29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. ***26B****, P-5.032 (2002)*

Asymmetries of Impurity Radiation in the W7-AS observed with Soft-X-Ray Tomography

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1 Introduction

Observations of the soft-x radiation near the triangular plane of the Wendelstein 7-AS were made. The x-ray emissivity distribution in this cross-section can be reconstructed by using tomography [1, 2, 3]. In many cases, especially in high-β- and HDH-plasmas[2], the tomographic reconstructions reveals that the x-ray emissivity is not constant on the equilibrium magnetic flux surfaces, calculated by the NEMEC code [4]. In high-β-plasmas an indentation of the emissivity distribution on the inboard plasma edge exist. More complex poloidal asymmetries are observed in HDH-plasmas (with low-β).

2 Asymmetries in high-β plasmas

2.1 Dependence on β_0

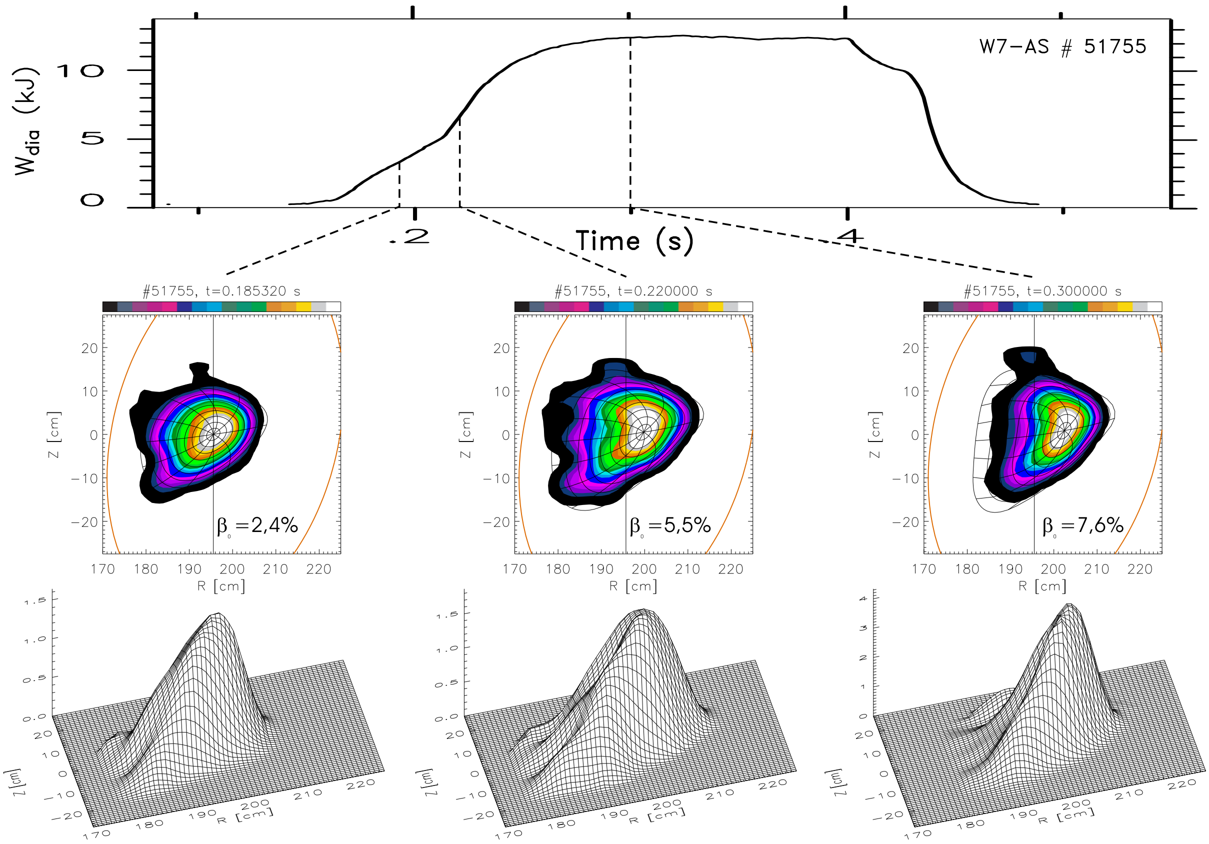

Fig. 1: Development of the indentation with increasing β_0 for shot #51755.

