Statistical study of foreshock transients in a global hybrid-Vlasov magnetospheric simulation

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Upstream of Earth's bow shock lies the foreshock, a region permeated by bow shock-reflected electrons and ions propagating against the incoming solar wind. The interaction between the reflected ions and the solar wind leads to instabilities, which generate Ultra Low Frequency (ULF) waves in the foreshock. Another feature of the foreshock are various propagating transient structures. A particular type of transients are foreshock cavitons, which are characterized as simultaneous depressions of plasma density and magnetic field bounded by edges where these parameters are enhanced.

Cavitons are proposed to form as a consequence of the non-linear evolution of two ULF wave types. They are carried by the solar wind towards the shock, but have been found to propagate sunward in the solar wind rest frame. Studies have shown that cavitons can accumulate reflected suprathermal ions inside them as they approach the bow shock, causing significant heating and bulk flow deflection in their interiors. These signatures resemble those of Hot Flow Anomalies (HFAs), transients which are associated with interplanetary magnetic field (IMF) discontinuities interacting with the bow shock. As the evolution of cavitons is independent of IMF discontinuities, the hot, evolved transients are classified as spontaneous HFAs (SHFAs). SHFAs arriving to the shock have been found to cause perturbations to the shock surface and the magnetosheath downstream of it.

In this work, a numerical statistical study of cavitons and SHFAs is conducted with Vlasiator, a global hybrid-Vlasov code. Individual transients are tracked, allowing us to examine their formation rate, propagation characteristics and evolution in addition to their physical properties. Our results show that cavitons and SHFAs form in a uniform region near the bow shock, and there is a distinct distance to the shock within which cavitons can become SHFAs. The density and magnetic field depressions inside cavitons appear well correlated, although shallow compared to spacecraft measurements. We find that both transient types propagate sunwards in the solar wind rest frame, agreeing with earlier studies. Our statistical data set allows us to calculate the propagation velocity, which shows a similar value for all tracked transients. Our results also suggest that the velocity has a southward component.