Anomalous Transport for a Wide Range of Different Impurity Species Observed at Wendelstein 7-X

A. Langenberg[1], Th. Wegner[1], B. Geiger[1], O. Marchuk[2], N. Tamura[3], R. Bussiahn[1], M. Kubkowska[4], A. Mollén[1], H.M. Smith[1], N.A. Pablant[5], P. Traverso[5], C. Brandt[1], H. Thomsen[1], J. Schilling[1], B. Buttenschön[1], A. Czarnecka[4], S. Jabłoński[4], G. Fuchert[1], S.Bozhenkov[1], H. Damm[1], E. Pasch[1], J. Brunner[1], J. Knauer[1], R. Burhenn[1], M. Beurskens[1], R.C. Wolf[1], and the W7-X Team

[1] *Max-Planck-Institut für Plasmaphysik, Greifswald, Germany*
[2] *Institut für Energie und Klimaforschung-IEK-4, Jülich, Germany*
[3] *National Institute for Fusion Science, Toki-City, Japan*
[4] *Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland*
[5] *Princeton Plasma Physics Laboratory, Princeton, NJ, USA*

Introduction

In this paper, the plasma volume averaged impurity confinement of Wendelstein 7-X (W7-X) has been characterized for numerous different impurity species, covering a wide range of atomic charges (Z=12-44) and atomic masses (M=28-184). The experimental findings are compared to theoretical neoclassic and turbulent transport expectations and suggest the presence of a turbulence dominated impurity transport. These results are in agreement with observations from recent transport studies, based on direct measurements of impurity diffusion profiles, performed at W7-X [1,2].

1. Experimental Method

For an experimental determination of global transport properties, trace amounts of several different, non-recycling impurity species have been injected into stationary plasmas with constant heating power, temperature, and electron density. Fig.1 shows representative time traces of the main plasma parameters used for this study, repeated for each of the different impurity species injected. Two impurity injections with different deposition depths have been realized, using laser blow-off (LBO) [3] for edge deposition and the tracer-encapsulated solid pellet (TESPEL) [4] injection system for a core plasma impurity deposition. A fit of the exponential decaying impurity signal yields the impurity transport time τ_I (see green line in Fig.1(c)) being a direct measure of the global impurity confinement [3,5]. As the TESPEL injections in some cases were slightly perturbative to the plasma parameters (see *e.g.* density peaking at 3.0 s in Fig.1(a) for the W injection), in this work only the LBO injections were considered for the τ_I determination. The signals of highly ionized impurities, located well

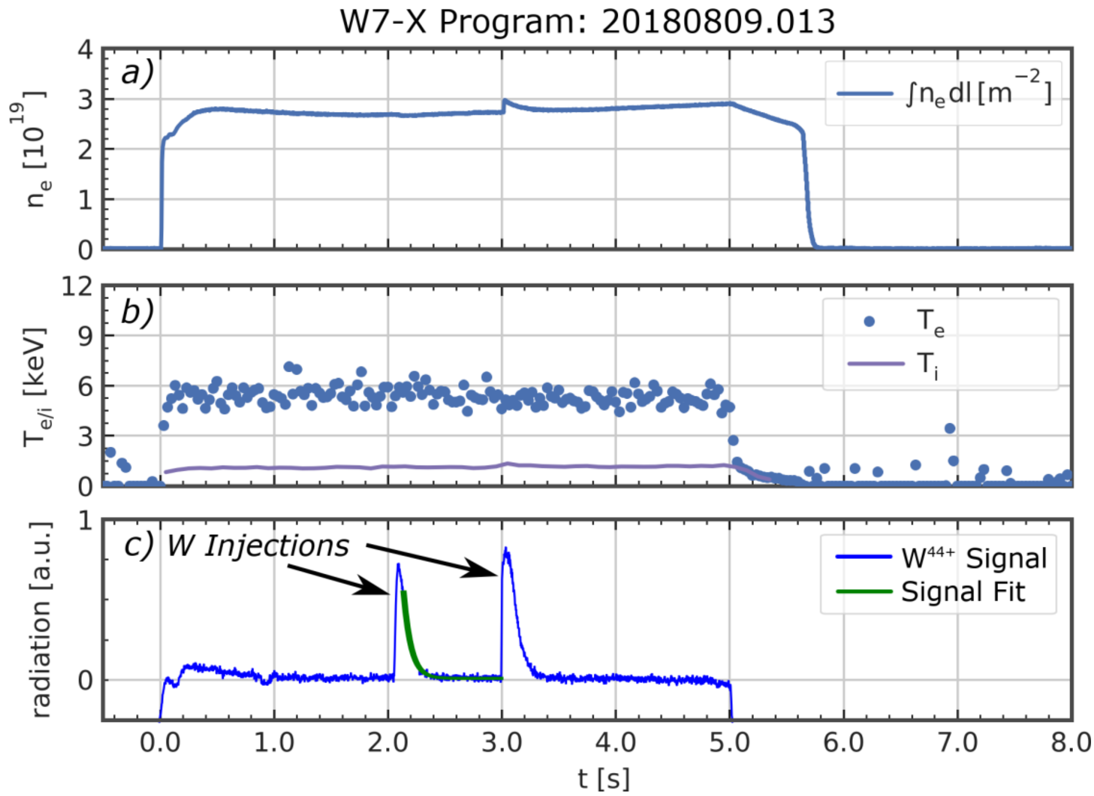

Fig.1: Time traces of a) line averaged electron density, b) central ion and electron temperatures, and c) brightness of W^{44+} emission lines after W injections at 2 and 3 s using LBO and TESPEL injection systems.

inside the bulk plasma, have been recorded making use of the HR-XIS and XICS imaging spectrometers [6].

