Plasma Dynamics of Electric Propulsion for In-Space Missions

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Space propulsion is the key component for the upcoming “space exploration era”. Space exploration is not only exciting but also crucial to our society given the impact to various scientific disciplines ranging from biology/chemistry/medicines in microgravity, sustainable habitats, satellite technologies, and national security to understanding of our universe. One of the most promising in-space propulsion systems is called electric propulsion (EP), which offers high thruster efficiency and specific impulse (fuel consumption efficiency) in comparison to conventional chemical propulsion. EP utilizes electricity and produces ionized gas, i.e. plasma, whereas chemical propulsion relies typically on combustion to gain thrust. Various in-space missions using EP devices have been successful, e.g. Deep Space 1, JAXA’s Hayabusa mission for sample return from an asteroid, and hundreds of military and commercial satellites. In addition, the demand towards higher power and thrust levels, i.e. larger engines, has significantly increased aiming for interplanetary missions, such as the Mars missions that are planned by NASA in mid-2020’s. Besides its unique and attractive performance as a propulsion device, EP contains many interesting plasma phenomena that are not yet fully understood, including plasma turbulence, plasma-wave instabilities, and plasma-material interactions. Advancements in computer simulation techniques and high performance computing capabilities have enabled one to develop and utilize high-fidelity models that solve the first-principles equations. One example is the direct kinetic (DK) simulation, in which gas-kinetic equations such as the Boltzmann and Vlasov equations are solved directly on discretized phase space. The DK simulation serves as an alternative to particle methods, which have been more widely used in the plasma community, in particular for time dependent phenomena such as plasma instabilities and oscillations. In this talk, I will present the status of EP research and development as well as recent findings and challenges in understanding the plasma dynamics of EP devices.