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The Dispersive Nature of the Heliospheric Termination Shock

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The Voyager spacecraft are the first man-made objects to cross the termination shock (TS), where the solar wind becomes sub-fast magnetosonic due to the interaction with the local interstellar medium. Voyager 2 observations revealed that classical single-fluid magnetohydrodynamic (MHD) or multispecies single-fluid MHD models are not sufficient to describe the microstructure of the TS and the observed nonlinear waves downstream the TS. Consequently, more sophisticated physical models, like multifluid, hybrid or fully kinetic solar wind models, are needed to capture nonlinear waves, dispersive shock waves, and ion-ion instabilities, where each ion species (and electrons) can move independently with their own bulk velocities, and the fluctuating parts of the ion velocities are often comparable to the mean velocity of the collective plasma fluid. The multifluid simulation of the TS by Zieger et al. [2015] shows a remarkable agreement with high-resolution Voyager 2 observations, reproducing not only the microstructure of the third TS crossing (TS3) but also the energy partitioning among thermal ions, pickup ions (PUI), and electrons across the shock. It was demonstrated that TS3 is a subcritical dispersive shock wave with low fast magnetosonic Mach number and high plasma ß. Here we present multifluid, hybrid, and particle-in-cell (PIC) simulations of the second TS crossing (TS2) by Voyager 2, which was somewhat stronger than TS3, with an observed compression ratio of 2.2. All three types of simulations confirm the dispersive nature of the TS in agreement with Voyager 2 observations. We conclude that TS2, just as TS3, is a subcritical dispersive shock wave with a soliton (overshoot) at the leading edge of the shock and a quasi-stationary nonlinear wave train downstream of the shock front. We compared the cross-shock electric field in the multifluid, hybrid, and PIC simulations and found a reasonable agreement. We show that the Hall electric field is dominating over the convective and ambipolar electric fields, which indicates that electrons play an important role in the shock transition. Finally, we demonstrate that the microstructure of the termination shock is controlled by dispersion rather than ion reflection, and only slightly affected by reflected solar wind ions in the hybrid and PIC simulations, which validates the multifluid model on fluid scale. The dispersive nature of the termination shock has important implications for the transition and acceleration of PUIs across the termination shock, which is revealed in the PUI distributions in our hybrid [Giacalone et al., 2021] and PIC simulations.