2. Global Confinement for Different Impurity Species

In Fig.2, the experimentally derived impurity transport times τ_I for numerous impurities, namely silicon, titanium, iron, nickel, copper, molybdenum, and tungsten are shown. As can be seen, the measured τ_I values are very similar for a wide range of different impurities under the variation of the atomic number A as well as the atomic charge Z and the charge to mass ratio Z/M , see also lower panel of Fig.2. In particular, although the impurity charge varies by about ΔZ = 55 % going from Ti^{20+} to W^{44+}, the observed change in τ_I is only of $\Delta\,\tau_I$ = 6±2 %. This shows at most a very weak dependence of impurity confinement for both, the impurity charge as well as the impurity mass. This trend has also been observed in earlier studies at Alcator C-mod and W7-X [6,7], although in those cases, the limited number of impurity species did not allow to draw any general conclusions on the Z and M dependence of impurity confinement so far.

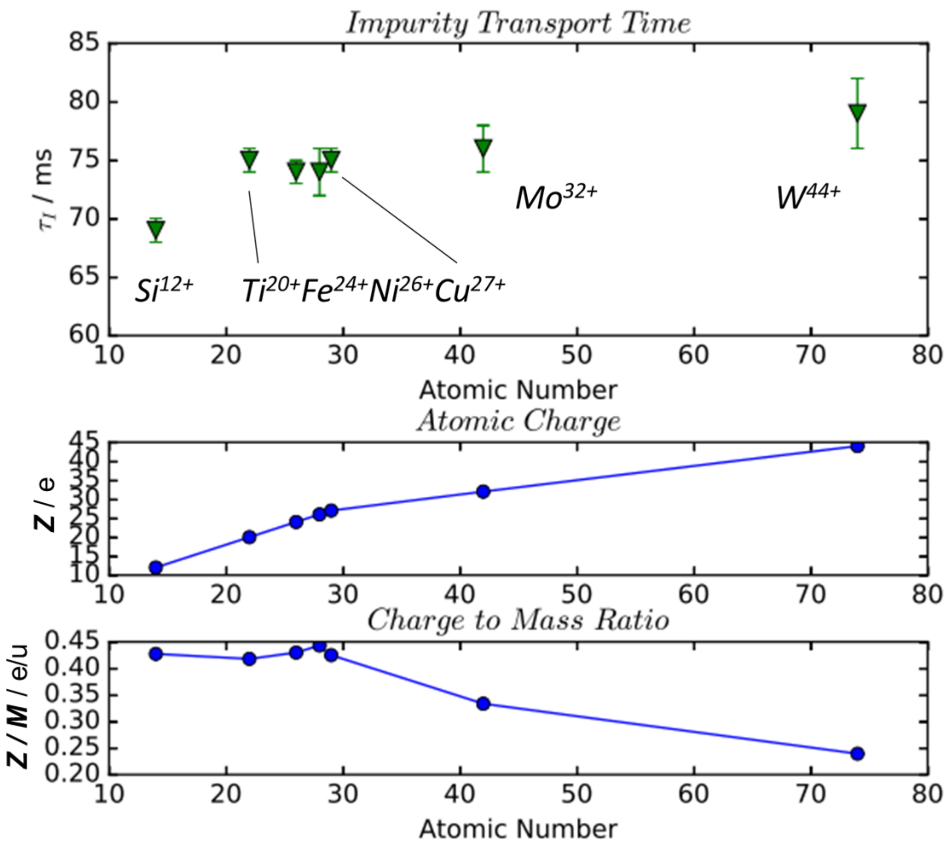

Fig.2: Experimentally obtained impurity transport times for various atomic numbers (upper panel) and the corresponding charge and charge to mass ratios of the impurity species (lower panel). Note the limited range of shown transport times.

Although not shown in this paper, initial results from the TESPEL injection experiments also show a similar trend of the above discussed weak Z and M dependence of $\boldsymbol{\tau_I}$.

3. Theoretic Expectations: Neoclassical and Anomalous Transport

The observed marginal effect of the impurity mass and charge state on the transport properties of highly charged impurities is in agreement with theoretical predictions when impurity transport is dominated by turbulent diffusion [8]. Here, a gyrokinetic model of quasilinear impurity transport yields a diffusion transport parameter D being independent of Z and M and which is dominant over the convective transport v. This model is also in line with recent experimental results based on direct measurements of impurity diffusion profiles, revealing anomalous transport in W7-X plasmas with impurity diffusivities much larger than neoclassically expected [1,2].

In contrast to the linear predictions for anomalous transport, models of classical and neoclassical transport in the high collisionality regime of multiple charged impurities predict a pronounced Z dependence of the impurity convection v [9,10] that would have direct impact on

measured τ_I values. In addition, the neoclassical diffusivities are predicted to be more than one order of magnitude smaller than the actually observed ones [1].
Both the observations are in line with turbulence dominated impurity transport at W7-X, at least within the operational regimes the machine has explored so far.

4. Summary and Conclusions

The experimental finding of a weak *M* and *Z* dependence for the confinement of highly charged impurities supports a turbulent dominated nature of the impurity transport at W7-X.
The combination of weak *Z* dependence and high diffusivities is beneficial for avoiding impurity accumulation in the planed long pulse operations of W7-X, especially for the high *Z* materials, including tungsten.

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