Particle acceleration and transport from young near-Sun solar wind unveiled by Parker Solar Probe

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The NASA mission Parker Solar Probe (PSP) has provided us in the last six years with unprecedented insights about the origin of solar energetic particles and the process of particle acceleration at travelling CME-driven shocks, via a combination of in-situ measurements and remote sensing. In its closest approaches to the Sun, as close as 0.05 AU, PSP not only explored the dense, highly magnetized and accelerating solar wind but also unveiled the early-on phase of particle acceleration and escape at some of the fastest shock waves ever observed in the solar wind. In previous works, we have coupled in a new synergy the acceleration and escape of charged particles at shock waves and the modification induced by a spatially dependent diffusion coefficient that incorporates oth self-generated turbulence close to the shock and preexisting turbulence far upstream (Fraschetti, 2021). The upstream particle intensity steepens within one diffusion length from the shock as compared with diffusive shock acceleration picture. The momentum spectrum, controlled by macroscopic parameters such as shock density compression, speed, far-upstream diffusion coefficient, and escape time at the shock, can be reduced to the widely used broken power law. The broad range particle energy spectra of GLE can be reproduced without invoking any transport effect, but as an imprint of acceleration process (Fraschetti Balkanski 2021). The time-dependent version of this acceleration-escape scenario allowed to explain one of the most unexpected findings by PSP, namely the "nose" in the energetic particle intensity (Do et al, 2025), as evidence of incipient particle energization, as reported by our analysis of the Labor day event of September 5th 2022. We also investigated the diffusion coefficient/energetic particle intensity correlation (Cuesta et al 2025). I will also outline a recent work (Das et al, 2026) that connects the hammerhead proton velocity distribution function, originally discovered by Verniero et al 2022, to transients, such as CME-driven shocks, and speculate on their origin. Additionally, joint multi-spacecraft efforts revealed unexpected heavy ion composition that might lead to new regime of particle transport through the turbulent interplanetary plasma. I will review some of the key observations and recent modeling efforts and expectations for the future closest approaches.

References:

Fraschetti, F., "Effect of Acceleration and Escape of Energetic Particles on Spectral Steepening at Shocks, ApJ, 909, 42, 2021.

Fraschetti, F., Balkanski, A.,"Imbalance acceleration/escape of energetic particles at interplanetary shocks: effect on spectral steepening, ICRC Proc., 1358, 2022.

Do, T. M., Fraschetti, F., Kota, J., Giacalone, J., Cohen, C. M. S. and McComas, D. J.,"Time-dependent Acceleration and Escape of Charged Particles at Traveling Shocks in the Near-Sun Environment", ApJ, 50, 2025.

Cuesta, M. et al, "Distinct Solar Energetic Particle Shock IntensityDiffusion Coefficient Relationships in the Inner Heliosphere", ApJ, 1, 993, 2025.

Das, B. S. et al., "Strong Prevalence of Hammerhead Velocity Distributions Close to the Heliospheric Current Sheet", ApJ, 1001, 1, 2026

Verniero, J. et al., "Strong Perpendicular Velocity-space Diffusion in Proton Beams Observed by Parker Solar Probe", ApJ, 924, 12, 2022.