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Interpretation of H_α Imaging Diagnostics Data on ASDEX Upgrade

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Introduction

The steep plasma density gradient in the edge region of H-mode scenarios is commonly attributed to the existence of an edge transport barrier. One of the mechanisms to influence the profile shape is suspected to be the penetration of neutrals [1], although a complete description of this phenomenon remains to be formulated. Besides the radial profiles of transport parameters, i.e. particle convection and diffusion, the profile shape of the plasma source term has to be considered. An experimental access is possible through the analysis of Balmer-α line radiation of hydrogen (H_α) which has to cover a large part of the scrape-off layer (SOL) and edge region to survey the at least 2D distribution of plasma fueling. The ASDEX Upgrade (AUG) tokamak is equipped with a pair of tangentially viewing cameras with high spatial ($dR < 5\,\mathrm{mm}$) and dynamic (14 bit) resolution for the divertor and midplane region. Two methods regarding the deconvolution of line integrated data are discussed and results obtained for L- and H-mode scenarios are presented. Volumetric information obtained from tomographic reconstruction of imaging diagnostics data is an important constraint for plasma modeling codes.

Instrumentation and Data Analysis

The plasma boundary is observed with two lenses placed in the limiter shadow at the low field side (LFS). Images are transmitted via an image guide to the detectors which have a dynamic range of 14 bit and are operated with a resolution of 696×520 pixels, resulting in a frame rate of 11 Hz. Exposure times range from about 0.5 ms to 20 ms depending on the viewing geometry and discharge scenario. An example of the divertor view is given in Fig.1. On this image one of the systematic problems of the H_α video diagnostics is seen: reflectivity of tungsten covered plasma facing components (in the 2006 experimental campaign of AUG only the strike point zones were equipped with graphite) complicates data deconvolution. A solid angle resolved measurement revealed the magnitude of the total reflectivity for the H_α-line of about 20-50% depending on the angle of incidence. To obtain the line of sight geometry the mapping is modeled with a central projection which considers additionally a barrel like distortion corresponding to the lenses used. Intensity calibration is done with a light source of well known emission spectrum. However, an optical system based on a glass made image guide is not suited for long term calibration. Compared to those made of pure silica, glass fibers are much more affected by UV-, γ-, and neutron-irradiation resulting in a loss of transmission. The characterisation of deteriorated fibers is counteracted by photo bleaching. Data presented here is based on a cross calibration with a different H_α measurement.

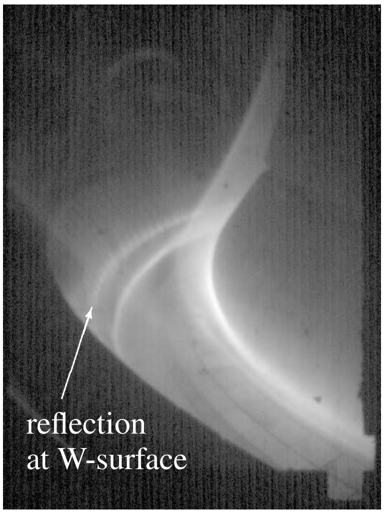

Fig.1: divertor view
#21903 , t in [1.56615;1.56655]s

Deconvolution of line integrated emissivity is done using two different methods. Global information is obtained using a tomographic reconstruction algorithm [2] which has been extended to cope with the additional complication of diffusive reflection. The regularisation term of this algorithm is the curvature of the emissivity profile, whereat the gradients of the emissivity are weighted differently perpendicular and parallel to the poloidal magnetic flux surfaces to account for the shape seen in the experiment (e.g. Fig.1). Reflection at surfaces is considered by introducing an additional iteration on reflection corrected input data in which data owing to reflection of the emissivity result of the previous iteration step is subtracted from the original line of sight integrals. Reconstruction calculations using simulated line integrals of a model profile support this procedure since a reduction of artefacts of the resulting profile is achieved.

