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Turbulent transport of W ions in Tokamak plasmas

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ABSTRACT

- The transport, accumulation and control of W impurity ions is a very important issue for the development of ITER.
- We analyze the turbulent transport of heavy ions (such as W) with a complex transport model which includes $E \times B$ and the polarization drifts, collisions, effective poloidal velocities and the parallel acceleration.
- A symmetry breaking mechanism of Hidden Drifts [1] is identified as the generator of an effective radial pinch velocity.
- The mechanism is confirmed by numerical simulations and the pinch is characterized in terms of model's parameters.

Transport model of W ions

- $\frac{dx}{dt} = K_*'[-\partial_2\varphi(\boldsymbol{x},z,t) + C_A\partial_t\partial_1\varphi(\boldsymbol{x},z,t)] + P_c\eta_1(t)$
- $\frac{dy}{dt} = K_*'[\partial_1\varphi(\boldsymbol{x},z,t) + C_A\partial_t\partial_2\varphi(\boldsymbol{x},z,t)] + V_p + P_c\eta_2(t),$
- $\frac{dz}{dt} = \frac{1}{\sqrt{A}}v_z,\ \ \frac{dv_z}{dt} = -P_{acc}\partial_z\varphi(\boldsymbol{x},z,t).$
- $\boldsymbol{x} = (x,y)$, V_p = average poloidal velocity, φ the turbulent potential and η_i collision velocities
- The dimensionless parameters:
- $K_*' = \frac{e\Phi}{T_i}\frac{a}{\rho_i},\ C_A = \frac{A}{Z}\frac{\rho_i}{a},\ P_{acc} = \frac{e\Phi}{T_i}\frac{Z}{\sqrt{A}},\ P_c = \mathrm{Z}\frac{\mathrm{a}}{\lambda_{\mathrm{mfp}}}, \nu = \frac{Z^2}{\sqrt{A}}\frac{a}{\lambda_{mfp}},\ \frac{\tau_d}{\tau_0},\ \frac{V_p}{V_*}$
- The correlations of the stochastic fields:
- $E(\mathbf{x},\mathrm{z},t) = \Phi^2\partial_2\left[exp\left(-\frac{x_1^2}{2\lambda_1^2}-\frac{x_2^2}{2\lambda_2^2}-\frac{z^2}{2\lambda_z^2}\right)\frac{sin\ k_0x_2}{k_0}\right]\exp\left(-\frac{t}{\tau_c}\right)\cos(\omega_0 t),$
- $C_i(t) = \langle\eta_i(0)\eta_i(t)\rangle = exp(-\nu|t|),\ \nu = \frac{Z^2}{\sqrt{A}}\frac{a}{\lambda_{mfp}},$

Methods : DTM and DNS

Decorrelation Trajectory Method (DTM)

A semi-analytical method [2] to recast the statistical problem of the transport model in a deterministic one, using conditional subensemble averaged fields. The results are only qualitatively correct. It serves as a fast, alternative tool for DNS.

Direct Numerical Simulations (DNS)

A statistical method [3] to solve the statistical problem as it is, without resorting to any approximations. An ensemble of stochastic fields is generated and the eqns. are solved for each realization. Lagrangian quantities are computed as correlations over the solution's ensemble. The method is exact-in-principle but hindered, in practice, by numerical effort.

Validation of the Hidden-Drifts

Hidden-Drifts [1] are a special type of order generated by an average poloidal velocity V_p superposed on the $E \times B$ stochastic drift. It consists of two average radial velocities in opposite directions, which exactly compensate. (do not yield an average velocity).

The perfect symmetry of the HDs is destroyed by the polarization drift and by the parallel acceleration parallel, which drive radial pinches [4,5].

