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First global hybrid-Vlasov (Vlasiator) simulation results on foreshock ULF wave activity

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For decades, a certain type of ultra low frequency waves with a period of about 30 seconds have been observed in the Earth's quasi-parallel foreshock. These waves, with a wavelength of about an Earth radius, are compressive and propagate obliquely with respect of the interplanetary magnetic field (IMF). The latter property has caused trouble to scientists as the growth rate for the instability causing the waves is maximized along the magnetic field. So far, these waves have been characterized by single or multi- spacecraft methods and 2-dimensional hybrid-PIC simulations, which have not fully reproduced the wave properties.

Vlasiator is a newly developed, global hybrid-Vlasov simulation, which solves the ordinary space using magnetohydrodynamics (MHD) and the three-dimensional velocity space using the Vlasov equation. The outcome of the simulation is a global reproduction of ion-scale physics in a holistic manner where the generation of physical features can be followed in time and their consequences can be quantitatively characterized. Vlasiator produces the ion distribution functions and the related kinetic physics in unprecedented detail, in the global scale magnetospheric scale with a resolution of 0.13 RE in the ordinary space and 20 km/s in the velocity space. We run two simulations, where we use both a typical Parker-spiral and a radial IMF as an input to the code. We observe the generation of the 30-second ULF waves, and characterize their evolution and physical properties in time, comparing to observations by Cluster spacecraft. We find that Vlasiator reproduces these waves in all reported observational aspects, i.e. they are of the observed size in wavelength and period, they are compressive and propagate obliquely to the IMF. In particular, we investigate the oblique propagation and discuss the issues related to the long-standing question of oblique propagation.