Transport analysis of the density build-up after L-H transition in ASDEX Upgrade

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Motivation

The H-mode is characterized by the formation of an edge transport barrier (ETB) in energy and particle transport, which results in enhanced energy and particle confinement. A matter of particular interest is, wether the improvement in particle confinement is caused by a reduction of diffusive transport and/or by an increase of the inward directed convective transport in the edge, as proposed in [1, 2]. The efficiency of fueling without pellets, i.e. gas puffing, in ITER is likely to be insufficient to reach the required operational density [3]. Therefore, an inward directed convective transport would reduce the necessity of a high particle source inside the last closed flux surface (LCFS). Transport analysis of transient events, like ELMs, gas modulation and L-H transition, is the only possibility to separate the contributions of convective and diffusive transport. For this reason, we used the density build-up following the L-H transition to perform predictive transport analysis, using the ASTRA code [4], and to asses the respective roles of diffusion and convection in the density build up.

Experimental setup

To perform predictive transport modeling, accurate and complete electron density profiles are required. Hence, we employed the integrated data analysis (IDA) [5], which delivers complete density profiles by combining the lithium beam and the line integrated interferometer diagnostic. Figure 1 shows time traces of the analyzed discharge. To simplify the modeling we analyzed the temporal density evolution of an H-mode, which was induced by pure ECRH (figure 1(a)), thus avoiding an additional particle source, e.g. NBI, within the LCFS. The divertor current was used to detect the L-H transition. After the L-H transition was triggered and the ETB was established, the plasma density increased (figure 1(b)), although the neutral gas

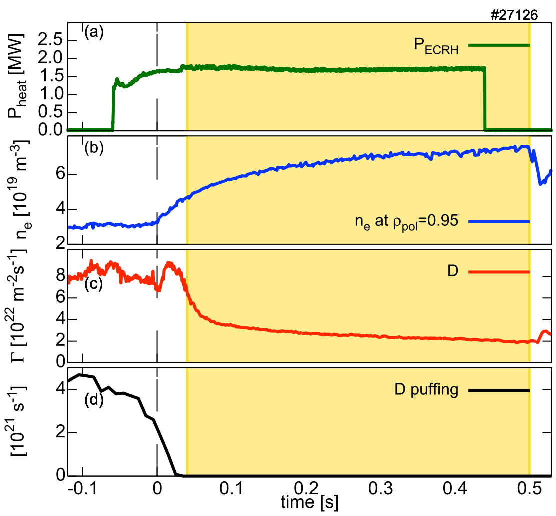

Figure 1: (a) ECRH power, (b) edge density, (c) neutral gas flux density in the divertor and (d) gas puffing relative to the L-H transition for discharge #27126 are shown. The yellow shaded area indicates the modeled time range.

flux density in the divertor (figure 1(c)) and the gas puffing (figure 1(d)) decreased [6]. The gas fueling was feedback controlled via density, therefore the valves were closing after the L-H transition. The modeled time range is indicated by the yellow shaded area in figure 1. We chose this time phase because of two reasons. First, we assume that the transport properties did not change during this phase and second, the temporal change in the divertor neutral gas density and hence, the source is rather low. The measured density profiles at different time steps have been used for comparison with the transport model described in the following.

Modeling

The general expression for particle transport is

$$\frac{\partial n(r,t)}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(r\,\Gamma_n(r,t)) = S_n(r,t), \tag{1}$$

where $n(r,t)$ corresponds to the plasma density and $S_n(r,t)$ to the particle source depending on radial location r and time t. The particle flux $\Gamma_n(r,t)$ reads

$$\Gamma_n(r,t) = -D_n(r,t)\,\frac{\partial n(r,t)}{\partial r} + v_n(r,t)\cdot n(r,t), \tag{2}$$

where $D_n(r,t)$ is the diffusive and $v_n(r,t)$ the convective contribution. Further off-diagonal terms, like thermo- or roto-diffusion were not considered. All terms regarding the density can be obtained from the measurements, but $D_n(r,t)$, $v_n(r,t)$ and $S_n(r,t)$ are unknown. To determine these quantities, we parametrized their profiles and varied the parameters to find the best match to the measurements. Furthermore, the quantities in the particle transport could vary temporally and spatially. For simplification, we assumed that the transport coefficients did not change in time in the analyzed interval.