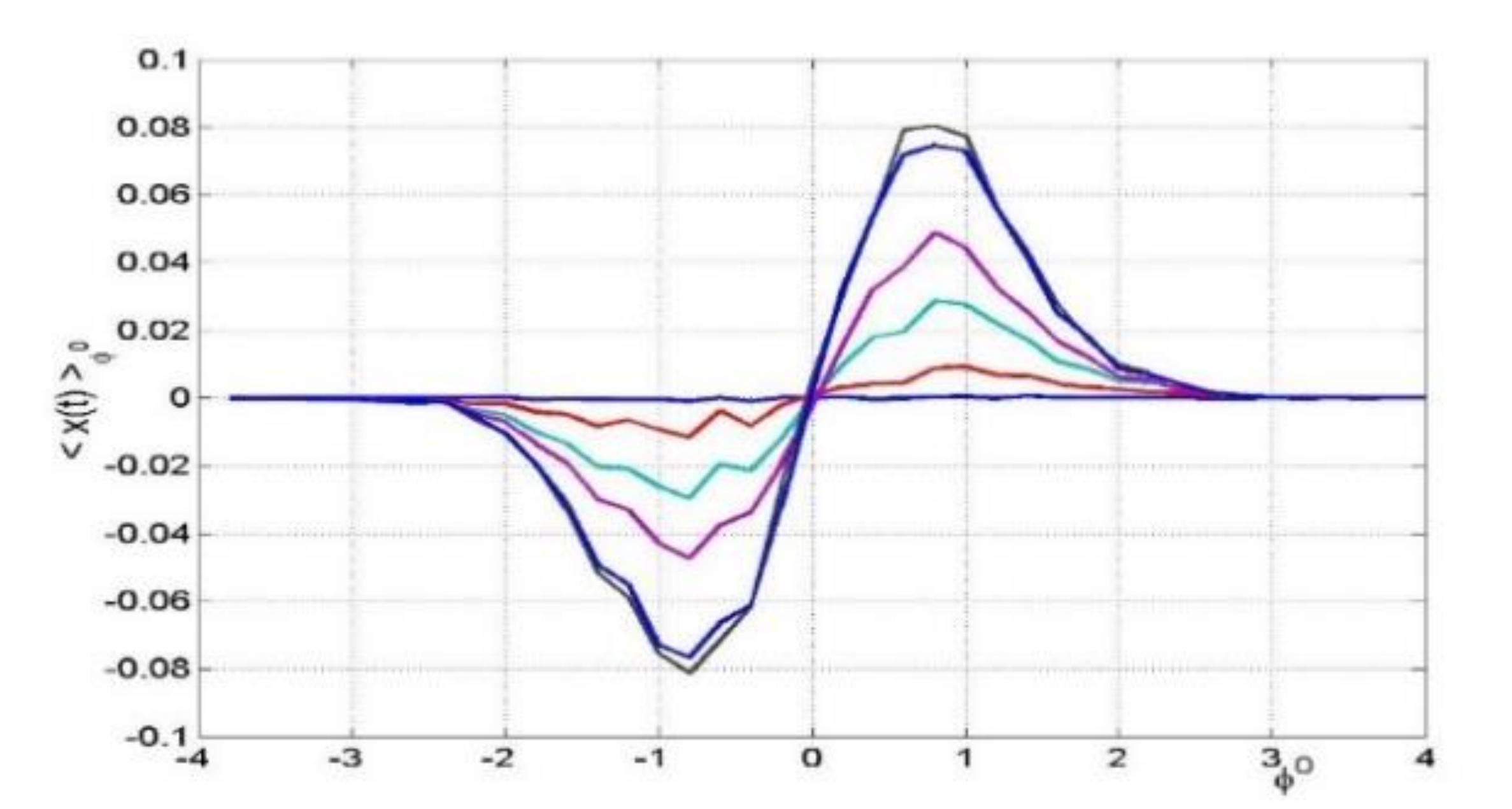

FIG. 1. The conditional average displacements as functions of the initial potential for different moments without polarization ($C_A = 0$) or acceleration ($P_{acc} = 0$).