Fig. 1 shows the development of the indentation with increasing β_0 (shot #51755, $\iota_a = 0.52$, $B = -0.9\,\mathrm{T}$, $I_{pl} = 0$). At low diamagnetic energy and β nearly no indentation is

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[2]HDH = High Density H-Mode

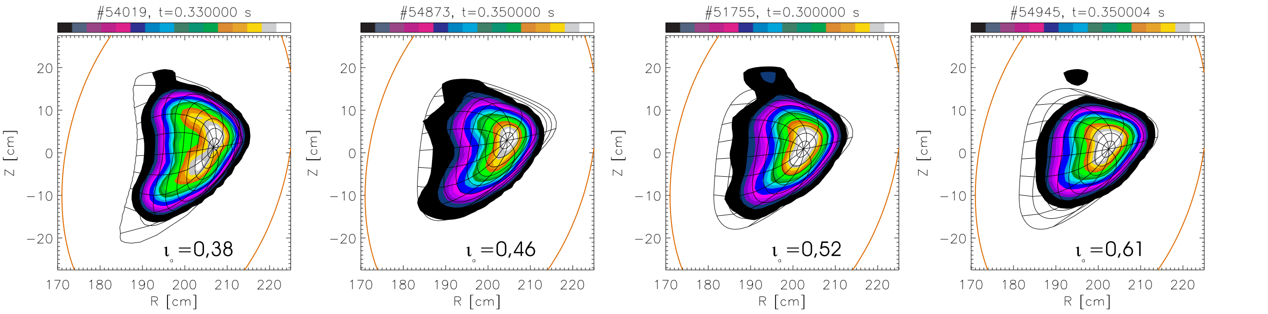

Fig. 2: Influence of the external generated edge ι_a on the indentation in net current free high-β plasmas.