As a second method a ray-tracing-fit has been set up to analyse regions of high contrast in more detail. A Lorentz shaped profile function is chosen to mimic the experimental data and the parameters determining position, amplitude and decay lengths (in/outwards) are adapted. To obtain the parameters of neutrals at the plasma edge, the 1D kinetic transport code KN1D [3] is used by specifying the plasma profile (n_e,T_e,T_i) and molecular pressure at the vessel wall $p_{H_2,w}$ (n_e and T_e are available from LFS diagnostics, T_i is estimated and $p_{H_2,w}$ is set to match the experimentally observed H_α-profile). This code solves the Boltzmann equations for the molecular and atomic velocity distribution functions by considering a large number of reactions (neutral-neutral collisions, excitation, ionization, charge exchange) between the various molecular, atomic and ion species on a fixed plasma background. The experimental H_α-profile is used as a constraint for the code parameters (e.g. n_e,T_e, T_i in the SOL often have to be estimated, especially at the HFS). This method is applied in the regions of the poloidal cross section indicated in Fig.2. The example of an experimental radial ε_{H_α}-profile and the corresponding KN1D-result indicates, that the Lorentz-shape is well suited (Figs. 2,3).

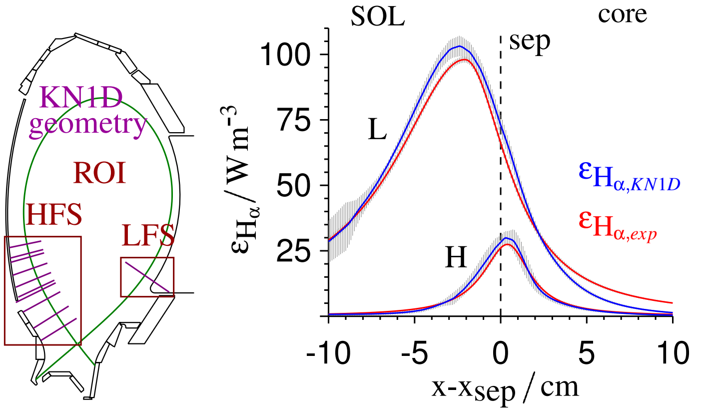

Fig.2: left: regions where ray-tracing-fit/KN1D-comparison is used; right: example for comparison of ε_{H_α}-profiles (LFS roi)

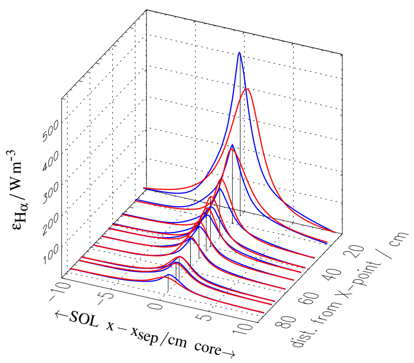

Fig.3: ε_{H_α}-profiles HFS (H) same colors as in Fig.2

Experimental Results

As a first example for the capability of the diagnostics, a pair of L- and H-mode discharges is compared. Data for both cases are taken from stationary phases of each discharge (L: #21347, H: #21402), for the H-mode a inter-ELM time slice was taken. For similar midplane line averaged density ($\overline{n_e} \approx 5 \cdot 10^{19}\,\mathrm{m}^{-3}$), parameters of neutrals are remarkably different which is suspected to correspond to the diverse plasma profiles at the LFS resulting from the reduced edge transport in H-mode. The H_α-emissivity profile is very broad in L-mode, has its maximum outside the separatrix and ranges to the far SOL. In H-mode, the H_α-profile is seen to be very narrow and having its peak value inside the last closed flux surface. Both profiles are depicted in Fig.2. At this position at the LFS, the neutral density in the far SOL in L-mode is about six times larger than in H-mode (Fig.4) - the SOL plasma density is large and in turn the recycled neutral influx is high. The corresponding plasma source profile is shown in Fig.5. In H-mode the rather narrow shape of the source distribution (logarithmic plot) is a consequence of the low SOL density and the magnitude of fueling might be related to a better particle confinement, but for a general conclusion the complete plasma boundary has to be considered.