Results

Polarization drift pinch

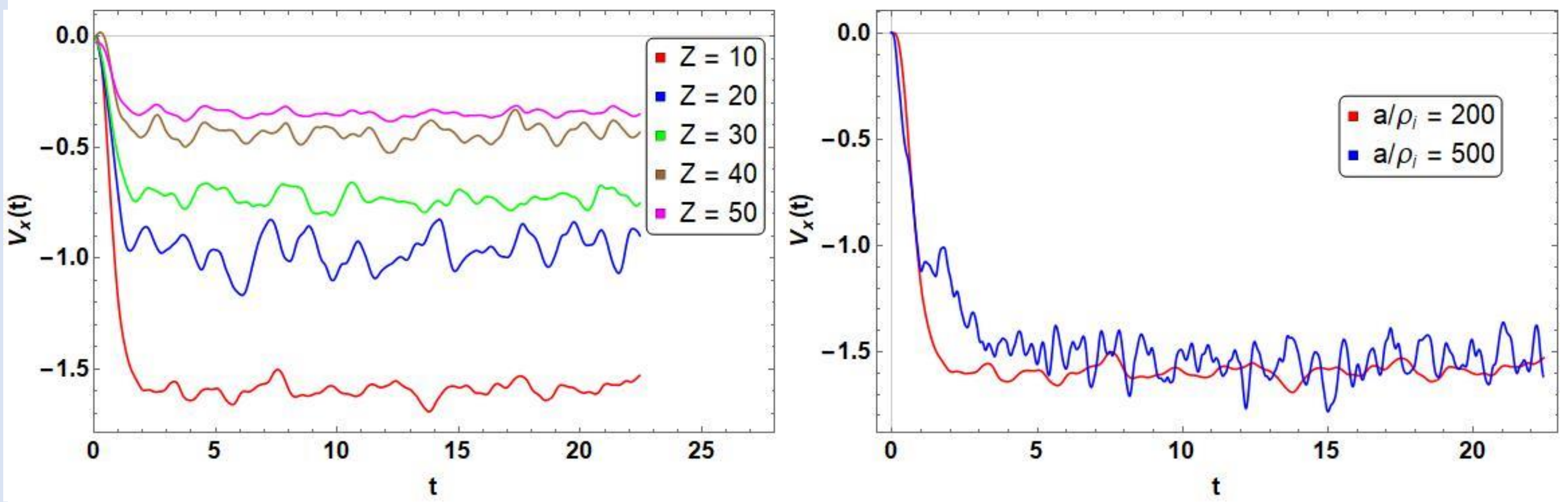

FIG. 2. The pinch $V_x(t)$ determined by the polarization drift: the dependence on Z for $a/\rho_i = 200$ (left panel) and for different sizes of plasmas and Z=10 (right panel).