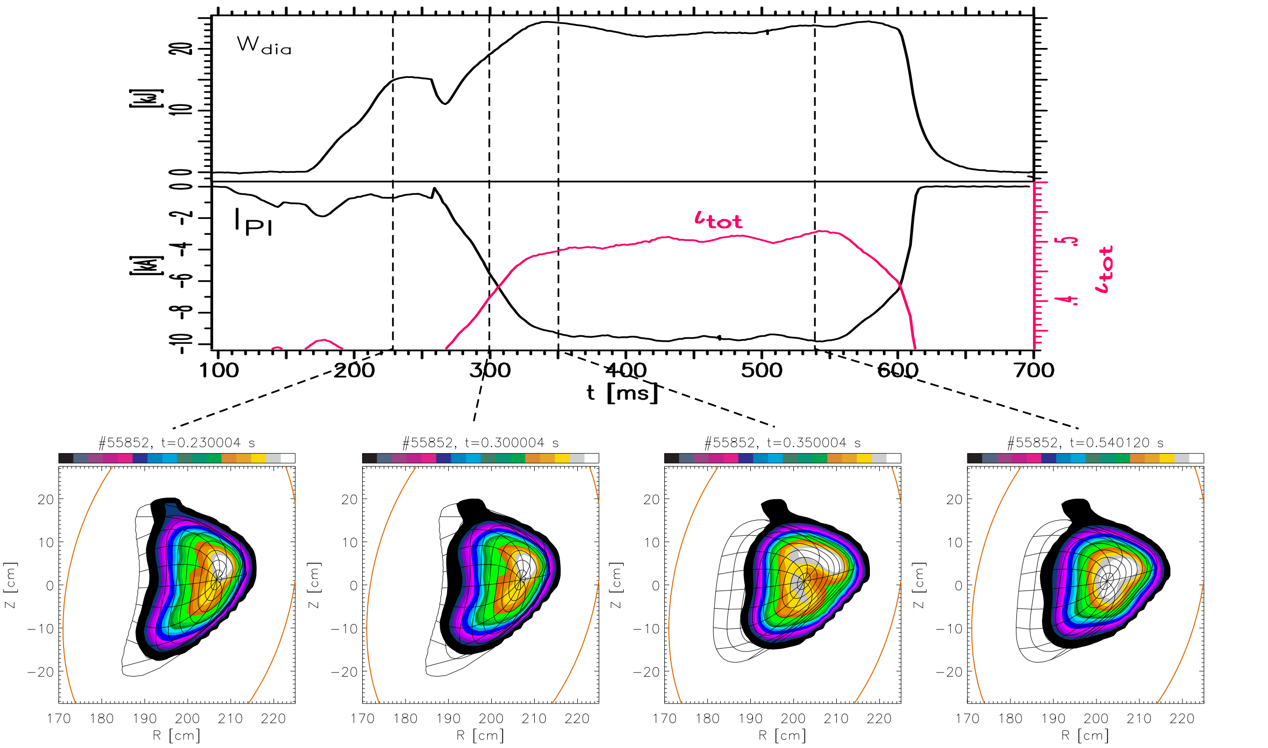

Fig. 3: Influence of an external driven plasma current (I_{pl}) on the indentation in shot #55852.

present (left image). With higher energy and β an indentation on the inboard plasma edge appears (middle image). At maximum energy the indentation is fully developed (right image, averaged-beta is $<\beta>= 3.2\,\%$ with a central-beta of $\beta_0 = 7.6\,\%$). Furthermore, the outward-shift (SHAFRANOV-shift) of the plasma with increasing β is clearly visible and is consistent with the equilibrium calculations (coordinate grid lines in the plot).

2.2 Dependence on ι_a

As next, in Fig. 2 the influence of the externally generated edge ι_a on the indentation is shown. The indentation shrinks with increasing ι_a. All selected shots have roughly the same averaged-beta and are net current free ($I_{pl} = 0$).

2.3 Dependence on I_{pl}

At last, Fig. 3 shows the influence of an external driven plasma current on the indentation. The ohmic-current flows in co-direction and is concentrated at the plasma center (because

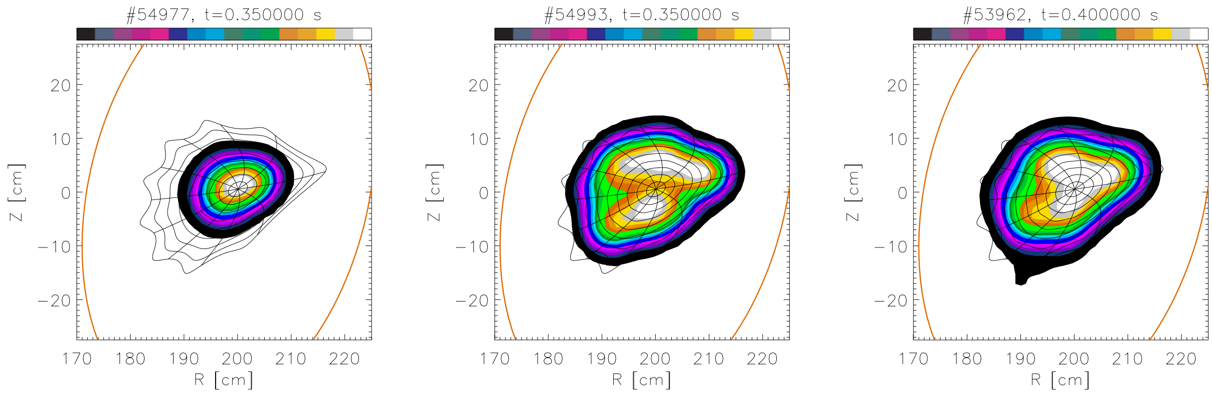

Fig. 4: Left: NC with $\iota_a = 5/9$*, middle: HDH with* $\iota_a = 5/9$*, right: HDH with* $\iota_a = 5/8$*.*

of the peaked T_e-profile), so that ι_0 is increased. Therefore it can be shown, that the indentation shrinks with increasing central ι_0 and I_{pl}. This is consistent to the dependence on the external generated edge iota (ι_a) in Fig. 2.

