Title: Energy Transfer across Boundary Layers in the Earth's Magnetosphere

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Abstract:
In this project, based on PRACE Tier-0 resources, a series of large-scale fully kinetic plasma simulations are performed to understand realistic energy transfer physics in collisionless space plasmas. Space such as between planets, stars and even galaxies is almost commonly filled with plasma with its density small enough to neglect particle collisions. In such a collisionless system, the boundary layer between regions with different plasma properties plays a central role in transferring energy and controlling the dynamics of the system itself. In a representative collisionless system, the Earth's magnetosphere, the energy input from the solar wind is transferred and changes its properties through different physical processes at various boundary layers, which eventually leads to the global dynamics of the magnetosphere and various energetic space weather phenomena such as auroral substorm. Although a number of theoretical, numerical and experimental studies have been performed to understand the boundary layer physics and related energy transfer processes in the magnetosphere, quantitative aspects of the transfer processes are still poorly understood. This is mainly because the realistic transfer processes basically involve a broad range of temporal and spatial scales from the electron kinetic to magneto-hydrodynamic (MHD) scales, which were difficult to be handled by previous research tools. Thus, the main goal of this project is to quantify the realistic energy transfer processes covering all necessary scales by effectively combining state-of-the-art fully kinetic simulations which cover a broad range of scales and high-resolution in-situ spacecraft observations which cover necessary scales to provide realistic parameters to the simulations. To this end, we systematically perform large-scale fully kinetic simulations using the high-performance VPIC code under realistic conditions obtained from the recently launched high-resolution MMS (Magnetospheric Multiscale) spacecraft. In this year, we particularly focused on the effects of turbulence on the energy transfer processes across the boundary of the magnetosphere called the magnetopause. First, we analyzed a large-scale VPIC simulation, which started from a laminar state, of an MMS observation event of the magnetopause. The results showed that the flow shear, which persistently exists across the magnetopause, drives multi-scale (electron kinetic to MHD scale) turbulence at the magnetopause and causes efficient plasma and energy transfer across the magnetopause. However, the amplitudes of the turbulent fluctuations observed by MMS tends to be stronger than the simulation. Then, we further performed a series of simulations considering background turbulence in the initial state as observed near the magnetopause. The new simulations demonstrated that the pre-existing background turbulence enhances the shear-driven turbulence at the magnetopause to the same level as observed by MMS. This indicates the importance of pre-existing turbulence to quantitatively understand realistic energy transfer processes at the plasmas boundary layers. Since turbulence is believed to commonly exist in many collisionless plasma systems, these new findings give us motivation to further explore the effects of turbulence in energy transfer processes at plasma boundary layers in space.