Parallel acceleration vs. polarization drift

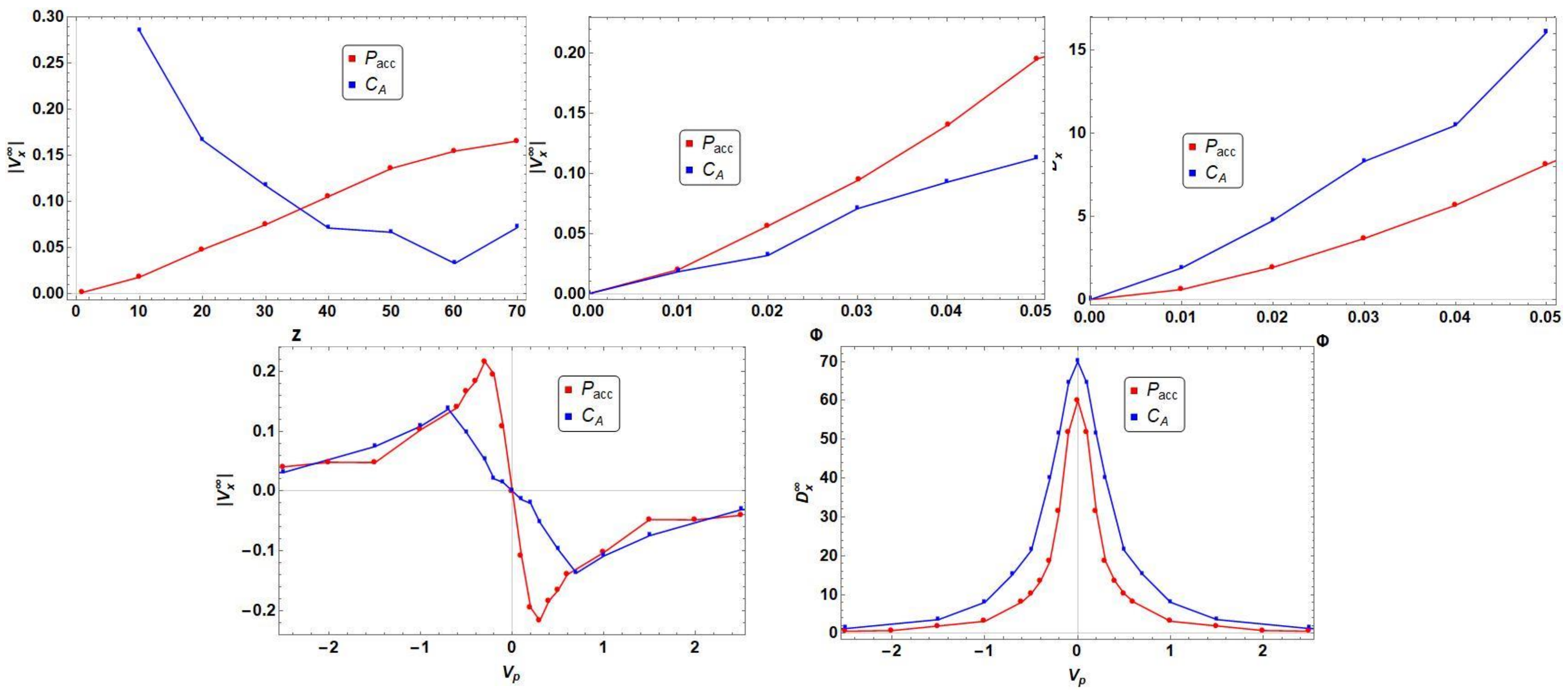

FIG. 3. V_x^∞ and D_x^∞ determined by the parallel acceleration (red) and by the polarization drift (blue) as functions of several parameters (V_p, Z, Φ).

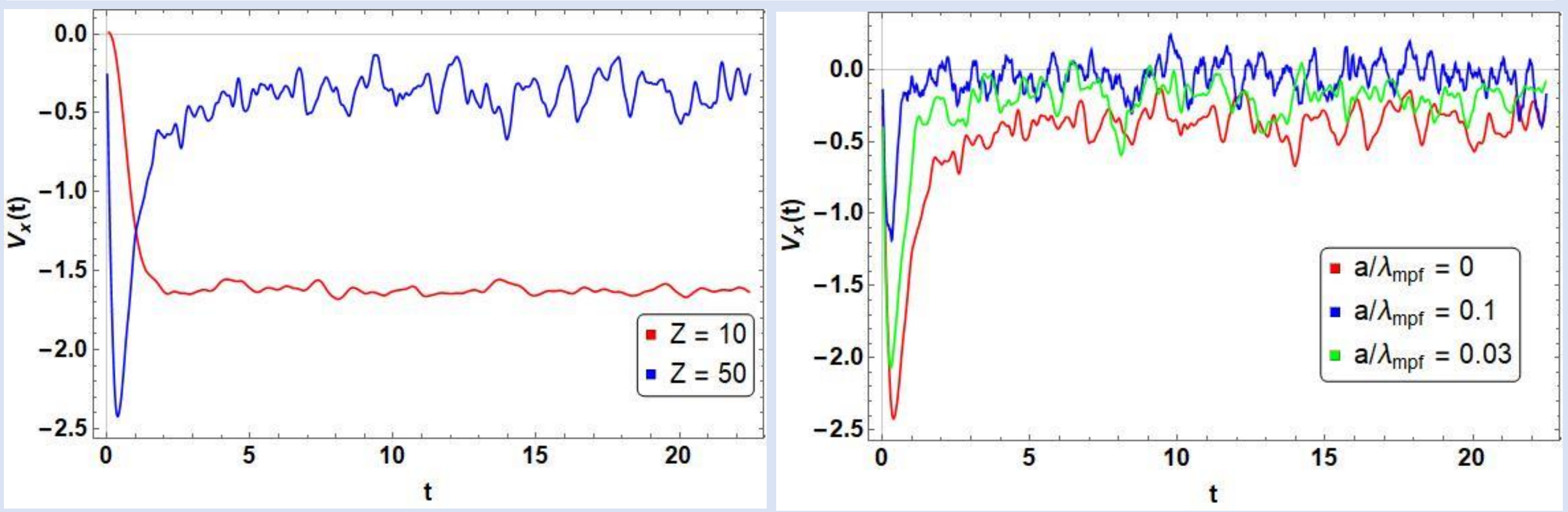

FIG. 4. Pinch velocities $V_x(t)$ determined by both mechanisms. Left panel: $V_x(t)$ in the collisionless case for $Z = 10$ $a/\rho_i = 200$ (red) and $Z = 50, a/\rho_i = 500$(blue). Right panel: the effect of collisions on $V_x(t)$ in the case of a large size plasma with $a/\rho_i = 500$ for $Z = 50$ at $a/\lambda_{mfp} = 0.03$ (Pc=1.5, v=5.5) and at $a/\lambda_{mfp} = 0.1$ (Pc = 5, v = 18.4).

CONCLUSION

- A new pinch mechanism is found: symmetry breaking of hidden-drifts in via parallel acceleration and polarization drift in the presence of poloidal velocities.
- The generated pinch is radial and explains, partially, the observed transport of tungsten to the center of the plasma.
- Typical values of the pinch are roughly $50m/s$ for JET and AUG plasmas and $\sim 80m/s$ for ITER.
- The main control parameter for the radial pinch is the poloidal velocity.

ACKNOWLEDGEMENTS & REFERENCES

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