To parameterize the diffusion profile, we assumed a constant core value, called D_{core}, and at the edge, we introduced a drop in the coefficient profile, which approaches a value called D_{edge} (figure 2(d)). The width of the ETB was set by the pedestal width, which is approximately 1.5 cm in ASDEX Upgrade. The convection profile in the core (v_{core}) was estimated from the initial n_e profile (figure 2(a)), for which v/D (figure 2(b)) can be estimated from the normalized density gradient $\frac{dn(r,t)}{dr}/n$ by assuming zero core particle flux ($\Gamma_n(r,t) = 0$), hence, zero source ($S_n(r,t) = 0$) and steady state condition ($\frac{\partial n(r,t)}{\partial t} = 0$) [7]. Additionally, we implemented a jump in the convection profile at the edge, which can be set by a variable called v_{edge} (figure 2(c)).

A diagnostic, which determines the neutral gas density within the LCFS [8] is currently not available at ASDEX Upgrade. Therefore, we also had to parametrize the source. The ASTRA package includes a subroutine, called NEUT, which calculates the ionization source rate and its distribution from a given neutral gas density at the LCFS (S_0) using the electron density and temperature profile. In the following, S_0 was used as an input parameter. For simplicity, we did not include a change of S_0 in time.

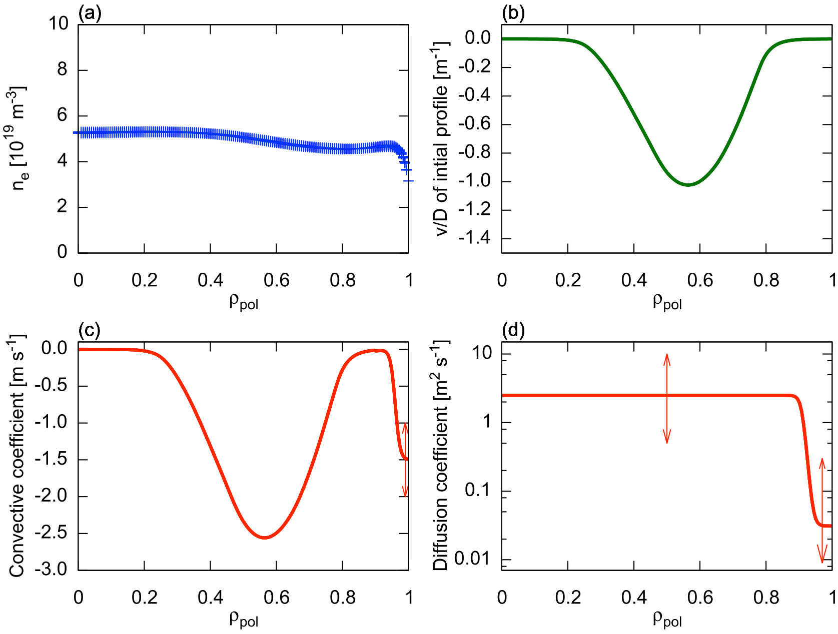

Figure 2: (a) initial n_e profile, (b) estimated v/D from n_e profile , (c) convection profile with variable edge value and (d) diffusion coefficient with variable core and edge value.

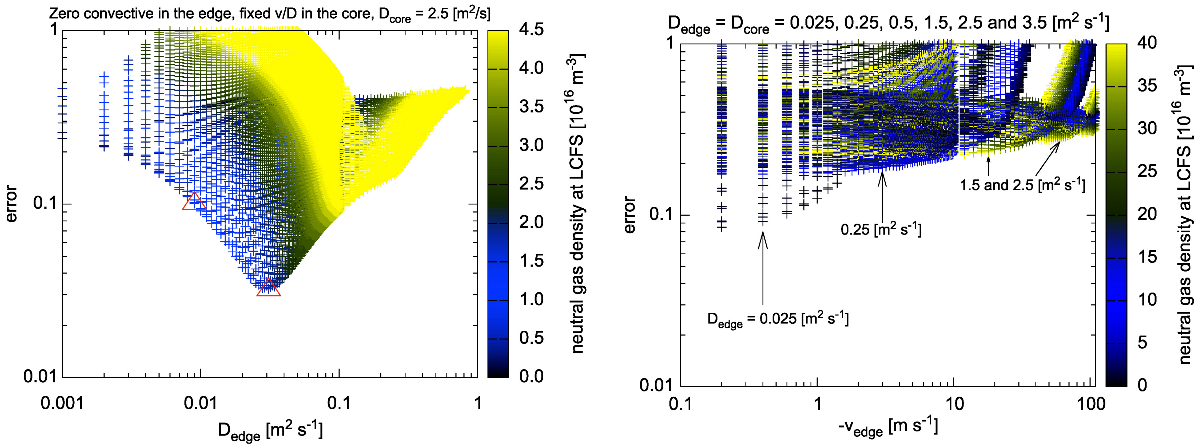

Figure 3: (left) only dip in diffusion profile, red triangles mark parameters for figure 3 and (right) only dip in convection profile.

