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The origin of energetic ions at the quasi-parallel bow shock: particle tracing in hybrid 3D simulations and spacecraft observations

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Shock fronts are known to be efficient particle accelerators. At Earth, ions with energies exceeding 100 keV are frequently seen upstream of the bow shock. This energization is generally attributed to diffusive shock acceleration, however, for this process to become effective the ions must first undergo an initial acceleration. How and where this takes place has not yet been determined, and it is one of the key unresolved issues in shock acceleration theory. There are a few proposed models, based for example on resonant wave-particle interaction or particle scattering from the quasi-perpendicular shock section, but there is yet no consensus on the subject, and there is still a lack of observational validation for the models.

We here investigate the nature of these ion acceleration processes at an oblique quasi-parallel shock using a series of parallelized 3D hybrid simulations in combination with Cluster spacecraft observations at the terrestrial bow shock. In the shock simulations, we primarily focus the analysis on the ion velocity distribution functions within the turbulent transition region upstream of the shock front, the identification of accelerated ions, and the back-tracing of individual particles in time. These methods allows us to investigate the physical processes at work in the system, and to determine where and how these ions gain their energy. A close comparisons between these energetic ions with in-situ spacecraft observations also allows us to establish what impact they may have on the formation of complex shock front structures at the terrestrial bow shock.