3 Asymmetries in HDH-plasmas

The left image of Fig. 4 shows a symmetric plasma in a normal confinement discharge (NC). NC-plasmas have a central peaked n_e- and T_e-profile. Contrary to the high-β case, no indentation on the inboard plasma edge can be shown. The middle and the right image of Fig. 4 show plasmas in the HDH-regime (low-beta, $\beta_0 < 1.5\,\%$, $B = -2.5\,\mathrm{T}$). Because of the better energy confinement in this regime the electron temperature and density at the edge is higher than in the NC-regime. Therefore, the soft-x emission profile is much broader. In addition stationary poloidal asymmetries can be shown. On the right image a structure with a poloidal period of $m = 3$ appears. Due to the finite β (diamagnetism, SHAFRANOV-shift, currents) the central iota ι_0 should be higher than the edge iota $\iota_a = 5/8 = 0.625$. If ι_0 exceeds the the rational value of $2/3 \approx 0.667$, then the observed asymmetry may be explained as an $(3,2)$-island of the magnetic flux surfaces.

4 Reliability of the tomographic reconstructions

The used tomography system consists of 256 rays (8 cameras with 32 diodes each). All tomographic reconstructions in this paper were made with the maximum entropy method [1, 2] on a quadratic grid with 20×20 pixels and $2 \times 2\,\mathrm{cm}$ pixel size. A measurement error of about $3\,\%$ is taken into account for each diode. Reconstructions of relevant test distributions reveal no significant artefacts. The observed poloidal asymmetries above are so strong, that they can be seen clearly in the raw data profiles already, independent from any inversion algorithm.

5 Conclusions

Generally, two possibilities of explanation for poloidal asymmetries exist: either the calculated magnetic flux surfaces are partly incorrect, or the intrinsic impurity density is not constant on the magnetic flux surfaces.

The first case may be true for high-β plasmas. The main reason for the observed indentation are toroidal plasma currents neglected in the equilibrium calculations. Toroidal currents, other than PFIRSCH-SCHLÜTER (e.g. Bootstrap, Okawa, Ohmic), are usually neglected, because their distribution is partly unknown. Furthermore, the exact pressure profile is needed as input for the NEMEC code. Uncertainties in the electron pressure profile, calculated from THOMSON-scattering data, and in the partly unknown ion temperature profile can be additional sources of error.

Because of the higher magnetic field in low-β HDH-plasmas, the effect of the driven toroidal currents on the magnetic flux surfaces is much lower. Therefore, the reason for the observed poloidal asymmetries is probably an asymmetric impurity density. Because of the high parallel conductivity and mobility of the electrons, the electron temperature and -density is nearly constant on the magnetic flux surfaces. Since almost all soft-x radiation comes from the intrinsic impurities, the impurity density must be asymmetric, if the soft-x radiation is asymmetric. Small inhomogeneities in the electron- or proton-pressure are connected with large inhomogeneities in the impurity pressure, because only the total pressure must be constant on the magnetic flux surfaces and because of the quasi-neutrality. Due to the high collisionality of the impurities ($\nu_{Ii}^{\star} \approx 10$), the asymmetries in the impurity density cannot be averaged-out toroidally. Poloidal asymmetries in the impurity radiation - with different shape and reason - were already found in the JET-tokamak earlier [5]. Their understanding is an indicator for the understanding of the whole plasma equilibrium and the impurity transport.

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