in a straightforward way. A suitable set of lines of sight and additional assumptions as toroidal symmetry enable the direct reconstruction of the radial H_α radiation profile and finally the neutral particle density(s. below). For spectrally resolved diagnostics the analysis of the spectrum delivers further information on plasma processes as charge exchange collisions which in turn are closely connected to ion temperature. The data can also be used to verify model calculations that reconstruct emission data along arbitrary sightlines.

2. Experimental setup

For the reasons outlined above a new diagnostic was built at ASDEX Upgrade to detect the emission of the H_α transition around the separatrix in the main chamber about 20 cm below the magnetic axis. The diagnostic consists of a fan of seven lines of sight oriented tangentially to the plasma (Fig. 1). The separation of the sight lines at the tangent point of the middle beam is 9.2 mm with the beam diameter being about the same size. The optical system inside the torus is coupled to a 1-m spectrograph using fiber optics. It is equipped with an intensified CCD-camera and produces a spectral resolution of 45 pm. Therefore the lines of the two hydrogen isotopes may be resolved and the line ratio is proportional to the plasma's D/H ratio (see also [6]).

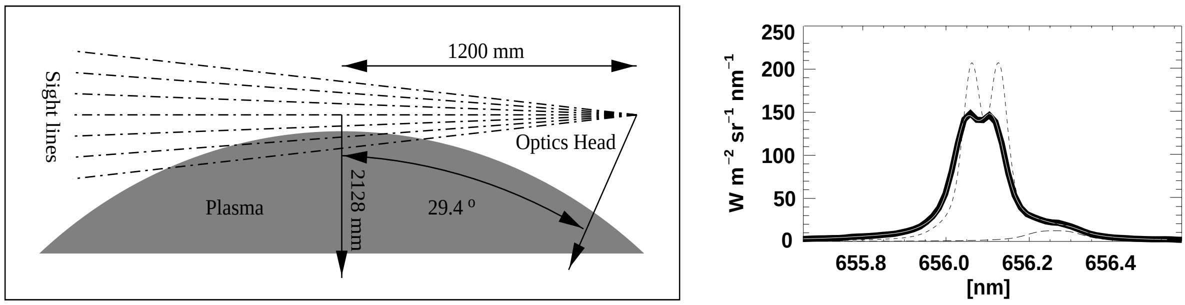

Fig. 1. Left:: Setup of H_α diagnostic at ASDEX Upgrade. **Right**: Spectrum; Measured: thick black; Fit: White line inside the thick black line; dotted: Spectral deconvolution; dashed: hydrogen contribution

3. Data reduction

The spectral line shapes measured by the system described above can be analysed if a suitable model of the line profile is available. In our case the radiation is produced by atoms originating from dissociation of molecules – i.e. Franck-Condon-neutrals with energies of 3 to 5 eV – and from charge exchange (CX) collisions. The latter ones produce a gaussian line shape which basically reflects the ion temperature of the location of their production. Since the spectrum in one line of sight is a spatial integral containing contributions from several different temperatures one basically has to integrate over an infinite number of CX gaussians for each spectral line. It turns out that normally a sum of four gaussians for each of the zeeman components of each of the hydrogen isotopes is sufficient to fit a typical spectral shape within the statistical errors. The fit example in Fig. 1 shows components with 1, 2, 14 and 122 eV which may be qualitatively attributed to Frank Condon- and CX contributions . However the determination of an ion temperature profile requires a spectral and spatial deconvolution of the experimental data which turns out to be extremely unstable. Alternatively one may try to synthesize spectra using distributions modeled by EIRENE. This approach has been initiated, but has not been successfully performed yet.

For the spectrally integrated data a deconvolution approach is much less problematic. We model the radial radiation distribution using a spline representation. The spline coefficients are fitted to produce the intensity distribution across the channels after convolution in toroidal symmetry. In addition the coefficients are optimized to maximize the smoothness of the radial radiation distribution that is then converted to a particle density using the relation $I(H_\alpha) = n_H \cdot n_e \cdot \epsilon(T_e, n_e)$ with $I(H_\alpha)$: H_α intensity, n_e: electron density, n_H: density of neutral hydrogen, $\epsilon(T_e, n_e)$: emissivity [photons s^{-1} m^3]. The electron density is measured using the fast Lithium beam, T_e is determined with a Thomson laser scattering system and the emissivity data are taken from the ADAS database [8]. In the left part of Fig. 2 we show the deconvolution of the radial H_α emission in a shot where the location of the separatrix was shifted radially in time. It is clear that the main feature of the emission shifts together with the separatrix marked by the yellow line. There is also a non shifting feature around r=2.16 m which is attributed to local limiter recycling. For our data reduction we suppress the data from the outer feature

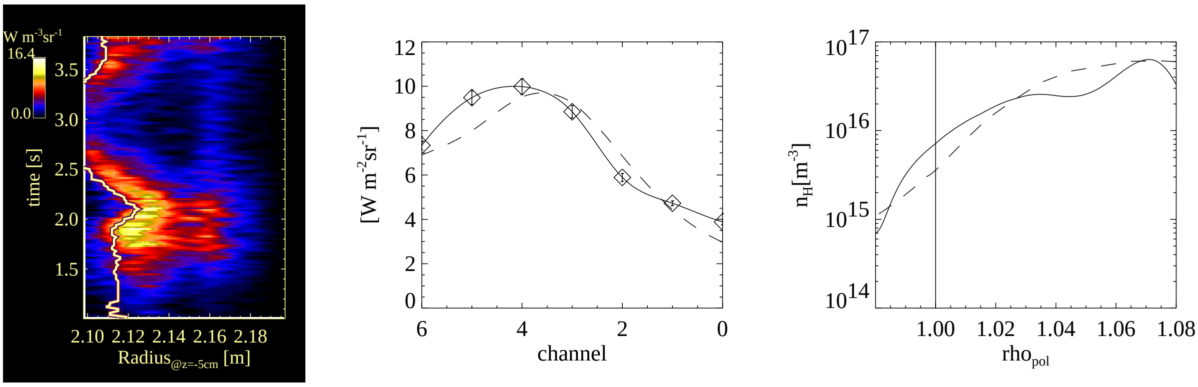

Fig. 2. Left: H_α distribution during a separatrix-shift. **middle and right**: Comparison of experimental data (diamonds) and data modeled using EIRENE (dashed) (shot #10249).

