Report: DOE Plasma Science Center Travel Fellowship

A Direct Kinetic Simulation for Secondary Electron Emission from an Emissive Surface

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My visit to Princeton Plasma Physics Laboratory (Princeton, NJ) was from March 4th to March 8th, 2013. The purpose of this visit is to look for and start collaborations with Dr. Igor Kaganovich.

<Overview of the research>

The discharge plasma in Hall thrusters is known to be in a non-equilibrium state due to nonlinear interactions between electromagnetic fields, channel walls, and many types of collisions. In order to control such complex plasmas, transport of the velocity distribution functions (VDFs) of each plasma species must be understood. Although particle methods have been well developed and used to capture the non-equilibrium effect, these methods suffer from statistical noise due to the use of macro-particles. My research focuses on developing a direct kinetic (DK) simulation in which kinetic equations are solved and the VDFs are obtained by discretizing the phase space. Two ongoing projects are described as follows.

1. *Hall thruster simulation:* A 1D hybrid-DK simulation in which a DK simulation is used for heavy species and a fluid model is employed for electrons. [Hara, K. et al. Physics of Plasmas, **19**, 113508 (2012)] Time averaged results and low frequency oscillation mode (~10 kHz) are in good agreement. The difference can be seen in the high frequency regime (~100 kHz) as shown in Fig. 1. The hybrid-DK simulation does not suffer from the statistical noise due to macro-particles. As a result, spatial and temporal evolution of the plasma density is well resolved. A 2D hybrid-DK simulation is currently being developed.

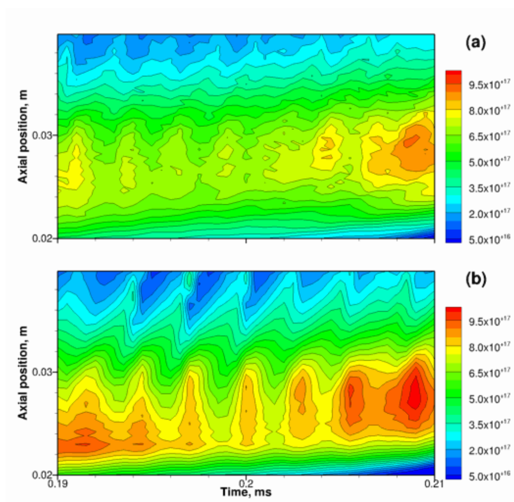

Fig. 1 Spatial and temporal evolution of the ion number density in the Hall thruster discharge channel: (a) hybrid-PIC (b) hybrid-DK

2. *Secondary electron emission analysis:* A full-DK simulation, which employs a DK method for both ions and electrons, is used to assess collisionless sheath theory in the presence of secondary electron emission from the dielectric materials. The results will be presented at the IEEE Pulsed Power and Plasma Science Conference.

<Visit to PPPL>

Dr. Igor Kaganovich and I have set two goals for the future collaborations. In addition, I had fruitful discussions with other researchers in PPPL including Dr. Yevgeny Raitses, Dr. Greg Hammet, Dr. Ammar Hakim, and the students who are working with Dr. Igor Kaganovich.

1. *Collisionless nonlinear phenomena*: A DK simulation is very useful to investigate the nonlinear plasma phenomena because there is no statistical noise that is inherent in particle simulations. For instance, the nonlinear Landau damping is captured using a DK simulation, as shown in Fig. 2. It can be seen that the wave is damped at the initial stage but experiences a nonlinear undamped behavior at time steps larger than 10 times the inverse of electron plasma frequency. Recently, kinetic electrostatic electron nonlinear (KEEN) wave has been studied by the laser-plasma community. A laser beam interacts with the background plasma and excites various waves. In order to investigate the transport of waves, a DK simulation may be advantageous over particle simulations due to the absence of statistical noise. During my visit to PPPL, we have discussed the numerical setup in a teleconference with Dr. Stephan Brurner (Ecole Polytechnique Federale de Lausanne, Switzerland), Dr. Richard Berger and Dr. Jeff Banks (LLNL). The numerical results obtained from my collisionless DK simulation will be compared with their results. In addition, a discontinuous Galerkin Vlasov solver developed by Dr. Ammar Hakim and Dr. Greg Hammet may be also used for comparison.

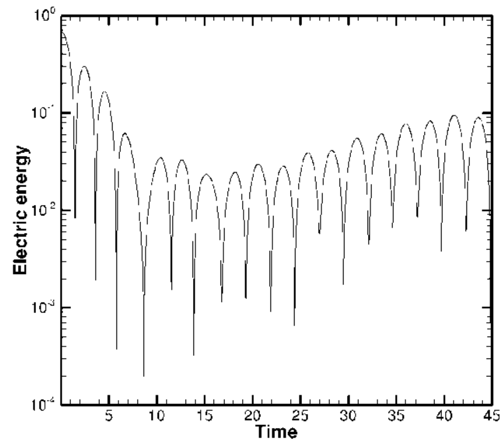

Fig. 2 Evolution of electric energy in nonlinear Landau damping

2. *Two-stream instability induced by secondary electron emission*: The effect of secondary electron emission on the VDFs of the bulk plasma is studied by Michael Campanell (PPPL) *et al.* using their 1D full-PIC simulation, EDIPIC. They have shown that two-stream instability contributes as a mixing of secondary electrons and the bulk plasma, which plays an important role in determining the sheath structure in a Hall thruster. However, as mentioned earlier, a DK simulation may be more useful to investigate the nonlinear instability because it does not suffer from statistical noise. Once the DK simulation is applied to this problem, we can benchmark both codes to investigate the numerical and physical effects. In addition, the 2D transport needs to be investigated because of the complex magnetic field geometry in a Hall thruster. The Large Scale Plasma (LSP) simulation in PPPL and a 2D full-DK simulation will be compared.