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ULF foreshock under radial IMF: THEMIS observations and global kinetic simulation Vlasiator results compared

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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 with an average angle of 20 degrees 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 six-dimensional phase space utilising the Vlasov equation for protons, while electrons are a charge-neutralising fluid. 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 characterised. Vlasiator produces the ion distribution functions and the related kinetic physics in unprecedented detail, in the global scale magnetospheric scale with a resolution of a couple of hundred kilometres in the ordinary space and 20 km/s in the velocity space. We run Vlasiator under a radial IMF in five dimensions consisting of the three-dimensional velocity space embedded in the ecliptic plane. We observe the generation of the 30-second ULF waves, and characterize their evolution and physical properties in time. We compare the results both to THEMIS observations and to the quasi-linear theory. We find that Vlasiator reproduces the foreshock ULF
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 discuss the issues related to the long-standing
question of oblique propagation.