Geophysical Research Abstracts, Vol. 7, 06559, 2005
SRef-ID: 1607-7962/gra/EGU05-A-06559

Saturation of the sweeping mechanism: hybrid expanding box simulations

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We present hybrid expanding box simulations of the interaction of left-handed Alfvén waves with protons, alpha particles and oxygen O^{5+}. We investigate properties and the saturation of the sweeping mechanism: The Alfvén waves are initially nonresonant with the ions and the expansion bring them to the cyclotron resonance with O^{5+} ions, then with alpha particles, and finally with protons. The numerical simulations indicate that O^{5+} ions are efficiently heated in the perpendicular direction but are only slightly accelerated. The saturation appears mainly due to the O^{5+} temparature anisotropy as long as the oxygen thermal velocity is much smaller than the local Alfvén velocity. When the oxygen thermal velocity becomes comparable with the local Alfvén velocity the acceleration becomes stronger and the saturation is influenced by the oxygen/proton differential velocity. During the heating and acceleration the oxygen ions are able to absorb only a limited amount of the available energy so that the presence of oxygen ions has a minimum influence on alpha particles and protons for the parameters used in the simulations; on the other hand, the heating and the acceleration of alpha particles and protons are not very efficient. The simulations are discussed within the context of observations and theoretical models of the evolution of MHD turbulence in the outer corona and accelerating solar wind.