Role of the Surface Charging in the Solar Wind Interaction with a Small, Non-magnetized, Electrically Non-conducting Body Studied in a Two-dimensional Electromagnetic Full Particle Simulation

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Abstract

The solar wind interaction with a small, non-magnetized, electrically non-conducting body is studied using a two-dimensional electromagnetic full particle simulation. The solar wind magnetic field is introduced into the simulation scheme as an initial condition together with the electric field generated by the motion of the solar wind. The solar wind magnetic field controls the direction of flow of thermal electrons, causing an asymmetry of the negative charging of the downstream side surface. In the absence of the photoelectrons, the solar wind electrons are expelled by the negative charging at the terminator, and behave differently from traditional theory.

1. Introduction

The solar wind interaction with an insulating, non-magnetized body such as the moon is characterized with the particle absorption and the surface charging [1]. The solar wind particles that hit the moon are absorbed by the surface, creating a plasma cavity called the lunar wake behind the obstacle [2]. At the boundary of the wake, it has been believed that an ambipolar electric field is formed due to the difference of the thermal speed of ions and electrons rushing into the central void of the wake [3]. Due to the electron thermal speed higher than the solar wind speed, the nightside surface of the obstacle in the solar wind flow is hit only by electrons, and charges negative [4]. Lunar Prospector observations evidenced the negative charging of the nightside surface of the moon [5].

To deal with the solar wind interaction with a non-magnetized, non-conducting body on which the surface charging plays an important role, it is desirable to treat the electrons as particles. Kimura and Nakagawa [7] included the surface charging in their 2-dimensional, full-particle electromagnetic code and succeeded in reproducing the ambipolar electric field at the wake boundary, the ion acceleration into the central void, and the intense electric field at the terminator. Nakagawa and Kimura [8] introduced the solar wind magnetic field into the particle-in-cell simulation and showed that the magnetic field controls the electron flow, causing an asymmetry of the surface charging. On the other hand, there is a criticism that the effect of surface charging is exaggerated in the simulation where Debye length is relatively large with respect to the size of the obstacle.

The present paper highlights the effect of the surface charging on the electrons' motion for different ratio of the Debye length to the size of the obstacle.

2. Two-dimensional Electromagnetic PIC Simulation

The simulator used in this study is fully described in Nakagawa and Kimura [8]. The equations of motion of ions and electrons distributed around the obstacle are solved together with the Maxwell equations. The thermal speeds of ions v_i and electrons v_e are set as $v_i : v_{sw} : v_e = 1 : 8 : 32$, where v_{sw} is the bulk speed of the solar wind. The direction of the solar wind magnetic field is assumed to be 45 degrees from the solar wind flow. The magnitude of the solar wind magnetic field is set so that the Larmour radius is smaller than the size of the obstacle, which results in the cyclotron frequency 12 times as large as the plasma frequency. The results from 3 simulation runs in which the radius of the obstacle is (i) 4 times (ii) 8 times and (iii) 16 times as large as the Debye length are compared. No emission of photoelectrons or secondary electrons is considered.

3. Results

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Figure 1 shows two-dimensional plots of the magnitude of the electric field in x-y plane obtained from 3 simulation runs of different Debye lengths. The area of intense electric field in the vicinity of the terminator becomes smaller as the Debye length becomes smaller. Streaks of intense electric field extending from around the terminator is due to the electrons expelled by the negative charging of the surface of the obstacle, flowing along the magnetic field lines that are convected bhy the solar wind bulk flow. Figure 2 shows the density of ions and electrons for the simulation run (iii), for which the Debye length is smallest with respect to the obstacle size. The streaks of electros that are expelled by the negative charging of the nightside surface extend from the terminator. Although the area of the intense electric field due to the surface charging is restricted within the Debye length, the streaks of electrons, an effect of surface charging, extends along the magnetic field line even in the smallest Debye length case.

Figure 3 shows the density profiles of ions (gray curves) and electrons (black curves) at several distances downstream from the obstacle, obtained from the simulation run (iii). It is interesting to note that the electrons are preceded by ions at the boundary of the wake in the vicinity of the obstacle, where they are rushing into the central void of the wake. This is contrary to what had been believed [3]. It is supposed to be due to he negative electric potential of the nightside surface of the body, which retards the solar wind electrons coming to the wake boundary. Negative excess of charge is found in the central wake at farther downstream (x = 2 - 3 RO).