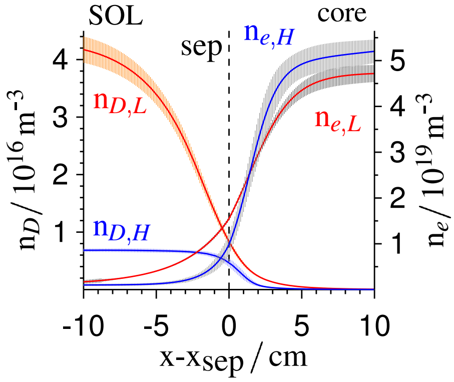

Fig.4: neutral and electron density profiles for L- and H-mode (LFS roi)

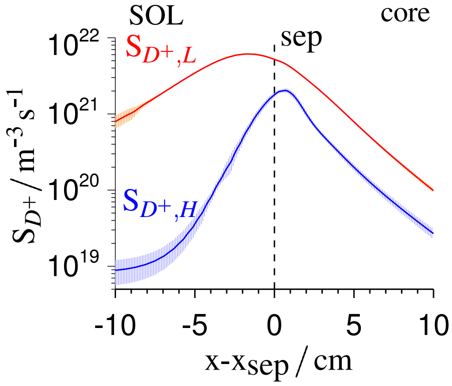

Fig.5: ion source profiles for L- and H-mode (LFS roi)

The same procedure as described for the LFS can be applied at the HFS (e.g. Fig.3 for H-mode). In fact, the largest H_α emission close to the separatrix is observed to be at the HFS in the region above the X-point (lower single null discharge). Depending on the SOL parameters the appearance of H_α radiation can be dominated by emission from a region close to the vessel wall and a profile-fit can no longer be applied, which is the case for the L-mode discharge discussed here. Results from tomographic reconstructions for the same time slices as the LFS profiles described above are presented in Figs. 6 and 7. These give volumetric information about the divertor conditions.

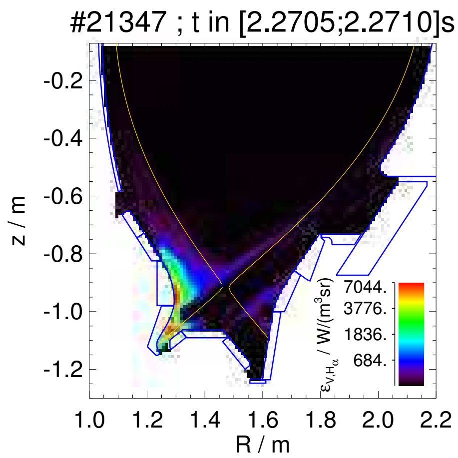

Fig.6: ε_{H_α}-profile L-mode (dR=dz=1cm)

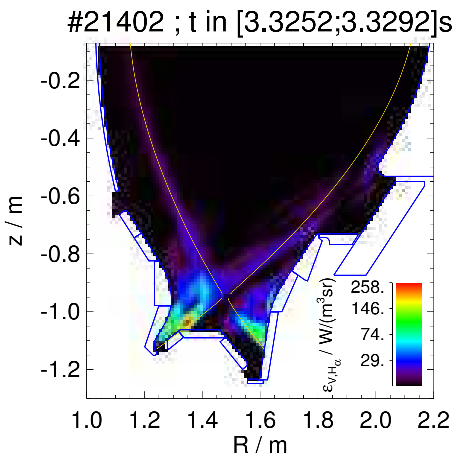

Fig.7: ε_{H_α}-profile H-mode (dR=dz=1cm)

In this L-mode case the neutral flux density measured by neutral pressure gauges located behind the tiles is about 5 times larger than for the compared H-mode discharge ($1.4 \cdot 10^{22} m^{-2} s^{-1}$ vs $3 \cdot 10^{21} m^{-3} s^{-1}$ at $z = -0.6\,m$) suggests the presence of a cold and dense plasma at the L-mode HFS. The amplitude of H_α emissivity in H-mode is much lower and appears near the strike points which indicates the less detached inner target compared to L-mode and attached outer target. Since the H_α profile appears to be very narrow at the HFS separatrix in H-mode, the ionization probability in the gap between vessel wall and plasma edge has to be low which would imply a rather cold and thin SOL in that region.

