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Understanding the Physical Links Between Energetic Storm Particle Events and large Gradual Solar Energetic Particle Events

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Fast coronal mass ejections or CMEs drive shock waves through the corona and the interplanetary medium and are believed to produce both, the large gradual solar energetic particle (SEP) events and the energetic storm particle (ESP) events observed at 1 AU. While there is little doubt that the ESP events are accelerated by in-situ CME shocks, evidence that the large SEP events are accelerated by the near-Sun CME shocks is circumstantial. The primary candidate for accelerating energetic particles at CME-driven shocks is the diffusive shock acceleration (DSA) theory, comprising the first-order Fermi mechanism at quasi-parallel shocks and the shock-drift mechanism at quasi-perpendicular shocks. However, major criticisms of the DSA theory are: (1) ESP events rarely exhibit clear signatures consistent with theoretical predictions, and (2) self-excited Alfvén waves that play a crucial role in scattering and accelerating the particles are seldom observed upstream of IP shocks near Earth. In a survey of observations from solar cycle 23, we identified $\sim$10 ESP events with clear signatures of the two types of DSA mechanisms. In addition, we find striking similarities between particle properties during 6 of these ESP events and those observed during many intense, large gradual SEP event in which the associated $<$0.2 MeV/nucleon ion population is extremely delayed and arrived $\sim$day later with the IP shock. In all cases, the ESP properties are largely governed by interactions between the particles and upstream waves that are clearly identified in the power spectrum of the in-situ magnetic field fluctuations and are most likely excited by accelerated protons streaming away from the shock. In this paper, we explore the commonalities between ESP and large SEP events and discuss our results in terms of mechanisms responsible for their acceleration at in-situ and near-Sun CME-driven shocks.