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Turbulent transport of impurities in stellarators

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Keeping a low content of impurities in the plasma, in order to avoid intolerable radiation and fuel dilution levels, is necessary in order to achieve high performance conditions in present day experiments and to make thermonuclear fusion feasible at reactor scale. It is therefore of paramount importance to quantitatively understand the mechanisms that determine the impurity transport in the plasma. In stellarators, neoclassical transport has typically been thought to dominate. However, the first experimental campaigns of Wendelstein 7-X (W7-X) have shown that the turbulent component is essential to understand impurity transport in this device. The calculation of turbulent transport requires to solve the gyrokinetic system of equations, which, for the three-dimensional geometry of stellarators, implies a high computational cost, in particular when several species with disparate masses are accounted for. Moreover, there have historically been many fewer numerical codes capable of handling stellarator geometry compared with the numerous tools available to address the turbulent transport problem in axisymmetric tokamak configurations. Therefore, it has not been until recently that multispecies nonlinear gyrokinetic simulations have been carried out for large stellarators, like LHD or W7-X, (see [1] and [2], respectively). In the present contribution, the turbulent transport of impurities in stellarators is comprehensively studied with the δf gyrokinetic code `stella` [3], whose mixed implicit-explicit algorithm makes nonlinear multispecies simulations more affordable than fully explicit schemes. The results demonstrate for W7-X that: ordinary diffusion carries the largest fraction of the total turbulent impurity transport under ITG and TEM turbulence, although the second drives impurity transport less efficiently than the former; that thermo-diffusion is practically negligible; that the convection in the absence of impurity pressure gradients can be radially inwards or outwards, depending on the turbulence-driving gradients; and that both the diffusion and the convection coefficients are strongly reduced when the main ion and electron density peaking is increased, see figure 1 (left), which is particularly relevant for pellet-fueled W7-X high performance scenarios [4]. Comparing different stellarator configurations, namely, W7-X, TJ-II, LHD and NCSX it is found that the size of the normalized turbulent diffusion and convection are comparable across three of them, with appreciably lower transport coefficient for LHD, see figure 2 (right). Apart from these results, obtained at trace impurity concentration, the role that non-trace impurities have on the bulk turbulence is also addressed.

References:
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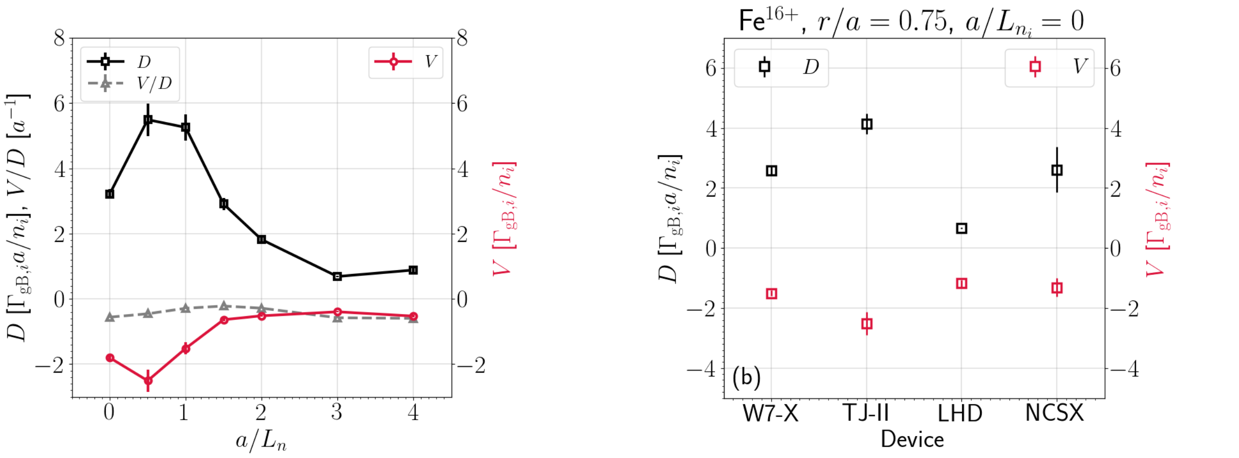

Figure 1: (Left) For W7-X, normalized diffusion (D) and convection (V) coefficients for Fe^{16+} as a function of the main ion density gradient and for a normalized ion temperature gradient of a/L_{Ti}=4. (Right) Coefficients D and V for Fe^{16+} and for the stellarators W7-X, TJ-II, LHD and NCSX under pure ITG turbulence with a/L_{Ti}=4.