Due to the complicated character of SOL-physics, code packages are commonly used to disentangle the fundamental physical structures, taking plasma diagnostics data into account. Results from H_α video diagnostics are an important constraint for plasma modeling, as is briefly discussed with a second example. The SOLPS package (fluid code B2.5 coupled to the Monte Carlo code EIRENE) has been used to model the low density ($\overline{n_e} = 2.7 \cdot 10^{19}\,\mathrm{m}^{-3}$) ohmic AUG discharge #21303 [4] (Figs.8,9). To assess the code result, usually upstream and target profiles are compared. Although for instance the ion flux densities to the targets can be matched fairly well (peak values within a factor of 1.5), differences in the volume plasma parameters are being noticed when comparing radiation profiles. In this case shown here, the SOL near the inner target is too hot for radiation from recombination to appear like seen in the experimental data. The means to achieve a better description of HFS SOL plasma parameters with the SOLPS code are under investigation.

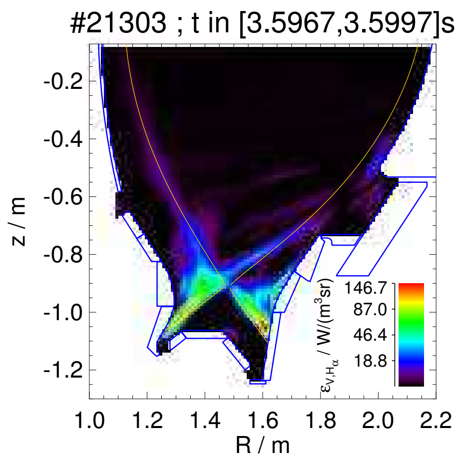

Fig.8: ε_{H_α}-profile low density OH discharge (dR=dz=1cm)

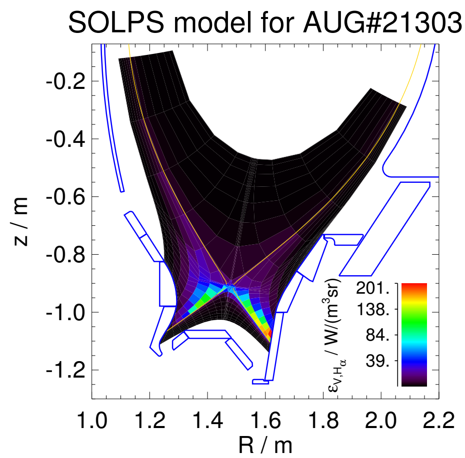

Fig.9: ε_{H_α}-profile SOLPS (20 rad. × 50 pol. grid)

Conclusion

At the AUG tokamak a video diagnostics approach is used to obtain information on penetration and influx density distribution of neutral hydrogen with H_α-sprectroscopy. Reflections at tungsten covered plasma facing components and deterioration of glass made image guides in a harsh environment are causes of systematic uncertainties. Two methods (profile-fit, tomography) are applied to describe neutral penetration at the LFS and HFS and to get volumetric information about the divertor state which are important constraints for edge plasma modeling codes.

References

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[2] J. C. Fuchs, et al., Proc. of the 21th EPS Conference on Controlled Fusion and Plasma Physics, Montpellier, 1994, Vol. 18B, part III, 1308-1311

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[4] M. Wischmeier, et al., submitted to CPP, presented at PET 11 (2007)