Electron Velocity Distribution Functions from the Solar Wind to the Corona

M. Maksimovic[1], V. Pierrard[2], J. Lemaire[2] and D. Larson [3]

[1]*Space Science Department of ESA/ESTEC, Noordwijk, The Netherlands*
[2]*Institut d'Aéronomie Spatiale, Brussels, Belgium*
[3]*Space Science Laboratory, University of Berkeley, California, USA*

Abstract. Typical electron velocity distribution functions observed at 1 AU from the Sun by the instrument 3DP aboard of WIND are used as boundary conditions to determine the electron velocity distribution function at 4 solar radii in the corona. The velocity distribution functions (VDF) at low altitude are obtained by solving the Fokker-Planck equation, using two different sets of boundary conditions. The first set typically corresponds to a VDF observed in a low speed solar wind flow (i.e. characterized by "core" and "halo" electrons); the second one corresponds to high speed solar wind (i.e. characterized by "core", "halo" and "strahl" populations). We use the observed electron VDFs as test particles which are submitted to external forces and Coulomb collisions with a background plasma. Closer to the Sun, the relative density of the core electrons is found to increase compared to the densities of the halo population. Nevertheless, we find that in order to match the observed distributions at 1 AU, suprathermal tails have to be present in the VDF of the test electron at low altitudes in the corona. Note that the present work has been submitted to Journal of Geophysical Research [6]. This is the reason why we present here only an extendend summary.

What is the origin of the nearly isotropic halo component which is observed permanently in the solar wind electron velocity distribution functions (VDFs) ? Do these halo electrons have their origin in the corona or are they due to other processes like sophisticated wave-particle interactions or for instance large scale interplanetary CIR-shocks reflections ? Up to now, nobody has answered in a comprehensive way to this question.

In order to answer to this question, we have solved the Fokker-Planck equation for a test population of solar wind electrons submitted to Coulomb collisions with a background solar wind plasma. Our model has been greatly inspired and is very similar to the Lie-Svendsen et al. model [1,2] but with alternative boundary conditions and distributions of background plasma.

As test particles, we use velocity distribution functions observed at 1 AU by the 3DP instrument onboard the WIND spacecraft [3]. This is our upper boundary condition. The density and temperature distributions obtained with an exospheric solar wind model by Maksimovic et al. [4] have been used to simulate the corresponding distributions of the background or target particles. Since the Lorentzian or Kappa functions are suitable to characterize the suprathermal tails of the electron VDFs in the solar wind [5], we use these functions in the present work. Note that κ is the index characterizing the power law decrease of the electron VDFs suprathermal tails ($f(v) \propto v^{-\kappa}$).

Our results indicate that, in order to match the observed distributions at 1 AU, suprathermal tails must exist in the lower corona; but they are much less important close to the Sun than those measured at larger distances. We have examined two different cases: (a) a typical low-speed solar wind with a Maxwellian background plasma ($\kappa_e = \infty$); at 1 AU, the VDF of the test electrons is fitted with a Lorentzian function corresponding to $\kappa = 3.6$; and (b) a typical high-speed solar wind with a Lorentzian background plasma with suprathermal particles ($\kappa_e = 3$); at 1 AU, the VDF of the test electrons, which is displayed on Figure 1, is fitted by a Lorentzian whose index kappa is equal to $\kappa = 2.4$. Integrating the Fokker-Planck equation for the test electrons from 1 AU to 4 Rs, we find that the electron VDFs have less important suprathermal tails in the low corona, corresponding to $\kappa = 10.1$ for the slow wind model (case a) and to $\kappa = 4.2$ for the fast wind model (case b). Figure 2 shows the VDF which is obtained at 4 Rs for this latter case. As expected, the suprathermal tails are less attenuated by Coulomb collisions in the fast wind than in the slow one.

From our study, it appears that starting with Maxwellian distributions in the corona, there is no way

