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Injection of heavy ions into shock acceleration

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Solar energetic particle events are commonly divided into gradual and impulsive events, with diffusive shock acceleration (DSA) and acceleration in resonant wave processes in solar flares as the main acceleration mechanisms, respectively. The gradual events typically have much larger particle intensities and coronal elemental abundances, while impulsive events typically show higher mean ionic charges, enhanced ^{3}He/^{4}He ratio, and enhanced heavy ion abundances.

However, gradual events have been shown to be highly variable in their heavy ion statistics at the highest energies, with some events showing characteristics typical to impulsive events. One proposed solution to this variability is a selective acceleration at shock waves driven by coronal mass ejections, and a compound seed population consisting of coronal / solar wind plasma and ions preaccelerated by flares.

The idea of selective shock acceleration is sensitive to the injection threshold, i.e., to the factors that determine whether or not a given incident ion is picked up by the DSA mechanism. Such factors are, for example, speed of the incident ion, shock obliquity angle, and the level of turbulence in the electromagnetic field.

We have previously studied the injection of heavy ions using Monte Carlo simulations, which confirm the idea of selective ion injection. However, in these simulations, self-consistent modeling of particle transport perpendicular to the mean magnetic field is not included. In the present work, we use a self-consistent quasi-neutral hybrid simulation to study the injection problem. Results from the two numerical approaches are compared and their similarities and differences discussed.