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TURBULENT TRANSPORT OF IMPURITIES IN 3D DEVICES

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ABSTRACT

- The evidence of a **large diffusive turbulent contribution to the radial impurity transport in W7-X** has been experimentally supported during the first campaigns and numerically validated with gyrokinetic simulations.
- The **absence of impurity accumulation** in W7-X so far is attributed to this large diffusive term.
- To what extent is this a **distinctive feature of W7-X?**
- In this work, the turbulent **diffusion (D) and convection (V)** coefficients are obtained **for carbon and iron** impurities **in W7-X, LHD, TJ-II and NCSX** by means of gyrokinetic simulations performed with the code

BACKGROUND

EXPERIMENTAL EVIDENCE SUPPORTING TURBULENT IMPURITY TRANSPORT IN W7-X

- **Impurity confinement time** (τ_I) is **independent on the charge state** of the impurities [Langenberg PPCF'19]
- The size of the **diffusion coefficient** inferred from STRAHL analyses is **O(1) m^2s^{-1}** while **neoclassical** estimations predicts **O(10^{-3}-10^{-2})** m^2s^{-1} [Geiger NF'19]
- **Longer τ_I** is also measured when **ITG is stabilized** through the ion to electron temperature ratio T_i/T_e [Wegner NF'20]
- When **pellet induced enhanced performance** is accessed and turbulence is reduced the density profile of argon develops **large gradients** [Langenberg IAEA'21] and **τ_I increases** [v.Stechow submitted'21].

NUMERICAL VALIDATION OF IMPURITY BEHAVIOUR IN W7-X

- First **gyrokinetic nonlinear simulations with stella** [Barnes JCP'19] to characterize Γ_Z driven by TEM and ITG turbulence in W7-X [García-Regaña JPP'2021]

$$\Gamma_Z = -n_Z\left(D_{Z1}\frac{\mathrm{d}\ln n_Z}{\mathrm{d}r} + D_{Z2}\frac{\mathrm{d}\ln T_Z}{\mathrm{d}r} + C_Z\right)$$

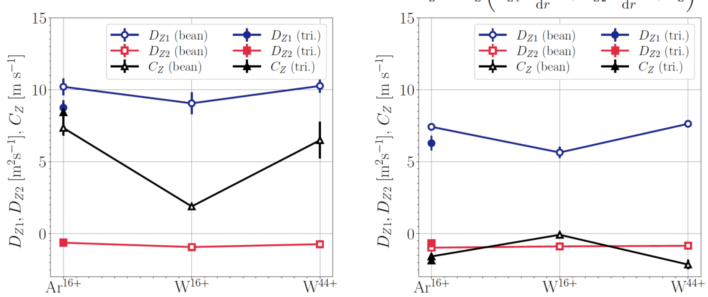

Fig 1. Diffusion (D_{Z1}), thermo-diffusion (D_{Z2}) coefficients and (anti-)pinch (C_Z) for three different impurities at W7-X in the presence of ITG and TEM turbulence driven by a/L_{ti}=4.0 and a/L_{ne}=4.0, respectively.

- ✓ Weak charge dependence is obtained.
- ✓ The size of D_{Z1} is in the range of 5-10 m^2s^{-1}, which is reasonably close to the experimental values.
- **TEM turbulence** should **drive** comparatively **less Γ_Z than ITG**.
- **Thermo-diffusion** is practically **negligible** in both cases and, while **TEM** drives a weak **anti-pinch** through C_Z, **ITG drives** a **moderate pinch**.

ITG STABILITY, TURBULENCE AND Γ_Z IN W7-X, LHD, TJ-II AND NCSX

- For the ITG scenario driven solely by the gradient *a/L_{ti}=4.0,* how is, at r/a=0.75 for each configuration the stability, turbulence spectrum and, most importantly, the transport coefficient for the impurities?

Device	a [m]	N_{fp}	R_0 [m]	B_r [T]	ι	$\hat{s}$	$\{N_x, N_y, N_z, N_{v_\parallel}, N_\mu\}_{\mathrm{nl}}$	$\{k_x^{\min}\rho_i, k_y^{\min}\rho_i\}_{\mathrm{nl}}$
NCSX	0.323	3	1.44	1.52	0.57	-0.823	{103, 75, 96, 24, 12}	{0.069, 0.067}
TJ-II	0.192	4	1.5	0.82	-0.625	-0.119	{103, 64, 96, 24, 12}	{0.075, 0.1}
W7-X	0.514	5	5.51	2.64	0.886	-0.150	{76, 109, 96, 24, 12}	{0.047, 0.05}
LHD	0.636	10	3.67	2.58	-0.763	-1.569	{134, 67, 96, 24, 12}	{0.066, 0.067}

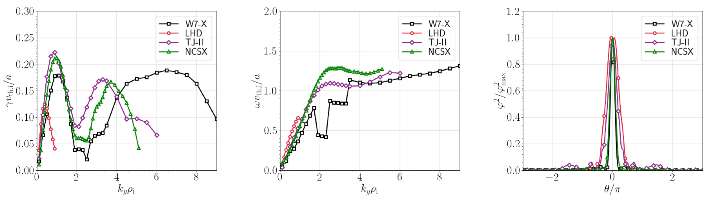

Fig 2. Normalized growth rate (left) and frequency (centre) as a function k_y (k_x = 0); parallel mode structure for the fastest growing mode for each device.

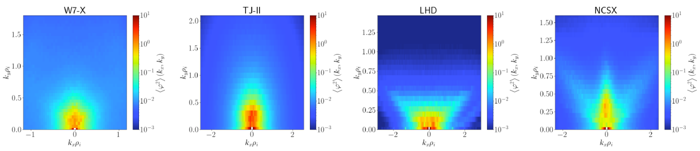

Fig 3. spectrum of the flux surface averaged square of the turbulent electrostatic potential.

$$\Gamma_Z/n_z = -D\mathrm{d}\ln n_Z/\mathrm{d}r + V$$

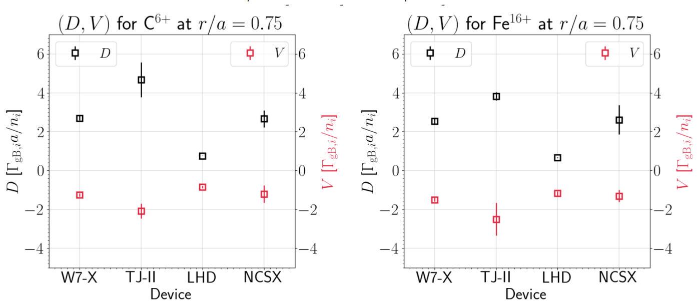

Fig 4. D and V for C^{6+} (left) and Fe^{16} (right).

- ITG drives in all cases net inward convection, which yields to the formation of peaked impurity density profiles, as V/D<0.
- Despite the differences in the values of V or D between (W7-X, LHD, TJ-II and NCSX), V/D is comparable in all cases (except for LHD):
  (V/D) = *a*(0.47, 1.12, 0.45, 0.44) for C
  (V/D) = *a*(0.59, 1.77, 0.66, 0.5) for Fe.

CONCLUSION

- D is not stronger in W7-X than in other devices and, indeed, the resulting impurity peaking factor that ITG produces is rather similar.
- Although ITG leads to peaked impurity density profiles, the gradient in equilibrium is fairly low for all devices or, at worst, moderate (for LHD).
- Next step: investigating Γ_Z in reduced turbulence scenarios.

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