thereby also supressing other deconvolution errors that originate from the finite intensity in our outermost raw data channel #0. We also used the neutral particle modeling code EIRENE [1] to simulate the intensity distribution for selected plasma shots. The middle part of Fig. 2 shows the comparison of experimental raw data and modeled raw data for shot #10249. The time is chosen directly before an L–H transition. These data agree within 30% on an absolute scale which is remarkable given the fact that the EIRENE calculations are coupled to the measured neutral particle influx and have no fit parameters for the integral intensity. The statistical uncertainty of each raw data point is 5% at most. To the right the simulated neutral atom density is compared to the neutral particle density derived from the experimental data by deconvolution and conversion to neutral particle densities as described above. The data agree within 50% which shows that both methods produce comparable results from different types of input data. However, local differences of both curves have to be investigated further because the reasons may be found either in the experimental data or the modeling. A shift of an intensity maximum may, for example, be a problem caused by the use of magnetic diagnostics to map the positions of different diagnostics as well as a problem in the calculation of the penetration depth of the neutrals in the model. To rule out ambiguities like this, work is underway to improve the accuracy of parameters like the separatrix position [5] and to quantify properties like fluctuations of the electron density and their influence on the model calculations.

4. Results and discussion

We analysed a number of shots using the spectroscopic method described above in order to determine the connection between the neutral particle density measured at the separatrix – $n_{H,sep}$ – and the gas influx to the plasma – Γ_{wall}. At ASDEX Upgrade the neutral particle flux is routinely measured at various locations in the vacuum vessel. Fig. 3 shows – from left to right – the radial neutral particle density distribution, the same distribution devided by Γ_{wall} and then renormalized, the time trace of $n_{H,sep}$ and the time trace of Γ_{wall}. The shot consists of two phases, a strong gas puff until 3.6 s and a cryo pumped phase afterwards. Obviously the variation of $n_{H,sep}$ is a factor of two while the gas influx varies by about a factor of seven. This behaviour

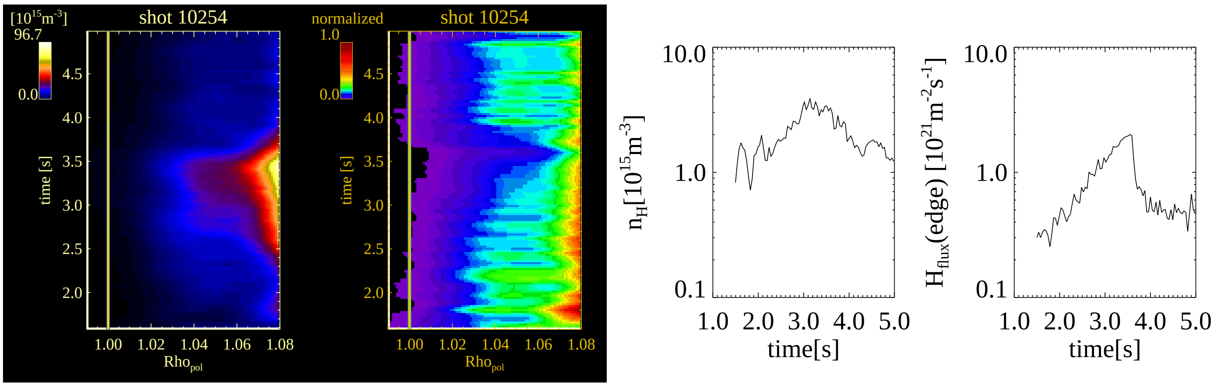

Fig. 3. Time dependent distribution of neutral H; the same normalized to wall flux, time-trace of H density at separatrix, and neutral particle flux at the wall

is also demonstrated in the radial profile which is divided by Γ_{wall} and then renormalized. The relative magnitude of $n_{H,sep}$ decreases during the gas puff phase and increases again after the closing of the valves. For shots with continuous density ramps but without cryo pump we also find a lower relative increase of $n_{H,sep}$ but there are hints that the ratio between $n_{H,sep}$ and Γ_{wall} is different with and without cryo pump. However $n_{H,sep}$ increases less than proportional with respect to Γ_{wall} in both cases. As a result $n_{H,sep}$ varies from $1 \cdot 10^{15}$ to $2 \cdot 10^{16}$ atoms m^{-3} over all shots analysed so far. This is a certain contradiction to EIRENE calculations in [9] stating a very low dependence of $n_{H,sep}$ on Γ_{wall} during the divertor I phase of ASDEX Upgrade. However the neutral densities for the divertor II phase as measured here seem to be lower than during the divertor I phase. Altogether one has to keep in mind that the gradient of the neutral particle density profile is very steep (Fig. 2) making at least the absolute value of $n_{H,sep}$ sensitive to uncertainties in the determination of the separatrix position.

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