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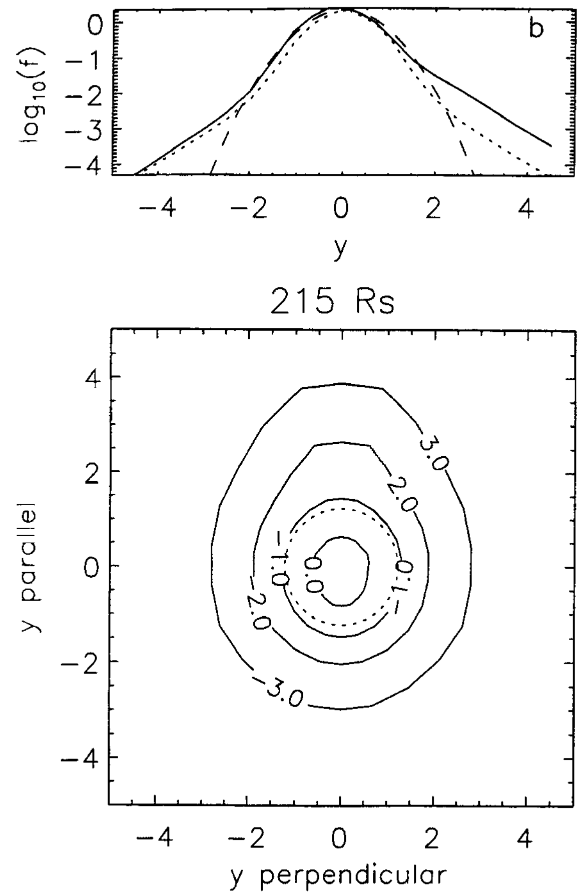

FIGURE 1 Typical high-speed solar wind electron VDF measured by the electrostatic analyzer 3DP on WIND, on the 28 01 1997 at 13:36, and taken as boundary condition at 1 AU. In the top panel, two cross sections of the phase space density are shown as a function of the normalized velocity parallel $y_{\parallel}$ (solid lines) and perpendicular $y_{\perp}$ (dotted lines) to the magnetic field direction. The Maxwellian velocity distribution with the same thermal speed is shown by a dashed line. In the bottom panel, the velocity distribution functions are represented by isocontours of constant phase space density in the $y_{\parallel}, y_{\perp}$ plane. The dotted circle corresponds to the Maxwellian thermal velocity $y = \sqrt{3/2}$.

to produce suprathermal tails in the solar wind if external forces and Coulomb collisions are the only processes acting in the solar wind. The Maxwell-Boltzman function is an exact solution of the Fokker-Planck equation but it corresponds to a corona in hydrostatic equilibrium. Note that Lie-Svendsen et al. [1,2] come to the same conclusion. Starting with Maxwellian distributions in the corona, the model discussed by Lie-Svendsen et al. is only able to reproduce the strahl population of the solar wind but not the halo component (see Figures 1 and 5 in [1])

In conclusion, the presence of non-thermal electron VDFs in the corona is an indispensable ingredient in our model, since we wish to match the halo electron population which is observed in the inner heliosphere.

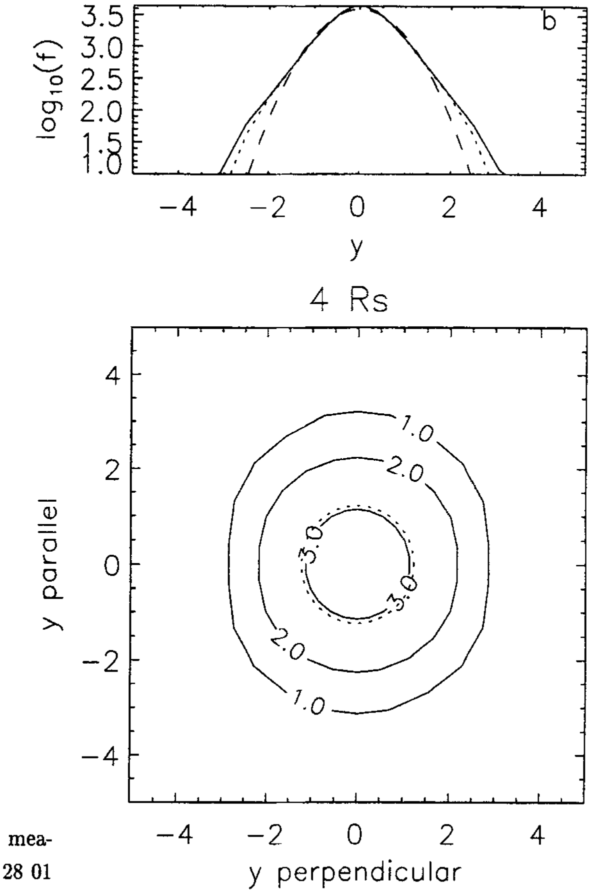

FIGURE 2 Electron velocity distribution functions obtained at 4 Rs by solving the Fokker-Planck equation with the velocity distribution functions presented in Figure 1 taken as boundary condition at 1 AU. The plots have the same format as in Figure 1. Note that here the phase space density is four orders of magnitude larger than it is in Figure 1, at 1 AU.

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