Chapter 5
Spacecraft Charging in Non-Maxwellian Plasmas at GEO Altitudes

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ABSTRACT

Spacecraft charging phenomenon at GEO altitudes is revisited by highlighting various spacecraft missions, spacecraft orbits, surface charge mitigating techniques, and particle distribution models. A comparative analysis is presented to study the onset of negative charging for spacecraft with single Maxwellian, Kappa, and q-nonextensive distributions. Since the plasma constitutes a mixture of two clouds having cold and hot electrons with their distinct thermal energies and densities, therefore it is important to investigate surface charging with double extensive and non-extensive distributions as well as analyzing the current-balance equations (CBEs) both analytically and numerically. The Whittaker function integral is employed to solve the power-law integrals. The q-distributed electrons show more pronounced energy tails to obey Tsallis statistics having nonstationary equilibrium states. Non-extensivity effect strongly modifies the CBE for spacecraft charging, supporting better in the limit $q<1$ in contrast to Maxwell and κ distributions. Numerically critical and anticritical thresholds are also identified to understand the onset of negative charging of various space-grade materials.

INTRODUCTION

Plenty of spacecraft and satellites orbit around the Earth for their special purposes, including the weather satellites, communication satellites, navigation satellites, scientific satellites, etc. From smartphones to broadcast and weather forecasting, satellites directly influence our daily lives and provide access to various space environments for scientific discoveries. The direct exposure of plasma disturbances to spacecraft generates charging or discharging on its surfaces and excess of charge affects the functionality of onboard electronic devices. This may in turn lead to incorrect analyses and conclusions about space

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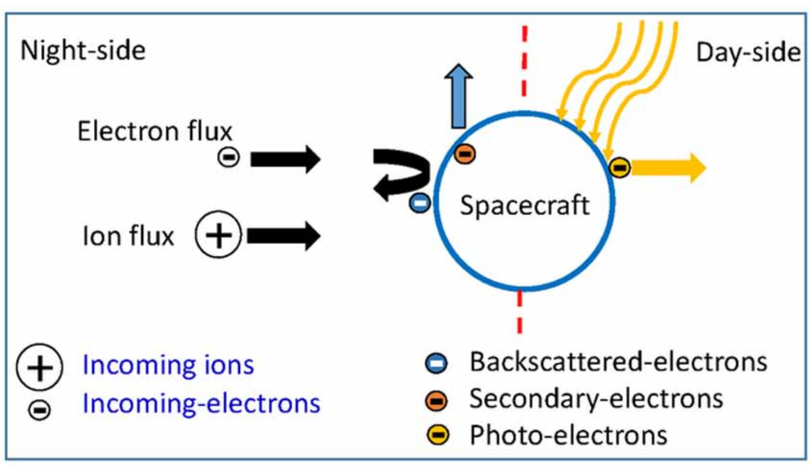
plasma environments. The surface charging also reduces the lifetime and performance of spacecraft & spaceships.

Space is a vibrant and complex realm, full of particles, radiations, and objects spanning a wide range of sizes (from very small size to very large size). The Earth is positioned at third in planets having an average distance of 150 million km from the sun. The solar wind as streams of charged particles moving with a speed ranging from 300-to-700 km per second compresses the Earth's magnetosphere via the pressure force during the dayside and stretches it on the night side. The interaction of solar wind results in the formation of asymmetrical Earth's geomagnetic field lines and an energetic hot plasma is eventually propelled towards the Earth from magnetotail, reaching geomagnetic altitudes at midnight. Hence space plasma environments can affect satellites and spacecraft as well as the climate on Earth.

Spacecraft and satellites can be charged by a number of charging combinations at GEO altitudes (Harris, 2003) including the (i) ambient electrons and ions, (ii) ambient electrons and ions with photoelectrons, (iii) ambient electrons and ions with secondary electrons, and (iv) ambient electrons and ions with both photo- and secondary electrons. The level of charging depends on the energy of plasma particles that are often described by the particle distribution functions. The use of sophisticated designs and quality materials has prevented spacecraft against the electrostatic discharges.

Spacecraft charging primarily depends on the charging mechanisms, including the plasma bombardment and photoelectric effect (see Fig.1). If a spacecraft is subjected to the plasma bombardment in eclipse, it will acquire a negative charge or potential (around 1kV) on its surface (Harris, 2003). Such a negative potential is frequently observed in many regions of Van Allen radiation belts and in magnetotail environment.

Figure 1. Surface charging mechanisms that account for plasma bombardment and photoelectric effects



On the other hand, if solar radiations interact with the surface of spacecraft in sunlit side, it would lead to trigger a photoelectric effect and in turn releases photoelectrons from its surface. This produces a net positive charge about 2-3V potential on the spacecraft's surface (Harris, 2003). Thus, a spacecraft has negative potential in shady region of the Earth due to plasma bombardment and maintains a positive potential in sunny regions owing to the photoelectric effect.