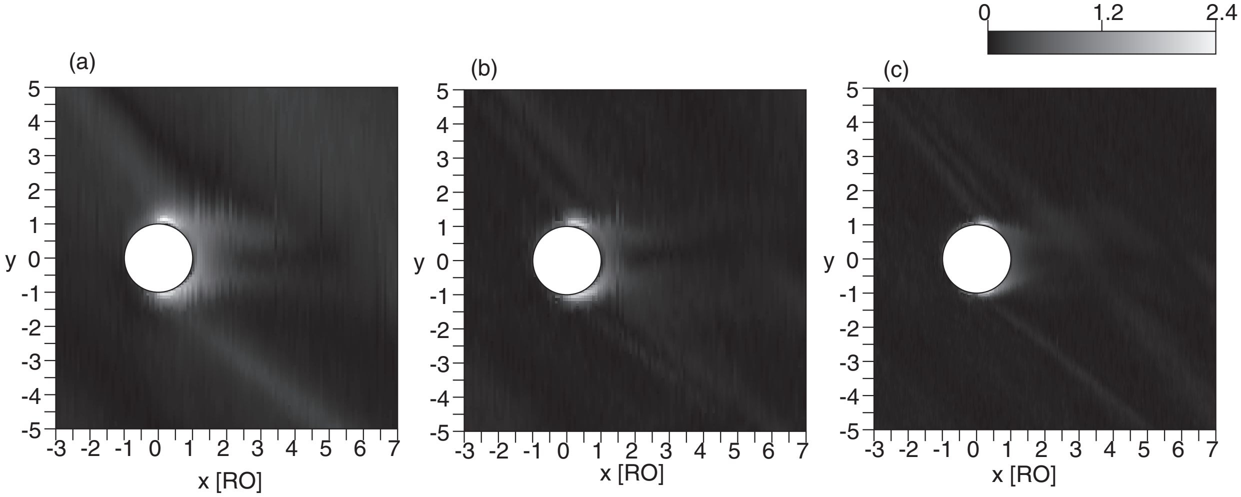

Figure 1. Two-dimensional plots of the magnitude of the electric field (*Ex, Ey*) in the x-y plane for simulation runs in which the Debye length is (a) 1/4, (b) 1/8, or (c) 1/16 of the radius of the obstacle RO.

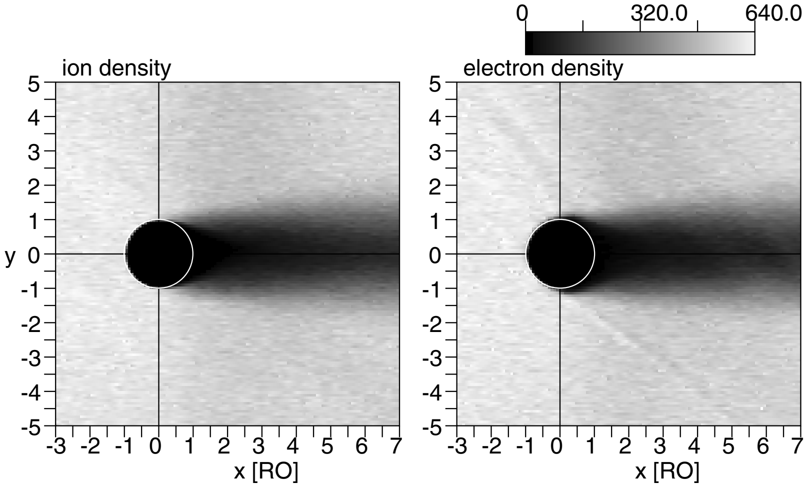

Figure 2. Two-dimensional plots of the ion density (left) and electron density (right).for the simulation run (iii).

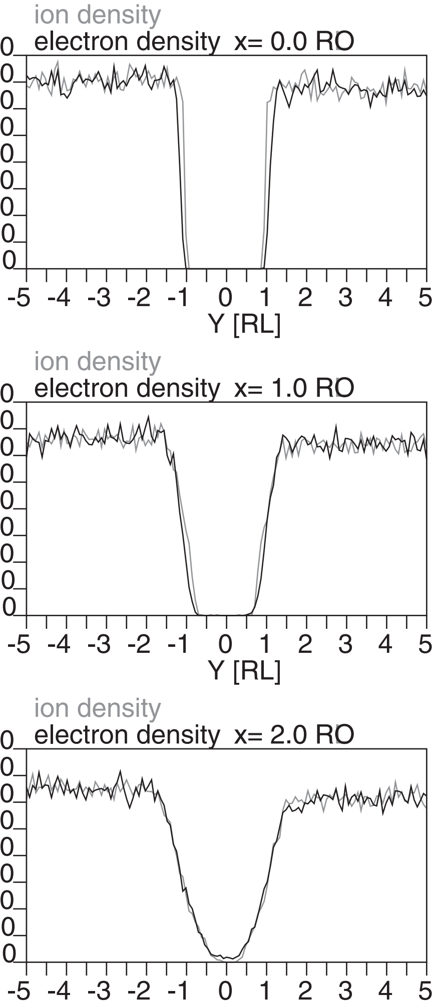

Figure 3. The densities of ions (gray) and electrons (black) plotted against the distance *y* (*y*=0 is at the center of the wake) at several distances *x* downstream from the obstacle. In the top two panels, it is recognized that ions enter the void faster than the electrons. The result of the simulation run (iii).

4. Conclusion

The nightside surface charging is due to the electron thermal speed higher than the solar wind bulk speed, which is a basic nature of the solar wind plasma, plays a significant role even in the small Debye length case. The surface charging and the negative excess of electric charge in the central wake are supposed to be caused by higher energy component of the electrons, while the density profile at the wake boundary is mainly constituted by the lower energy component that can be easily retarded by the surface charging. It causes the delayed entry of electrons preceded by ions at the wake boundary.

5. Acknowledgments

The simulation code used in this study was provided by S. Kimura, now at NTT Software Corporation, when he was a graduate student of Tohoku Institute of Technology. This study was supported by the JSPS grant-in-aid for scientific research project 21540461.

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