Results of the parameter scans

In this section, we show the results of two parameter scans. In the following we varied D_{core}, D_{edge}, v_{edge} and S_0. As initial condition we took the density profile shortly after the L-H transition and the measured density at the LCFS set the boundary condition. To compare each run, we introduced a measure for the "error" of the run, which is defined as:

$$error = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{\int_{\rho_{pol}=0.85}^{1.0} |n_e^{ASTRA} - n_e^{exp}|/n_e^{exp} \rho_{pol} dV}{\int_{\rho_{pol}=0.85}^{1.0} \rho_{pol} dV} dt \tag{3}$$

This measure compares the density output of the ASTRA run with the density measurements with emphasis on the edge and this is averaged throughout the temporal evolution.

In the first parameter scan we assumed a dip in the diffusion coefficient and zero edge convec-

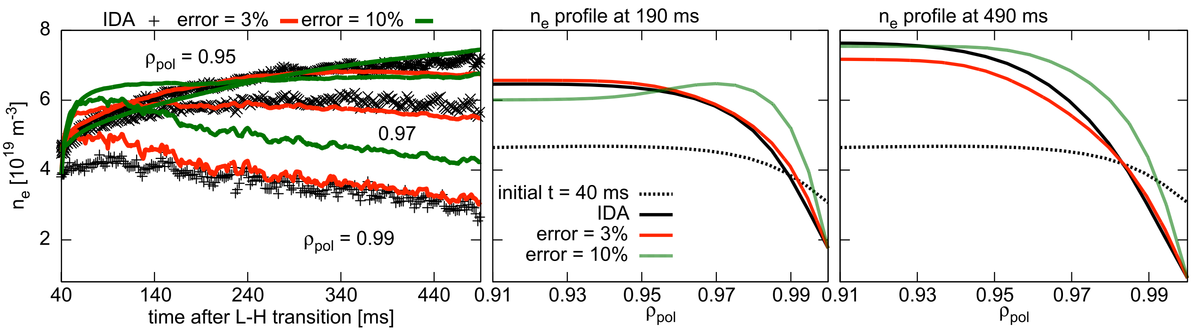

Figure 4: (left) n_e time traces at ρ_{pol} =0.95, 0.97 and 0.99 for IDA, two runs with an "error" of 3% and 10% (red triangles in figure 3), (middle) corresponding n_e profiles at 190 ms after L-H transition and (right) at 490 ms after L-H transition.

tion. Figure 3 (left) shows the error versus D_{edge} and its dependence on S_0 in the color scaling. The lower envelope of this plot gives the best result for a given D_{edge}. We can already conclude that a dip in the diffusion coefficient reflects the particle transport reasonably, although we did not consider a time variation of the source S_0. Alternatively, to determine if a transport barrier in the diffusion coefficient can be fully replaced by a strong convective term, we set D_{edge} equal to D_{core} and we varied v_{edge} and D_{core} in the second parameter scan. Figure 3 (right) shows the result of this parameter scan, where we varied v_{edge}, D_{core} and S_0. Interestingly, the error is significantly higher, which already indicates that an inward directed pinch can not fully replace a decrease in the diffusion profile at the edge. Figure 4 shows the density evolution of the best run (error of $\sim$ 3%) and of one run with an error of 10 % only using a reduction of diffusion transport in the edge (marked by red triangles in figure 3 (left)). With the exception of the initial phase the time traces and the corresponding edge density profiles of the best run matches the measurements reasonably well.

We were able to show that a reduction in diffusive particle transport cannot be fully replaced by an increased inward directed convective term. Further analysis of this discharge is in progress to estimate whether a combination of a dip in the diffusion and convection profile delivers better results. Moreover, we plan to extend the analysis to further discharges with slightly different parameters, i.e. gas fueling rate.

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