8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Reversal of the Parallel Drift Frequency in Anomalous Transport of Impurity ions

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Heavy ion accumulation leads to the radiative energy loss in fusion reactors, which may cause the degradation of the plasma confinement. Therefore, it is crucial to understand heavy ion transport in fusion plasma.

In many theoretical studies of plasma turbulence, it is conventional to replace the parallel advection term $v_{\|}\nabla_{\|}g_s$ by $ik_{\|}v_{\|}g_s$, with $k_{\|}$, a parallel wave number, and g_s, the distribution function of the specie "s". This insinuates that the particles with positive and negative parallel velocities along the magnetic field lines also have opposite parallel frequencies, and since the particle transport related to the parallel dynamics is proportional to this parallel frequency, the flux from particles with $v_{\|} > 0$ is canceled or at least significantly reduced by the flux from $v_{\|} < 0$.

In our recent work [1,2], we propose a new method to resolve the parallel dynamics in gyrokinetic turbulence, e.g., resolving $v_{\|}\nabla_{\|}g_s$ by $i\kappa v_{\|}g_s$, with $\kappa(=\kappa_r + i\kappa_i)$, a complex-valued parallel advection operator defined as $\kappa \equiv \nabla_{\|} ln g_s$. Using this, we find for the first time that the ion parallel drift frequency $\kappa_r v_{\|}$ can reverse sign in velocity space when the amplitude variation of the electrostatic potential fluctuation is strong along the magnetic field line z, by using for example a large magnetic shear $\hat{s}$, as shown in Figure 1. In consequence, the particle transport related to the parallel dynamics $\Gamma_{s,\|}$ is strongly enhanced, rather than reduced or suppressed, which is totally different to the conventional understanding.

The reversal of the ion parallel drift frequency is a novel phenomenon in plasma physics. It displays that the parallel drift frequency is very complicated in kinetic plasma, which cannot be simply described with a parallel wavenumber. Future work should consider the proper description of the parallel drift frequency of various ions and electrons in various plasma systems, its influence on various transport fluxes, and dependencies on different turbulence regimes and magnetic configurations.

References
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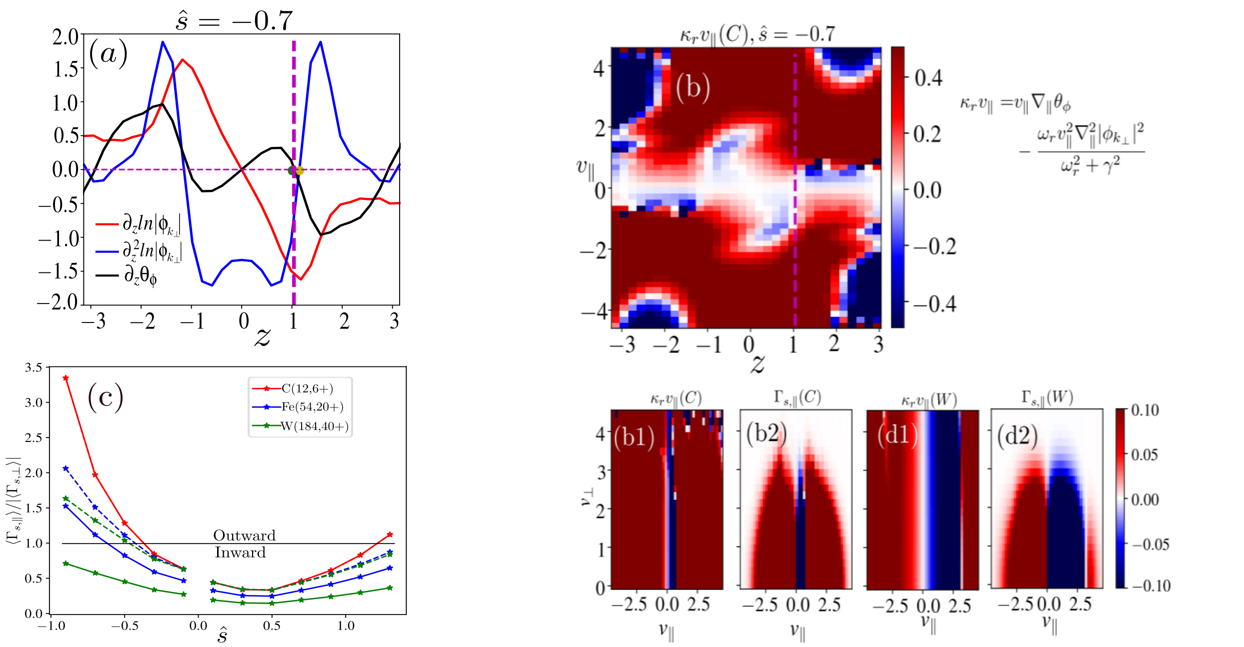

Figure 1. Due to the strong amplitude variation $|\Phi_{k_\perp}|$, $\kappa_r v_{\|}$ of carbon ions starts to reverse sign at around z>1.0 (Fig.b) where the derivative of the phase $\partial_z\theta_\Phi$ is close to zero, as marked by the magenta vertical lines in Fig.a and Fig.b. Fig.b1 and Fig.b2 show respectively $\kappa_r v_{\|}$ and $\Gamma_{s,\|}$ of carbon in $(v_{\|}, v_\perp)$ plane at z=1.37, where $\kappa_r v_{\|}$ as well as $\Gamma_{s,\|}$ $(\sim\kappa_r v_{\|})$ reverses sign at around $v_{\|}\sim0.7$. Compared to carbon ions, $\kappa_r v_{\|}$ of tungsten also reverse sign, but in higher $v_{\|}$ region (Fig.d1), and hence the contribution to the flux $\Gamma_{s,\|}$ is smaller (Fig.d2). With a larger $\hat{s}$, the amplitude effect is stronger, $\kappa_r v_{\|}$ reverses sign in lower $v_{\|}$ region, the outward $\Gamma_{s,\|}$ is strongly enhanced and can exceed the inward $\Gamma_\perp$.