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The early-phase growth of ULF waves in the ion foreshock observed in a hybrid-Vlasov simulation

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Large-amplitude ULF waves are usually observed in the foreshock region ahead of quasi-parallel shocks and their generation is driven by the backstreaming ions. In the early phase of the wave growth, the waves are growing with time and traveling in space simultaneously. Therefore, it is very difficult to observe the wave growth properly using single-point measurements such as single spacecraft observations, because the spatial and temporal variations cannot be decoupled. This has also brought difficulties into understanding the detailed physical connection between the foreshock ion properties and the wave properties. In comparison, it is more straightforward to study this problem in global simulations, as simulation results are available everywhere in the foreshock at all times. Here we perform detailed analysis of the ULF wave growth and its relationship with the ion distribution using a Vlasiator simulation (a hybrid-Vlasov code). We calculate the phase speed of the ULF waves and observe the wave growth in the wave frame continuously. We show that the growth rate of the ULF waves decreases with time due to the decrease in beam velocity and the scatter of the ion distribution. And we compare the calculated growth rate with the dispersion relation solved by LEOPARD (a dispersion solver with arbitrary ion distribution input) based on the corresponding ion distribution obtained from the simulation results, and we will discuss the related physical mechanisms such as the ion-ion beam instability when the wave growth can be explained by ion distribution and discuss possible reasons when there is any discrepancy.