# Study of anisotropic electrons distributed around the wake of an ionospheric sounding rocket by a 1D Vlasov-Poisson simulation

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Ionospheric sounding rockets travel in plasma at supersonic velocity with rarefied regions called 'plasma wakes'. In a rocket wake, plasma waves with frequencies near the upper hybrid resonance (UHR) frequency, plasma frequency, and Z-mode cutoff frequency in the wake are observed as reported by Yamamoto [PhD. thesis, Tohoku University, 2001]. From the results of the S-520-26 rocket experiment, Endo et al. [JGR, 2015] suggested that the waves observed in the wake were electrostatic waves such as electrostatic electron cyclotron harmonic (ESCH) waves and UHR mode waves because plasma waves with long wavelengths cannot be generated in a narrow region like the rocket wake. The intensities of these waves, as well as of whistler mode waves observed in the same experiment, had spin-phase dependence, which is different depending on kinds of plasma waves. These results indicate that there was inhomogeneous spatial distribution of hot electrons with some anisotropic velocity distribution functions around the rocket wake.

In order to investigate inhomogeneity of hot electrons around the rocket wake, we are now developing a Vlasov-Poisson code. In the simulation with this code, we can calculate wake filling process of ambient ions and electrons in one-dimensional space along the X-axis, which is parallel to the ambient magnetic field. The grid spacings of the space and of the velocity spaces of electrons and ions are $\Delta X = \lambda_D$ ($\lambda_D$: Debye length), $\Delta V_e = 0.1V_{the}$ ($V_{the}$: thermal velocity of electrons), and $\Delta V_i = 0.0025V_{the}$, respectively. The range of the space is $-600\lambda_D X 600\lambda_D$, and a void is set at $-25\lambda_D X 25\lambda_D$ at the initial time. The ranges of the velocity spaces of electrons and ions are $-10V_{the} V_e 10V_{the}$, and $-15V_{thi} V_i 15V_{thi}$ ($V_{thi}$: thermal velocity of ions), respectively. The time step $\Delta t$ is $\Delta t = 0.1\,\omega_p^{-1}$ ($\omega_p$: plasma frequency). Accordingly, the CFL (Courant-Friedrichs-Lewy) condition, which should be satisfied to carry out numerical simulations stably, is $E/E_0 1$ ($E_0 = \lambda_D \omega_p^2 m_e / e$), where E is the electric field, $m_e$ is the electron mass, and e is the elementary charge. The rational CIP method [Xiao et al., CPC, 1996] is applied to solve the Vlasov equations, and Fourier transform [Birdsall and Langton, Taylor & Francis Group, 2008] is used to obtain electric fields through the Poisson' s equation. If we assume that the plasma is also flown in the y direction, the plasma distribution along the X-axis as a function of time can be understood as that as a function of distance in the y direction.

In our current code, electric oscillations whose amplitudes increase with time are observed outside the wake near the wake boundaries, which makes the CFL condition be unsatisfied at $t=469\Delta t$ (corresponding to 3.4 mm downstream). However, the calculation has to be proceeded until at least $t \tilde{} 60000\Delta t$ because we are going to check the velocity distribution functions in the region including the tail of the wake (about 0.4 m downstream) to discuss plasma waves observed in the S-520-26 rocket experiment. Therefore, the electric oscillations must be damped such as by selectively and artificially attenuating the electric fields or by making the density gradients at the wake boundaries be shallower. Even in the calculation before $t=469\Delta t$ with our current code, we can see several hot electrons such as multi-stream electrons on the wake axis, and a single beam component outside the wake. The multi-stream electrons are considered to be composed of electrons periodically coming into the wake from the outside, and the single electron beam may be owing to the reflection of electrons by the polarized electric field at the wake boundaries.

 

In this presentation, we will describe the configuration and schemes of our simulation first, and then will show the calculation results. We will especially discuss the spatial distribution of anisotropic electrons and their generation process.

Keywords: wake, sounding rocket, Vlasov-Poisson simulation, velocity distribution function, ionosphere

 