A Nonlinear Fluid Model for Weak Double Layers and Electrostatic Waves in the Solar Wind

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Weak double layers (WDLs) and coherent electrostatic waves in the range of frequencies above the proton plasma frequency, $f_{pi}$, and smaller than or of the order of the electron plasma frequency, $f_{pe}$, have been observed in the solar wind at 1 AU. A soliton model, which treats the solar wind plasma as a fluid of hot protons and hot α particles streaming with respect to protons, and suprathermal electrons having a $\kappa$-distribution, is found to sustain slow and fast ion-acoustic solitons and double layers. The slow ion-acoustic mode is a new mode that occurs due to the presence of alpha particles. This mode can support both positive and negative solitons and double layers. The slow ion-acoustic mode can exist even when the relative streaming, $U_0$, between alphas and protons is zero, provided alpha temperature, $T_\alpha$, is not exactly equal to 4 times the proton temperature, $T_p$. An increase of the $\kappa$- index leads to an increase in the critical Mach number, maximum Mach number and the maximum amplitude of both slow and fast ion-acoustic solitons. The fast ion-acoustic mode can support only positive potential solitons. The predicted amplitudes and widths of slow ion-acoustic double layers are found to be in an excellent agreement with the observed amplitudes and widths of WDLs. The fast Fourier transform (FFT) of the ion-acoustic solitons/DLs would produce a broadband spectrum with a main peak between 0.35 kHz to 1.6 kHz, and $E = (0.01 – 0.7) \text{ mV m}^{-1}$ which are in excellent agreement with the observed electric fields $\sim (0.0054 – 0.54) \text{ mV m}^{-1}$ associated with the low-frequency waves observed in the solar wind at 1 AU. It is proposed that WDLs and low-frequency coherent electrostatic waves, observed by Wind spacecraft in the solar wind at 1 AU [1], might be generated by the slow and fast ion-acoustic solitons and double layers.